GUIDEBOOK 4

GUIDEBOOK TO PERMAFROST AND RELATED FEATURES ALONG THE ELLIOTT AND DALTON HIGHWAYS, FOX TO PRUDHOE BAY, ALASKA

Edited by

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Cover photo: *Final linkup of 'haul road' at South Fork Koyukuk River, September 27, 1974. View looking south. Photo courtesy of Alyeska Pipeline Service Company.*

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PREFACE

Brief outlines of the history, development, climate, physiography, permafrost and ground ice, geology, vegetation, and soils along the Elliott and Dalton Highways between Fox and Prudhoe Bay are provided in this guidebook. A detailed road log is accompanied by strip maps of the route at scales of 1:63,360 and 1:250,000, beginning at Fox at the southern end of the Elliott Highway and terminating at the northern end of the Dalton Highway at Prudhoe Bay. Exposures of seasonally and perennially frozen ground mentioned in the text may no longer be visible due to thawing and slumping.

This guidebook was prepared in cooperation with the State of Alaska Department of Natural Resources Division of Geological and Geophysical Surveys (DGGS), the U.S. Department of Interior Bureau of Land Management (BLM), the Alyeska Pipeline Service Company, and the North Slope Borough. Portions of the road log are based on work by Hamilton (1979a) and Robertson (1981), and on recent editions of 'The Milepost' (published by the Alaska Northwest Publishing Company). The State of Alaska Department of Transportation and Public Facilities (DOTPF) provided considerable assistance in determining milepost locations.

A number of individuals faithfully read and edited various versions of this guidebook, and special thanks are extended to them, particularly John R. Williams, Glenn E. Johns, Michael C. Metz, and Frank R. Fisher. Ray Norman of the Arctic Environmental Information and Data Center, University of Alaska, Anchorage, prepared the strip maps. Tom O'Brien and Bobby King, National Mapping Division, U.S. Geological Survey, Denver, provided valuable assistance in arranging for the preparation of the strip maps. K.S. Pearson (DGGS) provided a cartographic review of the manuscript. The Cold Regions Research and Engineering Laboratory, the Department of Energy, and BLM provided support for preparation of the text and maps, and DGGS provided funds to publish the guidebook.

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INTRODUCTION

This book is a guide to permafrost terrain along the highway from Fox, Alaska, northward for some 800 km to the shore of the Arctic Ocean (fig. 1). The route parallels the Trans-Alaska Pipeline System (TAPS) and covers three major regions: the forested and subalpine interior, the mountainous Brooks Range, and the tundra-covered Arctic Slope. Although the southern portion of the route lies within the discontinuous permafrost zone, the entire route is

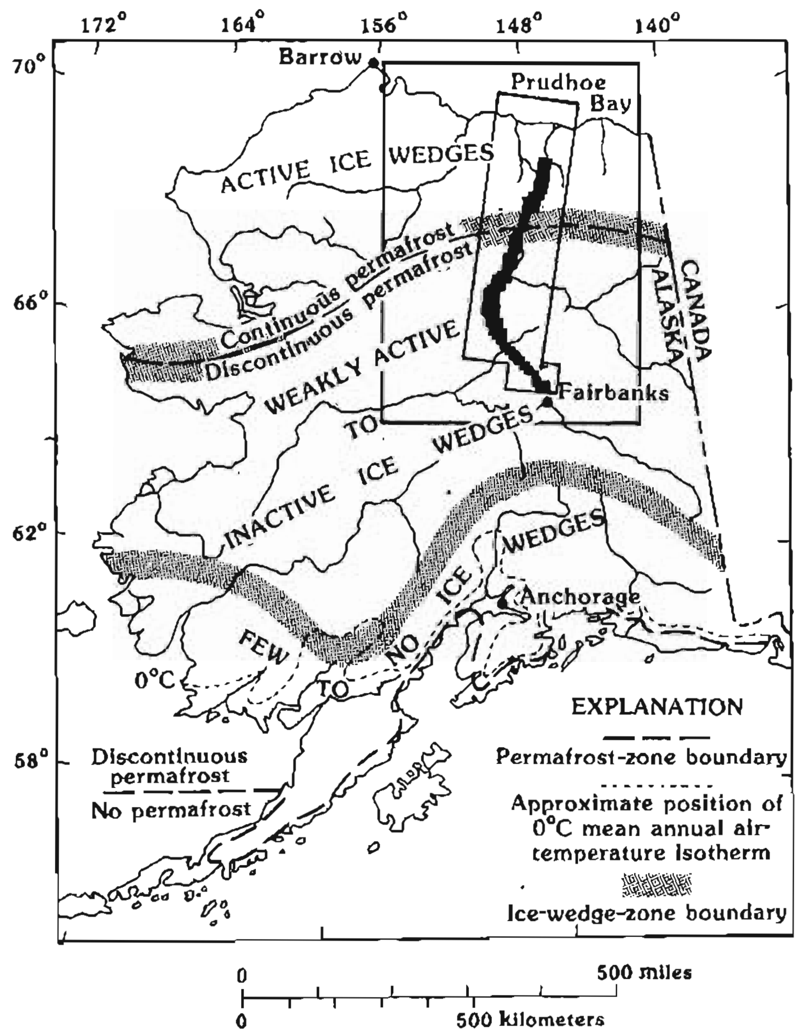

Figure 1. Field-trip route and distribution of ice wedges and permafrost in Alaska. Details of the areas within the outlined rectangles are provided in figure 2. The area within the smaller rectangle is covered by geology, vegetation, and soil maps (figs. 7, 8, 12 and 13) (modified from Péwé, 1966, fig. 3).

dominated by permafrost close to the ground surface. The occurrence of permafrost is influenced by past and present climate, geologic characteristics, hydrology, vegetation, and soil cover. The interrelationship of these conditions and their influence on the formation, preservation, and degradation of permafrost and related ground ice features are discussed and illustrated in this guidebook. Examples of natural and man-induced (anthropogenic) modifications to permafrost terrain are illustrated, particularly those related to the freezing of ground water and changes in surface drainage and vegetation.

HISTORY AND DEVELOPMENT ALONG THE ELLIOTT AND DALTON HIGHWAYS

Elliott Highway

The history of the Elliott Highway dates from the early days of gold mining in 1902, when Felix Pedro and Tom Gilmore discovered gold north of Fairbanks. The highway begins at Fox, where it leaves the Steese Highway. It extends northwestward to Livengood, and then west to Manley Hot Springs, a distance of 233 km.

By 1903, mining communities had sprung up at Fox, Olnes, Gilmore, and Chatanika. The narrow-gauge Tanana Valley Mines Railroad was constructed in 1905 to haul freight from Chena, at the mouth of Chena Slough on the navigable Tanana River, 34 km north to Gilmore and Pedro Creeks. An 8-km branch was also built to Fairbanks. Two years later, the Tanana Valley Mines Railroad was extended 32 km to Chatanika. The Tanana Valley line was incorporated into the federally owned Alaska Railroad in 1917. The Happy-Fairbanks section of the line has been modernized and now forms part of the Alaska Railroad. Train service was discontinued on the Happy-Chatanika section in 1931.

In 1914, Jay Livengood and N.R. Hudson discovered gold near what is now the community of Livengood. To serve the promising new developments, the Alaska Road Commission constructed an 87-km sled road from Olnes to Livengood between August and December 1915. The Fairbanks Commercial Club helped finance the construction, and the route was located by R.A. Jackson. About 900 metric tons of freight was hauled over the road during the winter of 1915-16. The road became less important in the 1920's, when the Alaska Road Commission built the Dunbar-Brooks sled road to the west of the Olnes-Livengood route through less hilly country in Minto Flats.

In the early 1930's, the Alaska Road Commission decided to improve the original sled road from Olnes to Livengood to accommodate wagon traffic. Designated the Elliott Highway after Malcolm Elliott, president of the Alaska Road Commission, the road was extended from the Steese Highway near Fox to Livengood---a total distance of 114 km. By 1936, about 64 km of the road was in good enough condition for use by automobiles. Two years later, gravel surfacing was completed and the road became an all-weather highway. The road was completed to Manley Hot Springs in 1958. Since 1960 the road has been improved between Fox and Livengood; new bridges were built, and the first 32 km or so was paved.

Hickel Highway

In the 2 years following discovery of oil at Prudhoe Bay in 1968, a winter ice road was constructed north from Livengood to northern Alaska. The road, called the Hickel Highway after Walter Hickel, then governor of Alaska, was a bulldozer-bladed trail over which trucks drove on the exposed frozen ground, crossing streams on ice bridges. Because the surface organic mat was disturbed in many places, substantial summer thawing took place, and portions of the road became a quagmire. The road crossed the Yukon River on an ice bridge in the Yukon Flats, 11 km upstream from Stevens Village. After crossing the Yukon and Kanuti Flats, the trail crossed the present Dalton Highway just north of Old Man Camp and turned west to Bettles. The ice road continued up the John River through Anaktuvuk Pass in the Brooks Range, and on to Prudhoe Bay west of the Sagavanirktok River. Spur roads went to Dietrich, Coldfoot, and Prospect Camps on the south side of the Brooks Range and to Galbraith Lake on the north side.

Dalton Highway

Dalton Highway begins at Mile 73.1 (118 km) on the Elliott Highway, several kilometers west of Livengood. It was built by Alyeska Pipeline Service Company in two sections. The first section, constructed between August 1969 and July 1970 and extending approximately 90 km from Livengood to the Yukon River, was formerly referred to as the "TAPS Road." The second section, the 577-km-long "haul road" between the Yukon River and Prudhoe Bay, was built in seven segments in five months between April 29 and September 29, 1974 (McPhail and others, 1976). The points where these segments joined are posted with road signs along the route. A total of 18 million m^3 of gravel was used for the road and for construction of airfields at the pipeline construction camps. This "haul road" was named for James Dalton by the Alaska Legislature in 1981. Dalton had been active in petroleum and construction activities in northern Alaska since the mid-1940's.

Although the Elliott and Dalton Highways are state owned and maintained, they pass through land with a variety of owners---mostly federal. The largest portion of land, managed by the BLM, is a strip called the utility corridor (U.S. Department of Interior, 1980; fig. 2; see also Division of Policy Development and Planning, 1977). The land was withdrawn by Public Land Order 5150 in 1971 to provide for transportation and transmission lines and pipelines. The corridor, 19 to 37 km wide, extends from Washington Creek on the Elliott Highway to Pump Station 2, some 100 km south of Prudhoe Bay; the remaining section of the road crosses state lands. Adjacent federal land is managed by the National Park Service (Gates of the Arctic National Park and Preserve) and the Fish and Wildlife Service (Yukon Flats National Wildlife Refuge). Few private individuals own land along the Dalton Highway, although there are numerous mining claims in the Koyukuk River valley in the vicinity of the old mining towns of Coldfoot and Wiseman.

On October 5, 1980, the State Legislature authorized public summer use of the Dalton Highway north of the Yukon River. Beginning in summer 1981, the Dalton Highway from the Yukon River to Dietrich Camp was open to the public from June 1 to September 1 each year. In other months, and north of Dietrich Camp, travel was limited to holders of permits, which were issued only to industrial and commercial users and to residents of the area. (See Laycock (1979) for an early account of the road.)

Trans-Alaska Pipeline System

The Elliott and Dalton Highways parallel more than 800 km of the Trans-Alaska Pipeline System, built and operated by the Alyeska Pipeline Service Company, which is owned by eight oil companies with holdings in the Prudhoe Bay oilfield. The route provides excellent opportunities to view the pipeline and its support facilities.

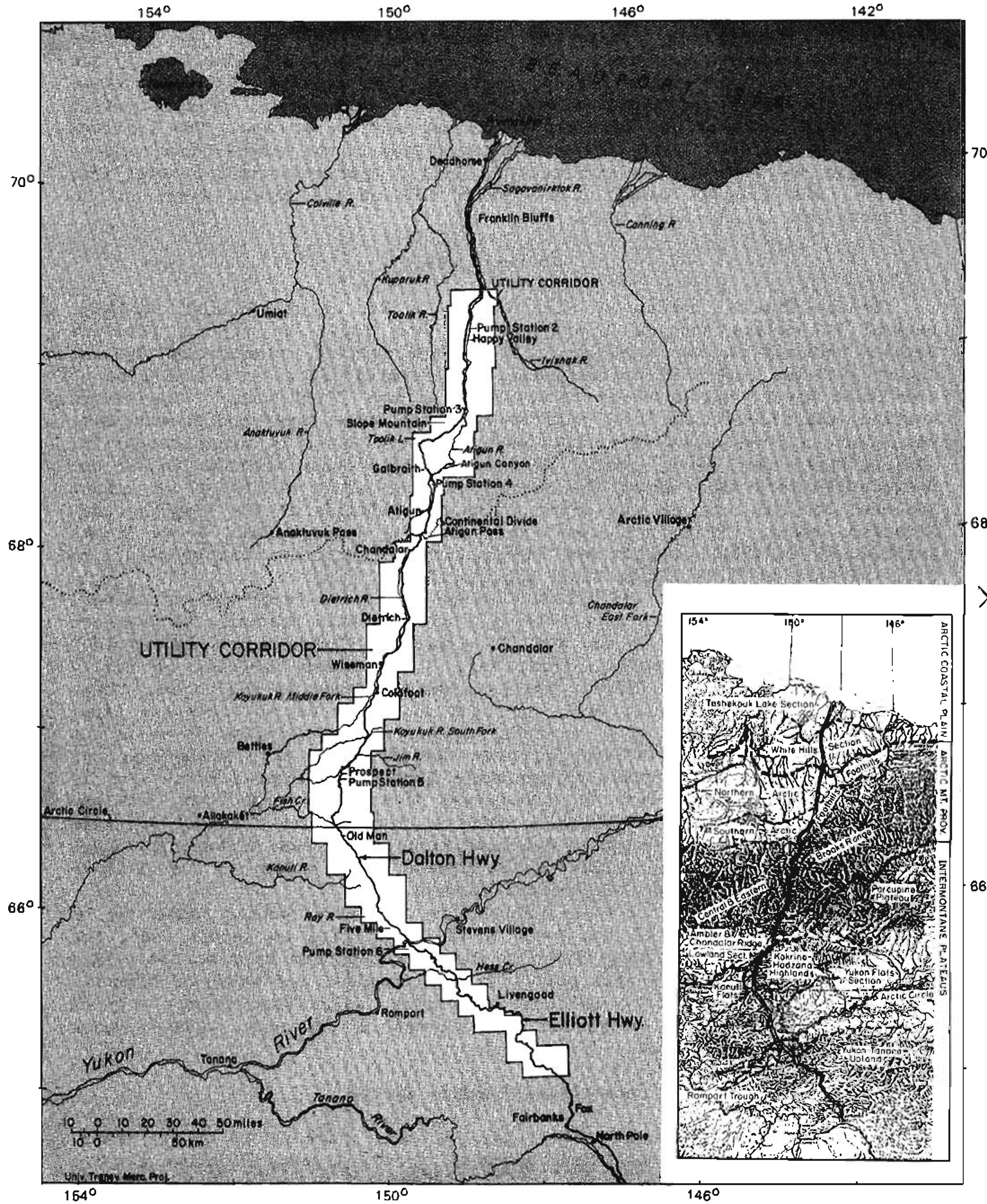

Figure 2. Map of field-trip route (delineation of the utility corridor from U.S. Department of Interior, 1980; physiographic map modified from Wahrhaftig, 1965, pl. 1, and Raisz, 1966).

The pipeline was constructed between 1975 and 1977 following 6 yr of intensive engineering design, environmental planning, and mobilization. The 1.2-m-diameter pipe went on-line on Aug. 1, 1977, carrying up to 1.6 million barrels of crude oil a day from Prudhoe Bay to Valdez, 1,300 km to the south. By the end of 1982, more than 2.67 billion barrels of oil had been shipped through the system.

There are seven pump stations north of Fairbanks. Pump Stations 1, 2, 3, 5, and 6 are built on ice-rich soils and have refrigerated foundations to prevent thawing of permafrost, which could cause differential settlement of the structures.

Because of permafrost conditions, more than half of the pipeline is above ground. The construction mode used---elevated or buried---depended on soil conditions and on the anticipated effects of the hot oil line on the permafrost (the oil temperature is 60°C at Prudhoe Bay and 32°-35°C at Valdez). Normal burial (fig. 3a) was used in thawed or thaw-stable soils and in bedrock. Burial was allowed where thawing of permafrost would not cause loss of soil support for the pipe. Conventional burial also allowed for resisting the forces generated by the thermal stresses and the high internal pressure in the large-diameter pipe. Special refrigerated buried sections were used for animal and highway crossings in thaw-unstable soils where the pipe had to be buried. Where thawing of the permafrost would create thaw-unstable conditions, the pipeline is elevated. In elevated sections, the pipeline is supported on bents made of two vertical support members (VSM's) and a horizontal beam, which are designed to allow lateral or longitudinal movement (fig. 3b). Elevated sections were built in a zigzag configuration so that longitudinal expansion or contraction of the pipe caused by temperature changes is converted into lateral movement. The pipe is anchored every 250 to 550 m onto support platforms supported on four VSM's. Gate and check valves are located along the line, particularly at stream crossings and major overland sections, to allow stopping of the oil flow when necessary.

A gravel overlay workpad was used for constructing almost all the pipeline; two short experimental snow and ice pads were used for segments totaling 11 km. North of Atigun Pass the gravel overlay in aboveground pipeline areas was placed on polystyrene insulation 3.75 to 11 cm thick. The insulation was designed to reduce the necessary thickness of the gravel overlay and to prevent thawing of permafrost (Metz and others, 1982). A total of 26.4 million m^3 of gravel was used for construction of the entire pipeline workpad, and related facilities.

The VSM's are of three general types: a) thermal (corrugated with heat pipes), b) adfreeze (without heat pipes), and c) end bearing. The soils surrounding VSM's in warm permafrost are kept frozen by heat pipes with radiators (fig. 3c). The heat pipes are used to maintain frozen conditions around the VSM's since the disturbance caused by the workpad would cause thawing of the permafrost and failure of the support structure. Two heat pipes in each thermal VSM contain liquid ammonia and ammonia vapor. The tops of the pipes extend above the VSM and are fitted with aluminum cooling fins (radiators) either 1.2 or 1.8 m long. The longer radiators provide for additional dissipation of heat from heat pipes longer than 10 m. As vapor cools in the top of the heat pipe in winter it condenses and flows to the bottom where it absorbs heat, turns to vapor, and rises to the top, forming a continuous, nonmechanical heat removal system. The process ceases when the air becomes warmer than the ground. The net result is removal of heat from the ground in the winter, which promotes refreezing of the ground around the VSMs or keeps the permafrost from thawing. North of Atigun Pass, heat pipes are not

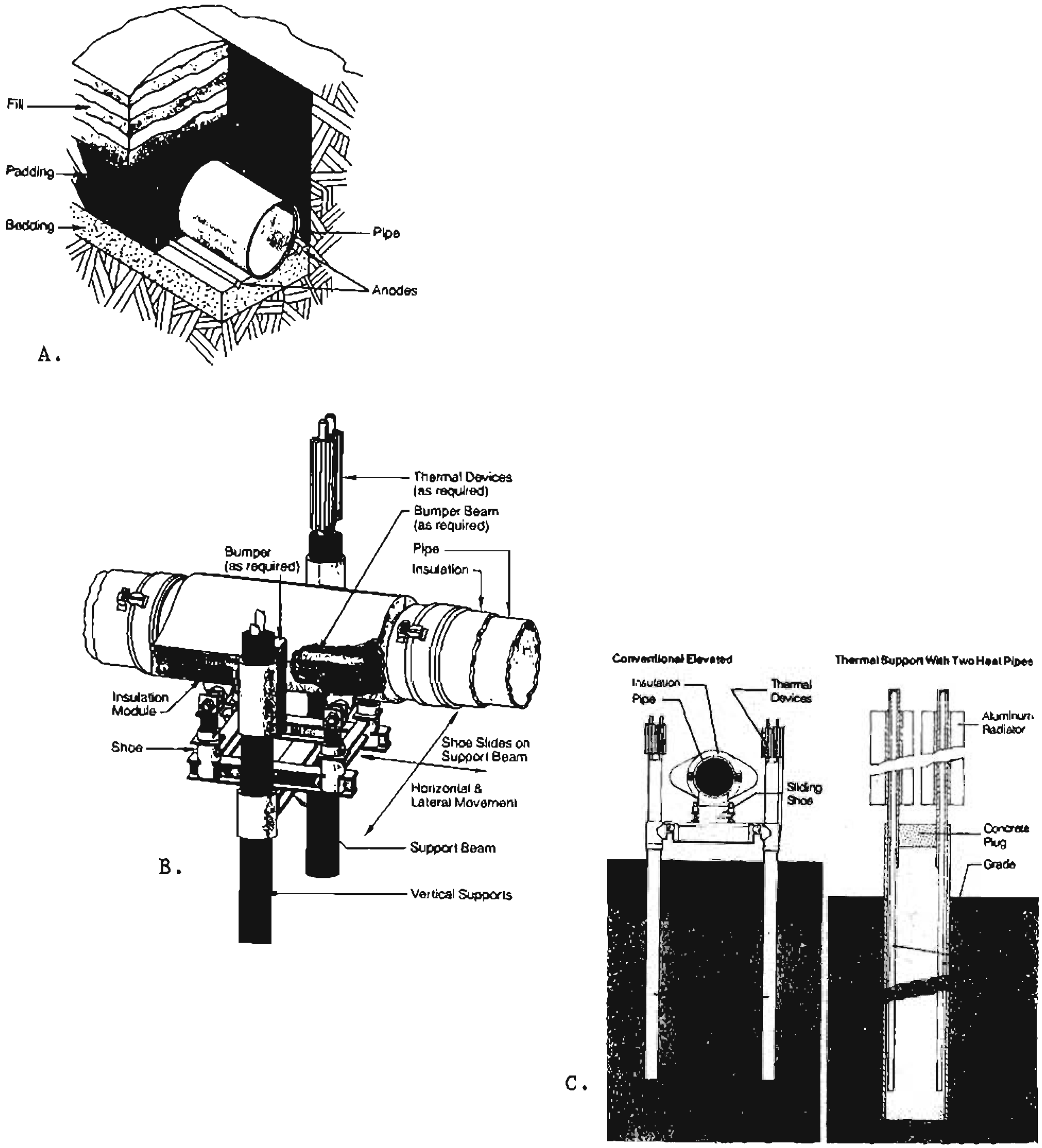

Figure 3. Buried and elevated construction modes for the oil pipeline (diagrams courtesy of Alyeska Pipeline Service Company). A. The buried mode was used where the ground was thawed, in frozen or thawed bedrock, and in some permafrost conditions, which on thawing would be thaw stable. B. Elevated mode. C. Cross sections of the elevated mode showing details of the heat pipes.

generally required in the VSM's since the insulated workpad is designed to prevent thaw of the cold permafrost. However, if massive ice is present they are used to cool the ice below its natural temperature in order to increase its load carrying capacity.

End-bearing VSM's were designed to support the pipe in areas where firm material such as bedrock or massive gravel deposits are encountered at shallow depths. Most end-bearing VSM's did not require freezeback for additional stability. North of the Yukon River some VSM's and heat pipes were field mitred and tilted outward to provide additional room for lateral movement of the pipe. Several summaries of the geotechnical aspects of the pipeline are available (Liguori and others, 1979; Luscher, 1981), as are numerous Alyeska Pipeline Service Company data sheets and publications.

Communication along the pipeline is accomplished via a microwave system with a satellite backup system linking earth stations at Pump Stations 1, 4, and 5 and the Valdez Terminal.

CLIMATE[1]

The interior is a zone of temperature extremes and of relatively high precipitation compared to the Arctic. During summer, storms track through the region from the south or southwest, but most of the precipitation is of the convectional type, and is widely scattered and variable (Watson, 1959). Most precipitation occurs during summer. During the winter, the interior is dominated by relatively dry continental polar air masses, and sinking cold air creates high atmospheric pressure. Occasionally, maritime air intrudes into the area from the west or southwest, causing major snowstorms (Bilello, 1974) and, rarely, winter rain. Alpine areas within the interior typically have less extreme temperatures but more precipitation than forested areas at lower elevations.

North of the Continental Divide is a region of extremely low winter temperatures, low summer temperatures, and relatively low precipitation. Unlike the continental interior, wind is a major environmental factor throughout much of the year. Although winds rarely exceed 17 m/s on the Arctic Coastal Plain, it is seldom calm (Conover, 1960). Winds cause considerable drifting of snow, poor visibility, and severe wind-chill factors during the coldest months (Searby and Hunter, 1971).

During July and August, a sea breeze from the open water of the Arctic Ocean dominates the coastal climate (Moritz, 1977; Kozo, 1979). Radiational heating of inland tundra surfaces creates a local pressure deficit, which causes colder air from the ice-dominated Arctic Ocean to move inland, resulting in a prevailing northeasterly wind. These conditions often cause cloudiness and coastal fog, which extends inland and persists until the air is warmed by radiation. The inland extent of the sea breeze phenomenon is at least 17 km (Kozo, 1979), although fog and the prevailing northeasterly wind are observed considerably farther from the coast.

This climatic description is based on stations and data reported by Haugen (1982). The ranges of temperature and precipitation values are summarized in table 1. Estimated mean annual air temperatures along the route are shown in figure 4.

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[1] See Haugen (1982) and Haugen and Brown (1980) for additional details.

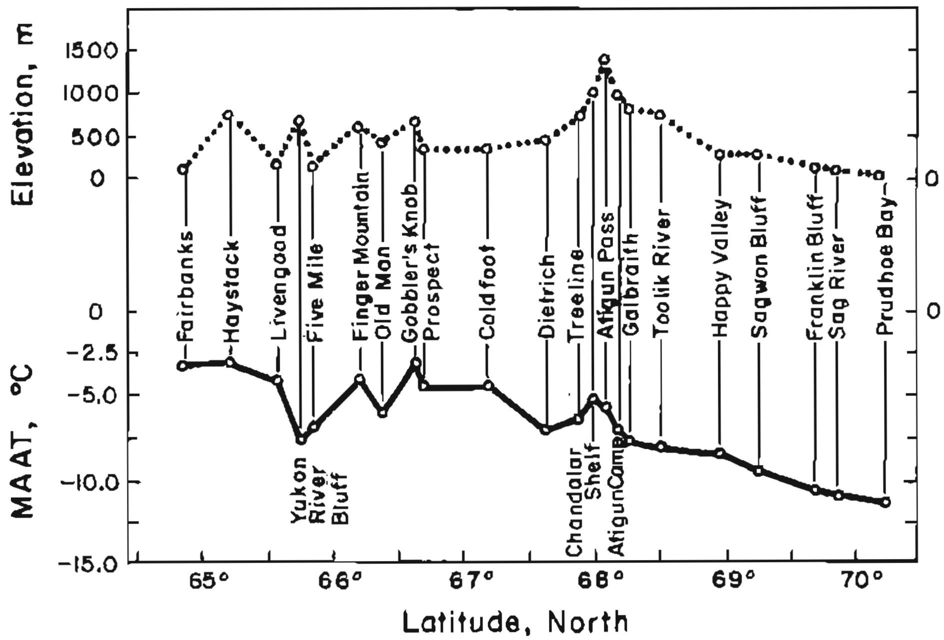

Figure 4. Estimated mean annual air temperature (MAAT) as a function of elevation and latitude along the field-trip route (prepared by Haugen based on data from Haugen, 1982).

Table 1. Ranges of annual climatic values; summary of 1975-79 stations (Haugen, 1982).

	Interior	Brooks Range	Foothills	Coastal Plain
Degree-days				
Thawing	1,182-1,904	453-1,189	760-1,125	318-897
Freezing	2,767-4,513	3,173-3,888	4,225-5,412	4,409-5,642
Thaw season				
Length (days)	123-168	87-131	104-139	91-128
Starting dates	Apr 18-June 1	May 3-June 10	May 18-June 27	May 25-July 9
Precipitation (mm)				
Frozen	NA	57-181	87-110	125-142
Unfrozen	84-367	117-292	52-157	58-81
Total	168-445	295-450	140-267	183-223
Temperature (°C)				
Mean	-6.9 to -3.7	-6.9 to -5.9	-11.1 to -6.2	-12.8 to -10.3
Range (mean diurnal)	12.8 to 14.6	10.8 to 12.6	7.6 to 11.6	7.6 to 9.6
Range (extremes)	-53.3 to +33.0	-37.8 to +26.1	-53.3 to +30.0	-50.6 to +28.9

Temperature

Temperature regimes include some of the most extreme ranges encountered on the North American Continent. The all-time low temperature for the United States, -62°C, was recorded at Prospect Creek Camp on January 24, 1971. Most locations have extreme minimum temperatures below -50°C, and at least half the stations have summer maximum temperatures over 30°C, a range of more than 80°C.

Average annual air temperatures are estimated to range from -11.5°C at Prudhoe Bay to -4°C at some of the stations south of Dietrich (fig. 4). The extremely low temperatures recorded at valley stations (for example, Prospect, Coldfoot, Dietrich) are a result of inversions of the vertical temperature profile, caused by cold air draining downslope. Higher elevations (represented by Gobbler's Knob and Chandalar Shelf) are above the average height of the inversion and have higher average winter temperatures. Lower summer temperatures at higher sites reflect a normal decrease of temperature with elevation.

Temperature patterns for the entire region typify a continental climate for the entire year, except for the maritime influence on summer temperatures in the region north of Happy Valley. The mean annual diurnal range of temperatures (amplitude × 2) serves as an index of continentality. This range averages less than 8°C north of Happy Valley Camp and more than 10°C south of it. The highest mean annual diurnal temperature range is 13.7°C (at Five Mile). Values of 12° to 13°C, however, are common between the Brooks Range and Happy Valley and at the interior stations with low elevations.

Thawing degree-day[2] (°C) accumulations range from approximately 1,850 degree-days at the Yukon River to fewer than 500 in the Prudhoe Bay area. The length of the thaw season ranges from approximately 160 days at the Yukon River to 105 days at Prudhoe Bay. At higher elevations along the route (Chandalar, Atigun Pass, and Atigun Camp), thawing-degree-day accumulations are similar to those north of Sagwon.

Freezing degree-days (°C) usually range from slightly less than 3,500 in the southern portion of the route to about 5,000 in the north. The year-to-year variation of thawing degree-days at any given site is considerably less than the variation of freezing degree-days.

Summer temperature gradients with latitude and elevation may be compared to vegetation distribution and growth characteristics. The altitudinal and latitudinal treeline of the white spruce forest occurs within the road transect at approximately 720 m elevation near Finger Mountain and Gobbler's Knob and the latitudinal treeline occurs 40 km north of Dietrich. Application of the so-called 'Nordenskjold formula' for determination of the temperature equivalency of treeline (Haugen and Brown, 1978) gives an approximate July mean temperature of 12°C, which agrees with temperatures that have been measured at treelines along the Dalton Highway (Densmore, 1980).

Temperature-vegetation gradients on the Arctic Coastal Plain indicate that thawing-degree-day accumulations are linearly related to distance south of the coast (Haugen and Brown, 1980; Walker, 1981).

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[2] Thawing and freezing degree-days represent the cumulative departure of mean daily temperatures above or below 0°C, respectively.

Precipitation

Although distinct differences exist in precipitation amounts and characteristics, variations with latitude and elevation are not as readily defined as variations with temperature. Annual total precipitation ranges from 140 mm at Sagwon to more than 400 mm in the Atigun Pass - Chandalar Shelf area. The 30-yr normal precipitation value of 360 mm at Bettles is probably representative of all but the higher elevations from treeline in the Brooks Range south to Old Man Camp. South of Old Man Camp to the Yukon River, total precipitation distinctly decreases, not generally exceeding 300 mm at Five Mile Camp. The greatest single-day totals registered are 89 mm at Chandalar (July 27, 1975) and 52 mm at Prospect (July 24, 1977).

During most years, rain is the dominant form of precipitation. To the south, the thaw season becomes longer and the percentage of precipitation that falls as rain becomes larger. South of Chandalar, about two-thirds of the annual precipitation is unfrozen. Intense precipitation occurs during thunderstorms south of the Continental Divide. Thunderstorms are less common north of the Divide. Weak low-pressure centers passing from west to east, often along the boundary of the summer Maritime Polar Front, are responsible for perhaps half the summer precipitation in the Arctic. The immediate coastal area, however, is usually under the influence of maritime air, which causes cloudy skies and fog, onshore winds or sea breezes, and precipitation that is more frequent but lighter than that to the south.

Benson (1982) reported that, because of measurement problems, the amount of snowfall on the Arctic Slope may be underestimated by a factor of 3.

PHYSIOGRAPHY[3]

North of Fox, the road traverses the Yukon-Tanana Upland and Kokrine-Hodzana Highlands of the Intermontane Plateau Province, which is broken by the east end of the Rampart Trough (fig. 2). The uplands consist of even-topped, rounded ridges with elevations of 600 to 1,200 m that are replaced to the north beyond the Yukon River by more rugged mountains. Next, the road progresses into the Ambler and Chandalar Ridge and Lowland Province, which begins at the South Fork Koyukuk River. The southern part of this section is a discontinuous line of gently irregular to rugged ridges with elevations of 900 to 1,400 m. Farther north and extending to Coldfoot is a region of lowlands and low passes (60 to 600 m in elevation) that contains several east-west-trending ridges.

East-west-trending topography continues in the Brooks Range, which begins abruptly at Coldfoot. Ridges rise to rugged, glacially sculptured peaks of about 1,300 to 2,000 m elevation in the south and 2,300 to 2,700 m in the north. Differences in erosion of belts of sedimentary and metamorphic rock have produced the east-west grain of the topography. Cliff and bench slopes characteristic of glacially eroded bedded rocks are also present. Major rivers flow north and south in flat-floored, glaciated valleys.

North of the Brooks Range, the road drops abruptly to the hills and lowlands of the Arctic Foothills just north of Galbraith Lake. The southern part of the Foothills varies in elevation from 350 to 1,050 m and includes irregular buttes, knobs, mesas, east-west-trending ridges, and intervening, gently irregular tundra uplands. Elevation in the northern part of the Arctic

[3] Modified from Brown and Berg (1980).

Foothills decreases from about 350 m above sea level in the south to 180 m in the north. The foothills there are characterized by broad east-west-trending ridges and local mesalike mountains.

Finally, near the confluence of the Sagavanirktok and Ivishak Rivers, the road passes into the White Hills section and the Arctic Coastal Plain, which slopes gently to the Arctic Ocean. The flat topography of the Coastal Plain is broken by scattered pingos (ice-cored mounds), occasional low hills of Tertiary rocks, and bluffs bounding river terraces in Quaternary deposits. The Coastal Plain is poorly drained, and a significant part is covered by elongated and oriented thaw lakes and marshy thaw-lake basins.

PERMAFROST AND GROUND ICE[4]

Perennially frozen ground, or permafrost, is defined as a thickness of soil or other superficial deposit (or even of bedrock) that has been colder than 0°C for 2 or more years (Muller, 1947). Permafrost is continuous north of Atigun Pass and discontinuous in much of interior Alaska to the south, including areas within the valleys south of the Continental Divide in the Brooks Range (Ferrians, 1965; Ferrians and others, 1969). The term 'continuous permafrost' implies that permafrost underlies all or nearly all the landscape, including small ponds and streams, and has a temperature lower than -5°C at the depth of zero annual seasonal change or amplitude (about 15 m). In the zone of discontinuous permafrost, ground temperatures are higher than -5°C, and most north-facing and low areas are underlain by permafrost, but south-facing slopes and areas beneath bodies of water may be permafrost free.

Permafrost is thicker than 600 m in northern areas but is only one to several meters thick near its southern limit. Permafrost soils may be nearly ice free in coarse, unsaturated material and may contain more than 50 percent ice in fine-textured soils. The soil layer overlying permafrost thaws and freezes each year and is therefore termed the 'active layer.'

Permafrost underlies much of the route. The road traverses major portions of both the discontinuous and continuous permafrost zones (fig. 1). Temperature of the permafrost below the zone of seasonal temperature variation generally ranges between -5° and -1°C in the lowlands of the southern discontinuous zone (Ferrians, 1965). The mean annual air temperature there probably ranges between -7° and 0°C. In the continuous zone north of the Continental Divide, permafrost temperatures are believed to range between -11° and -5°C.

Considerable information on the permafrost terrain over which the route passes is available from pipeline and road borings (Kreig and Reger, 1976; Kreig, 1977; Tart and Ghuman, 1979) and is summarized on pipeline terrain maps (R&M Consultants, 1974) and in a route atlas of annotated stereo aerial photographs (Kreig and Reger, 1982). In addition, the location and mode of construction of the pipeline offer indirect evidence of ground-ice conditions.

The design of the pipeline required thaw-stable conditions for the buried mode; thus the pipeline is elevated where it is underlain by frozen, or possibly frozen, fine-grained soils likely to contain significant amounts of ground ice. In the northern section, VSM's with heat pipes are indicative of the presence of massive ice. Insulated, gravel-covered berms around some VSM's maintain or reduce the thickness of the active layer. Buried portions of the pipeline (except for where special designs were used) are in locations where unconsolidated deposits are relatively free of excess ground ice, in

[4] Modified from Brown and Berg (1980).

competent bedrock, or in nonpermafrost terrain. North of the Yukon River more than half of the pipeline is elevated.

Ground ice in permafrost, particularly its abundance and distribution, are significant considerations in route selection, road design, construction techniques, and maintenance practices. Ground ice occurs as pore fillings, films, lenses, layers, and other small segregated masses as thick as 15 cm, and as massive ice in the form of large sheets, wedges, and dome-shaped intrusions in peat mounds and pingos (see the discussion of pingos in the hydrology section). Segregated ice, which results from the separation of water from saturated soils during the freezing process, can occupy as much as 80 percent of the total volume of the upper 5 m or so of permafrost terrain (Sellmann and others, 1975). Vertical ice wedges, which commonly exceed 1 m in width at the top, have formed over many centuries in the permafrost and are responsible for the delineation of polygonal ground in the treeless tundra (Leffingwell, 1919; Lachenbruch, 1962). It is not uncommon, however, for ice wedges to show virtually no polygonal surface expression. Ice wedges are actively growing in the colder, continuous permafrost zone (fig. 1). Most segregated ice occurs in fine-grained, unconsolidated sediments. Ground ice is also found in coarse, unconsolidated materials and in apparently competent, frozen bedrock. Buried icings, pond ice, sheets of injected ice, and possibly buried glacial ice (Hamilton, 1982) can also be found in the permafrost.

The distribution of ground ice is highly variable, and in places masses of ground ice are abundant. Windblown silt (loess) commonly contains buried masses of ground ice (for example, near the Yukon River), and fine-grained colluvial, glacial, and fluvial deposits may also be ice rich. For example, highway drill logs of silt near Erickson Creek reveal large amounts of massive ice (Kreig and Reger, 1982, pl. 12). The dominant form of ice masses is the polygonal ice wedge.

South of the Brooks Range, the presence of permafrost and the thickness of the active layer are closely related to slope angle and aspect, vegetation, thermal properties of parent materials, and drainage. Vegetation is a general indicator of permafrost conditions. Within the regions covered by the guidebook, black spruce, larch, and bogs nearly always indicate the presence of permafrost within 0.6 m of the surface. White spruce and aspen usually indicate an area that is free of permafrost or that has an active layer 1 m or more thick. Pure stands of paper birch are found on sites free of permafrost or where the active layer has been temporarily deepened by burning or clearing. Generally, well-drained, south-facing slopes and sediments beneath the active channels of large streams are free of permafrost. Valley bottoms, north-facing slopes, and wet lower slopes are usually underlain by permafrost with an active layer thickness of 0.5 to 1.0 m. In perennially frozen areas, thaw bulbs exist beneath smaller streams. The overall thickness and lateral continuity of permafrost generally increase northward.

The Brooks Range is within the continuous zone of permafrost north of the Continental Divide and within the discontinuous zone south of the Divide. Both air and ground temperatures are extremely variable, as is the thickness of permafrost, but the bedrock and unconsolidated deposits on slopes are generally perennially frozen, except for south-facing slopes south of the Divide. The coarse-textured and freely drained material on upper slopes has a deep active layer, and the wet, fine-grained material on lower slopes has an active layer that is commonly between 0.5 and 1.0 m thick. Permafrost is, however, generally discontinuous beneath the flood plains and south of the Divide is probably absent in most places beneath the active channels of larger rivers like the Chandalar, Dietrich, and Middle Fork Koyukuk. Thaw bulbs occur beneath small drainages such as Minnie Creek. On the basis of observations made during pipeline construction, the valleys of the Dietrich and Koyukuk Rivers should now be considered to occupy the northern discontinuous permafrost zone. The fine-grained deposits of the Brooks Range usually contain large amounts of ice-wedge ice. Coarse-grained materials contain ice in their voids, as coatings on individual particles, or as massive bodies in mudflow cones, rock glaciers, and some talus deposits.

The Arctic Foothills and the Arctic Coastal Plain are underlain by thick permafrost that reaches a maximum depth of approximately 600 m at Prudhoe Bay (Gold and Lachenbruch, 1973). About 130 km south of the Arctic Ocean, ice-bearing permafrost is 200 m thick; it increases northward to more than 500 m (and locally to 630 m) near the shore at Prudhoe Bay (Osterkamp and Payne, 1981; Lachenbruch and others, 1982). Primary causes of changes in permafrost thickness are differences in thermal conductivity of the rocks and increased heat flow. Permafrost is thickest in the highly porous Tertiary and Quaternary deposits, successively thinner in the less porous Upper Cretaceous rocks, and thinnest in the least porous Lower Cretaceous rocks. Thickness of the active layer is generally less than 0.5 m in predominantly fine-grained soils. Unfrozen zones are generally limited to deep river channels, some of which have unfrozen gravel beneath them, and large, deep lake basins. Perennial springs indicate that local zones of unfrozen bedrock provide avenues for recharge and discharge of ground-water systems.

In the Arctic Foothills, ice-wedge polygons are particularly conspicuous in poorly drained depressions and drained lake basins. Ice-wedge polygons cover most of the Arctic Coastal Plain. Closed-system pingos have developed in some refrozen lake basin sediments of various ages. Although locally present in large amounts, other forms of massive ice show little surface expression. Ground ice was observed and logged by Alyeska in many VSM borings, in fuel-gas line trenches, and in the pipeline trench in areas where the pipe was placed in thaw-stable gravel beneath a silty, ice-rich surface layer. Development of thermokarst ponds indicates its presence in other areas.

HYDROLOGY

Streamflow and water-quality data have been collected at a number of sites along the Elliott and Dalton Highways. Many of the sites are part of the U.S. Geological Survey (USGS) network of hydrologic observation stations in Alaska, but many more were installed in connection with the Trans-Alaska Pipeline System and have since been discontinued. The purpose of these observations is to determine the flow characteristics of the principal rivers and representative small streams, the total runoff, and changes in water quality. Specific hydrologic studies were needed in connection with the pipeline to determine scour depth at bridges and crossings, to predict lateral channel erosion, to design river training structures, and to obtain preconstruction baseline water quality and biological data. The results of these studies are published in USGS Water-Supply Papers and in various technical journals.

Mean annual runoff (Feulner and others, 1971) along the route is less than 0.005 $m^3/s \cdot km^2$ in northern Alaska, between 0.005 and 0.011 $m^3/s \cdot km^2$ in the interior, and from 0.011 to slightly more than 0.022 $m^3/s \cdot km^2$ in the Brooks Range, where the orographic effect results in higher precipitation. Mean annual peak runoff is less than 0.27 $m^3/s \cdot km^2$, except in the Brooks Range, where it exceeds 0.54 $m^3/s \cdot km^2$. Annual low monthly runoff is zero north of the crest of the Brooks Range and less than 0.0014 $m^3/s \cdot km^2$ south of the range along the highway route. The lowest flow generally occurs in late

March or April; peak flow, provided by melting of the winter snow, takes place in May or June. The winter ice cover usually breaks up between late April and early June, the latter being characteristic of the northern part of the route. Freezeup generally occurs in late September or October.

Along the road in the central and northern Brooks Range, summer precipitation apparently is greater on the north side than on the south side (239 mm vs 165 mm; L.J. Onesti, pers. commun.). Watershed observations in the northern Dietrich River and the Atigun River indicate that 42 percent of the summer runoff is from summer precipitation and the rest from ground water and melting of snow and ice. June and July discharge from snowmelt and precipitation represent approximately 80 percent of the annual precipitation. The average annual sediment yield for streams in the Atigun Pass area varies from 87 to 1,240 metric tons/km^2.

Ground-water resources along the Elliott and Dalton Highways are meager compared to the prolific aquifers of the Tanana River Valley near Fairbanks (Williams, 1970; Feulner and others, 1971; Zenone and Anderson, 1978). From Fox to the South Fork Koyukuk River, the route crosses bedrock uplands with a varying thickness of generally fine-grained surficial deposits. These deposits are typically frozen to bedrock, except on southerly exposures. Valleys are commonly filled with frozen, fine-grained, unconsolidated deposits. Larger valleys like Hess Creek are filled with partially frozen coarse-grained alluvium. The Yukon River is large enough to maintain a talik or thaw bulb through the permafrost beneath its channel. The Middle Fork Koyukuk River and Dietrich River valleys have many areas of unfrozen ground beneath and near their channels. In some places the cover of fluvial gravel is thin, and much of the unfrozen underlying sediment consists of glaciolacustrine deposits and till that lack sufficient permeability to produce large amounts of water.

North of the Brooks Range, where permafrost extends from near the surface to depths of 200 to more than 600 m, ground water beneath permafrost in bedrock of pre-Tertiary age or in unconsolidated deposits of Tertiary age is generally too highly mineralized to be useful as a water supply. A collection gallery installed in gravel within the thaw bulb beneath a stable channel of the Sagavanirktok River at Prudhoe Bay (Sherman, 1973) was inadequate to supply the requirements for domestic and drilling water, and it eventually became clogged with silt. To accommodate winter demands, reservoirs were created in thaw lakes that were deepened and filled from the river during the summer. Wells were used to supply pipeline construction camps at Livengood, Dietrich, Old Man, Prospect, Galbraith, and other sites by locating unfrozen zones in gravel, commonly adjacent to streams. Ground-water sources, where available, provide a year-round supply of water that eliminates the need for storing and for hauling from a river.

Special cases of ground-water flow are described in the following sections on icings and pingos.

Icings

Icings (aufeis) are sheets of surface ice composed of a number of ice layers formed during successive overflows on broad, braided-river flood plains, narrow channels of small streams, or the ground downstream from seasonal or perennial springs. In rivers, icings generally form when water is forced to discharge at the surface because freezing has blocked the stream flow within the channel or the thaw bulb beneath it. Icings are fed not only by river water and underflow but also by discharge of ground water stored in

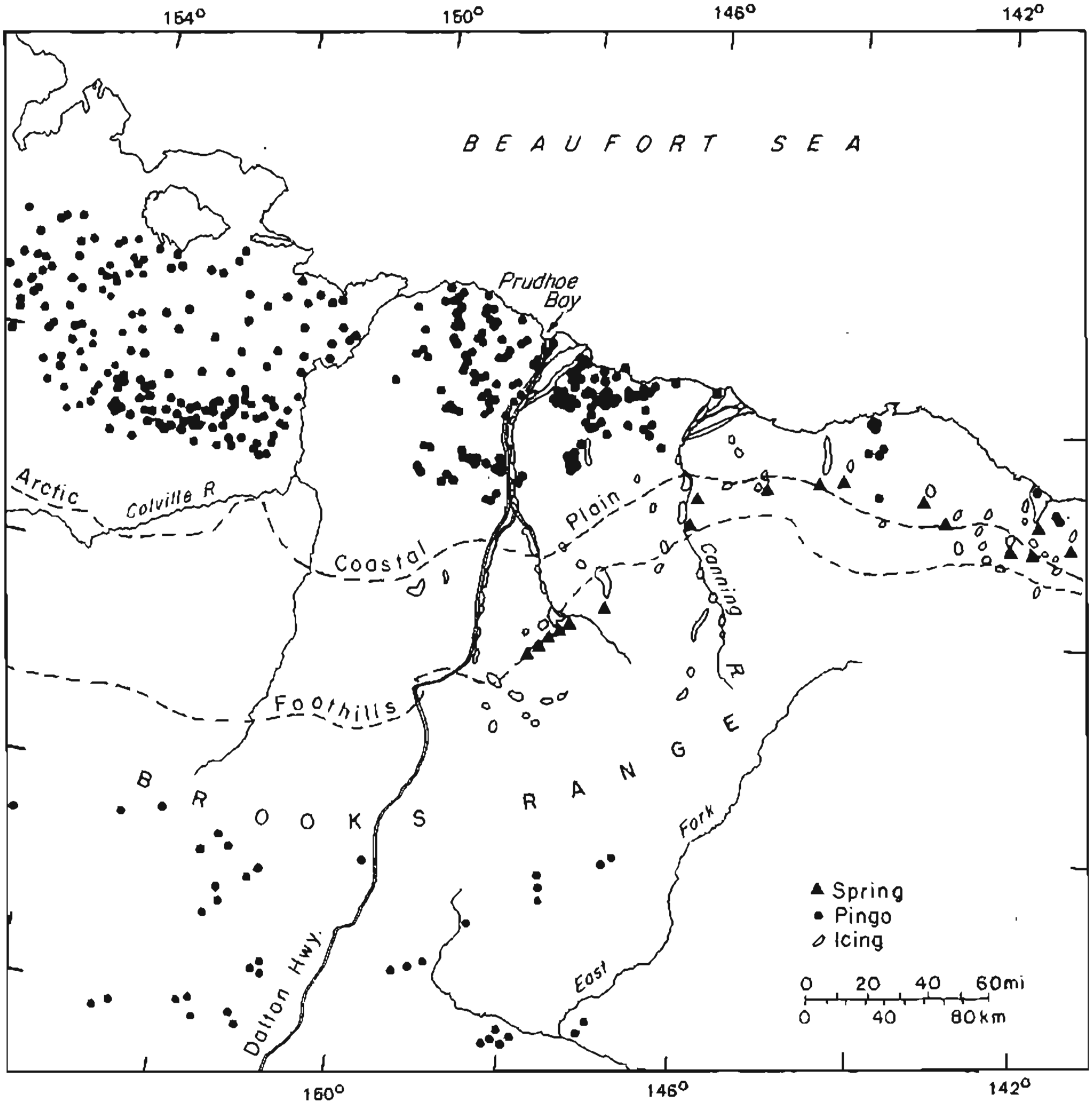

Figure 5. Location of pingos, icings, and springs in northeastern Alaska (based on Carter and Galloway, 1979, fig. 14; Hamiltom and Obi, 1982, fig. 1; Sloan and others, 1976, figs. 7, 8, and 11; and Ferrians, pers. commun.).

unfrozen, unconsolidated deposits of tributary alluvial fans and by water discharged from bedrock through solution channels, joints, and faults.

Icings are an important part of the annual cycle of stream flow, storing water in winter at the expense of stream flow and releasing it to augment stream flow during the thaw season. Only a few preliminary estimates of the effect of icings on stream flow are available (Williams and van Everdingen, 1973). This effect is particularly important in evaluating fish habitat and in designing structures along streams.

Processes of icing formation and measures that can be taken to eliminate them or divert them from sites where they cause problems have been discussed by Carey (1973). Periodic studies of icings have been made by the USGS since

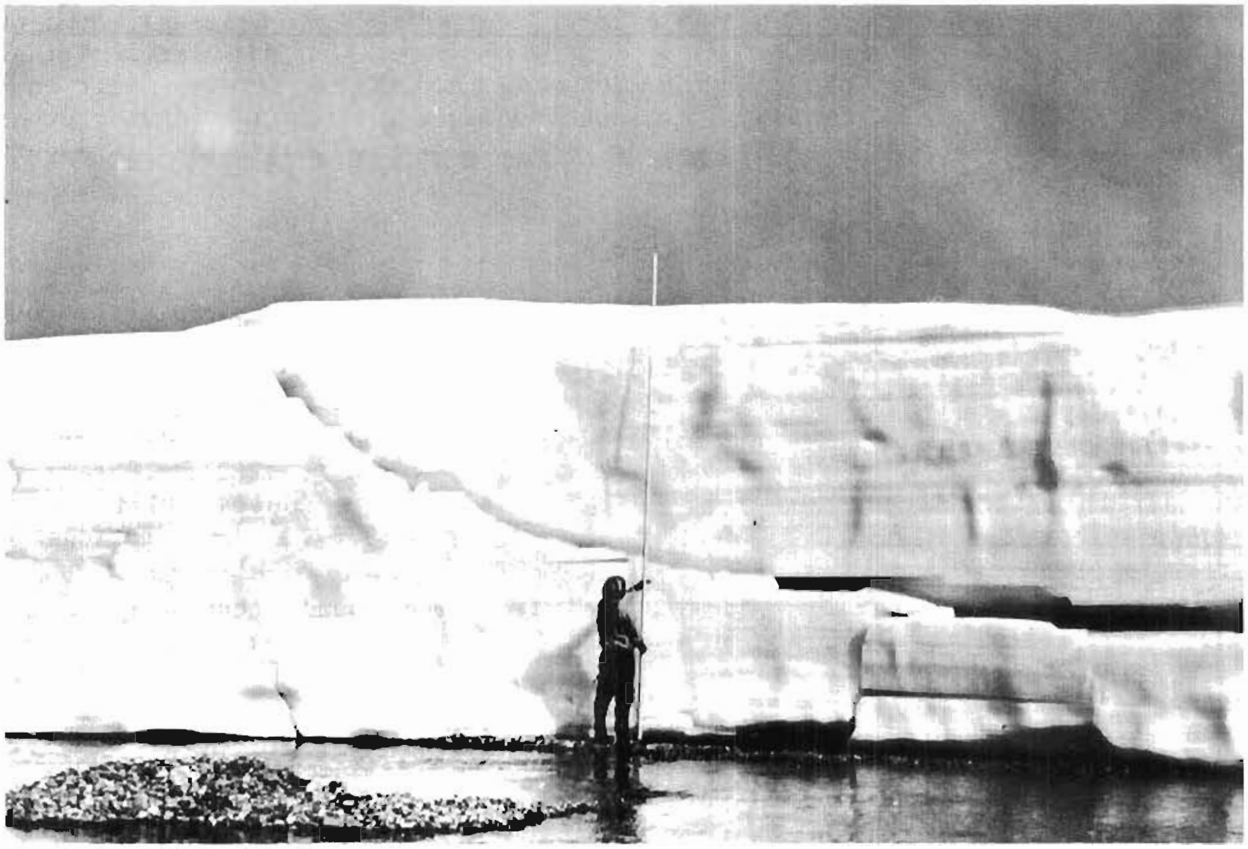

Figure 6. Echooka River icing, about 5 m thick. Layering in ice shows that numerous overflows built the icing (Sloan and others, 1976, fig. 10).

1969. Special emphasis has been placed on icings along the pipeline route and in the central and eastern Brooks Range, where they are fed by numerous springs issuing from faults bounding the Lisburne Limestone or from fractures and solution cavities within that formation (Williams, 1970; Childers and others, 1973; Williams and van Everdingen, 1973; Sloan and others, 1976; Sloan, unpublished data). Hall (1980) and Hall and Roswell (1981), in a comparison of the chemistry of icings and river water, indicated a possible bedrock source for water feeding icings on the Shaviovik, Canning, and other rivers of the eastern Arctic Coastal Plain.

Icings along the Elliott and Dalton Highways based on pre-pipeline observations (Sloan and others, 1976) are shown on the strip maps; the locations of icings in northeastern Alaska are shown in figure 5. Larger icings occur annually, but their size and thickness may vary, depending on meteorological and hydrologic conditions. Most of the icings between Fox and the Middle Fork Koyukuk River are confined in small stream channels, except at Fish Creek, where icings are produced by numerous springs issuing from schist bedrock. Slaughter (1982) reported annual variations of icings on Caribou Creek, situated northeast of Fox in the uplands. The Middle Fork Koyukuk River has icings that are generally limited to the main channel and which probably form by constriction of the channel flow and underflow by freezing. On the Dietrich and Atigun Rivers, broad icings occupy the entire braided flood plain. They seem to be supplied by water stored in the unfrozen gravel of tributary alluvial fans, by freezing of the river and its bed, and possibly by discharge of water from bedrock. East of the highway route, along the north flank of the Brooks Range, there are more than 50 spring-fed icings, some of which grow to be more than 5 m thick (fig. 6). Several of the larger icings (for example, those on the Kongakut, Echooka, and Ivishak Rivers), melt completely some years, but persist throughout the summer and winter during other years, as does the icing located on the west side of Galbraith Lake (Childers and others, 1977).

Pingos

Pingos are special hydrologic features that form under periglacial conditions. Leffingwell (1919) and Porsild (1938) were among the first to note pingos on the Arctic Coastal Plain in the continuous permafrost zone. More recently, nearly 300 pingos and pingolike mounds have been located in central Alaska in the discontinuous permafrost zone (Holmes and others, 1968), and 74 have been reported in the Brooks Range (Hamilton and Obi, 1982). More than 1,000 pingos have now been catalogued on the Arctic Coastal Plain (O.J. Ferrians, Jr., pers. commun.; Galloway and Carter, 1978). The locations of individual pingos or groups of pingos are shown in figure 5.

Pingos are perennial, conical-shaped ice-cored mounds that are, in exceptional cases, as much as 65 m high and 1,000 m in diameter (Mackay, 1979). The largest pingos are on the Arctic Coastal Plain, where they dominate the flat terrain. They can be seen along the Dalton Highway west of Franklin Bluffs. Studies of pingos in Alaska have been largely restricted to description and classification in open- and closed-system categories (following Müller, 1959). Little attention has been given to the mechanics of their formation.

Basically, open-system pingos, characteristic of interior Alaska and many of the southern valleys of the Brooks Range, are formed on lower slopes. There artesian pressure is likely to be greatest and artesian flow may be blocked or localized (Holmes and others, 1968), either in an alluvial aquifer buried by fine-grained deposits or in bedrock, as shown by the alignment of pingos along rock fractures and by the inclusion of bedrock fragments in pingo sediments. Most pingos are apparently of Holocene age, for the youngest sediments that have been deformed are no older than 7,000 yr in the interior (Holmes and others, 1968). Pingos postdate the late Wisconsin glaciation in the Brooks Range (Hamilton and Obi, 1982).

Closed-system pingos occur in regions of continuous permafrost and are formed by hydrostatic pressure caused by freezing of water-saturated sediments within the thaw bulb beneath recently drained lakes (Mackay, 1979). All the pingos of the Arctic Coastal Plain and those reported (Hamilton and Obi, 1982) from a northern valley of the Brooks Range and from the Noatak River Valley are of this category. Hall and Roswell (1981), however, believed that several pingos located in an area devoid of drained deep lakes near the Shaviovik River icing may be of the open-system type, supplied, like the icings, from an artesian system that perforates the permafrost.

Pingos in the Arctic Coastal Plain west of the Colville River are concentrated in areas, largely of dune sand, where the sand thickness exceeds 15 m. Only 8 percent of the 732 pingos have developed on thin sand, alluvium, and upland silt, and none have been formed on marine silt (Galloway and Carter, 1978; Carter and Galloway, 1979). Those pingos east of the Colville River and east of the Canning River, including the area of the Dalton Highway, have formed on the Coastal Plain, which is commonly underlain by 1 to 5 m of poorly bedded to massive, pebbly, silty sand and sandy silt, which in turn is underlain by more than 300 m of sandy gravel and gravelly sand.

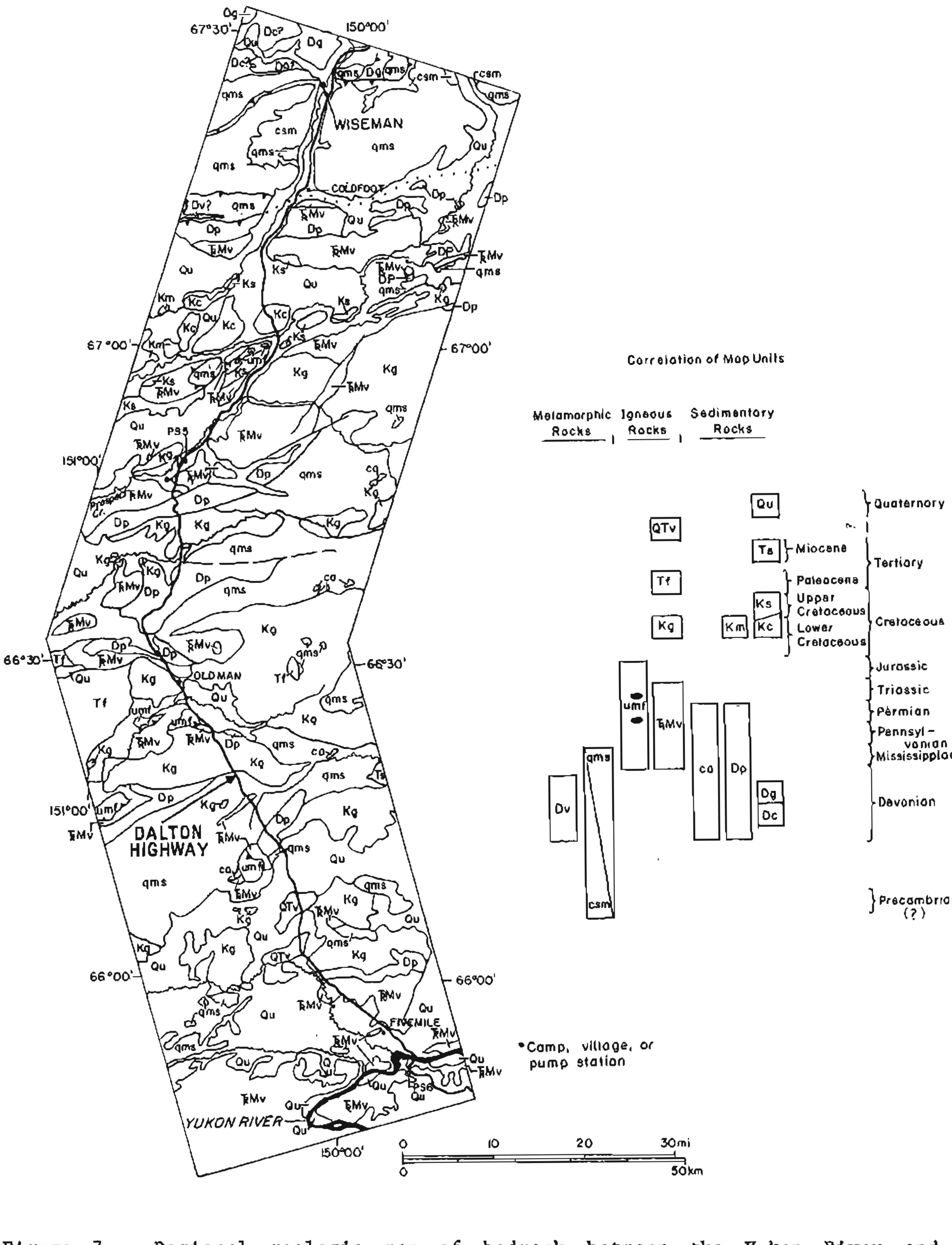

Figure 7. Regional geologic map of bedrock between the Yukon River and Wiseman (compiled from published sources by W.P. Brosgé and W.W. Patton, Jr.).

GEOLOGY

Bedrock Geology

The bedrock geologic maps (figs. 7, 8) furnish a generalized overview of the types and ages of bedrock units along most of the route (Brosgé and Patton, 1982). These maps may be supplemented by reference to a) a statewide map with a cross section along the pipeline corridor (Bennison, 1974) and b) the following more detailed maps of the route (see figure 15 for the locations of the 1:250,000 quadrangle sheets):

entire route at 1:1,000,000	(Beikman and Lathram, 1976)
Fairbanks (1:250,000) Quadrangle	(Péwé and others, 1966)
Livengood (1:250,000) Quadrangle	(Chapman and others, 1971)
Tanana (1:250,000) Quadrangle	(Chapman and others, 1975, 1982)
Beaver (1:250,000) Quadrangle	(Brosgé and Reiser, 1973)
Bettles (1:250,000) Quadrangle	(Patton and Miller, 1973)
Wiseman (1:250,000) Quadrangle	(Brosgé and Reiser, 1971)
Philip Smith Mountains (1:250,000) Quadrangle	(Brosgé and others, 1979)
Chandalar (1:250,000) Quadrangle	(Brosgé and Reiser, 1964)

Coverage of those portions of these quadrangles along the pipeline-highway corridor, including Quaternary deposits as well as bedrock, was prepared by the USGS in 1971 as basic information needed for the TAPS pipeline project (Ferrians, 1971b; Kachadoorian, 1971a, b, c). These 1:125,000-scale maps also cover the transportation corridor in the Arctic Coastal Plain and Foothills within the Beechey Point and Sagavanirktok Quadrangles (Ferrians, 1971a). The 1:125,000 maps, reduced to 1:250,000 scale, have been supplemented by mineral deposit information and republished by Mulligan (1974).

DESCRIPTION OF MAP UNITS IN FIGURE 7

Sedimentary rocks

Qu **Undifferentiated surficial deposits** (Quaternary)

Ts **Sedimentary rocks** (Miocene?)—tuff, siltstone, conglomerate and coal. Nonmarine.

Ks ***Conglomerate and sandstone*** (Upper and Lower Cretaceous)—clasts of quartz, quartzite, schist and igneous rocks. Nonmarine.

Kc **Igneous pebble conglomerate** (Lower Cretaceous; Albian)—clasts of mafic volcanic rocks, chert and graywacke. Marine(?).

Km **Marine graywacke and mudstone** (Lower Cretaceous; Albian)—clasts of volcanic rocks.

Dg **Unnamed graywacke and siltstone** (Upper and Middle[?] Devonian)—dark gray phyllite and polymetamorphosed chloritic meta-siltstone. Thin beds of marble in upper part.

Dc **Unnamed chloritic and calcareous meta-sediments** (Middle[?] Devonian)—brown and gray weathering partly calcareous slate and phyllite. Polymetamorphosed.

Dp **Phyllite and graywacke** (Devonian[?] or younger)—dark gray phyllite and fine-grained lithic wacke. Slightly metamorphosed.

ca **Undivided carbonate rocks** (Devonian(?) or younger)—marble and calc-silicate hornfels.

Igneous rocks

QTv **Volcanic rocks** (Quaternary or Upper Tertiary)—flat-lying flows of olivine basalt.

Tf **Felsic and intermediate volcanic rocks** (Paleocene)—porphyritic flows, breccia, conglomerate and tuff.

Kg **Granitic rocks** (Lower Cretaceous?)—porphyritic quartz monzonite; granodiorite and monzonite.

umf **Ultramafic rocks** (Jurassic?)—serpentinized peridotite and dunite.

TrMv **Volcanic rocks** (Triassic, Permian, Pennsylvanian and Mississippian)—pillow basalt, diabase and gabbro; chert and cherty mudstone.

Metamorphic rocks

Dv **Volcanic rocks** (Upper and Middle[?] Devonian)—mafic greenschist.

qms **Undivided quartz-mica schist** (Precambrian[?], Devonian[?], and Mississippian[?])—quartz-mica schist, chlorite schist and minor quartzite. Lower greenschist to almandine-amphibolite facies; andalusite-cordierite hornfels near Cretaceous granites.

csm ***Undivided calcareous schist and marble*** (Precambrian[?] to Devonian[?])—brown-weathering muscovite-quartz-calcite schist interbedded with schistose marble and quartz-mica schist.

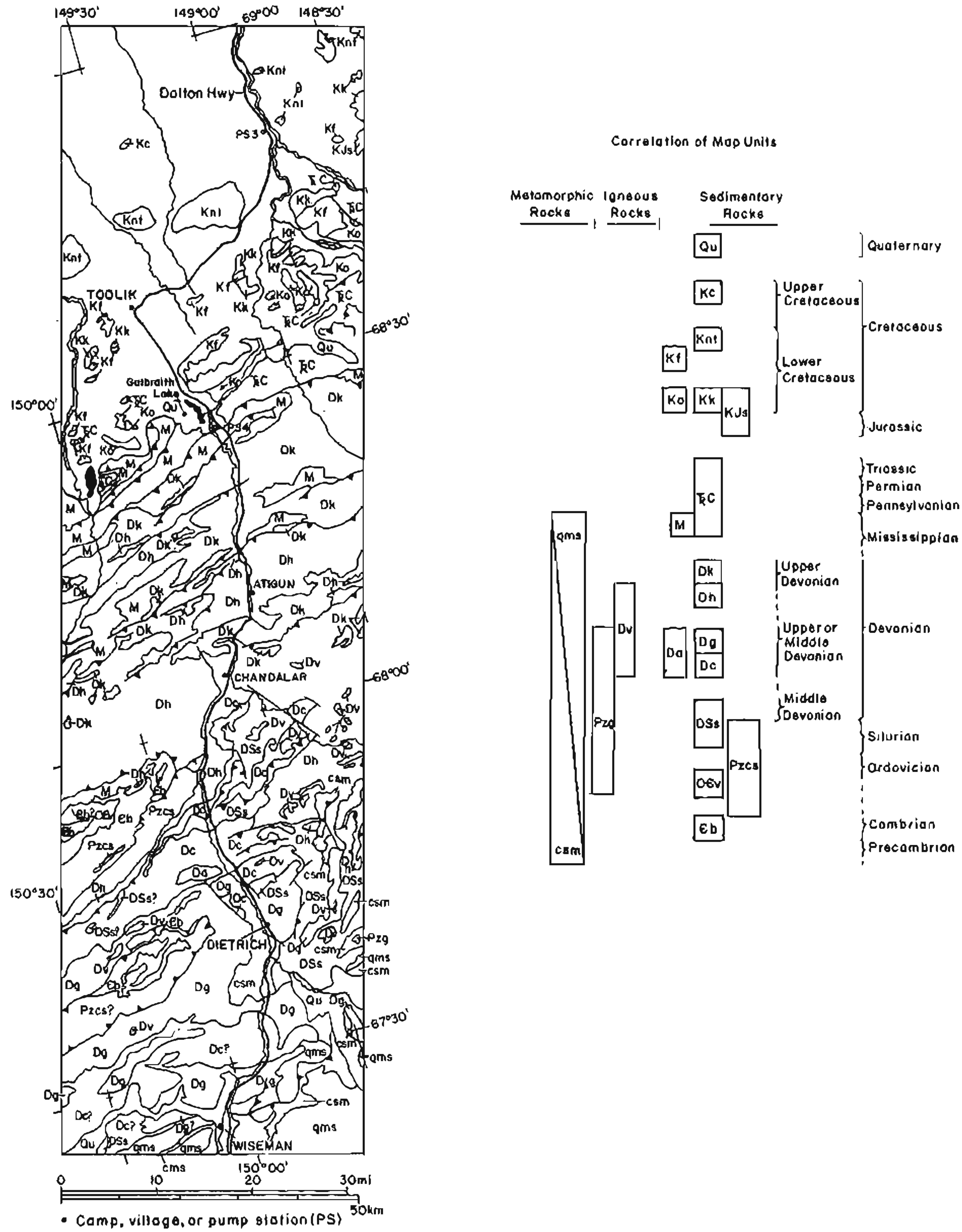

Figure 8. Regional geologic map of bedrock between Wiseman and Toolik (compiled from published sources by W.P. Brosgé and W.W. Patton, Jr.).

DESCRIPTION OF MAP UNITS IN FIGURE 8

Sedimentary rocks

Qu **Undifferentiated surficial deposits** (Quaternary)—shown only in the largest valleys.

Kc **Colville Group** (Upper Cretaceous)—sandstone, shale and tuff. Mostly nonmarine. Exposed thickness about 60 m.

Knt **Nanushuk Group and Torok Formation** (Upper and Lower Cretaceous; Cenomanian and Albian)—Nanushuk Group: conglomerate, sandstone and shale; fluvial and shallow marine; thickness at least 600 m. Underlying Torok Formation: marine shale and siltstone; more than 130 m thick.

Kf **Fortress Mountain Formation** (Lower Cretaceous; Albian)—polymict conglomerate, wacke, siltstone and shale. Marine and nonmarine. Thickness 1300 m.

Ko **Okpikruak Formation** (Lower Cretaceous)—rhythmically bedded siltstone, graywacke and conglomerate. Marine. More than 600 m thick.

Kk **Kongakut Formation** (Lower Cretaceous)—black shale and siltstone; floating chert pebbles in lower part. Marine. More than 300 m thick.

KJs **Kongakut Formation and Kingak Shale, undivided** (Lower Cretaceous and Jurassic)—black shale and siltstone. Marine. As much as 700 m thick.

TrC **Shublik Formation, Otuk Formation, Sadlerochit Group, Lisburne Group and Kayak Shale undivided** (Triassic, Permian, and Carboniferous)—Shublik Formation: black calcareous phosphatic shale and siltstone and gray limestone; marine; 30 to 150 m thick. Otuk Formation: varicolored chert laterally equivalent to Shublik Formation. Sadlerochit Group: siltstone, shale, sandstone and limestone; marine in this area; about 500 m thick. Lisburne Group: gray cherty limestone and dolomite; marine; about 700 to 1000 m thick. Kayak Shale: black shale, limestone and sandstone; marine; about 300 m thick.

M **Lisburne Group, Kayak Shale and Kekiktuk Conglomerate undivided** (Pennsylvanian and Mississippian)—Pennsylvanian part of Lisburne Group is thin to absent in this area. Kekiktuk Conglomerate: quartzite and granule conglomerate about 10 m thick present only in southernmost outcrops; rests unconformably on Lower Paleozoic rocks.

Dk **Kanayut Conglomerate** (Mississippian[?] and Upper Devonian)—quartzite, sandstone, conglomerate and gray to red shale and siltstone. Fluvial; deposited by southwestward-flowing streams. About 1000 m thick; absent where Kekiktuk Conglomerate rests on Lower Paleozoic rocks.

Dh **Noatak Sandstone, Hunt Fork Shale and Beaucoup Formation undivided** (Upper Devonian)—mostly drak gray shale and siltstone; interbedded wacke in upper part; some reefal limestone and conglomerate in lower part; minor sandstone throughout. Marine. Upper part is prodeltaic and shoreline deposits gradational into Kanayut Conglomerate. About 1500 to 2000 m thick; absent where Kekiktuk Conglomerate rests on Lower Paleozoic rocks. Metamorphosed to slate and phyllite in southern part of area.

Dg **Unnamed graywacke and siltstone** (Upper and Middle[?] Devonian)—dark gray and gray-green slate and phyllite, metagraywacke with mafic rock clasts, and chloritic metasiltstone; thin fossiliferous Upper Devonian limestones in upper part. Polymetamorphosed.

Dc **Unnamed chloritic and calcareous metasediments** (Middle[?] Devonian)—green, red, purple and dark gray slate and phyllite; brown and orange weathering calcareous slate, metasandstone and schist; gray marble. Polymetamorphosed.

Da **Unnamed volcanic conglomerate** (Devonian[?])—sheared mafic pebble conglomerate and breccia grades into volcanic phyllite.

DSs **Skajit Limestone** (Middle Devonian and Silurian)—gray, non-cherty marble, and gray and orange dolomite. As much as 600 m thick.

Pzcs **Unnamed calcareous meta-siltstone** (Lower Paleozoic)—gray and gray-green partly calcareous slate and meta-siltstone, and gray thin-bedded micaceous limestone. Weathers brown and orange.

OEv **Unnamed volcanic and sedimentary rocks** (Ordovician and Cambrian[?])—andesitic and basaltic pyroclastic rocks and volcanic conglomerate; black and green phyllite; sills and dikes of gabbro and diorite.

Eb **Unnamed black meta-siltstone** (Cambrian)—black, pyritic meta-siltstone and phyllite; thin fossiliferous limestone locally in upper part. Includes many small unmapped mafic sills and dikes.

Igneous rocks

Dv **Unnamed volcanic rocks** (Upper and Middle[?] Devonian)—gabbro and diabase sills as much as 100 m thick; pillow basalt flows 10-80 m thick. Metamorphosed to greenstone and greenschist.

Pzg **Granitic rocks** (Devonian[?] and/or Ordovician[?])—gneissic granodiorite and quartz monzonite with conflicting Ordovician, Devonian and Cretaceous isotopic ages.

Metamorphic rocks

qms **Undivided quartz-mica schist** (Precambrian[?], Devonian[?] and Mississippian[?])—gray to black, coarse to fine-grained quartz-muscovite-chlorite-albite schist, locally with biotite and garnet. Includes some mafic greenschist. Polymetamorphosed. Ages are from Dillon, Hamilton, and Lueck (1981) and Nelson and Grybeck (1980).

csm **Undivided calcareous schist and marble** (Precambrian[?] to Devonian[?])—brown weathering muscovite-quartz-calcite schist interbedded with schistose marble and quartz-mica schist. Polymetamorphosed. Altered to calc-silicate hornfels around granitic rocks (Pzg).

Glacial Geology of the Brooks Range[5]

The physiography of the Brooks Range has been strongly modified by repeated glacial advances during late Tertiary and Quaternary time. Glaciation has also been responsible for many of the surficial deposits within the range and in the foothills beyond its north and south flanks. The Brooks Range glacial sequence was defined initially by Detterman (1953) and subsequently modified by Detterman and others (1958), Williams (1962), Porter (1964, 1966), Hamilton and Porter (1975), and Hamilton (1978c, 1979d, 1982). Glacial deposits are divisible into three major groups, with the youngest group representing at least three separate episodes of valley-glacier advances that were followed by cirque-glacier expansion during the last 3,000 to 4,000 yr (table 2; fig. 9).

The oldest period of glaciation is represented by the informally named 'Gunsight Mountain' erratics. Large (1 to 2 m) boulders of highly resistant Kanayut Conglomerate were deposited during one or more glacial advances of presumably late Tertiary age that extended north from the Brooks Range into the Arctic Foothills (Hamilton and Hopkins, 1982). These erratics later accumulated as lag deposits in alluvium during a long interval of stream erosion and pedimentation when drainage courses beyond the north flank of the range flowed 50 to 100 m above their modern levels. Gunsight Mountain erratics and correlative deposits are restricted to piedmont zones and to uplifted plateaus along mountain fronts; they cannot be traced to existing mountain valleys.

Table 2. Central Brooks Range glacial sequence with suggested age assignments (Hamilton, 1982; Hamilton and Hopkins, 1982).

```
Fan Mountain                     LATE HOLOCENE
--------------------------------------------------
Itkillik II (Walker Lake)        LATE WISCONSIN
          ----------------------------------------
Itkillik I                       EARLY WISCONSIN(?)
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Sagavanirktok River              MIDDLE PLEISTOCENE
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Anaktuvuk River                  EARLY PLEISTOCENE
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Gunsight Mountain erratics       LATE TERTIARY
```

--- Minor nonglacial erosion interval

xxxx More significant erosion interval correlated with Pelukian marine transgression of Hopkins (1973)

XXXX Major erosion interval

[5] Prepared by T.D. Hamilton.

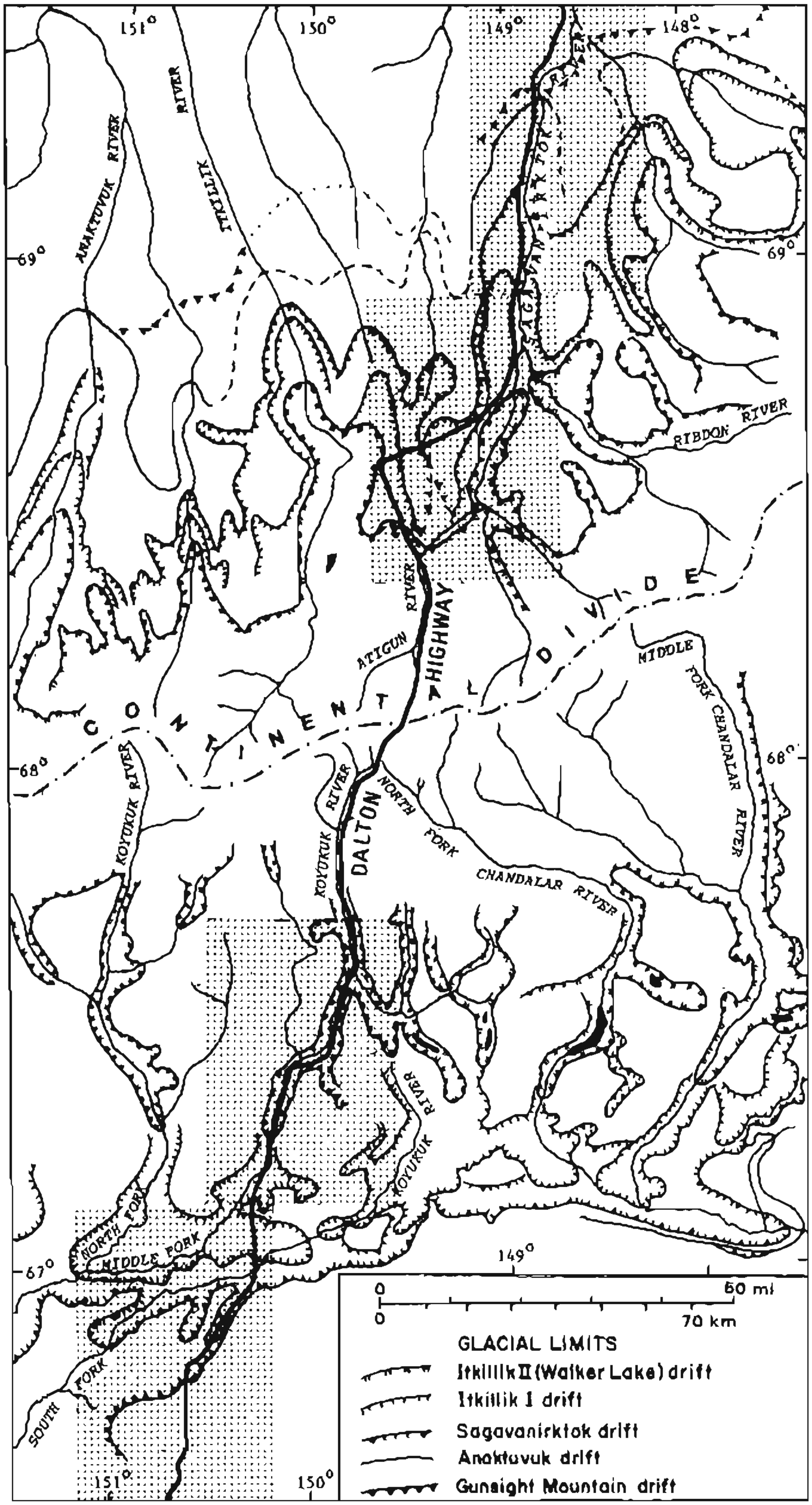

Figure 9. Glacial geology along the Dalton Highway. The index maps (shaded rectangles) show the locations of figures 71, 86, 125, and 129, which contain details of the glacial geology at 1:250,000 scale (Hamilton, 1978a,b, 1979c, 1982).

During a much younger glacial phase, the Anaktuvuk River Glaciation (Detterman and others, 1958), ice streams occupied the major mountain valleys of the present Brooks Range, but typically flowed across valley floors that were 100 m or more above the level of modern valley floors. Extensive moraines beyond the mountains are fairly continuous but subdued, with slope angles generally only 1° to 2°, drainage networks maturely developed, and complex thaw-lake basins demonstrating repeated cycles of lake formation. Erratics generally are sparse and, despite their large (1.5 to 2 m) size, typically are buried nearly flush with the ground surface. Piedmont drift sheets have been dissected by streams that flowed 40 to 65 m above their modern levels and eroded valleys as wide as 10 km. Concentric series of arcuate drainage courses separate subdued morainal ridges that could represent either several individual glacial advances or recession of a single ice tongue. Drift of Anaktuvuk River age commonly overlaps erosion surfaces of post-Gunsight Mountain age. Deglaciation was followed by a long interval of valley enlargement and pedimentation by fluvial and mass-wastage processes.

The youngest complex of drift sheets occurs on or close to modern valley floors and extends into valley centers, where it generally is within 40 m of modern stream levels. Drifts of younger and older glacial advances within this complex differ markedly from each other in weathering, soil development, and sharpness of surface morphology. The oldest drift sheet, assigned to the Sagavanirktok River Glaciation (Detterman and others, 1958), is relatively strongly weathered, subdued by mass wastage, and dissected by streams. Slope angles rarely exceed 4°, except where surfaces have been steepened by postglacial downcutting. A much younger appearing drift, assigned to the Itkillik Glaciation of Detterman and others (1958), was formerly assumed to be entirely of late-Wisconsin age (Porter, 1964; Hamilton and Porter, 1975). Recent radiocarbon dating and stratigraphic studies, however, demonstrate that initial glacial advances of Itkillik age took place prior to 50,000 yr B.P. (Hamilton, 1979d, 1982). Deposits formed during these advances are morphologically similar to and continuous with drift sheets that date from late-Wisconsin time, and they may still be ice cored in places. For these reasons, the outermost Itkillik deposits are believed to postdate the last major Pleistocene interglaciation and to be of early-Wisconsin age (Hamilton and Hopkins, 1982). Younger deposits of Itkillik age, dated at between about 25,000 and 10,000 yr B.P. in the south-central Brooks Range (fig. 10), are morphologically fresh and are still ice cored in some valleys. These drift sheets, equivalent in age to the late-Wisconsin substage of the standard North American glacial succession, have recently been assigned to the Walker Lake advance in the southern Brooks Range (Hamilton, 1982). The older term 'Itkillik II' is still used in valley systems north of the Continental Divide.

During the early- and late-Wisconsin episodes of glaciation, ice bodies originated mainly within a belt of cirques, about 30 km wide, that was centered somewhat north of the Continental Divide. Ice flowed northward along relatively short and steep glacial troughs with cirque-headed tributaries. Massive end-moraine belts dominate the surficial geology north of the range, and basins that formed behind end moraines as the glaciers retreated tended to fill rapidly with sandy sediment. Glacial valleys south of the Divide typically are longer and have gentler gradients. The absence of glaciation in many of their tributaries during the ice advances of Itkillik age led to complex flow patterns in which main-valley glaciers extended varying distances up those tributary valleys. Long (up to 50 km) depositional basins with complex geometries formed during glacier retreat, and filled slowly with clayey and silty sediments. Glacier tongues that extended beyond the south flank of the

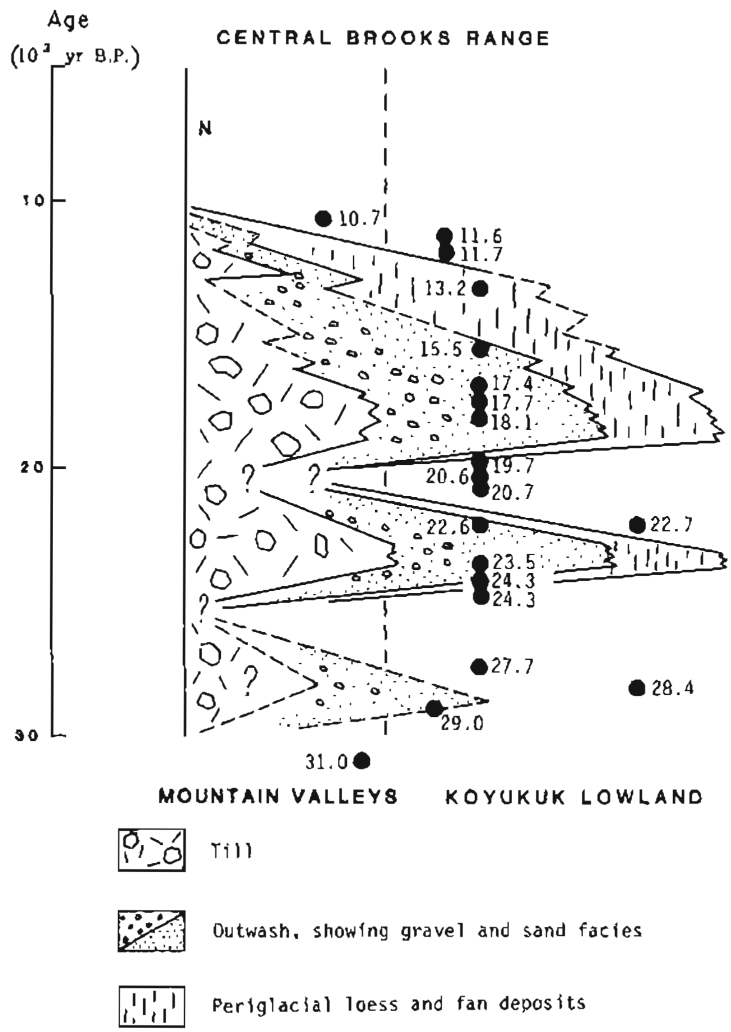

Figure 10. Time-distance diagram showing glacial and proglacial deposits of south-central Brooks Range. Radiocarbon dates (black dots) in thousands of years B.P. (modified from Hamilton, 1982, fig. 13).

range remained confined within the east-west-trending Chandalar and Koyukuk troughs. Deep erosion along parts of these river systems has exposed sections of Quaternary deposits as thick as 40 to 90 m that commonly contain successive layers of till separated by alluvium and lacustrine sediments beneath peat, loess, and thaw-lake deposits.

The youngest glacier expansions, of later Holocene (Neoglacial) age, are confined to cirques above about 1,500 m elevation. These advances have created complex assemblages of cirque moraines (Calkin and Ellis, 1981a) and caused widespread alluviation of cirque-headed mountain valleys (Hamilton and others, 1982).

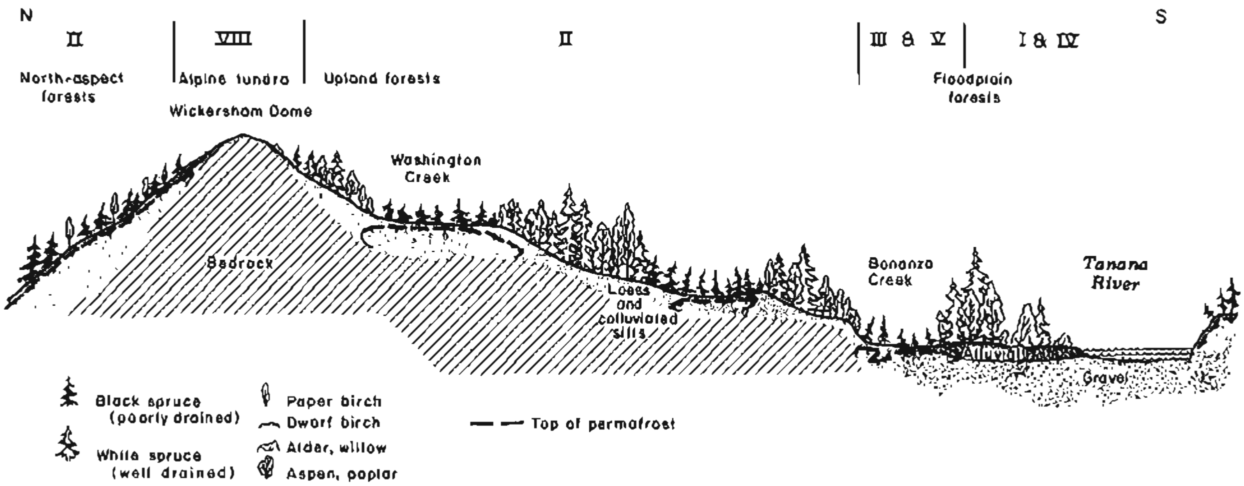

Figure 11. Idealized cross section of topography, vegetation, permafrost, and active layer from Fairbanks to Wickersham Dome (modified from Van Cleve and others, 1979, fig. 1).

VEGETATION[6]

The two major units of vegetation encountered along the route are tundra and taiga (boreal forest). From the beginning of the route at Fox to treeline in the upper Dietrich River valley, the route runs primarily through forested areas interrupted occasionally by treeless bogs in the lowlands and alpine tundra on some of the higher ridges.

The distribution of vegetation in the Yukon-Tanana Upland between Fairbanks and Wickersham Dome (fig. 11) can serve as a rough guide for discerning the relation between vegetation and permafrost between the Yukon River and the Brooks Range, although permafrost and the distribution of black spruce on south-facing slopes become much more widespread north of the Yukon River. Along actively meandering rivers, point bars usually show a successional sequence on freshly formed alluvium, with productive willow, balsam poplar and white spruce stands in a narrow, generally permafrost-free band along the rivers. On older terraces back from the river and on the outside of meandering rivers, black spruce and bogs underlain by a high permafrost table are dominant (fig. 11).

On south-facing slopes underlain by thick loess, highly productive aspen, birch, and white spruce are abundant to elevations of about 400 m. On north-facing slopes, in areas of thin loess, and in areas above 400 m, black spruce in all stages of postfire recovery is the dominant forest cover. At treeline, about 750 m, mixed black and white spruce stands are open and are dominated by nearly continuous shrub layers of shrub birch and alder.

For general mapping and descriptive purposes, the forest types can be subdivided into bottomland spruce-poplar forests, upland spruce-hardwood forests, and lowland spruce-hardwood forests. The tundra is divided into wet tundra, moist tundra, and alpine tundra and barren ground. Low and high shrub communities are also recognized (fig. 12; Selkregg, 1975a, b).

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[6] Prepared by L.A. Viereck.

Figure 12. Major vegetation types along the route (modified from Selkregg, 1975a, fig. 114, and 1975b, fig. 164).

Bottomland Spruce-Poplar Forest

Bottomland spruce-poplar forest is a tall, relatively dense forest along actively meandering rivers and streams. It is composed primarily of white spruce (Picea glauca) and balsam poplar (Populus balsamifera). Tall willows (Salix alaxensis, S. interior, S. arbusculoides, and others) and alder (Alnus tenuifolia) are early invaders on the freshly formed alluvium but are quickly replaced by rapidly growing balsam poplar stands, including horsetail (Equisetum pratense), bent reed grass (Calamagrostis canadensis), wintergreen (Pyrola spp.), and scattered shrubs of alder (Alnus spp.), prickly rose (Rosa acicularis), and high bushcranberry (Viburnum edule). Balsam poplar stands are gradually replaced by rapidly growing white spruce. Because of the dense shading of the spruce, the forest floor develops a thick mat of feathermosses (Hylocomium splendens and Pleurozium schreberi). Rose and high bushcranberry persist and a low shrub and herbaceous layer of lingenberry (Vaccinium vitis-idaea), twinflower (Linnaea borealis), and horsetail (Equisetum sylvaticum) is common in white spruce stands. This forest occurs on flood plains, low river terraces, and more deeply thawed, south-facing slopes of major river valleys in the interior. It is found extensively along the Yukon and Koyukuk rivers and is less extensive along their major tributaries.

Upland Spruce-Hardwood Forest

Upland spruce-hardwood forest is the most extensive forest along the route. It is composed of white spruce with scattered paper birch (Betula papyrifera), and aspen (Populus tremuloides) on moderate south-facing slopes. Black spruce (Picea mariana), often with scattered paper birch, grows on northern exposures and in poorly drained flat areas. The understory consists of mosses and low shrubs---prickly rose, currants (Ribes spp.), Labrador tea (Ledum groenlandicum), and blueberries (Vaccinium uliginosum)---on cool, moist slopes; grasses on dry slopes; and willows, alders, and resin birch (Betula glandulosa) in the high, open forests near treeline. White spruce trees as tall as 25 m occur in mixed stands near streams. Paper birch and aspen stands, one early stage of succession following fire, are usually even-aged and more uniform in size than spruce stands. Paper birch and aspen stands predominate on well- to excessively drained south-facing slopes.

Black spruce stands are by far the predominant vegetation type in the upland spruce-hardwood forest, especially along the route between Fairbanks and the Yukon River. They range from dense, closed stands to open and woodland types. Labrador tea, blueberry, resin birch, and diamondleaf willow (Salix planifolia ssp. pulchra) are the most common shrubs. The forest floor is dominated by feathermosses and lichens (Cladonia spp. and Peltigera spp.). In colder, wetter sites, Sphagnum moss and cottongrass tussocks (Eriophorum vaginatum) are common in open, slow-growing spruce stands.

Lowland Spruce-Hardwood Forest

Lowland spruce-hardwood forest is characterized by extensive pure stands of black spruce or by mixed stands of black spruce, paper birch, balsam poplar, and aspen. Tamarack or larch (Larix laricina) occurs in this type only as far north as Livengood. Diamondleaf willow, Labrador tea, shrub birch, blueberry, sedge, and bog moss compose the understory. Treeless bogs occur in depressions throughout this forest type. Large areas burned since 1900 are covered by willow scrub and by dense stands of small black spruce.

This type of forest grows on lowland sites on peat, glacial deposits, outwash plains, and alluvial valley bottoms.

High Shrub

The high shrub community consists of dense thickets of several species of willow and alder with a number of low shrubs, herbs, and grasses. High shrub consists of alder and willow on the flood plains of many large rivers in the Arctic, particularly in the mountains and foothills, where the active layer is deeper than in the surrounding uplands. Other species are the low shrub buffaloberry (Shepherdia canadensis) and bentgrass. Thickets of resin birch, alder, and willow---especially Richardson's willow (Salix lanata ssp. richardsonii)---are also found near treeline, and represent a transition between upland spruce-hardwood forests and alpine tundra. These thickets are often interspersed with lichens, low shrubs, and patches of alpine tundra. Crowberry (Empetrum nigrum), Labrador tea, Spiraea (Spiraea beauverdiana), blueberries, and reed grass occur in the understory.

Low Shrub Bogs

Low shrub bogs occur where conditions are too wet for tree growth---primarily in unglaciated areas, on old river terraces and outwash plains, in partly filled ponds and abandoned stream channels, and occasionally on gentle, north-facing slopes. Some areas contain a nearly continuous stand of low shrubs; others are characterized by a nearly uniform cover of sedges and moss. Bog surfaces that have elevated, meandering ridges are called strangmoors. Bog vegetation consists of varying amounts of sedges, Sphagnum and other mosses, bog cranberry (Vaccinium oxycoccus), bog rosemary (Andromeda polifolia), resin birch, Labrador tea, willows, and blueberries. Some low-lying saturated soils support cottongrass tussocks, and these areas are surrounded by zones of tall willow and alder. Widely spaced stunted spruce may occur on higher ground.

Moist Tundra

North of the Brooks Range, moist tundra varies from stands of nearly continuous and uniform cottongrass tussocks, which are locally interspersed with a sparse growth of sedges and dwarf shrubs, to stands with dwarf shrubs dominant. Mosses and lichens grow between the tussocks. Frost action creates small frost boils. Other plants in the cottongrass meadows include dwarf birch, willows, Labrador tea, bistort (Polygonum bistorta), blueberry, and cloudberry (Rubus chamaemorus). Moist tundra is the dominant plant community in the Arctic Foothills, where it is broken locally by river drainages along which high-shrub communities grow. Cottongrass tussocks 15 to 25 cm high cover large areas of gently irregular terrain on moderately drained silt or peat accumulations modified by frost action.

Wet Tundra

Wet tundra consists of an almost continuous cover of grasses and sedges (Carex spp. and Eriophorum angustifolium) rooted in mosses and lichens. On slightly raised ridges, dwarf shrubs may be found; in standing water, rooted aquatic plants such as mare's tail (Hippuris vulgaris) grow. Sedges are common. Differences in vegetation composition are related to the microrelief formed by growth of ice-wedge polygons. Many moss species grow in the understory, but few lichens occur in this wet habitat. Plants of secondary importance include cottongrass tussock, louseworts (Pedicularis spp.), and buttercups (Ranunculus spp.) in the wetter sites, and four-angled Cassiope (Cassiope tetragona) and purple saxifrage (Saxifraga oppositifolia) in raised, drier habitats as on ridges that form the margins of the ice-wedge polygons. Wet tundra is common in the coastal area.

Alpine Tundra

Alpine tundra communities occur in mountainous areas and on well-drained, rocky ridges within both the tundra and taiga. Vegetation is usually sparse and low. Dryas and lichens generally dominate, but low-growing herbs, grasses, and sedges also occur. Dwarf birch, resin birch, cranberry, alpine azalea (Loiseleuria procumbens), four-angled Cassiope, small Labrador tea, moss campion (Silene acaulis), and oxytropes (Oxytropis spp.) are common. Cushion plants such as moss campion and purple saxifrage occur in dry talus communities on well-drained ridges and scree slopes, where soils are thin and coarse textured. Alpine tundra is most common at elevations between 600 and 1,250 m. Above this elevation most of the mountains are bare of vegetation except for rock lichens, but a few flowering plants grow at elevations approaching 1,800 m.

The Brooks Range acts as a barrier to the northern advance of coniferous trees. Hare (1950) and Patric and Black (1968) suggested that the growth of northern forest in Alaska is determined by temperature because precipitation or substrate moisture is adequate. The July temperature equivalency of latitudinal treeline along the route is estimated to be 12°C (Haugen and Brown, 1980). On the basis of this relationship, air temperature during the growing season is presumably high enough to support the growth of white spruce in some areas north of the Brooks Range, such as in the vicinity of Umiat and Happy Valley. Therefore, in the absence of the Brooks Range arctic treeline would be farther north than it is (Viereck, 1979; Viereck and Van Cleve, 1983).

Disturbance Patterns

The upland vegetation between Fox and Livengood is characterized by man- and fire-caused patterns. Old mining roads, ditches, and railroad grades can be clearly discerned from lines of alder, willow, and birch that cut through black spruce forests. Abandoned fields, resulting from early attempts to clear land for agriculture or to fulfill homestead title requirements, are obvious in several locations along the road. Most of these fields now support dense stands of willows or young birch and aspen.

Old mine tailings, most of which date from the 1930's to the 1950's, can be seen in all stages of revegetation in the Fox and Livengood area. The coarse, ridged tailing piles are slow to be revegetated but are eventually invaded by shrubs and trees, especially willows and birch. Low areas between the tailing ridges are revegetated more quickly, often to dense stands of willow and alder. Several authors have reported that permafrost has begun to return in the tailing deposits in the Fairbanks-Fox area (Theis, 1944; Kreig and Reger, 1982).

The most conspicuous vegetation patterns along the route are those caused by wildfires. In the past, wildfires have burned more than 400,000 ha/yr in interior Alaska. Fire-suppression efforts have reduced this total in the past decade to about 240,000 ha/yr. Most of the fires in interior Alaska are caused by lightning during the hot, dry summer. However, between Fox and Livengood many of the fires date from the early 1900's and were probably caused by early gold miners. Many of the slopes adjacent to the early mining towns were also logged for firewood, cabin logs, and mine supports, and this activity has affected the general vegetation pattern.

FLORA[7]

In the interior, uplands with only modest topographic relief support taiga in its various forms. Forested sites yield 24 to 50 plant taxa. The extensive tussock tundra of the Arctic Foothills has a range of 13 to 60 taxa per site. There the primary taxa are highly predictable, the floristic differences between sites being due largely to forbs that occur in small amounts and consequently do not signify differences in structure.

In the mountains, where there is a large altitudinal range and a variety of habitats, floristic diversity is greater---about 250 taxa---yet two adjacent mountains may share only 60 percent of the flora. This difference in floras probably reflects different rock types at these sites, one being predominantly conglomerate, the other being predominantly limestone. Comparable differences in flora exist on the Arctic Coastal Plain, where one substrate is highly calcareous (Prudhoe) and the other is largely acidic (Barrow).

The route is an outstanding latitudinal transect, along which can be traced the successive disappearance of the conspicuous trees and shrubs. These northern limits are valid only for this particular route, but it is doubtful if the relative position for specific taxa will vary greatly. The location of these limits is presented in the road log.

Several taxa have been found that significantly extend their previously known ranges. Species common in the taiga south of the Brooks Range that have since been found in the Arctic on dry bluffs and terraces formed by the Sagavanirktok River include the two-color sedge (*Carex aurea*) and low northern sedge (*C. concinna*), northern bedstraw (*Galium boreale*), and twinflower (*Linnaea borealis*). Several alpine species are found disjunct from previously known populations, and these help refine distribution maps for matted sandwort (*Arenaria chamissonis*), the sedge *Carex albonigra*, rockcress (*Draba cana* and *D. macounii*), fleabane (*Erigeron grandiflorus*), koenigia (*Koenigia islandica*), spring beauty (*Montia bostockii*), scamman oxytrope (*Oxytropis scammaniana*), chickweed (*Stellaria umbellata*), and pennycress (*Thalaspi arcticum*).

Significant floristic records of bryophytes and lichens are found north of the Yukon River and include taxa new to science, taxa new to North America or to Alaska, or additional collections of very rare plants in Alaska. Details as to these records can be found at the Herbarium of the University of Alaska Museum at Fairbanks; many of the bryophyte records have been cited by Steere (1978) and Steere and Inoue (1978). Several of the most interesting cryptogams are part of an assemblage of rare mosses and lichens found on limestone---especially on well-watered cliffs---in the Brooks Range. One of these is the narrow endemic *Andreaeobryum macrosporum*, restricted to a few sites in northwestern North America but locally common at three sites along this route: Sukakpak Mountain, Wiehl Mountain, and 'Mt. Hultén' (Murray and others, 1980).

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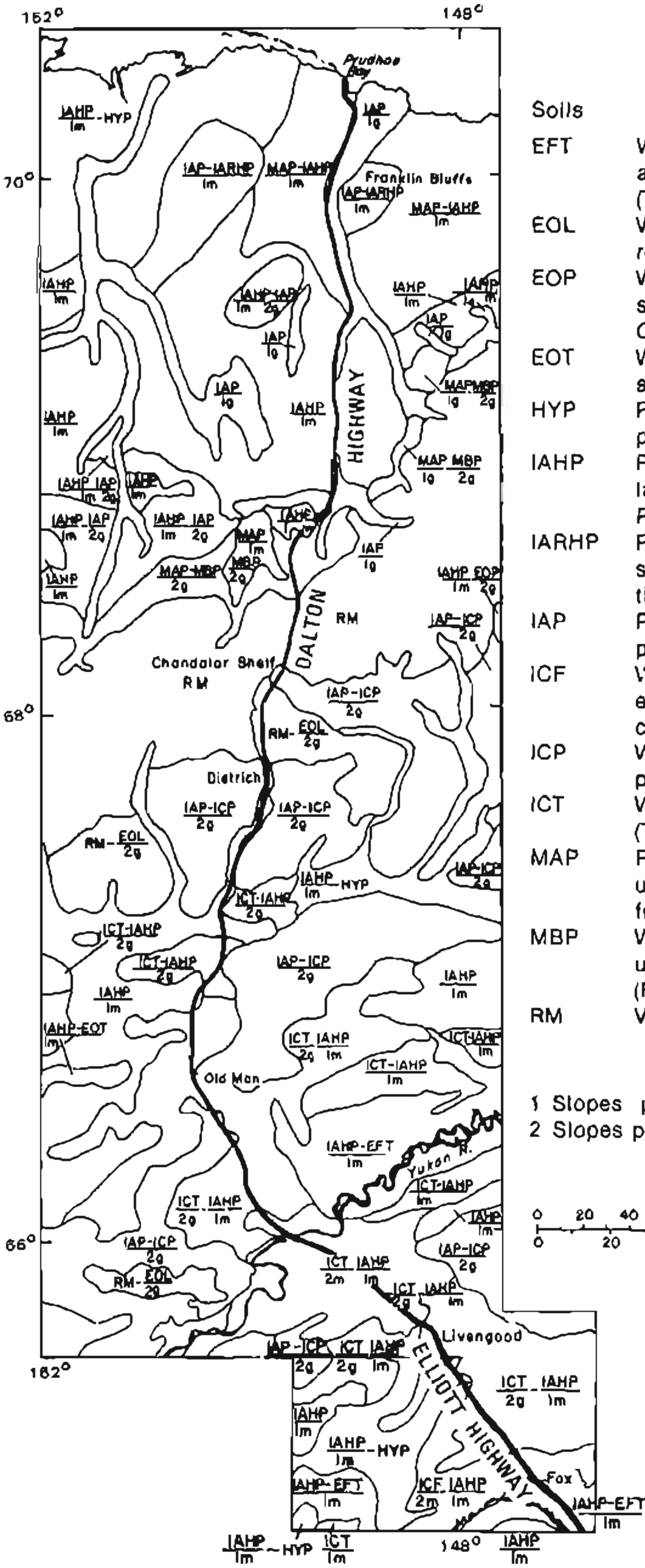
[7] Prepared by D.F. Murray.



Soils

EFT	Well drained soils in stratified materials on flood plains and low terraces (Typic Cryofluvents)
EOL	Well drained gray soils; shallow bedrock (Lithic Cryorthents)
EOP	Well drained loamy or gravelly gray soils; deep permafrost table (Pergelic Cryorthents)
EOT	Well drained loamy or gravelly gray soils (Typic Cryorthents)
HYP	Poorly drained fibrous peat; shallow permafrost table (Pergelic Cryofibrists)
IAHP	Poorly drained soils with peaty surface layer; shallow permafrost table (Histic Pergelic Cryaquepts)
IARHP	Poorly drained soils with many frost scars; shallow permafrost table (Ruptic Histic Pergelic Cryaquepts)
IAP	Poorly drained soils; shallow to deep permafrost table (Pergelic Cryaquepts)
ICF	Well drained brown soils; contain lenses of fine-grained material (Alfic Cryochrepts)
ICP	Well drained thin brown soils; deep permafrost table (Pergelic Cryochrepts)
ICT	Well drained brown soils; nonacid (Typic Cryochrepts)
MAP	Poorly drained soils with dark, nonacid upper layer; shallow to deep permafrost table (Pergelic Cryaquolls)
MBP	Well drained soils with dark, nonacid upper layer; deep permafrost table (Pergelic Cryoborolls)
RM	Very steep rocky or ice-covered land

Slope Group	Textural Group
1 Slopes predominantly less than 11°	g Very gravelly
2 Slopes predominantly more than 11°	m Loamy (medium)

0 20 40 60 80 100 km
0 20 40 60 mi

Figure 13. Major soil types along the route (modified from Selkregg, 1975a, fig. 105, and 1975b, fig. 154).

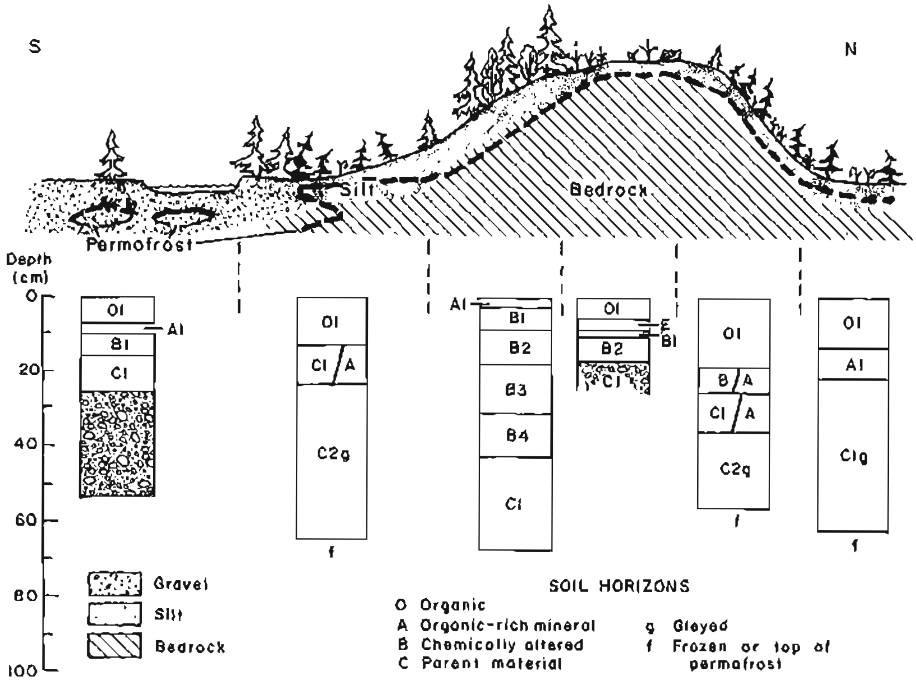


Figure 14. Schematic cross section of soil, permafrost, and vegetation relationships between Fairbanks and the Yukon River. Horizontal distance is about 5 km. Maximum local relief is about 1000 m (prepared by K.R. Everett).

SOILS[8]

The soils encountered along the route have developed in a low-temperature regime in which biological and chemical transformations are slow and in which soil horizons---the results of these processes---are subject to physical dislocation as a result of freeze-thaw processes. The distribution of the principal soil associations encountered along the route is presented in figure 13 along with their related textures and permafrost conditions (Selkregg, 1975a,b; Soil Survey Staff, 1975; Rieger and others, 1979).

Through the Yukon-Tanana Upland between Fairbanks and Livengood the road crosses broadly rounded hills and ridges whose summit elevations range from 700 to approximately 1,000 m. For about 55 km, or half the distance between these points, the hills and ridges are composed of Precambrian or Paleozoic metamorphic rocks, formerly known as the Birch Creek Schist. The topography of the remaining distance to Livengood is similar, but cut predominantly in argillite and graywacke of late Paleozoic and Jurassic-Cretaceous age. Idealized soil sections as a function of topography and parent material are shown in figure 14.

Lowland soils on flood plains and terraces over shallow permafrost include Pergelic Cryofibrists (fibrous organic soils) and Histic Pergelic Cryaquepts (half-bog soils) with a thick (>20 cm) organic surface horizon over silty or fine-sandy subhorizons. Alluvial soils that lack permafrost or are

[8] Prepared by K.R. Everett; see Appendix A for a more detailed explanation of soil taxonomy and classification.

perennially frozen below 1.5 m are Cryofluvents. Where permafrost occurs shallower than 1.5 m, the alluvial soils are termed Pergelic Cryorthents. Upland soils on south-facing slopes are generally well-drained silt loam, free of permafrost, and have developed under white spruce. They are Alfic Cryochrepts (Subarctic Brown Forest soils). Their counterparts formed in gravelly or stony materials weathered from the local bedrock are Typic Cryochrepts. In some localities, gravelly Pergelic Cryorthods (Podzolic soils) are found.

On both north-facing slopes and long footslopes and in the valleys are poorly and very poorly drained Pergelic and Histic Pergelic Cryaquepts formed under black spruce, moss and shrubs. Above 750 m to about 1,000 m is a complex of alpine soils, including Pergelic Cryaquepts, Pergelic Cryorthents, Pergelic Cryochrepts, and Pergelic Cryorthods.

Between Livengood and the Yukon River, the road passes through hilly terrain where local relief ranges between 150 and 600 m. Bedrock consists of upper Paleozoic and lower and middle Mesozoic metamorphic and volcanic rocks. Except for the highest ridge tops and steep slopes, the area is mantled by loess that becomes very thick close to the Yukon River. On south-facing slopes, the soils formed beneath white spruce, birch, and aspen stands that are free of permafrost are Typic Cryochrepts. On poorly drained sites, especially on north-facing slopes underlain by permafrost, Pergelic and Histic Pergelic Cryaquepts form beneath black spruce, moss, and sedge. Organic soils (Pergelic Cryofibrists) are common in poorly drained sites such as filled meander cutoffs in larger valleys. Pergelic Cryorthents are common on steep slopes of any exposure and on many alpine summits and ridges.

North of the Yukon River, the road passes into the Kokrine-Hodzana Highlands. The soils are, for the most part, slightly acidic to slightly alkaline silt loams. In the southern part of this area, near the Yukon River, loess is a significant component, and the soils are gray and fine-textured Alfic Cryochrepts (Subarctic Brown Forest soils). Moderately well-drained soils on slopes are neutral to slightly alkaline and commonly consist of fine-textured upper horizons overlying coarse, weathered bedrock fragments. Acidic, base-poor soils composed of gravelly materials (Pergelic Cryorthents) derived from granites are common on the uplands. Organic soils or mineral soils with thick organic horizons occur in tussock meadows associated with drainageways.

In the foothills and mountain areas south of the treeline, mass movement on steep forested slopes produces complexes of poorly drained, gray, mottled silt loam or gravelly, acidic soils with relatively thin organic horizons (Perglic Cryaquepts). In this complex, similar poorly drained soils with thick organic horizons are Histic Pergelic Cryaquepts. Seasonal thaw is generally less than 50 cm, except on hilltops and gravelly terraces, where deep thawing of well-drained soils occurs along with oxidized horizons (Pergelic Cryorthents or Pergelic Cryorthods).

In the higher parts of the Brooks Range, most of the area consists of steep, exposed bedrock and coarse, unstable colluvial deposits with local areas of poorly or very poorly drained gravelly and stony soils (mostly Pergelic Cryorthents). Some soils with a significant organic component are Pergelic Cryaquepts or Histic Pergelic Cryaquepts. Stable, relatively well-drained glacial and colluvial deposits have gravelly soils with dark, leached upper horizons and reddish, iron-stained subhorizons.

North of the Continental Divide, permafrost generally shallower than 50 cm retards internal drainage. Thus, as a consequence of the low temperatures and poor drainage, most soils exhibit wet, shallow, poorly differentiated profiles with a significant organic component that is generally little decomposed. Horizons with contorted admixtures of darker, more highly decomposed organic materials are common in mineral subhorizons down to and into the permafrost.

Most soils of the Arctic Foothills are poorly drained and have developed in such fine-textured materials as silt loam and silty clay loam. Poorly drained soils (Pergelic Cryaquepts, Upland Tundra soils) occur on long slopes and in broad valleys. These tundra soils are found under a tussock microtopography, and most are acidic. A few moderately well-drained to well-drained gravelly soils (Pergelic Cryorthents) occur on ridges and on terraces marginal to larger rivers. Organic soils, mostly Pergelic Cryofibrists (bog soils), are uncommon and occur mostly in polygonal ground of old drained lake basins.

On the Arctic Coastal Plain, soils are poorly drained and generally do not thaw to depths of more than 50 cm. In most soils, organic materials of variable thickness overlie silt-loam mineral horizons (Pergelic and Histic Pergelic Cryaquepts, Meadow Tundra soils). A few soils, especially those in depressions, may exhibit a sufficient thickness of organic materials to be termed organic soils (mostly Pergelic Cryofibrists). Other soils restricted to well-drained sites display well-developed horizons and bright oxidation colors (Pergelic Cryaquolls). Most soils are alkaline. Some well-drained soils with organic-rich surface horizons over gravel (Pergelic Cryoborolls, Arctic Brown soils) have free carbonates in their profiles (Everett and Brown, 1982).

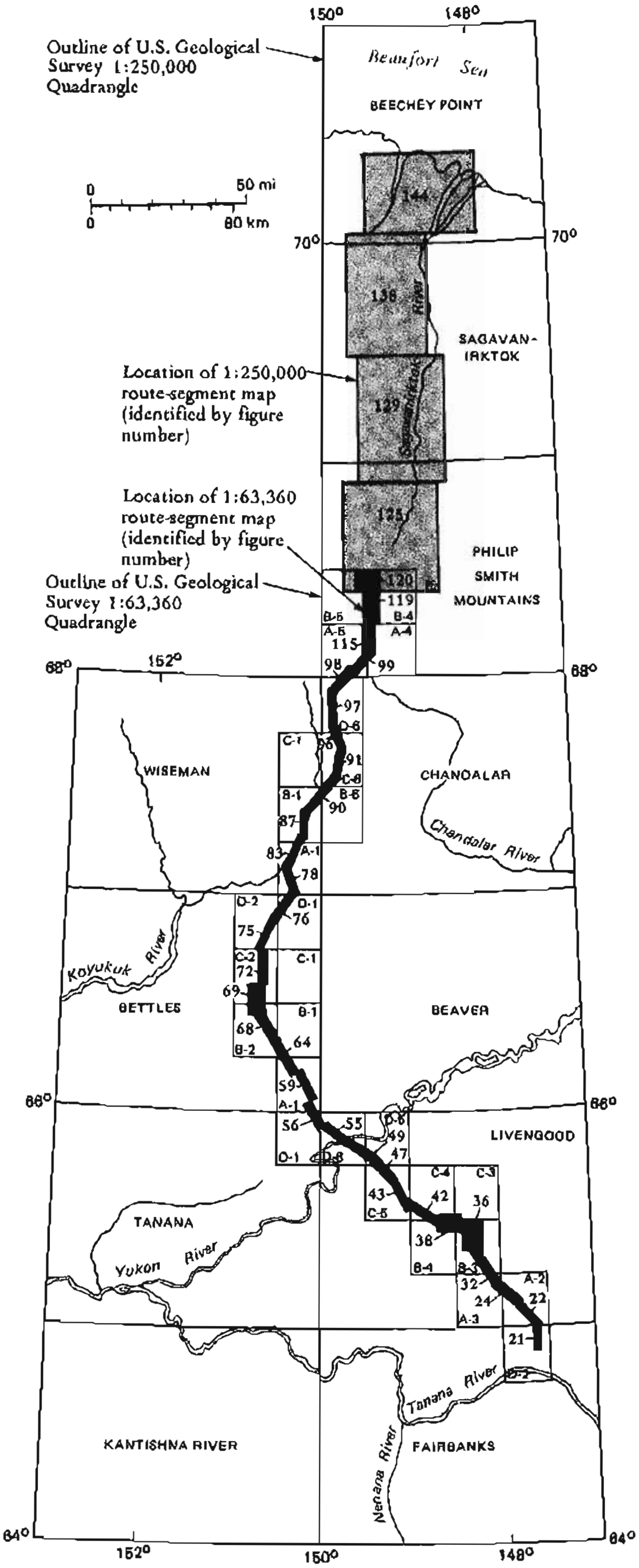


Figure 15. Index to 1:63,360 and 1:250,000 U.S. Geological Survey topographic maps covering guidebook route.

ROAD LOG

INTRODUCTION

The road log is based on numerous sources, including the observations of the contributors listed in the Preface. The log of the Elliott Highway is based on many years of observations made during road construction and mining activities, including highway investigations (Livingston, 1966; Livingston and Balvin, 1977; Livingston and Kahler, 1979). The log of the Dalton Highway is based on early observations of the TAPS road and numerous summer observations north of the Yukon River. Specific published references are Hamilton (1979a), Brown and Berg (1980), and Robertson (1981). Other references are cited for particular descriptions.

The strip maps are based on the 1:63,360- and 1:250,000-scale topographic maps, as shown in the index sheet (fig. 15). Mileposts (E for Elliott Highway, D for

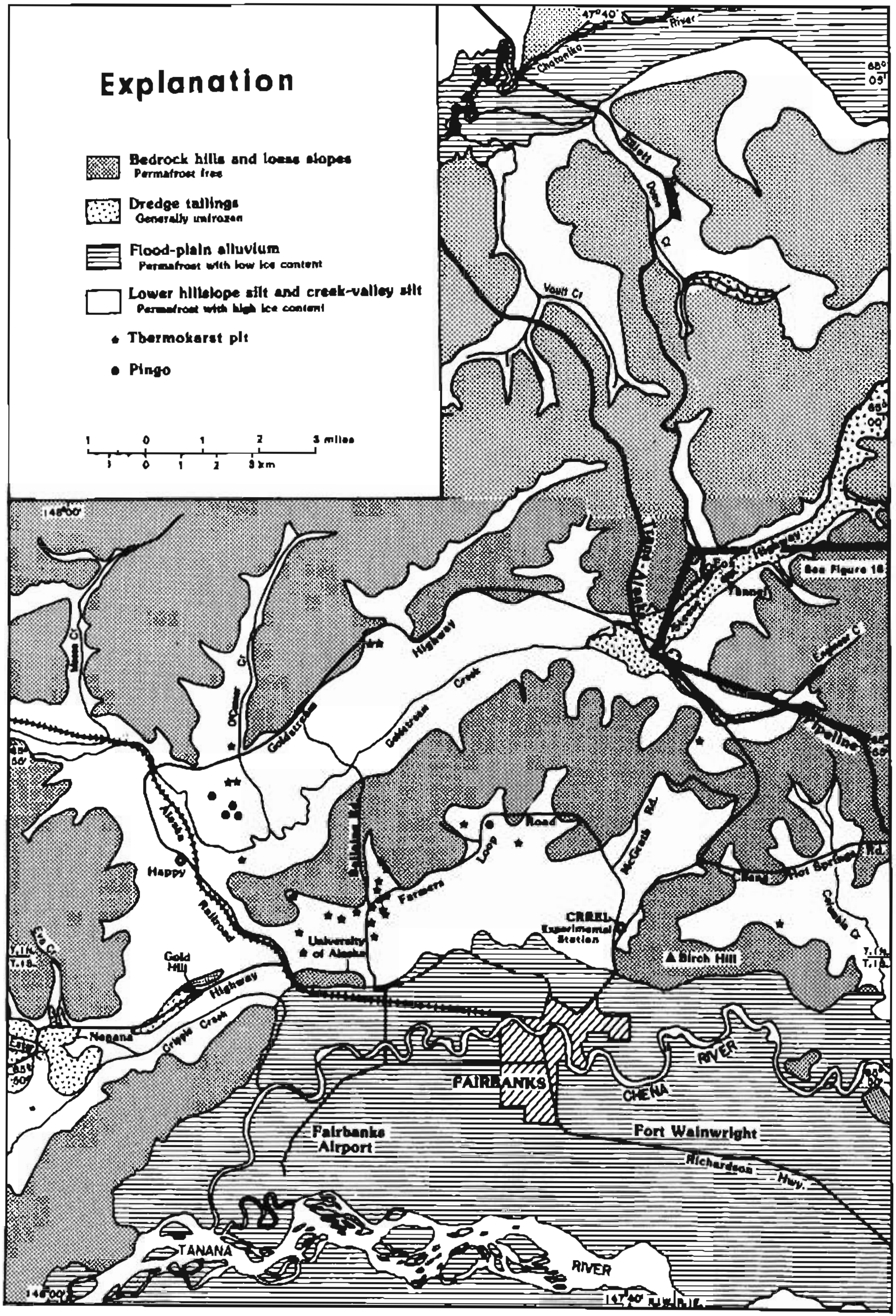


Figure 16. Generalized permafrost map of the Fairbanks area, Alaska (modified from Reger and Péwé, in press, and Péwé, 1958).

Dalton Highway) run from Fox to Deadhorse and are given on the maps and in the log in miles. North of Livengood, official milepost signs had not actually been placed along the road when this log was prepared. Every effort has been made to ensure that mileposts presented in this log will agree with those actually installed. However, some discrepancies are likely to occur. South of Livengood, there may be some discrepancies because of recent road realignments. The locations of icings are based on observations made before construction of the pipeline (Sloan and others, 1976).

Accompanying this field-trip guidebook is a companion publication entitled "Air-photo Analysis and Summary of Landform Soil Properties Along the Route of the Trans-Alaska Pipeline System" (Raymond A. Kreig and Richard D. Reger, 1982, Alaska Division of Geological and Geophysical Surveys Geologic Report 66). It contains 30 airphoto plates, of which 18 are along the route covered by this guidebook. Each plate is annotated with a discussion of geomorphic features, soil and permafrost types, and soil-boring data. Hereafter in the route log the location of plates from Kreig and Reger (1982) will be indicated on the strip maps and a brief summary of the appropriate features will be given.

FOX

Fox, located 16 km northeast of Fairbanks, is the official starting point of this field trip and guidebook. It is the site of a former mining camp that predates 1905. A substantial amount of information on permafrost and its distribution, construction practices, and gold mining, which is available as part of the publications of the Fourth International Conference on Permafrost and other sources, will not be repeated here (see, for instance, Boswell, 1979; Péwé, 1982; Reger and Péwé, 1983). Figure 16 illustrates the general distribution of permafrost in the Fairbanks area, enroute to Fox, and north to the Chatanika River. A number of interesting permafrost-related subjects can be observed in the valley and uplands surrounding Fox. The trans-Alaska pipeline crosses the valley in both the elevated and buried modes (see previous discussion on construction modes).

Fox illustrates classic stripping and dredging operations of placer gold mining (figs. 17 and 18). The frozen 'muck' (organic, ice-rich silt) was stripped from over the gold-bearing gravel by directing large volumes of water onto the materials through hydraulic 'giants.' These devices, which resembled large hydraulic cannons, helped thaw and wash away the silt. Frozen gravel

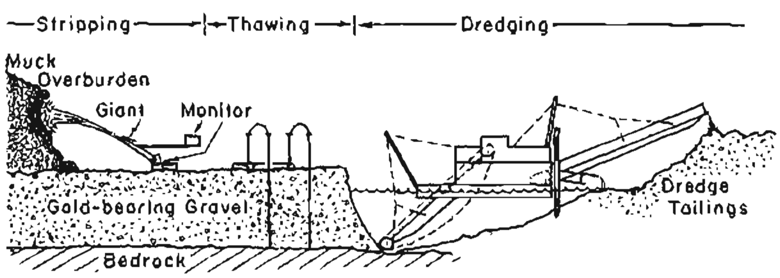


Figure 17. Diagrammatic cross section showing sequence of operations used in placer gold mining in the Fairbanks area (modified from Boswell, 1979, p. 78).

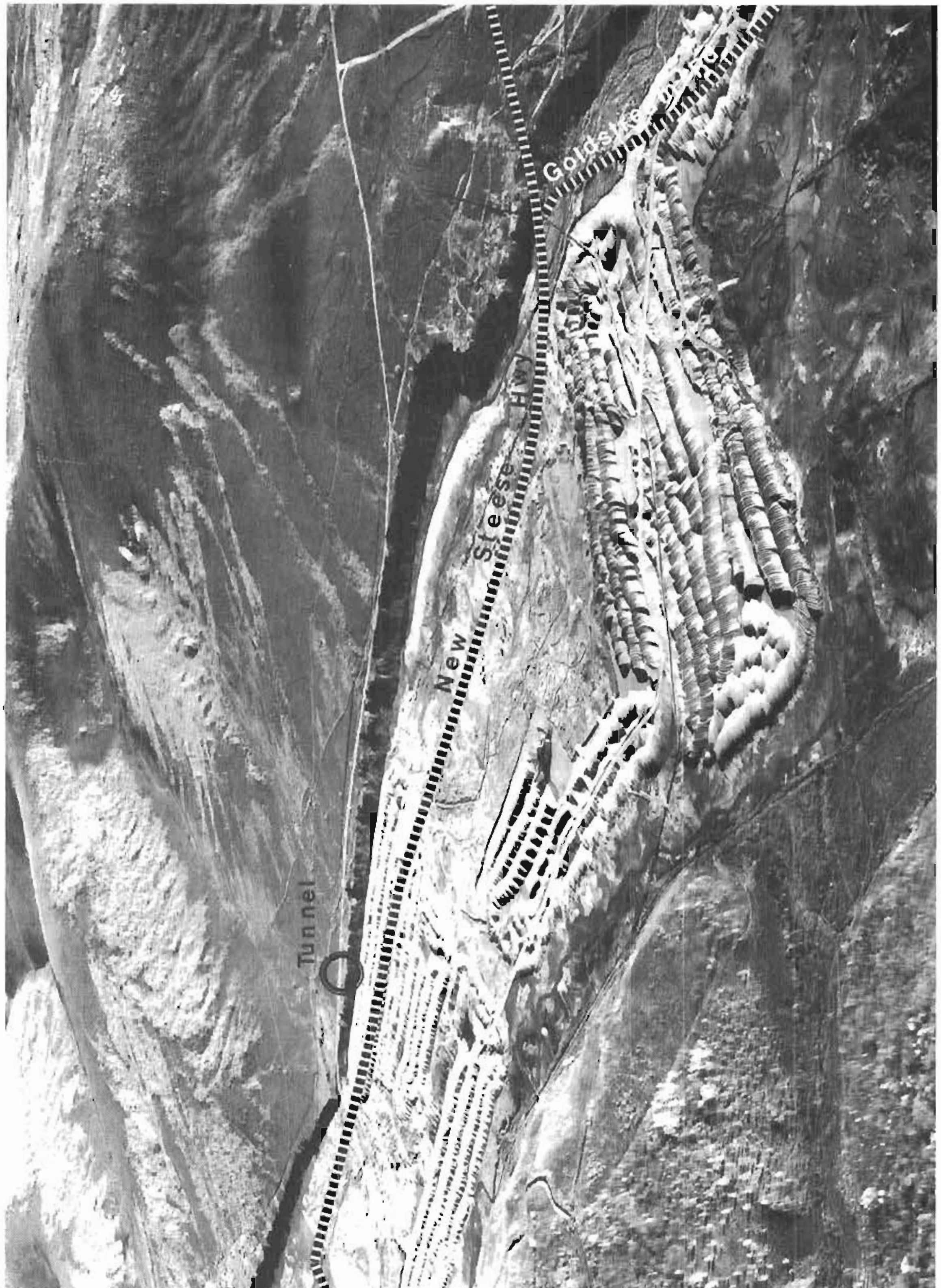


Figure 18. Oblique aerial photograph of dredging operations in the vicinity of Fox. See text for discussion of permafrost and related features (photograph 2431 taken by B. Washburn on September 27, 1938; Boston Museum of Science).

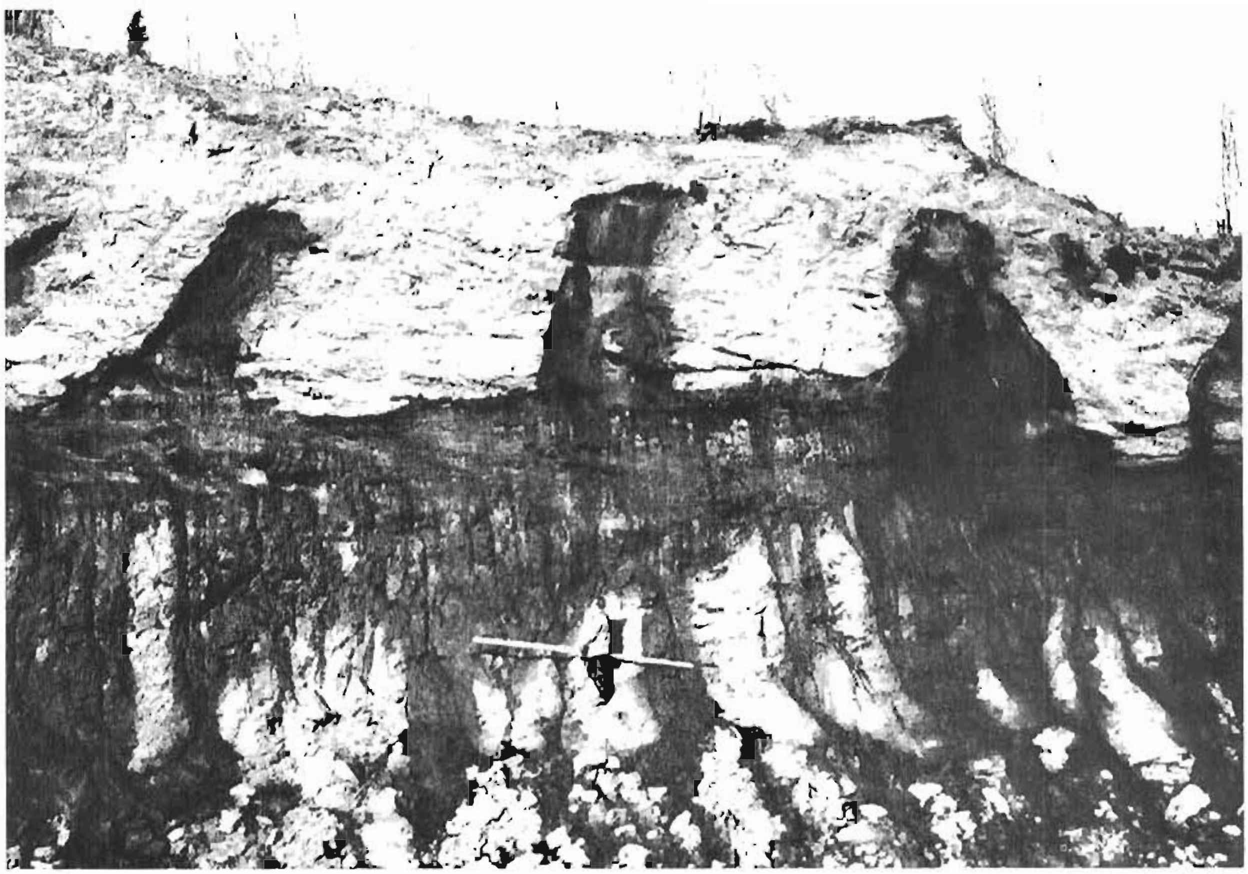


Figure 19. Highway cut made through ice wedges at Fox in October and November 1977. See Sellmann and others (1979) and Osterkamp and others (1980) for details (photograph taken by P.V. Sellmann in spring 1978).

was thawed by driving well points into the material and circulating cold water through pipes to thaw the sediment. Once the gravel and the upper meter of bedrock were thawed, gold dredges picked up the gravel, passed it through the sorting and recovery equipment, and then discharged the worked material from a conveyor at the rear. The hummocky tailings piles formed by these dredging operations can be seen throughout the Fox area. Discontinuous permafrost, which is locally ice rich, has returned to portions of these tailings (Theis, 1944; Kreig and Reger, 1982). An excellent description of the operation of the United States Smelting, Refining and Mining Company is available (Boswell, 1979), and exhibits on mining history and methods used in the Fairbanks area can be seen in the University Museum at Fairbanks.

Stripping of the frozen muck overburden exposed excellent examples of ground-ice features, mainly ice wedges, which serve as stratigraphic markers for the Quaternary deposits of the Fairbanks area (Péwé, 1975b, 1977). Details of the upper section are exposed in the permafrost tunnel at Fox (fig. 16). Large ice masses were recently exposed in a highway cut located just south of the tunnel entrance but have since melted back and are no longer visible (fig. 19).

The Fox tunnel was excavated by the U.S. Army Cold Regions Research and Engineering Laboratory during the early and mid-1960's (Sellmann, 1967, 1972;

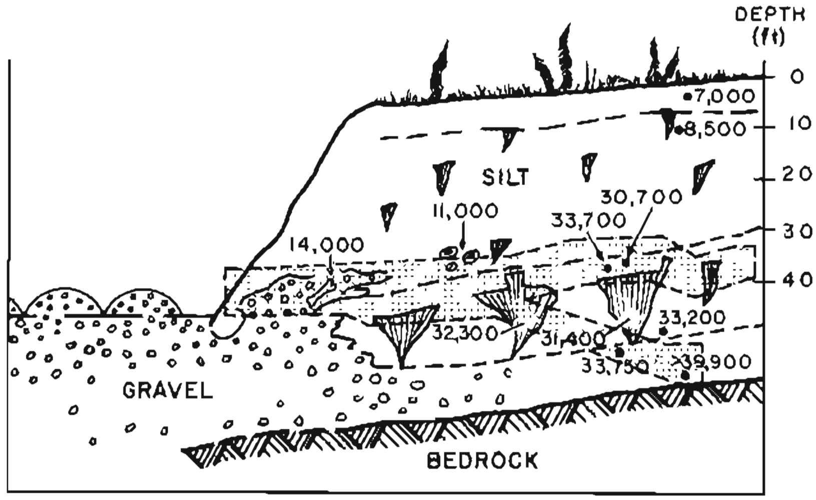


Figure 20. Idealized section showing ice-wedge distribution and radiocarbon dates in the Fox tunnel. Radiocarbon ages are given in uncorrected years before present (B.P.). The location of the main tunnel and inclined drift are shown schematically (modified from Sellmann, 1972, fig. 9).

Swinzow, 1970). It enters a near-vertical silt escarpment left at the edge of the valley by the gold-mining operations (figs. 16 and 18). Tunneling was performed by a prototype continuous mining machine (Alkirk cycle miner) that had never before been used in permafrost. When operating properly, the machine could cut as much as 2.1 m of tunnel in an hour. In late 1965, a 1.2-m-diameter vertical shaft was augered through 15 m of permafrost to provide cold air ventilation in the winter.

Most of the tunnel passes through thick, ice-rich, retransported silt, termed 'muck' by the early miners because of its fetid smell. The distinctive odor in the tunnel is common to most permafrost excavations in this region. It results from the oxidation of exposed organic materials in the silt. This organic material originated as plants and animals that lived in the valley. Bones of extinct large-horned bison and other large Ice Age mammals were exposed during excavation of the tunnel.

The retransported silt eroded from loess on the upper slopes and ridge crests fills the valleys of the southern Yukon-Tanana Upland to depths as great as 110 m. Much of it was carried downslope by streams and by slope and rill wash, although the occasional presence of folded layers indicates that some soil flow occurred. Valley-bottom deposits also include loess that was deposited by wind in the lowlands. Below the silt are the gold-bearing gravels that date from the early Pleistocene. The gravels are underlain by the Birch Creek Schist, a general term for the metamorphic bedrock of the Yukon-Tanana Upland. The upper portion of this schist is generally highly weathered. In valleys containing placer deposits, the gold is found in the upper meter of the weathered and jointed schist.

In stratigraphic sections exposed in the Fox tunnel (fig. 20), a lower zone of large ice wedges 1 to 2 m across underlies a zone of smaller 30-cm-wide ice wedges. Radiocarbon dates from the lower ice-wedge zone range from about 31,400 to 33,200 yr B.P. and in the upper zone range from about 8,500 to

14,000 yr B.P. Above the zone of small ice wedges another change occurs, which marks the transition to a silt that does not contain ice wedges. Radiocarbon dates above and below this break place its age at between 8,500 and 7,000 yr B.P. This transition zone is believed to mark the lower limit of Holocene thawing.

The inclined drift passes through the thin zone of much older gravel and reaches the top of the disintegrated Birch Creek Schist. The gravel is encountered about 1.5 to 3 m below the floor of the main tunnel at a sharp but irregular contact. The alignment and stratification of the pebbles indicate that the gravel was stream deposited. The gravel is bonded by ice, but unlike the silt it does not contain ice wedges. In fact, the lower end of one large ice wedge in silt terminates at the gravel contact.

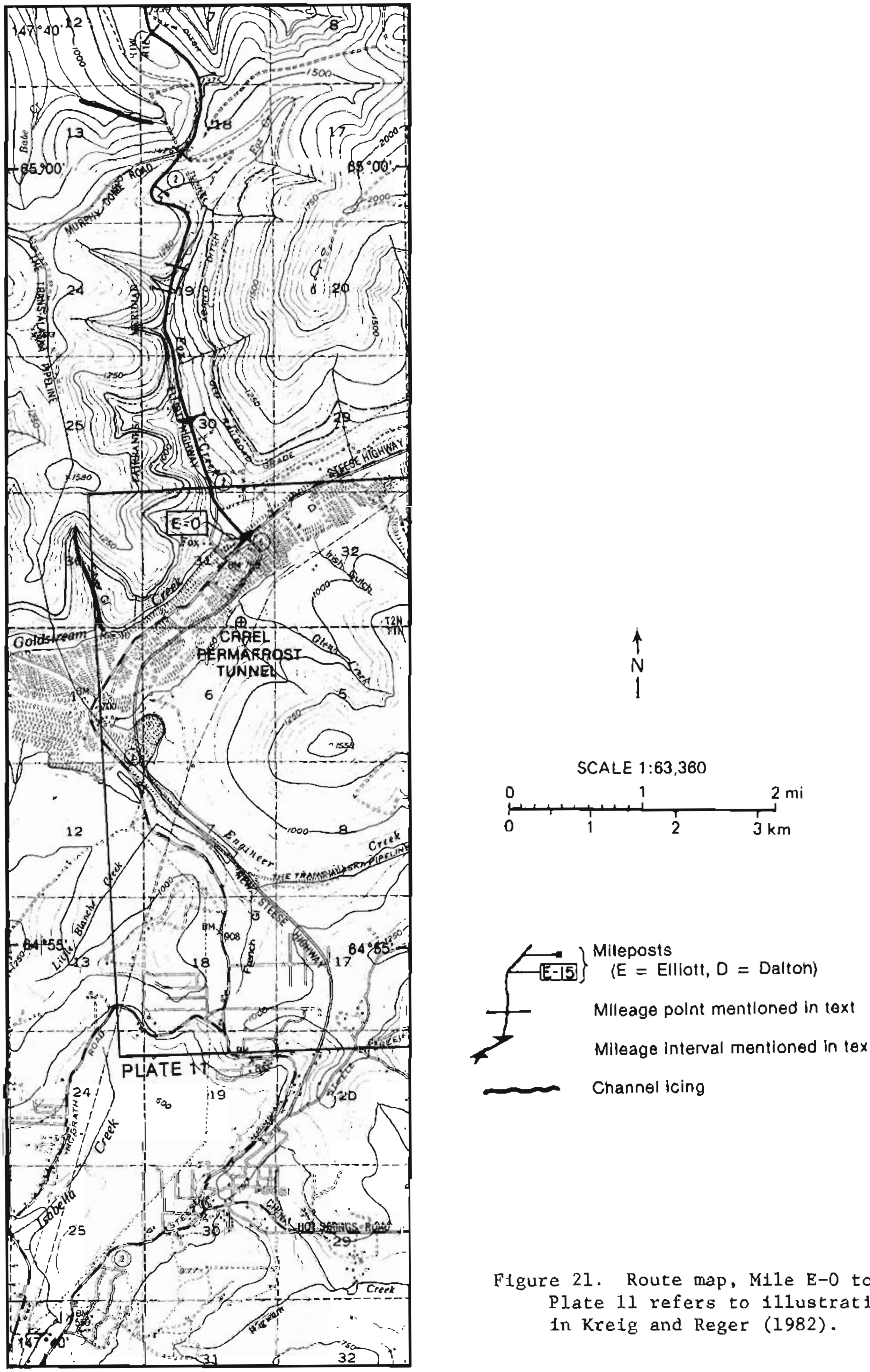


Figure 21. Route map, Mile E-0 to E-4. Plate 11 refers to illustration in Kreig and Reger (1982).

FOX - LIVENGOOD

E-0.0 [9]: Junction of Elliott and Steese Highways.

E-0.0 to E-1.0

Here the distribution of typical interior vegetation types can be observed. Black spruce occurs on lower slopes that are underlain by permafrost close to the surface. Hardwoods, both birch and aspen, dominate the south-facing slopes. They are particularly evident when one is traveling north. In the uplands southeast of Fox is a vegetation pattern controlled by substrate conditions that is typical of the Yukon-Tanana Upland. Upland loess has been nearly completely removed from the higher ridges, leaving bedrock with only a thin cover of loess, colluvium, and residual soils. The ellipsoidal and triangular ridges that point upslope are composed of 'flatiron'-shaped bodies of frozen-in-situ loess and retransported silt. Permafrost is shallow under black-spruce-covered 'flatirons,' and is deeper under well-developed aspen and birch that typically grow on their upper margins (fig. 18). The sharp vegetation boundary between stunted black spruce on retransported silt and stands of large aspen, birch, and white spruce on unfrozen loess is useful for roughly separating permafrost and nonpermafrost terrain in this part of interior Alaska. However, large white spruce and birch trees can also grow on lower slopes where ice-rich permafrost occurs only 1.2 to 2.4 m below the surface (Kreig and Reger, 1982, pl. 11).

Where the highway was constructed over sections of ice-rich permafrost, it caused thermal disturbance of the permafrost. This disturbance resulted in considerable thaw settlement, which has required continuing maintenance of the road. Several cuts have been made in the Birch Creek Schist along the west side of the road. Aspen is found on upper slopes and alder grows near the rock cuts. A spring located 0.6 km north of the road intersection flows year-round, and has been a source of fresh water for many Fairbanks and local residents for the last 30 yr. An old mining operation can be seen in the valley.

E-2.2

Davidson Ditch, which parallels the road from Fox, is located higher up on the hillside to the west (see fig. 21; it is not visible from the road). As the road ascends, the ditch crosses it at this point and then parallels it on the lower slope to the east. The 116-km-long ditch, built to bring water from the headwaters of the Chatanika River to the Fairbanks placer-mining operations, was constructed between 1924 and 1929 (Boswell, 1979). The width of the bottom of the ditch was originally 3.7 m, and it had a constant grade of 0.4 m/km and a water depth of 1.1 m. At operating capacity, it delivered about 307 million L/day of water. Fifteen inverted siphons were used to cross the numerous creek bottoms. The largest siphon crossed the Chatanika River. It had a maximum head of 166 m and was slightly less than 2,438 m long. The inside diameter of the pipe was 1.2 to 1.4 m. The ditch was excavated through frozen soil and rock using tractors, graders, power shovels, and hand tools. Over 1.15 million m^3 of earth were excavated and moved. During the winter, icings caused many problems in the operation of the ditch. Ice overflow filled the ditch and dynamite had to be used to open a narrow trench prior to spring runoff. Other techniques used to keep the ditch open included moss-insulated underdrains and paper dams to confine the spreading ice overflow.

[9] Letter E stands for Elliott Highway; numerals show mileage.

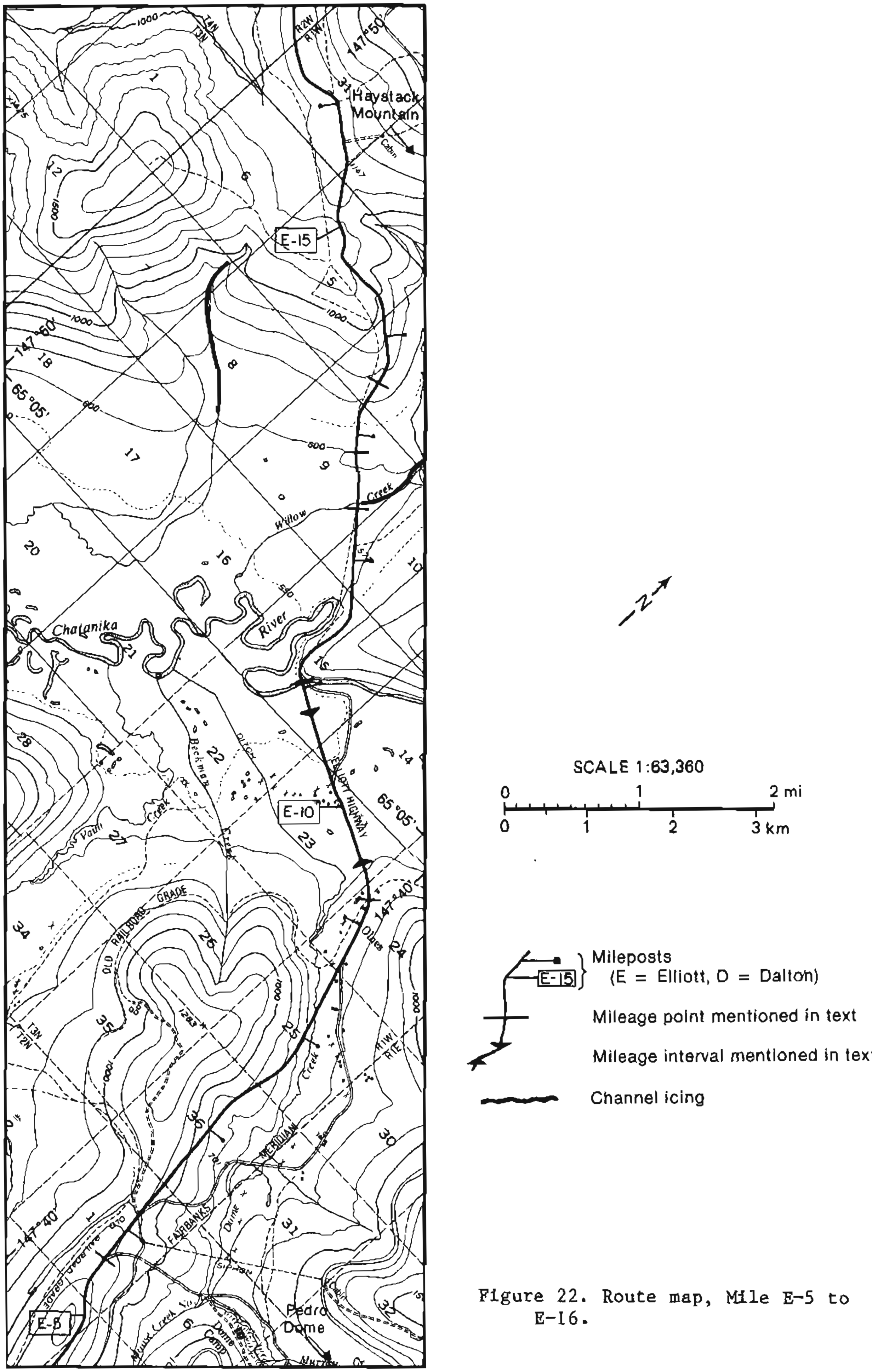


Figure 22. Route map, Mile E-5 to E-16.

Where it doubles back across the east side of the valley, the location of the ditch can be occasionally seen from the road as a line of trees. Above it on the east side of the valley the bed of the old Tanana Valley Mine Railroad can still be seen above Davidson Ditch. The railroad connected Chena (a former town at the mouth of Chena Slough), Fairbanks, and the mining camps at Fox, Gilmore, Olnes, Dome City, and Chatanika from 1905 to 1931.

E-3.3

This is the summit of the drainage divide. Davidson Ditch passes back to the west about 100 m beneath the present road through a tunnel constructed in the Birch Creek Schist. The old railroad also crossed the pass into the Chatanika River drainage at this location. Panoramas visible for the next few kilometers north of here give an impression of the percentage of the landscape that is frozen. Permafrost covers 50-60 percent of the area. Terrain vegetated with stunted black spruce is generally frozen, while slopes vegetated with deciduous forest (aspen, birch) are generally unfrozen except on north-facing and some lower east- and west-facing birch-covered slopes, which may be discontinuously frozen (R. Kreig, pers. commun.).

E-4.5

Haystack Mountain (780 m) can be seen ahead. The mountain marks the western boundary of the Poker - Caribou Creeks Research Watershed, which is operated under an interagency agreement to study the hydrology and climate of this interior region (Lotspeich and Slaughter, 1981; Haugen and others, 1982). The line of trees on the hill to the east marks the location of the Davidson Ditch. Between here and Livengood, the loess is generally thinner than 1.5 m on the hills. The highway section is located in bedrock, which results in noticeably better roadway conditions. Throughout this region, trees were burned and cut down during the peak of the gold-mining period. Black spruce and solifluction lobes are present on some north-facing slopes.

E-5.5

In the valley below is the road to Dome City and the Eldorado Mining Camp. To the east are Pedro Dome and Dome Creek. Dome City is the site of an early mining camp. Placer gold mining, which used hydraulicking and large dredges as recently as the early 1960's, produced many excellent exposures of retransported organic-rich silt of late-Pleistocene age. The frozen, buried placers are 15.2 to 61 m deep (Mulligan, 1974). A pair of enormous (4.1-m-long) mammoth tusks that weigh approximately 160 kg each came from these deposits; they are exhibited in the University of Alaska Museum. The tusks, which were found with a fairly complete skull, other bones, and considerable well-preserved mammoth hair, have been dated at 32,700 ± 980 yr B.P. (ST-1632) (Péwé, 1975b, 1977). Small streams crossing the slumped silt cliffs at Dome Creek have exposed large ice masses that may still be observed.

From the silt in these exposures, a partial carcass of *Bison superbison crassicornis* was recovered by miners and Otto W. Geist of the University of Alaska in 1951. The carcass consisted of a head (complete with hide, horns, and one ear), four legs with hooves, and much torso hide about 3 mm thick. An initial date of more than 28,000 yr B.P. (L-127) was obtained on a piece of the carcass. In 1965, a date of 31,400 (+2,040 or -1,815) yr B.P. (ST-1721) was obtained by the radiocarbon laboratory of the Geological Survey of Sweden. A photograph of the carcass is on display at the University of Alaska. Pieces of the fur and hide of a female superbison recovered from nearby Fairbanks Creek have been dated at 11,950 ± 135 yr B.P. (ST-1633) (Péwé, 1977).

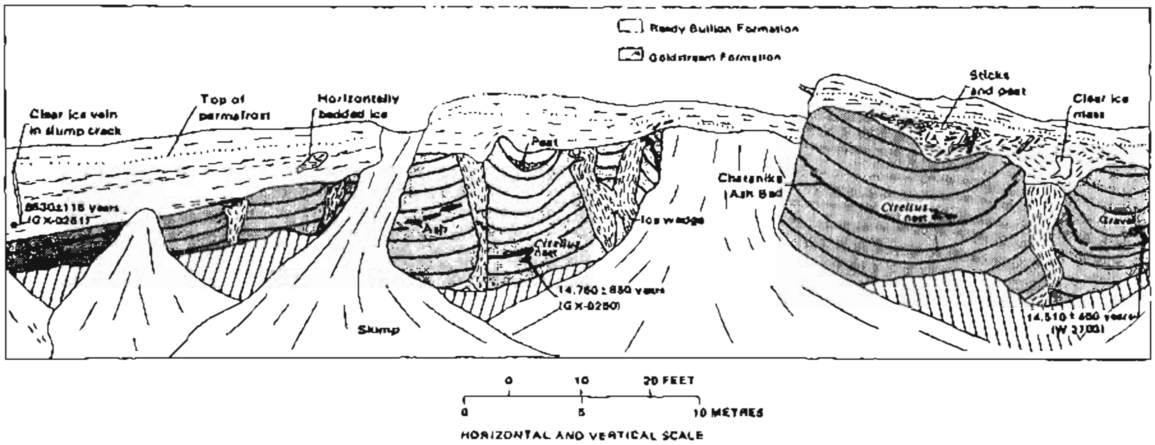


Figure 23. Bank of the Chatanika River 2 km downstream from Elliott Highway bridge. Goldstream Formation (Wisconsin) with ice wedges and Chatanika Ash Bed is overlain by the Ready Bullion Formation (Holocene) (modified from Péwé, 1975a, fig. 10).

E-9.2 : Olnes.

Olnes was a mining camp and station on the Tanana Valley Mine Railroad. On the slopes to the north beyond the bridge are more examples of frozen silt flatirons. Solifluction lobes are visible on north-facing slopes to the west, which have a sparse cover of black spruce and a thick ground cover of mosses.

E-9.5 to E-10.8

Black spruce bogs are visible on a fan of retransported frozen silt from the Dome Creek drainage. The frozen silt covers an old terrace gravel of the Chatanika River. Placer gold was mined from underground shafts and drifts sunk to the base of the alluvium and into the upper meter of bedrock, and many tailing piles of gravel from the underground workings are present on the surface (Mulligan, 1974). Gravel was hauled to the surface during winter and washed during the summer.

E-11.0 : Chatanika River.

A band of balsam poplar of various ages is conspicuous on the point bars. Although the Chatanika River is a small stream, in Wisconsin time it was large enough to carry away silt deposited in it by its tributaries. Rounded flood-plain gravel is close to the surface and overlies the Birch Creek Schist at a depth of about 55 m.

The type section for a distinctive volcanic ash bed is located 2 km downstream from the Chatanika River bridge, where the river has exposed a cut in the frozen muck (Péwé, 1975a, 1977). The Chatanika Ash Bed occurs within and near the top of the Goldstream Formation (Péwé, 1975a). At that location, the Goldstream Formation is overlain by a thick deposit of retransported silt and buried forest beds, the Ready Bullion Formation of Holocene age. The ash bed, a white, vitric, laterally persistent volcanic ash layer about 1 to 10 mm thick, occurs about 4 m below the top of the Goldstream Formation (fig. 23). One of its outstanding characteristics is that it is greatly contorted by ice-wedge growth; in many places adjacent to the ice wedges, the ash bed is almost vertical. A radiocarbon date of 14,760 ± 850 yr B.P. (GX-0250) was obtained for a ground squirrel (Citellus) nest 4 m below the ash layer. A date of 14,510 ± 450 yr B.P. (W-2703) was obtained for Citellus coprolites from silt 1 m above the ash. The ash is thus considered to be about 14,600 yr old.

The road was rerouted up the hill between here and about 1 km north of the bridge because of erosion caused by the Chatanika River. This rerouting was expected to be in ice-poor silt because this terrain is covered by tall birch forest. However, during construction massive ice was exposed.

E-12.4 : Willow Creek.

This flat terrain with permafrost within 0.5 m of the surface is covered by an open black spruce - larch forest. Prior to road and bridge reconstruction the entire valley floor filled with winter icings. Installation of the vertical-walled, timbered bridge and two levels of culverts has solved the problem. The subgrade was raised to permit installation of a two-layer system of culverts. After the lower culverts fill with ice, the upper ones continue to carry the overflow. A small thermokarst pond exists on the east side of the road where the ground ice has melted.

E-12.8

A cabin and a meat house are located on a low mound on the west side of the road. The mound is an open-system pingo. The roadcut through the pingo exposed 6 m of pure ice. The buildings have settled about 1 m as the underlying ice melted due to the heat generated by year-round occupancy.

E-13.5

The road ascends a hill in which schist was exposed within 2 m of the surface to the west and ice-rich frozen silt was exposed to the east.

E-18.1

From this pullout on the west side of the road, there is a view to the north across the valley of the Washington Creek Fire Ecology Experimental Area, the Wickersham fire scars, and old homestead fields that are now revegetated with birch and aspen. Following the Wickersham fire in 1971, this area was designated as a research area for studying the effects of fire on upland vegetation. In 1975, another fire burned 1,376 ha in the upper Washington Creek valley. That fire, which was exceptionally intense and fast-moving, threatened the oil pipeline, which was under construction at the time.

Because of its proximity to Fairbanks and the University of Alaska, this site provided an excellent opportunity to study the effects of fire on the mature black spruce ecosystem. The study has been a joint effort of the University of Alaska, the U.S. Forest Service Institute of Northern Forestry, and the Bureau of Land Management. The interaction of vegetation and permafrost were simulated by removal of organic material from the forest floor by burning and by mechanical means. In addition, a heated-soil experiment in the 135-yr-old black spruce stand was established to examine the effect of artificially increased temperature on the thickness of the active layer and on tree and forest-floor productivity. In 1976 and 1978, a series of experimental fires were conducted to provide before-and-after measurements of various intensities of fire in the black spruce and to study fire behavior under varying weather and fuel-moisture conditions. The studies conducted here have contributed especially to understanding the limiting factors in this nutrient-poor, cold-dominated, low-productivity forest site (Dyrness and Grigal, 1979; Dyrness, 1982; Van Cleve and others, 1983).

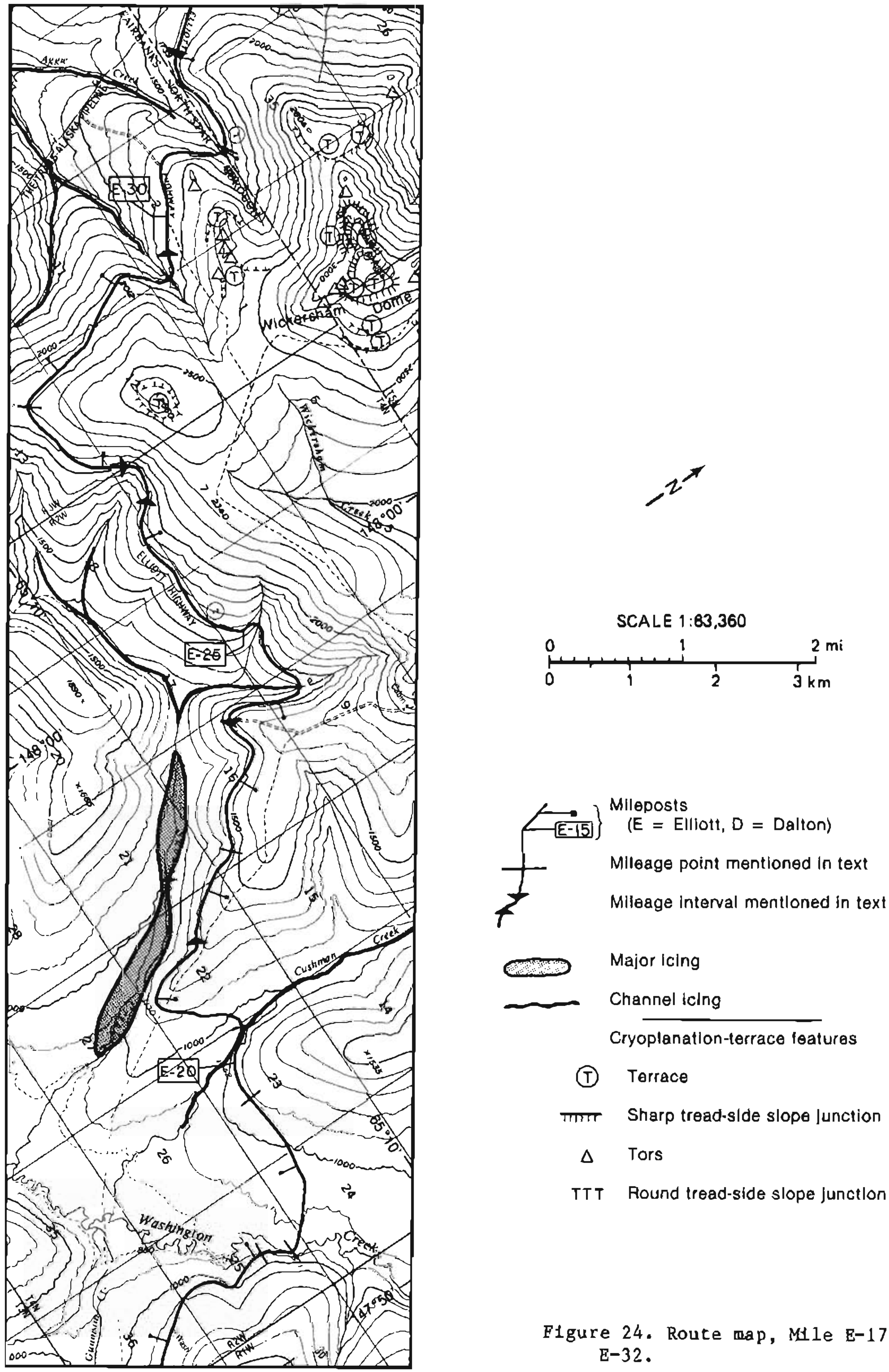


Figure 24. Route map, Mile E-17 to E-32.

E-18.3 : Washington Creek.

E-19.7 : Entrance to Washington Creek Fire Ecology Experimental Area.

E-20.3

The road crosses Cushman Creek. Along Cushman Creek to the northeast is the site of the U.S. Forest Service fireline-permafrost investigations on the effects of firelines on the permafrost terrain. It is located about 1.6 km up the creek from the road at the fire boundary. Birch Creek Schist is exposed on the southeast side of the creek. The new section of road is built on ice-rich silt.

E-21.5 to E-23.6

The road passes into and out of the 1971 burn area.

E-22.4

A cleared fireline can be seen on the opposite slope to the west. Because the Wickersham fire was close to Fairbanks, a major effort was made to suppress it, which included the construction of 113 km of fireline averaging 12 m in width. Many of the firelines were on soils underlain by ice-rich permafrost.

Subsidence and thermal erosion following fireline construction has been a major problem associated with fire suppression in the taiga of Alaska. Following the Wickersham fire, a large fireline rehabilitation project was undertaken by the Bureau of Land Management (Bolstad, 1971; Knapman, 1982). The effort included seeding and fertilization as well as construction of water barriers across firelines on steep slopes. A number of these barriers, constructed of material originally removed from the fireline, can be seen on the hillside opposite Mile 22.4 on the highway. The Institute of Northern Forestry also initiated studies to determine the effect of the fire and fireline construction on soil temperature and on the thickness of the active layer (Viereck, 1982). Figures 25 and 26 show the condition of the fireline immediately following construction and in 1980, 9 yr later. The results of this study (figs. 27 and 28) show that the active layer thickness in the unburned black spruce stand is about 40 to 50 cm, with little year-to-year variation; in the burned stand the active layer thickness has gradually increased through 1981, when the annual thaw reached 2.1 m. Thaw on the fireline, which was scraped to mineral soil, increased in thickness until 1980, when it seemed to stabilize; it then reached a depth of 2.2 m in 1981. Analyses of the annual freeze-thaw cycle at the three sites (fig. 28) show that thawing begins at about the same time in May and June but extends longer and is deepest beneath the fireline. Refreezing of the active layer is completed in December beneath the unburned stand, in late January beneath the burned stand, but not until the end of February beneath the fireline. Revegetation of the burned area has been slow. The fireline has developed a dense moss and herbaceous cover.

Detailed studies of the plant succession following fire in the black spruce type have been conducted on the Wickersham burn and other burns of known age in interior Alaska. Six stages (fig. 29) have been recognized in the approximately 100 to 200 yr that it takes for a mature spruce stand to develop following fires.

After most fires, black spruce replaces itself on the burned site, primarily because it has cones that retain seed until the tree is burned. Most cones do not burn, but later open and disperse their seeds, an adaptation to fire. Because the thick organic layer of the forest floor seldom burns completely, except in a very severe late summer fire, revegetation is rapid and

Figure 25. Fireline conditions immediately following the 1971 Wickersham fire (photograph taken by L.A. Viereck).

Figure 26. Condition of the fireline shown in figure 25 in 1980 (from Viereck, 1982, fig. 2).

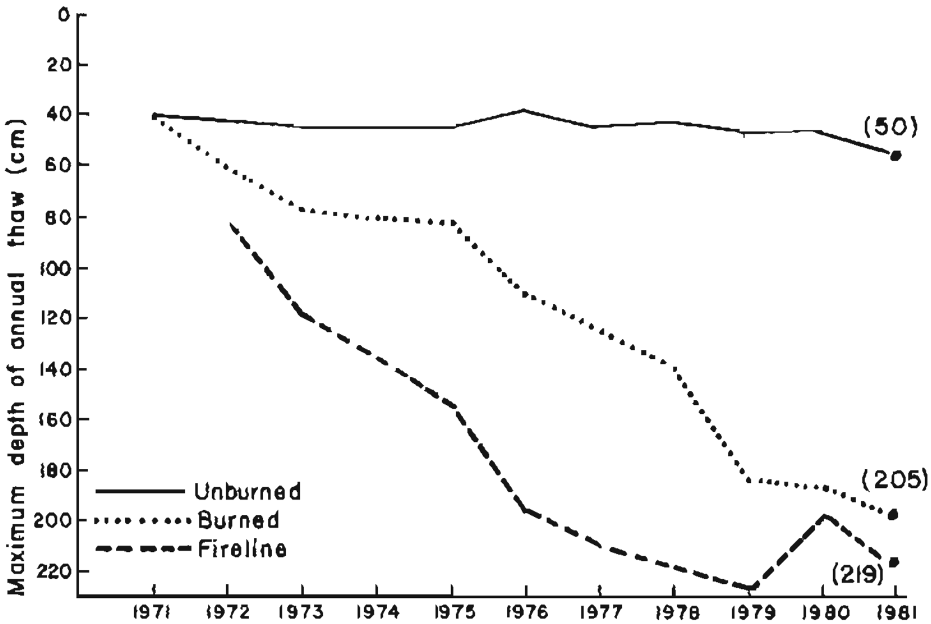


Figure 27. Change in maximum thaw depth of the unburned control, fireline, and burned stand, 1971 to 1981 (modified from Viereck, 1982, fig. 9).

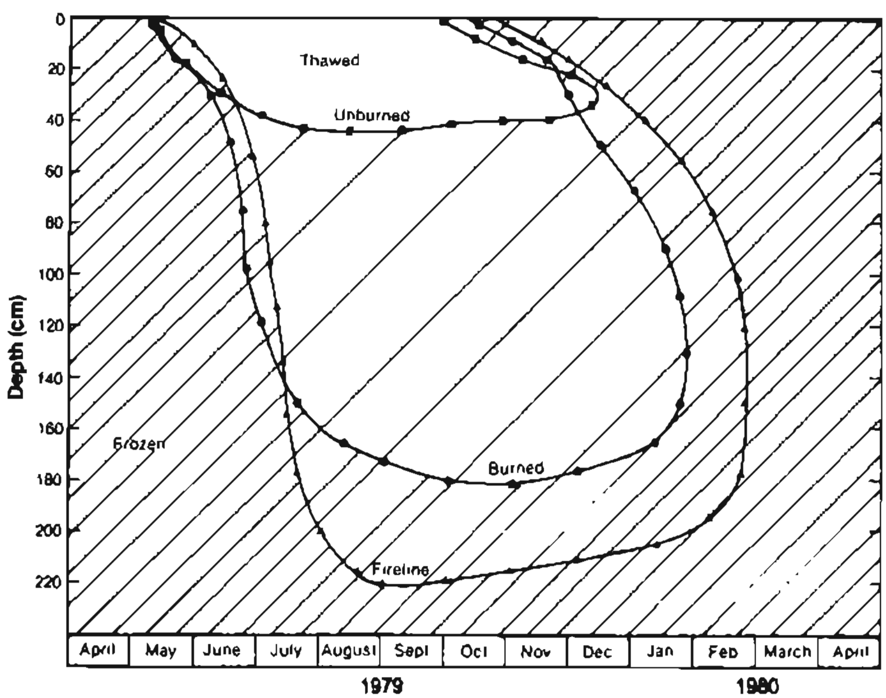


Figure 28. Time and depth of freeze and thaw for the unburned control, fireline, and burned black-spruce stand for the period April 1979 through March 1980 as determined by probing and by soil temperature measurements (from Viereck, 1982, fig. 11).

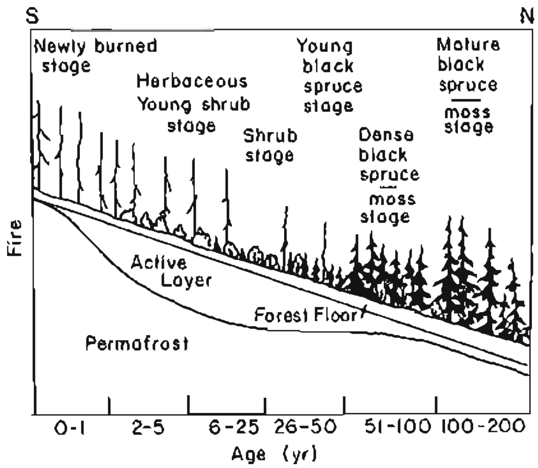


Figure 29. Stages in forest succession following fire in a black - spruce ecosystem underlain by permafrost (modified from Van Cleve and Viereck, 1981, fig. 13.3).

is accomplished mostly by resprouting from roots and other plant organs that are not destroyed by the fire. Some species that bear light seeds, such as fireweed, invade, and others develop from seed buried and preserved in the unburned organic layer. Because both herbs and shrubs grow rapidly, there is an herbaceous stage and a shrub stage, even though the slow-growing black spruce is usually established within a few years of the fire. About 25 to 50 yr after the fire, black spruce dominates the herbs and shrubs. At this time, a rather dramatic change takes place in the forest floor with the invasion and development of feathermosses and lichens. This moss-lichen floor builds up a thick organic layer, which is probably the most important factor that eventually leads to establishment of low soil temperatures and a shallow active layer (fig. 29). In the later stages of the succession these low soil temperatures and the shallow active layer result in a decrease in biomass and production, in part through accumulation of nutrients in unavailable form in the organic layer of the forest floor.

Black spruce stands of a wide variety of ages can be seen along the route. Some that have been studied in detail include the Wickersham burn (1971), the Globe Creek (misnamed) burn (1958), and the Hess Creek burn (1966). Most of the unburned black spruce stands in the Washington Creek Fire Ecology Area area are of two ages, about 70 yr and 140 yr (Viereck and Dyrness, 1979; Viereck and others, 1979; Van Cleve and Viereck, 1981).

In most places, regeneration of the vegetation following fire in black spruce forest results directly in another black spruce stand. However, hardwood stands of aspen and birch may develop following fire on south-facing slopes formerly covered by white spruce, especially where the fire has removed most of the organic layer. Thus, birch and aspen stands are common on south-facing slopes along the route, especially in the first 10 km north of Fox and on south-facing slopes near Livengood. On all but the driest of sites, the aspen and birch will eventually be replaced by black or white spruce.

E-26.5 to E-26.8

To prevent winter road icings, insulated underdrains were constructed along the highway to collect water on the east side and carry it beneath the road to be discharged downslope. This technique successfully reroutes most of the surface water.

E-27.7

Wickersham Dome wayside is located on a shoulder of Wickersham Dome on a low summit of alpine tundra at an elevation of 670 m. The Sawtooth Range, ap-

Figure 30. Upright, well-formed white spruce, all approximately 40 yr old, growing in shrub birch and willows above the older established treeline on Wickersham Dome (Viereck, 1979, fig. 4).

proximately 80 km to the west, is visible on a clear day. On the east side of the road and behind Wickersham Dome is the early foot trail between Fairbanks and Livengood. Wickersham Dome was named after James W. Wickersham, pioneer, judge, author, and Alaska Delegate to Congress. The pipeline is visible from here for a long distance to the south, crossing over five ridges.

Open treeline stands of scattered black and white spruce can be seen to have a nearly continuous layer of shrub birch, alder, and willow. Above the highway, treeline can be observed as scattered upright trees, typical of many treeline sites in Alaska (fig. 30); wind-pruned, low, matted 'krummholz' tree forms are lacking.

Two common treeline phenomena can be observed. One is the 'candelabrum' type of spruce clump described originally from Labrador. Black spruce commonly reproduces by layering, the rooting of the lower branches in the moss mat. This results in a tree clump, all stems originating from one individual, with the oldest and tallest stem in the center surrounded by progressively smaller and younger trees. Several of these clumps can be seen in figure 30.

A second phenomenon of treeline observed at Wickersham Dome that is not apparent in the treeline on the south slope of the Brooks Range is the prevalence of small trees 1 to 3 m in height scattered between larger trees (fig. 31). The younger trees, all about 40 years old, apparently originated during the warmer summers of the late 1930's and early 1940's. A similar

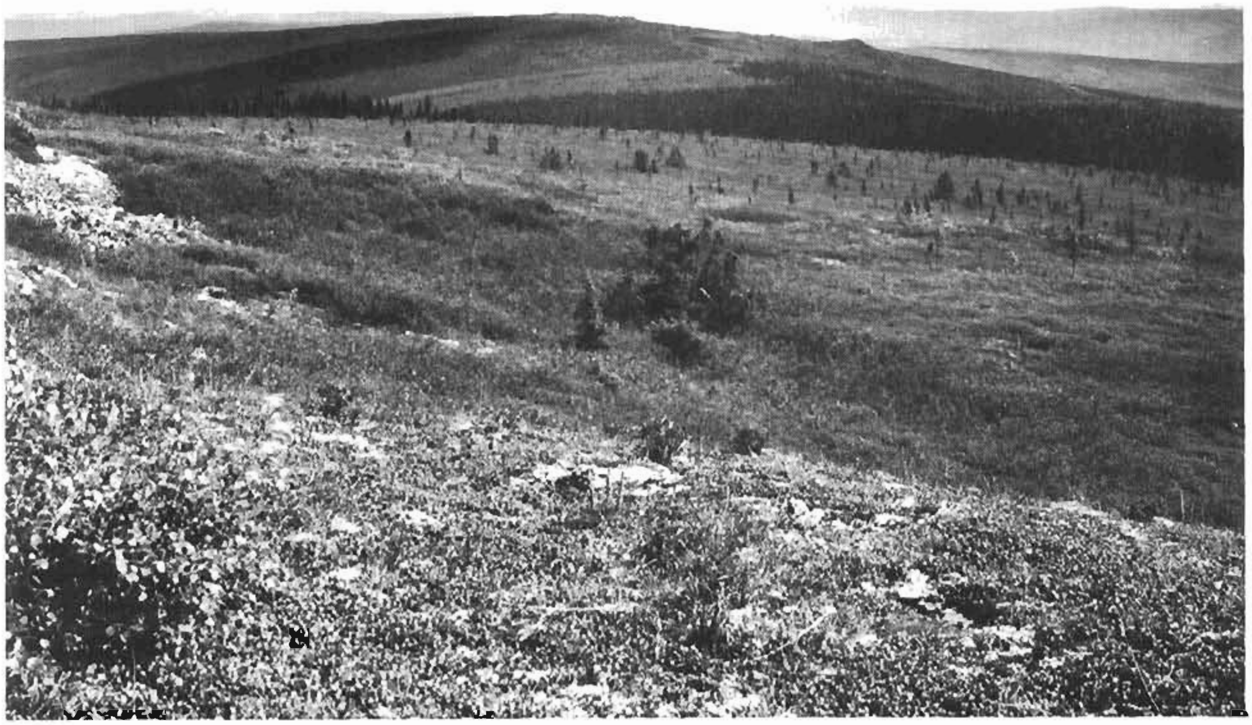


Figure 31. Scattered spruce, all approximately 40 yr old, growing in the shrub-birch zone above the old stabilized treeline on Wickersham Dome (Viereck, 1979, fig. 3).

invasion of tundra areas by trees during the same period occurred in northern Europe.

E-29.5

Stabilization berms can be observed on either side of the road as it crosses the creek bottoms here and 2.3 km to the north. They are used to prevent subgrade failures that result from subsidence as ground ice melts. The berms are designed so that longitudinal failures produced by subsidence are moved from the edge of the road out to the edge of the berm. The berms are a minimum of 1 m thick and 5 m wide. This design reduces road maintenance.

E-29.7

By this pullout, there is an insulated perennial spring on a permafrost slope. Prior to insulation, the spring created serious winter maintenance problems as water overflowed the road, causing icings. During reconstruction of the road, the spring was excavated extensively on the uphill side and a perforated drain pipe was installed. Preformed Styrofoam insulation was placed above and below the pipe and under the roadbed. A T pipe was inserted in the downhill side of the road with a main cutoff valve. This permits the water to come up in a standpipe to form a drinking fountain for summertime use. In the winter the water flows out on the downslope toe of the road, thus moving the icing problem from the road to the area downhill of the road. The water source is a fault zone in the Birch Creek Schist.

E-29.7 to E-32.1

On the northwest side of Wickersham Dome are extensive stands of black spruce. On the west side, the pipeline passes through a slope of aspen and birch. Stabilization berms are present along the road shoulders. A tor can be seen to the northeast along this section of the road. The summit and flanking ridges of Wickersham Dome provide an opportunity to observe tor and cryoplanation terrace development on metamorphic rocks of the Yukon-Tanana Upland. The bedrock there is a complexly folded and faulted sequence of sericitic quartzites interbedded with thin beds of quartz-sericite schist and carbonaceous quartz schist. Cryoplanation terraces are bedrock steps or terraces on ridges and hilltops that are cut into all bedrock types and are best developed on closely jointed, fine-grained bedrock (Nelson, 1982; Reger, 1975; Reger and Péwé, 1976). Terrace scarps vary from 1 to 75 m in height. The tread or flat area may be up to several hundred meters wide and long, and slopes from 1° to 5° parallel to the ridge crest. Permafrost occurs within several meters under a frost-rived rubble cover. Some terraces in Alaska were active when the mean summer temperature was between +2° and +6°C. The terraces and related features shown in figure 24 were among those mapped by Reger (1975) in his comprehensive study of the cryoplanation terraces of interior and western Alaska.

E-31.0 : Aggie Creek.

This is the boundary of Fairbanks North Star Borough. The bedrock cuts are in schist and argillite.

E-34.1

A section of buried pipeline is visible to the north. During late spring, the snow over the warm pipe melts first, as seen in figure 33. The revegetated trail west of the pipeline was cut in the late 1960's to provide access to distant ridge-top communication sites (Rickard and Slaughter, 1973). Along the road are outcrops of the Tolovana Formation, which consists of limestone, graywacke, and argillite.

E-35.7

Purple argillite of the Tolovana Formation is exposed along the old Elliott Highway, which may be seen on the east side of the valley. The road crosses stunted black spruce forest formed on ice-rich permafrost slopes. Several roadcuts were made through graywacke and argillite.

E-37.1 : Globe Creek (fig. 34).

To reduce winter icing on the small streams, many crossings have timber bridges instead of metal culverts, as at Globe Creek. The vertical wood side-walls prevent ice from forming on the sides, as it does on the cold metal culverts. Water continues to flow under the ice cover. Highway construction in Alaska has proven that at stream crossings the placing of support structures in the streambed should be avoided to avert icing of streams that usually do not ice thickly over. The road is on ice-rich permafrost. To the north are two dome-shaped summits commonly referred to as the 'Grapefruit' Rocks.

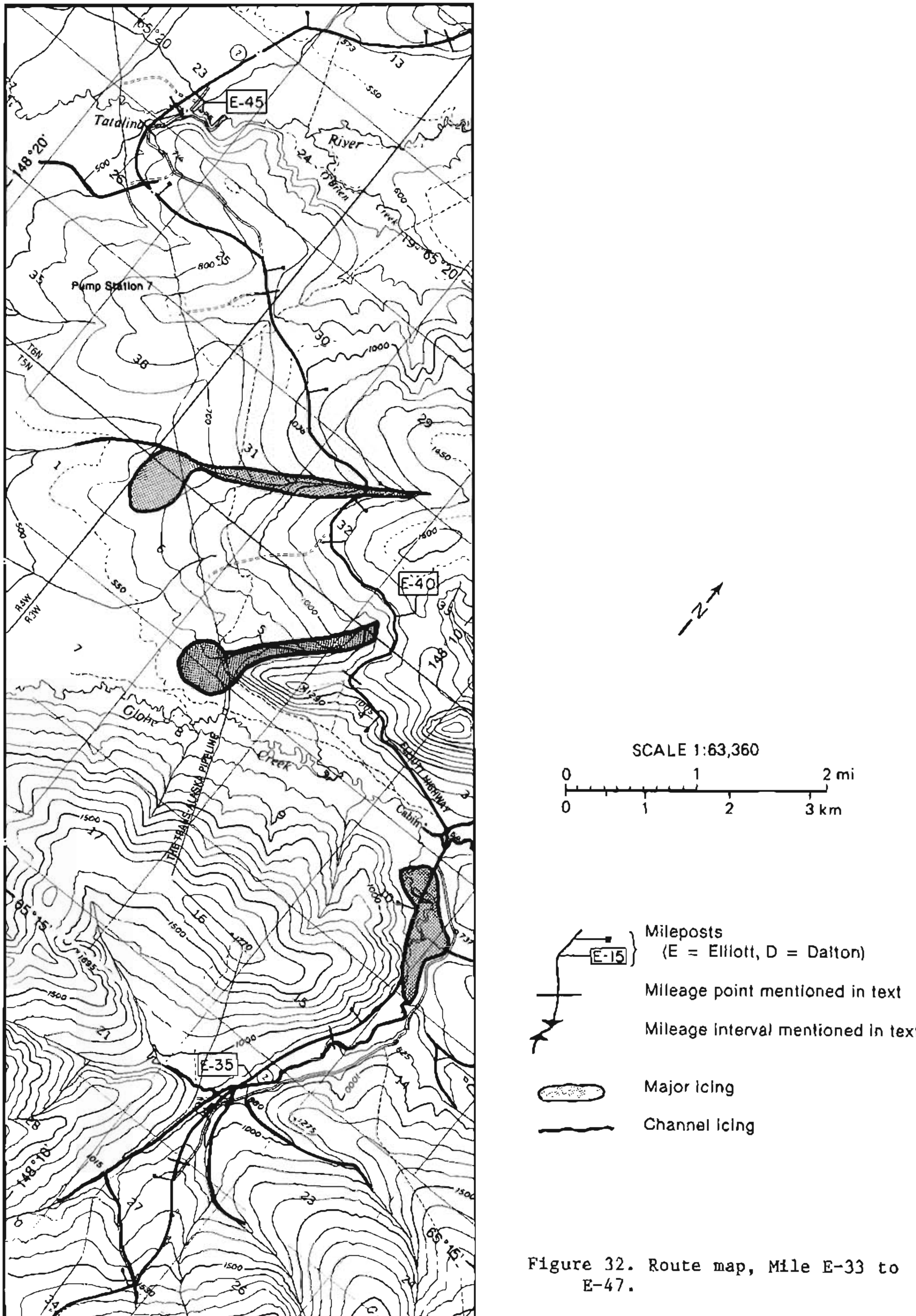


Figure 32. Route map, Mile E-33 to E-47.

Figure 33. View of the trans-Alaska pipeline in its elevated mode in the valley bottom and buried mode on the slope and ridge top. Snow has melted over the soil warmed by the heated oil pipeline. The wide strip devoid of forest cover was cut over in the late 1960's for access trails (see Rickard and Slaughter, 1973) (photograph taken by Bruce Brockett on April 12, 1982).

Figure 34. Single-span bridge and timbered abutment across Globe Creek designed to prevent icing over the channel (photograph taken by Bruce Brockett on April 12, 1982).

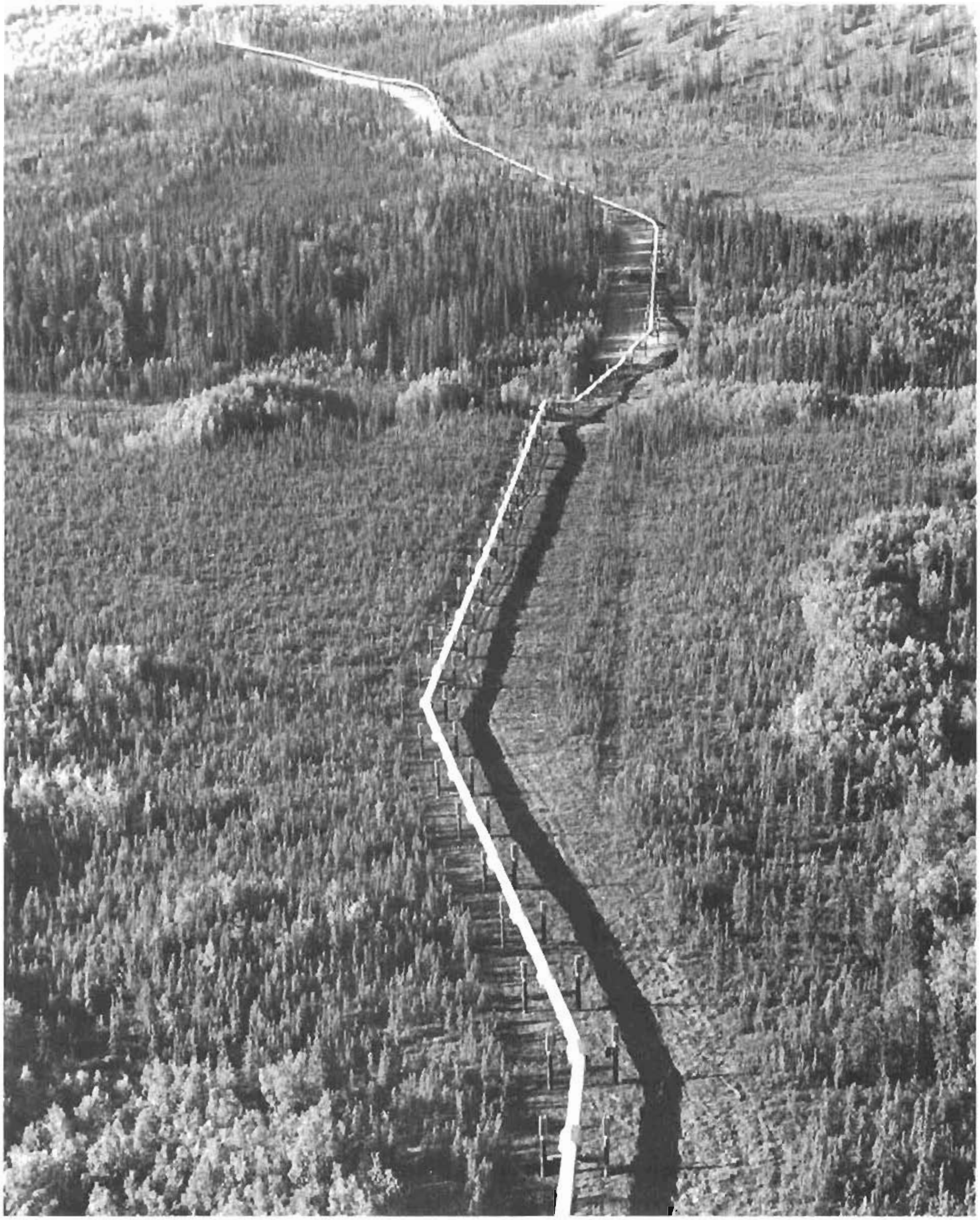


Figure 35. Looking north to Globe Creek. The elevated pipeline was constructed by use of a snow pad in order to prevent thawing of the ice-rich permafrost. The normal gravel work pad can be seen on the north side of Globe Creek. Photograph courtesy of Alyeska Pipeline Service Company.

E-39.3

The Grapefruit Rocks to the east are popular with climbers. The parking area is underlain by argillite. Limestone colluvium is upslope. The elevated pipeline may be seen to the south. Snow-pad construction was used south of Globe Creek because the permafrost beneath the pad was so ice rich that it would have been too unstable to support a gravel pad (fig. 35; Johnson and Collins, 1980). Ice lenses up to 4 m thick were encountered within 1.5 m of the surface during test borings. The construction mode of the pipeline changed from elevated to buried in frozen bedrock above the upper limit of the 'flatiron.' This point is also the upper limit of the snow pad which was used on the steep, ice-rich portion of the slope below the top of the flatiron. Except for the lower slopes and flatiron ridges, the loess has been completely stripped from the bedrock hills.

E-40.8

The Sawtooth Mountains are visible to the west as are a section of buried pipeline and the Tatalina Valley to the southwest. The roadbed consists of argillite. There has been some ditch erosion and rubble has been placed on the east side to protect the toe of the road.

E-42.0 : Entrance to Pump Station 7.

E-44.5

The road is cut in argillite with a thin cap of silt.

E-44.8

The Tatalina River bridge is built with timbers to prevent thick icing buildup over the streambed. The old Elliott Highway is on the southeast side of the valley. The elevated pipeline crosses the valley and ascends the slope to the north.

E-47.2

The Tatalina Valley is to the east. Permafrost is close to the surface on the flat valley bottom. The large cuts were made in graywacke and sandstone. A fire, erroneously referred to as the 'Globe Creek fire,' burned about 750 ha in 1958.

E-47.4

Graywacke is exposed in a large cut to the west.

E-49.4

A small group of homesteads and a local school are visible.

E-51.4

The White Mountains are visible to the east. This area forms the divide between the Tolovana and Tatalina Rivers.

E-52.5

A large roadcut has been made through argillite.

E-52.8 to E-55.7

Here the road is built on permafrost containing considerable ice. Note the stabilization berms. Roadcuts made through ice-rich permafrost (fig. 37) have stabilized as organic-rich soils slumped over the receding cuts. Between

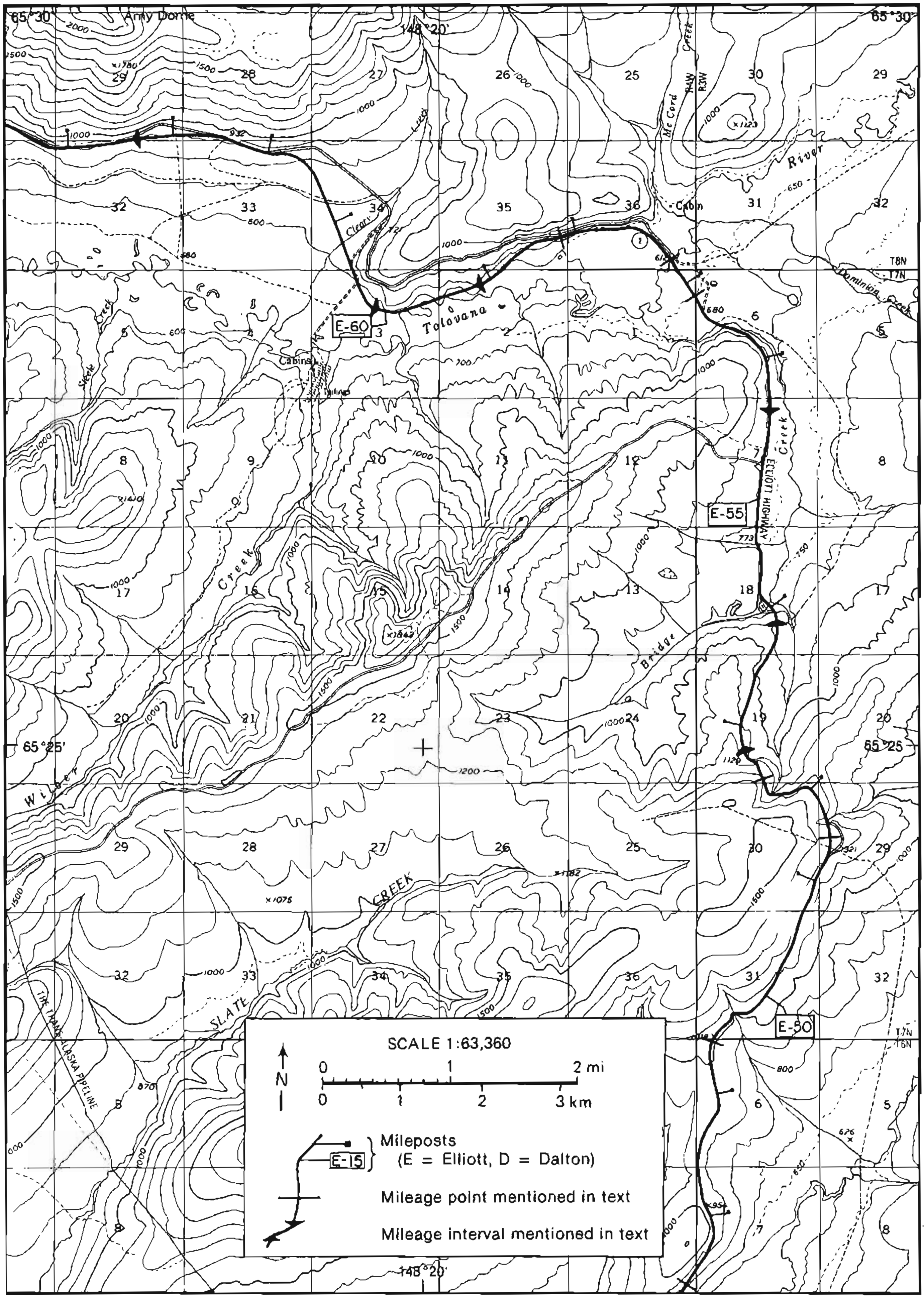


Figure 36. Route map, Mile E-48 to E-64.

Figure 37. Roadcut exposing ice wedges in vicinity of Mile 53 of the Elliott Highway (photograph taken by R.A. Kreig).

sections E-53.9 and E-55.7 the road passes over permafrost with ice masses 3 to 10 m thick.

E-56.9
A small thermokarst pond is visible to the east along the old road.

E-57.2 : Tolovana River bridge and campground.
Stands of tall white spruce grow along the river. In 1979-80 the road was relocated between here and the junction with the Dalton Highway. The old Elliott Highway is on the east side of the valley.

E-58.1
Roadcuts have been made through fractured argillite. Spoon-shaped slope failure occurred where two joint sets came together. A tuffaceous conglomerate is exposed on the ridge crest.

E-59.1 to E-60.1
Erosion by the Tolovana River occasionally exposes bluffs containing ice-rich sediments. Tall white spruce grow along the well-drained banks. There is a roadcut through conglomerate along the east side of the road. Placer mines have recently been reopened on Wilber Creek, a western tributary of the Tolovana River. This is the type locality for the Wilber Ash, which has been radiocarbon-dated in the Fairbanks area at <4,200 yr B.P. (Péwé, 1975a). The old Elliott Highway is seen on the east valley slope above the present road.

E-63.3 to E-65.4
There is a series of roadcuts in argillite and graywacke on the east side of the road.

E-66.8 : Olive Creek.
Old gold-dredge tailings are seen along the road. Cinnabar was found at the head of Olive Creek. Copper prospecting took place on the west side of

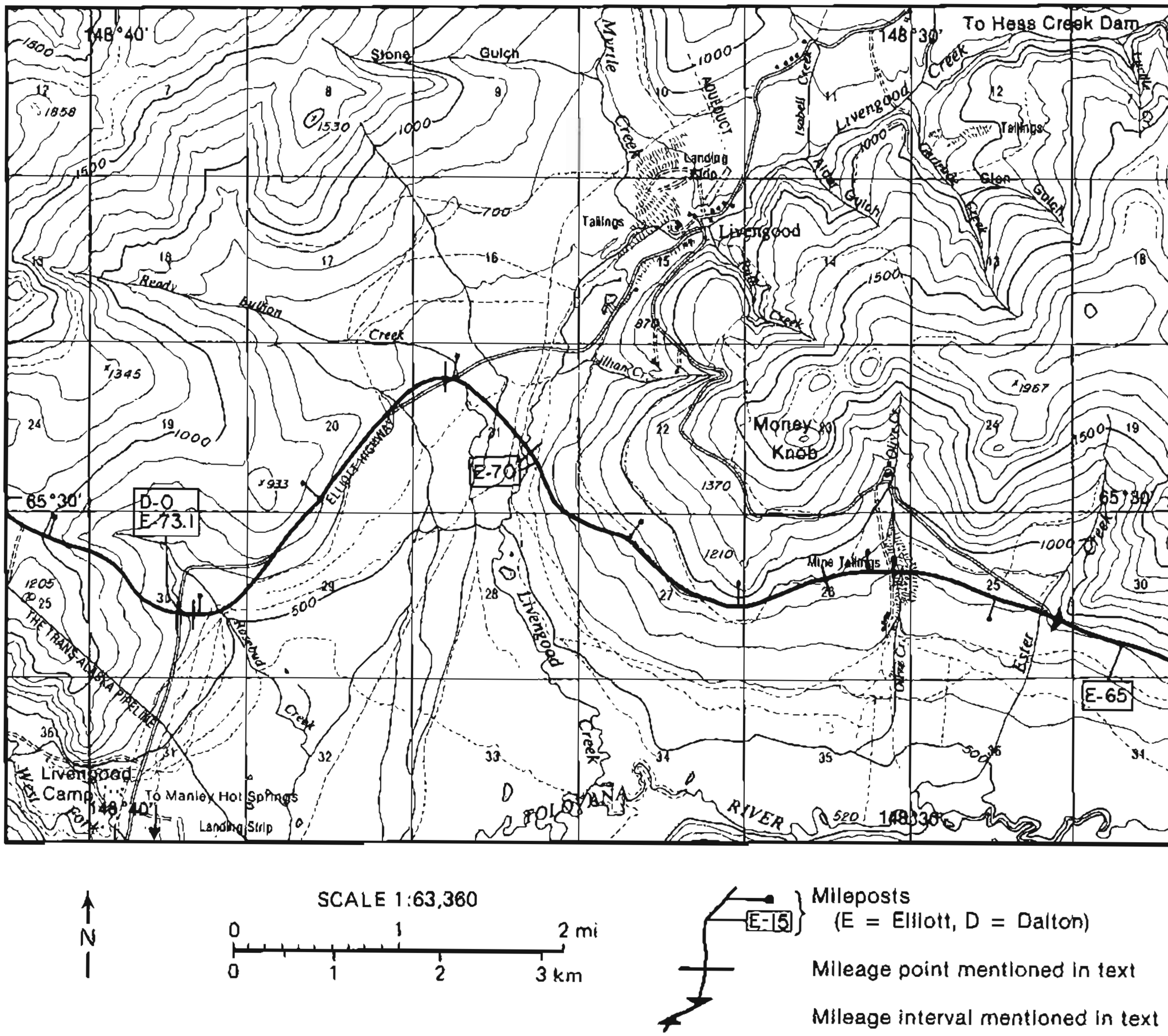


Figure 38. Route map, Mile E-65 to E-71.

the valley. A tramway operated on the west fork of Olive Creek. Surface ice from Lake City, to the west, was used for a water supply. A winter icing occurs just south of Olive Creek along the east side of the road.

E-67.3

The hill to the north is Money Knob, one of the source areas for the Livengood gold placers.

E-70.1 : Livengood Creek.
The ridge behind Livengood is of greenstone.

E-71.1

Junction with Livengood Road.

LIVENGOOD

The new section of highway bypasses Livengood, which was named after Jay Livengood who, with N.R. Hudson, discovered gold in the creek in 1914. Prospecting flourished on Livengood Creek but yielded only meager results, with about 10 mines commercially productive. Gold output in 1915 was approximately $80,000, at a price of about $20/oz. The daily wage was between $1.00 and $3.00. Considering the isolation of the new camp and the fact that many of the placer deposits were deep and required batters, cribbing, and hoists for proper development, the results of the first season's work were still encouraging to the miners.

A prospector named Casaden, relying on his Klondike experience, felt that the real paydirt should be on the benches above Livengood, not in the creeks. He was correct, and it was not long before the main pay streak was found. Livengood camp boomed, and by 1916 a total of 21 plants were engaged in mining the bench gravel above Livengood Creek. One was engaged in mining the creek gravels. These operations were carried on by underground mining. On other creeks, such as Gertrude, Ruth, Lillian, and Olive, five small plants were operating as open-pit mines.

In 1916, the Livengood area produced over $700,000 worth of gold, a ninefold increase over 1915. By 1917, some 27 plants were operating. In 1918, the camp reached its peak population of over 1,500 residents. At the same time, more than 5,000 people were living in the Livengood area, which included Eureka and Manley Hot Springs. It has been reported that a person could walk for 6.5 km underground through the interconnected drift mines. The peak years lasted until 1922. During that time, Livengood camp boasted two laundries, two restaurants, a hotel, three transportation companies, and four general stores. But by 1922, the population of the Livengood camp was on the decline.

Located 13 km northeast of Livengood is the site of the Hess Creek Dam and its reservoir (fig. 39). This was one of the largest earth-filled dams ever built on permafrost in Alaska and it impounded a reservoir of 144 ha. The dam was 24 m high and 485 m long at its crest. Dam construction was begun in 1940, was curtailed during World War II, and was completed in 1946. The dam was designed and built to divert water from the upper reaches of Hess Creek to the gold-mining areas in the valley of Tolovana River. A 1,000-m-long tunnel was excavated in the frozen silt and gravel near the upper end of the reservoir. A 1.1-m-diameter wood-stave pipe carried the water. The reservoir was emptied in the winter to allow refreezing of the embankment and related structures.

The spillway structure failed in the spring of 1962 when the reservoir overfilled and water was reportedly 1 m deep in the drainage channel. Headward gully erosion at the base of the spillway eventually undermined the spillway control works and the dam. There were considerable maintenance problems with the outlet tunnel throughout the life of the reservoir. However, several reports stated that permafrost need not be a deterrent to construction, operation, and maintenance of large earth-filled dams on the permafrost that exists in the interior of Alaska (Rice and Simoni, 1966; Kitze and Simoni, 1972; Simoni, 1975). Details of the design and construction of the dam are contained in the reports cited.

The dam and spillway have since been repaired, and it is once again in operation (fig. 40). Water is being pumped overland from the reservoir to ditches that flow to a large active placer-mining operation along Livengood Creek (fig. 41). At this open-pit mine, managed by Livengood Joint Venture,

Figure 39. Aerial oblique photograph looking south to Hess Creek Dam and reservoir (photograph taken by D. Atwood on July 19, 1982).

Figure 40. Closeup of the reconstructed spillway of Hess Creek Dam (photograph taken by D. Atwood on July 19, 1982).

Figure 41. Aerial photograph of the recently reopened placer-mining operation at Livengood (photograph taken by D. Atwood on July 19, 1982).

some 15-20 m of frozen overburden is being removed with rippers and bulldozers. The old technique of hydraulicking the overburden is no longer used to avoid excessive siltation in streams and rivers. The underlying 8 to 10 m of gravel is stockpiled and then processed in a washing plant. The runoff from this washing operation is discharged into a large settling pond, where suspended solids are removed.

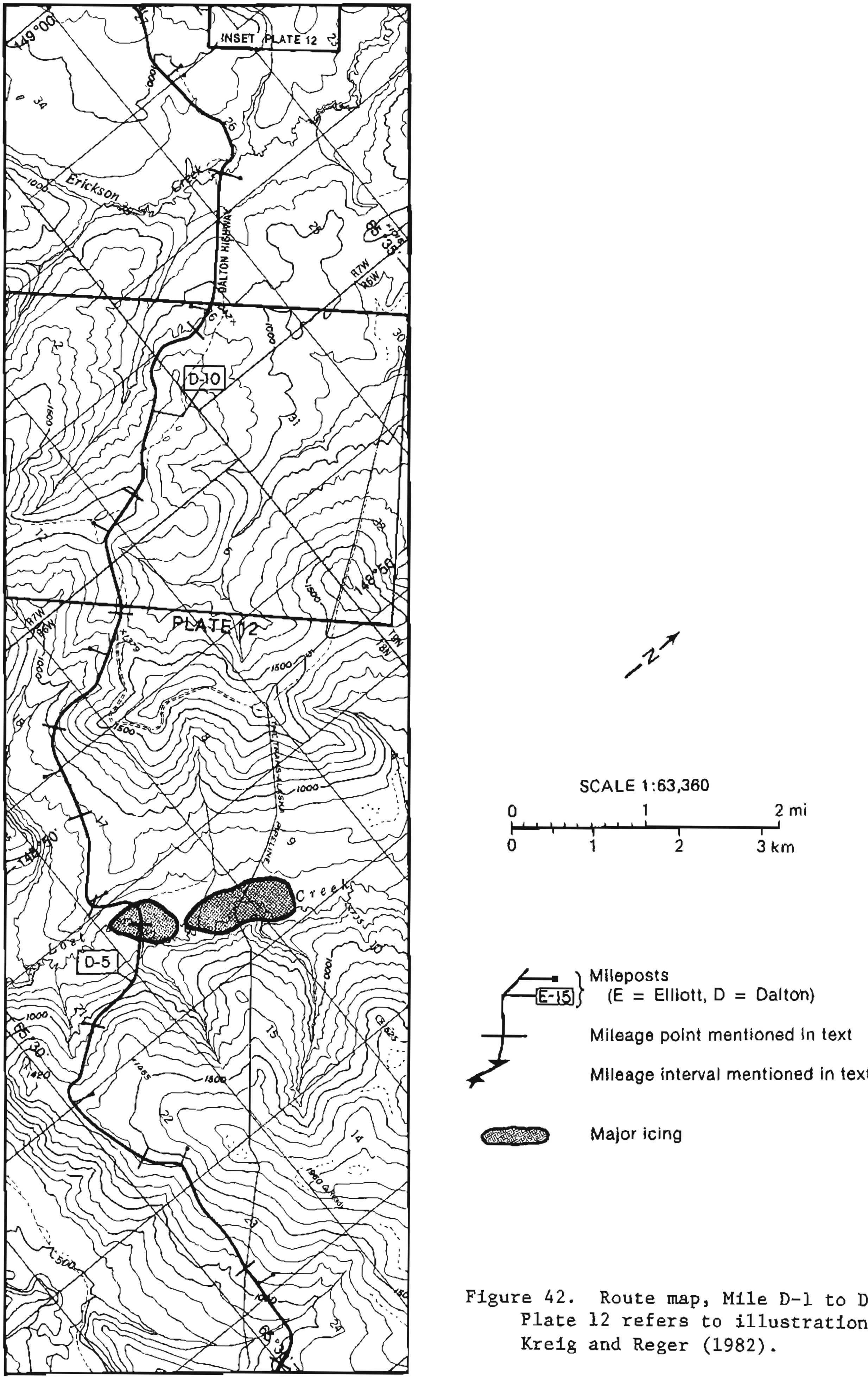


Figure 42. Route map, Mile D-1 to D-13. Plate 12 refers to illustration in Kreig and Reger (1982).

LIVENGOOD - YUKON RIVER

E-73.0
Good examples of stabilization berms may be seen.

D-0.0 (E-73.1) : Junction of Elliott and Dalton Highways.
This is the beginning of the 'TAPS Road' section of the Dalton Highway, built in 1969 and 1970 north to the Yukon River.

D-1.3
A long section of pipeline may be seen as it crests a hill.

D-2.2
The highway crosses the buried pipeline. Good examples of the buried and elevated pipeline construction modes may be seen. The pipeline is elevated on the lower slopes because of deep (4.6 to 6.1 m), frozen, thaw-unstable silts. The upper, south-facing slopes are generally thawed or have bedrock at shallow depths, thus allowing burial of the pipeline. The road crossing is a standard 'cased' crossing in thaw-stable soils.

D-3.2
There is a sweeping view of the pipeline and the Tolovana River area to the southeast.

D-4.5
The highway descends steeply into the valley of Lost Creek, which flows into the West Fork Tolovana River. The pipeline is visible stretching across the ridges of the distant hills.

D-5.5
Lost Creek passes beneath the highway.

D-6.0
A cut 10 m deep into an ancient alluvial terrace north of and 50 to 60 m above Lost Creek has exposed subrounded to subangular gravel containing small cobbles, which is overlain by a thin loess cap. The gravel is little weathered, but the upper 1 m shows oxidation stain. A large hilltop material site in bedrock is located east of the road.

D-6.6
An exceptionally well-developed, lichen-covered bluff may be observed to the west.

D-7.3
A steep, winding route leads out of the valley. The thickness of the loess throughout the Yukon-Tanana Upland varies with the distance to the silt source. As indicated previously, loess is thin or absent from Fox to this point. From here to just north of the Yukon River, most hills and ridges are covered with moderately thick, perennially frozen loess, apparently derived from the Yukon Flats of the Yukon River (Williams, 1962). The loess has been extensively reworked by fluvial processes that transported the silt to lower slopes and valley bottoms, where it was incorporated with organic materials. Both the frozen loess and retransported organic silt contain massive ice as thick as 17 m. Gullies in frozen upland loess have convex walls and narrow

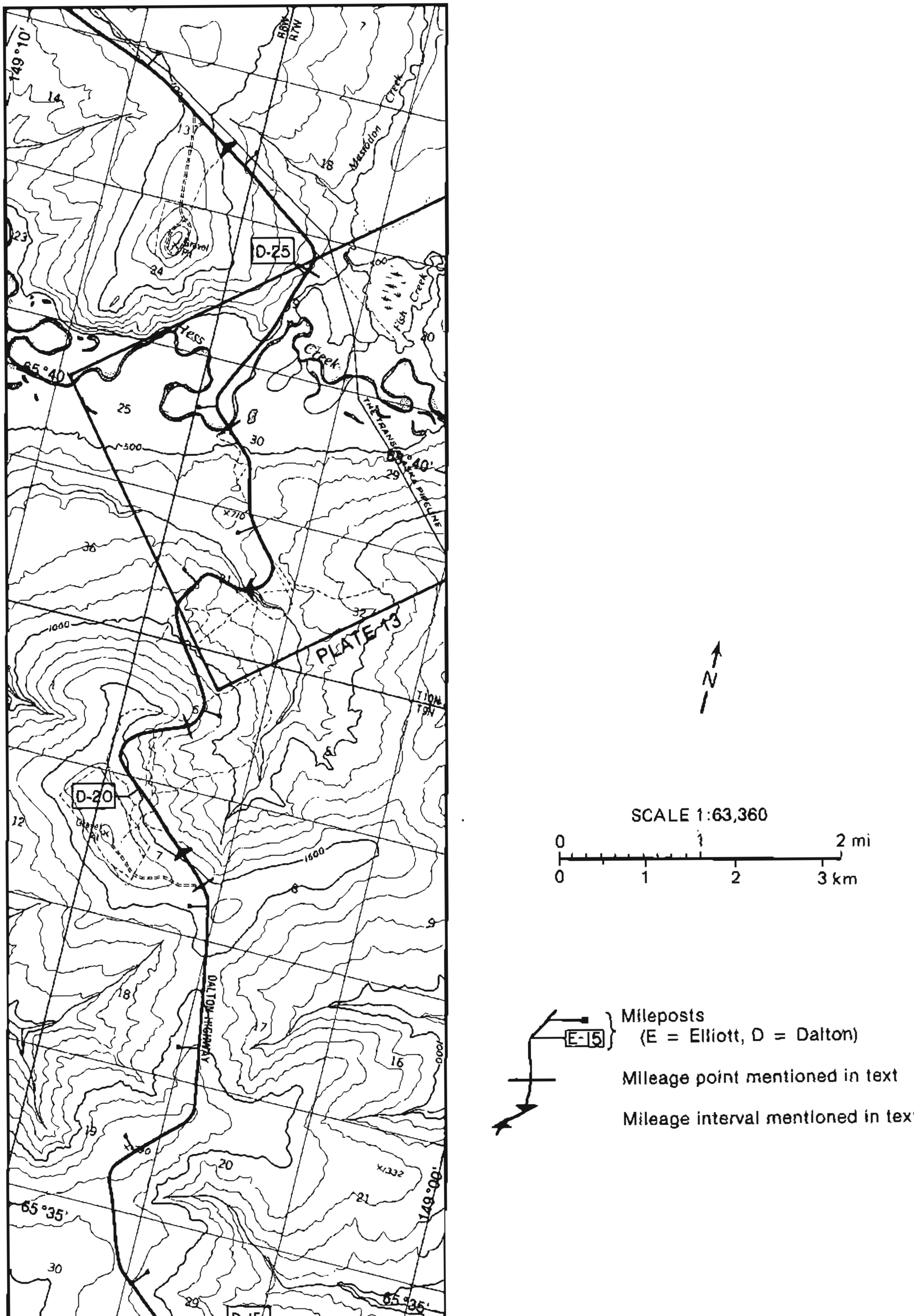


Figure 43. Route map, Mile D-14 to D-27. Plate 13 refers to illustration in Kreig and Reger (1982).

floors, in contrast to gullies with broad floors in unfrozen upland loess (Kreig and Reger, 1982, fig. 8). In general, the vegetation between Livengood and the Yukon River is primarily black spruce in stands of various ages. These stands are interspersed with birch stands of various ages, especially on some of the south-facing slopes. The understory of black spruce in the birch stands indicates that spruce will eventually replace the birch. Lichen-covered forest floors are observed in this vicinity.

D-8.4
An excellent example of a stunted black spruce forest may be seen.

D-9.3
The road follows a high ridge with a spectacular view of Erickson Creek valley and the pipeline. The pipeline parallels the road to the northeast, following the tops of the high ridges. Broken tree tops and the bent trunks of birch and black spruce show the effects of snow loads.

D-10.8
At this point the road is built over a 6.7-m-thick clear ice lens, the top of which is 1.5 m below the natural ground surface. Approximately 120 m southeast of here a test hole encountered 18 m of clear ice beneath 2 m of frozen silt. Similar ice masses are common in these uplands between Mile D-7 and the Yukon River (Kreig and Reger, 1982, pl. 12). The highway descends into the valley formed by one of the tributaries of Erickson Creek. A long segment of elevated pipe is seen to the east.

Between here and Hess Creek the road crosses a complex of hills that is 80 to 90 percent continuously frozen. Several vistas in this section provide an opportunity to get a feel for what terrain landscape elements are unfrozen. It is probable that only the steepest and most southerly facing slopes are unfrozen. Most of the sites vegetated with tall birch and spruce forest are continuously or discontinuously frozen (R.A. Kreig, pers. commun.).

D-12.0
The road crosses the silt-filled floor of Erickson Valley.

D-15.6
The highway passes through an expanse of dense black spruce and scattered birch. Some limbs on the birch trees have been broken by heavy winter snow loads.

D-19.2
A large material site in bedrock used for pipeline and road construction is located on the west side of the road. Roadcuts expose highly metamorphosed rocks.

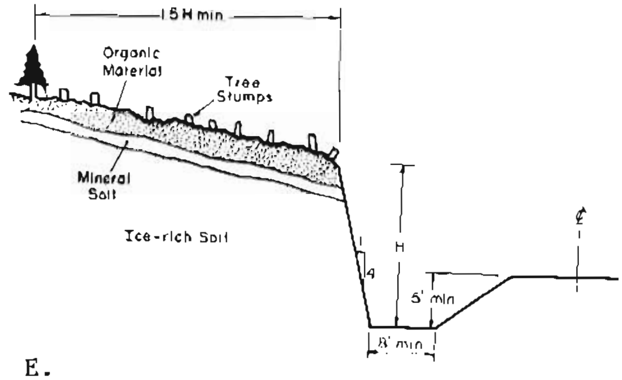
D-19.4 to D-22.5
The road was excavated through a series of massive ice wedges (fig. 44) (Smith and Berg, 1973; Berg and Smith, 1976; Pufahl and others, 1974; McPhail and others, 1975, 1976). Recession and recovery of this slope were typical of those of most ice-rich slopes along the road (fig. 44). Generally the cuts were nearly vertical, that is, with slopes of 1:4, to minimize the surface area exposed to the new thermal environment. Siltation along the west side of the road is evidence of continuing sediment transport from the receding cut banks. Subsidence under the road still presents maintenance problems.

A.

B.

C.

D.



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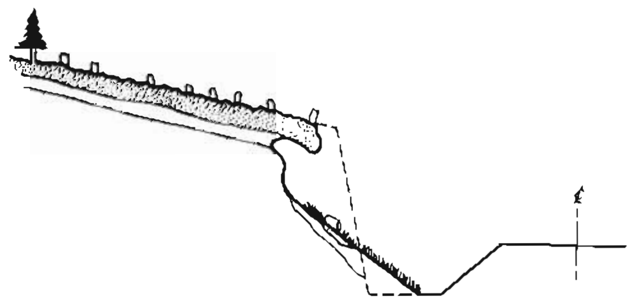

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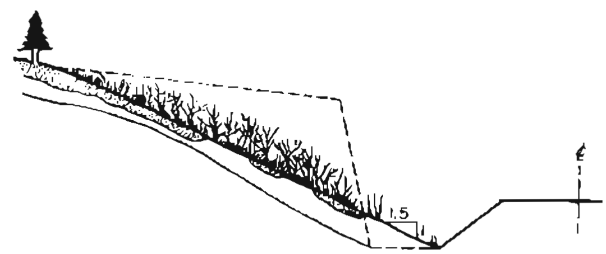


G.

Figure 44. Example of self-stabilization of roadcut containing ice wedges. A. Vertical exposure showing ice wedge soon after excavation, March 1970. B. Overhanging organic mat and accumulation of sediment at base of slope, June 1970. C. Stabilizing slope, June 1971. D. Partially vegetated slope, June 1973 (photographs taken by R&M Consultants, Inc.). Sections E, F, and G are schematic cross sections illustrating the self-stabilization process seen in the photographs (modified from Berg and Smith, 1976, fig. 74).

Figure 45. Aerial photograph of Hess Creek showing point bars, terraces, vegetation, and new bridge (photograph taken by D. Atwood on July 19, 1982).

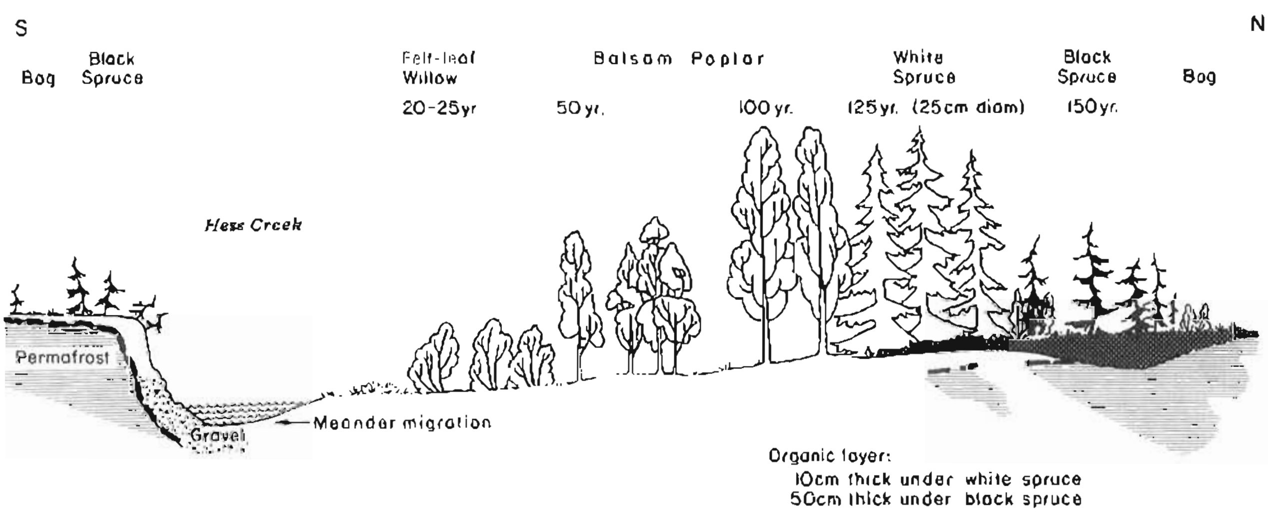


Figure 46. Section across Hess Creek showing relation between direction of meander migration, vegetation, and inferred permafrost conditions (modified from Kreig and Reger, 1982, fig. 9, and based on vegetation and soil observations by L.A. Viereck).

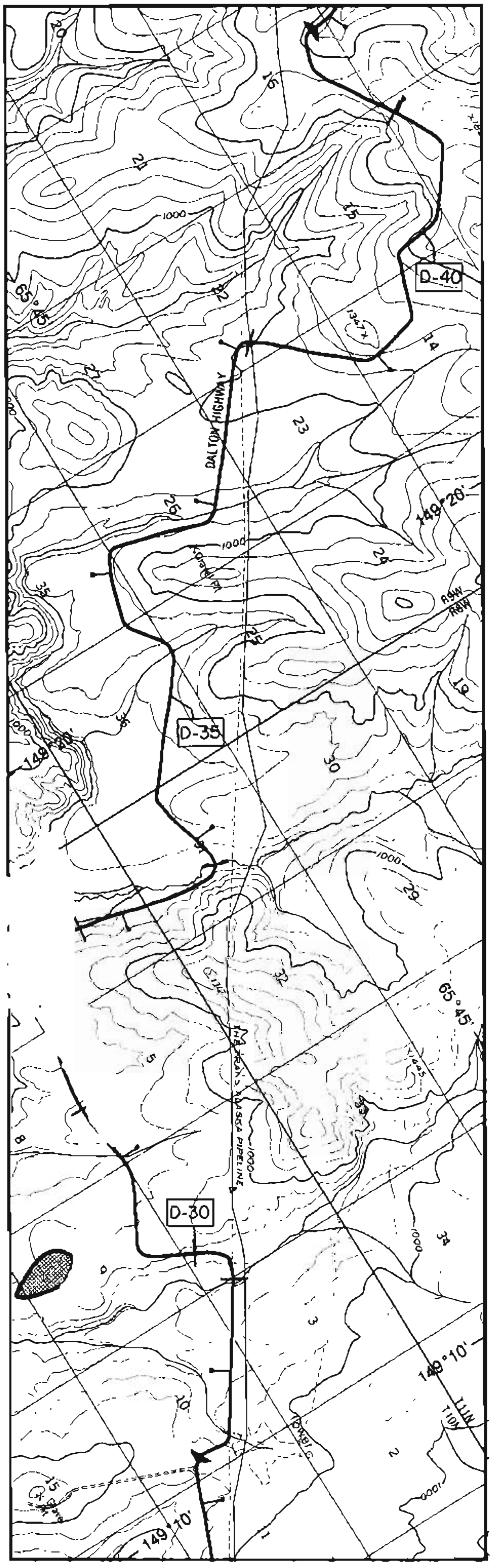


Figure 47. Route map, Mile D-28 to D-41.

D-20.8

The road begins its descent to Hess Creek. The roadcuts are in metamorphic rocks.

D-23.8

Hess Creek bridge (fig. 45) was reconstructed in late 1981 to prevent floating trees and debris from hanging up on the bridge piles. The new bridge has 36-m-long bulb-T-prestressed concrete girders. Hess Creek is the largest stream between the Elliott Highway and the Yukon River. As the river actively meanders, it cuts laterally into ice-rich permafrost. A recent cutoff 5 km downstream is less than 20 yr old. Old oxbows gradually fill with overbank flood deposits and organic material and eventually blend with the surrounding abandoned flood-plain surfaces. Sediments beneath the flood plain of Hess Creek consist of 1.2 to 4.5 m of organic silt and silty sand, which represents overbank deposits. These deposits are underlain by riverbed deposits of sand, with some gravel and sandy gravel extending to bedrock as deep as 23 m (Kreig and Reger, 1982, pl. 13).

The flood plain of Hess Creek illustrates the time required for permafrost to develop in exposed stream sediments (figs. 45 and 46; Viereck, 1970; Kreig and Reger, 1982, fig. 9). Permafrost is generally absent under the stream and on newly deposited point bars down to as much as 23 m. Test holes in this area, which were generally 15 m deep, failed to reach the base of permafrost. Deeper holes in flood-plain alluvium in the Fairbanks area and elsewhere demonstrate that permafrost generally thickens with increasing age of the alluvial surface (Williams, 1970). The fresh silt and gravel surfaces on the insides of the meander curves are first colonized by willows and alders, but are overtopped by balsam poplar in about 15 to 25 yr. Permafrost is usually absent during these early successional stages. Shade-tolerant seedlings of white spruce become established under the balsam poplar, and within 75 to 100 yr overtop the balsam poplar, which by that time have become overaged and decadent. As the white spruce stand matures and the balsam poplars die out, a mat of feathermosses develops a thick insulating organic layer on the forest floor, especially when the frequency of flooding is reduced. The insulating effect of the thick forest layer reduces the mean annual ground temperature and favors development of permafrost after 200 to 300 yr. As the active layer becomes shallow, white spruce is gradually replaced by black spruce. Eventually, permafrost incorporates all mineral soil, restricting annual thaw and plant roots to surface organic layers. Bog vegetation of scattered black spruce, _Sphagnum_ moss, and low shrubs (Labrador tea, resin birch, blueberry and diamond-leaf willow, and scattered thaw ponds with aquatic vegetation are present in the final stage of succession on the abandoned flood-plain terraces. This process of 'swamping' is common and has been reported elsewhere (Benninghoff, 1952; Williams, 1962). The south-facing dry bluff along Hess Creek is covered by grassland vegetation.

D-25.0

The view to the south includes elevated and buried sections of the pipeline as it crosses the Hess Creek valley, including a remotely operated valve site.

D-26.1 to D-28.4

The effects of a large lightning-caused forest fire that burned 13,000 ha in June, 1967, are still visible. In this vicinity, a dense population of the rare taiga vole (_Microtus xanthognathus_) has been reported (Wolff and Lidicker, 1981). From here north to the Yukon River, the vegetation consists mostly of old and locally open stands of black spruce.

Figure 48. Aerial photograph of probable open-system pingo west of Mile 32.8 on Dalton Highway (photograph taken by D. Atwood on July 19, 1982).

D-28.4
A large bedrock-material site is located on the west side of the road.

D-29.7
The road and the pipeline cross an unnamed creek and valley bottom. The elevated pipeline and a valve are close to the east side of the road.

D-30.0
Most of the rolling hills visible from here are just over 600 m elevation.

D-31.4
The Ray Mountains are visible to the west.

D-32.7
There is a probable pingo in the valley on the west side of the road (fig. 48). The bedrock cut on the east side of the road is in metamorphic rocks.

D-33.8 : Tributary of Hess Creek.
Several faults are evident in the stable bedrock cut.

D-38.1
The pipeline crosses under the road.

D-41.0
This site offers sweeping views to the south of the Hess and Troublesome Creek valleys. The most prominent peaks are Raven Creek Hill, Sawtooth Mountain, and Wolverine Mountain. The landscape exhibits rejuvenation of drainage. At Idaho Bar, some 30 km to the southwest, extensive (Pliocene?) gravel terraces are present up to 300 m above modern stream level. At that location, some of these high-level gravels contain gold placers.

D-41.8 to D-43.1
The road descends a steep grade into the valley of Isom Creek. Cuts along the west side of the road expose as much as 25 m of metamorphic bedrock and 10 m of loess and weathered rock.

D-43.1 : Isom Creek crossing.

D-47.8
The road begins its descent to the Yukon River. The black spruce show broken tops due to the buildup of snow and rime.

D-49.0
Several kilometers of the elevated sections of pipeline can be seen stretching across the distant hills. There is a good view of the Ray Mountains to the west.

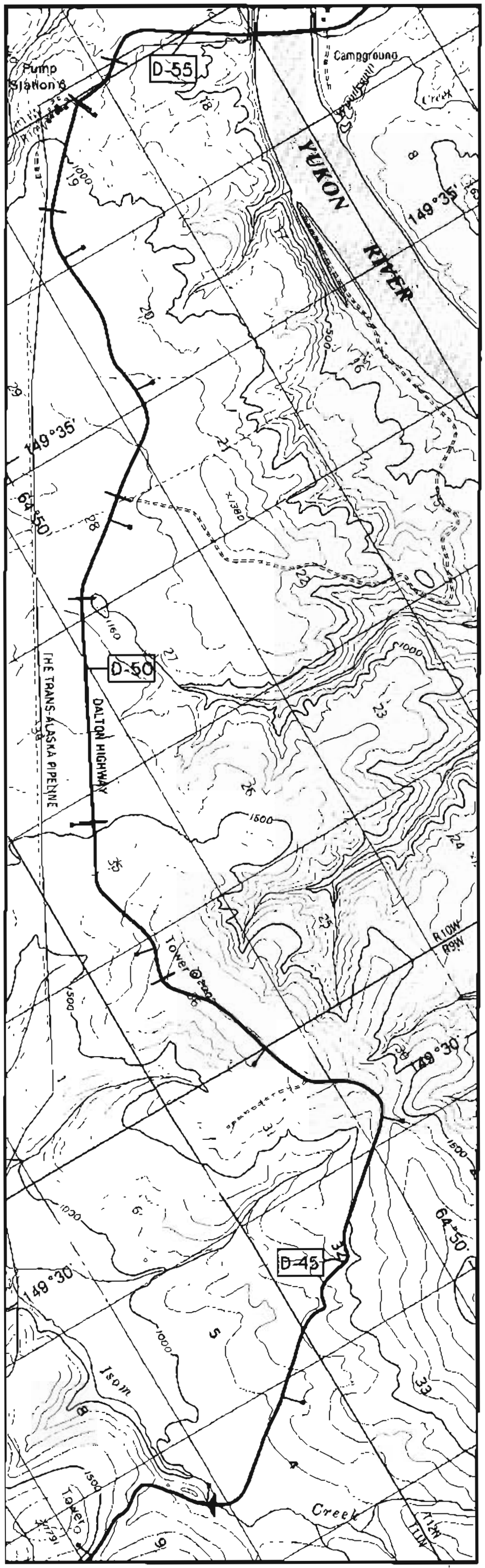
D-50.4
A thermokarst pond is located east of the road.

D-51.2
An old access road to the Yukon River winter ice crossing and hovercraft landing joins the highway here.

D-53.3
The Yukon River first becomes visible to the north. As the road descends, the pipeline can be seen suspended on the upstream side of the bridge.

D-54.0 : Pump Station 6.
Pump Station 6 was constructed with a refrigerated foundation to prevent thawing of the underlying ice-rich, organic silt and highly weathered bedrock. The microwave tower and the stack of the station's small refinery rise above the pump buildings and other structures. The refinery, more properly called a topping plant, produces fuel from crude oil taken from the pipeline to operate the turbine engines that drive the pumps. Similar small refineries are used at Pump Stations 8 and 10. Stations north of the Brooks Range use natural gas, transported from the Prudhoe Bay field in a 20- to 25-cm-diameter fuel-gas pipeline. The microwave tower is part of a communications network that links pump stations with each other and with the Valdez operations control center.

Pump Station 6 was located in an area that had an exposure of diorite at the south end of the station. Excavation at the tank farm near the outcrop and in the station area to the north revealed that the diorite body is a 60-



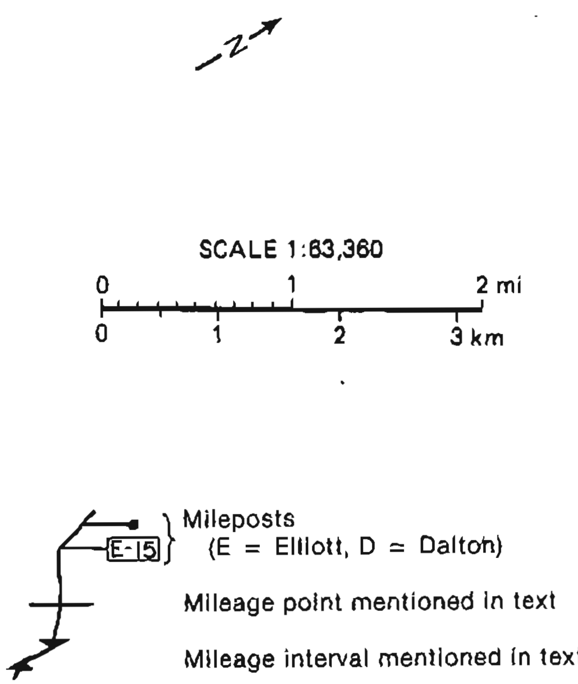


Figure 49. Route map, Mile D-42 to D-55.

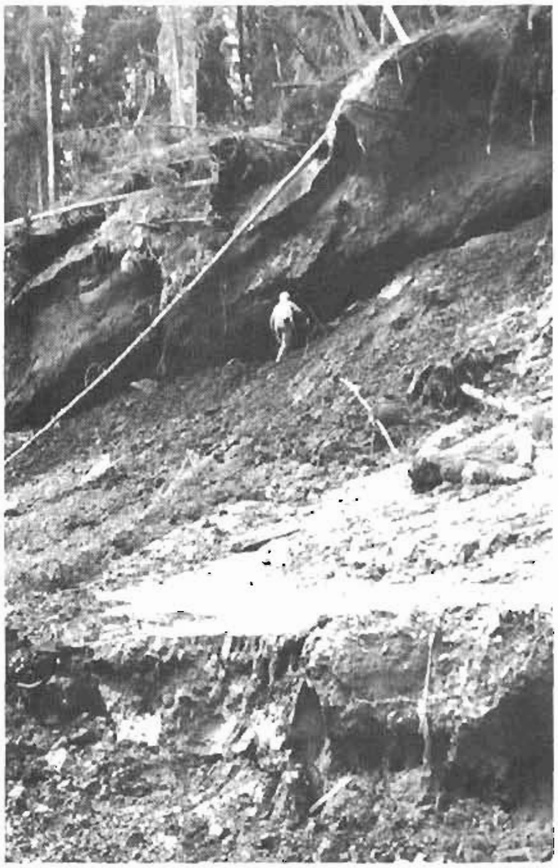


Figure 50. Exposure of ice-rich silt on south bank of Yukon River. The permafrost was thawing rapidly (Hamilton, 1979a, fig. 4; photograph taken by T.D. Hamilton on August 1, 1975).

m-thick sill that dips northward beneath the site at an angle of 30°. At the tank farm, the diorite is overlain by as much as 4.5 m of frozen siltstone and grit in which the bedding planes are separated by ice layers as thick as 1.3 cm. This ice-rich material, subject to settlement on thawing, had to be excavated before the tank foundations could be constructed. Excavation of the frozen loess from the remainder of the station revealed that the frozen sedimentary rocks were too thick to be excavated down to the underlying diorite sill. Therefore, the station building foundations were refrigerated to prevent potential settlement caused by thawing of the permafrost. These costly foundation problems illustrate a point that is not often considered in permafrost engineering---namely, that bedrock may contain such a high content of ice that it settles when thawed.

D-54.4
The road crosses over the elevated pipeline and there is a sweeping view of the Yukon River.

D-55.5 : E.L. Patton Bridge.
The bridge was named for the President of the Alyeska Pipeline Service Company after his death in 1982. A 20-m-high cut exposes silt above bedrock. Close to the bluff face, the silt is relatively coarse, well drained, and ice free. Farther south, it is oxidized to a depth of about 2 m, and gray, fetid-smelling, ice-rich, perennially frozen muck lies below this level. In the original road cut, ice wedges were exposed at the base of the oxidized zone, and they extended for an unknown distance down into the muck (Hamilton, 1979a) (fig. 50).

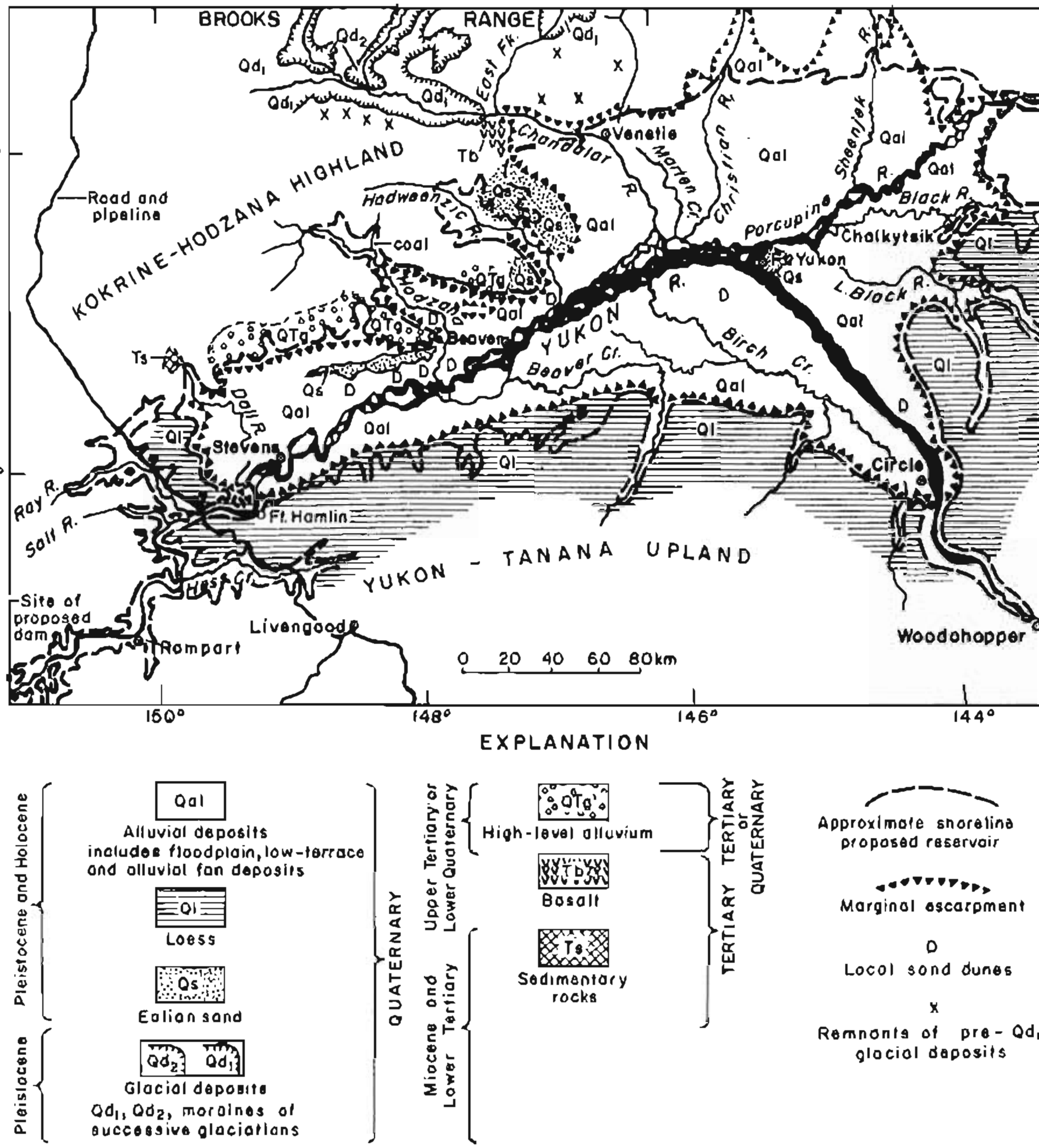


Figure 51. Generalized geologic map, Yukon Flats Cenozoic Basin (modified from Williams, 1964, fig. 1).

YUKON RIVER REGION AND CROSSING

The Yukon River is Alaska's largest river; it is the fifth largest in North America and the 20th largest in the world. It starts in Lakes Atlin, Bennett, and Tagish, near the British Columbia - Yukon Territory border in Canada, and flows northwestward and westward 3,175 km to the Bering Sea. It is navigable from Whitehorse, Y.T., for 2,850 km to the sea. Open season for navigation lasts from breakup of the ice in mid-May to freezeup in October. The river carries suspended glacial sediment in summer from the White River and other glacier-fed rivers in the Yukon Territory.

The river flows from Whitehorse through a generally narrow valley to Circle, Alaska, where it enters the Yukon Flats Cenozoic Basin, a 115-km-wide lowland that extends some 322 km along the river to Fort Hamlin (fig. 51). At Fort Hamlin the Yukon enters the Ramparts, a reach in which the river flows about 160 km to Tanana in entrenched meanders cut as deep as 670 m into uplands, which are underlain by resistant pre-Tertiary rocks and small basins of downfaulted blocks of soft Tertiary sedimentary rocks. Below Tanana the river flows through broad lowlands, here and there impinging against the bordering hills, before reaching its delta on the Bering Sea coast.

The river drains an area of about 835,000 km^2. Its flow, from the drainage area of 517,000 km^2 above Rampart (which is 85 km downstream from the Dalton Highway crossing) ranges from about 2,800 m^3/s in early spring to approximately 20,000 m^3/s during the late spring runoff. The maximum probable flood at Rampart was estimated at 1,000,000 m^3/s (Duncan, 1964). Breakup of the river ice in May (Gibbs, 1906; Williams, 1955) is a spectacular event accompanied by a sudden rise in river level and ice jams at narrows along the river, such as at Fort Hamlin (25 km upstream from the Dalton Highway crossing) where the river in some years is temporarily ponded behind ice jams.

In the early 1960's, studies were undertaken by the U.S. Army Corps of Engineers on the feasibility of constructing a dam on the Yukon River near Rampart. The basic premise was that a dam about 134 m high would be capable of generating about 4,000,000 kilowatts of electricity for a cost, at that time, of about $1 billion. The reservoir for this dam would have filled the valley where the E.L. Patton bridge is now located to a depth of nearly 120 m, and would have extended into the Yukon Flats (fig. 51) to create a reservoir of 27,913 km^2, containing 1,600 km^3 of water. The reservoir, the size of Lake Erie, would have required about 16 yr to fill if the entire annual flow of the river were to be stored (Gronewald, 1960). The potential effects of this large body of water on the permafrost beneath and adjacent to it, on the climate of the region, and on glaciation in the Brooks Range are interesting subjects for speculation and were discussed at the 14th Alaska Science Conference in 1963.

The Yukon River crossing was one of the major obstacles facing builders of the pipeline. Construction of the Dalton Highway began in 1969 from the Elliott Highway near Livengood northward to the Yukon River. Construction of the remainder of the highway from the Yukon River to Prudhoe Bay was pushed forward rapidly in 1974, and the road was completed within 5 months. At the same time, construction of the Yukon River bridge was begun. During its construction in 1974 and 1975 an ice bridge was used during winter and a hovercraft was used during summer (fig. 52).

The Yukon River bridge (fig. 53), a steel box-girder bridge with orthotropic deck and a temporary wood driving surface, was completed in 1975 for the Alaska Department of Highways by Manson-Osberg-Ghemm. Alyeska funded the additional work to accommodate the pipeline, which is supported along the upstream side of the bridge. The bridge was opened to truck traffic in October 1975. It is 700 m long and has a 5 1/2° grade, with the south bank being the highest.

Bedrock at the crossing and for many kilometers on either side is the Rampart Group of Permian age (Brosgé and others, 1969; Kachadoorian, 1971c; Chapman and others, 1971). These rocks have been intruded by dikes and sills of gabbro, diorite, and diabase of Triassic age and have been dated in one locality as being 205 m.y. old (Brosgé and others, 1969). The rocks are exposed only in local river bluffs and on isolated hilltops, so that the details of their stratigraphy, structure, and intrusive relations remain

Figure 52. Before construction of the Yukon River bridge, two air-cushion transporters ferried supply trucks for the trans-Alaska pipeline across the river. The vehicles, termed 'hovercraft,' were supported on a cushion of air and were pulled across by cables (photograph courtesy of Alyeska Pipeline Service Company).

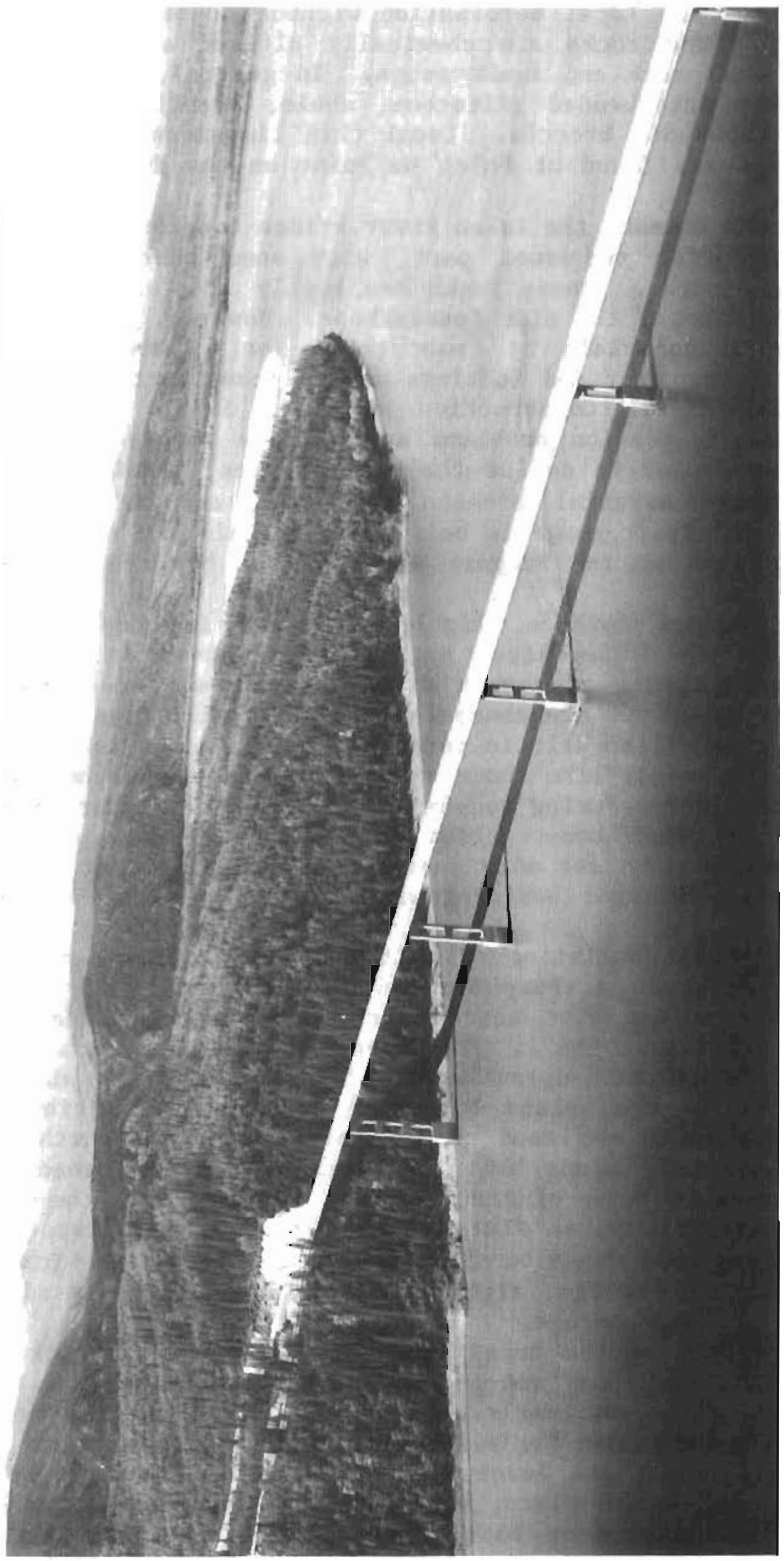


Figure 53. View of Yukon River and E.L. Patton Bridge looking west downriver. Ice-rich cut in figure 50 is visible at south end of bridge (photograph taken by T.L. Péwé on July 14, 1977).

obscure. However, they appear to strike northeast and to dip about 30° N. at Pump Station 6. Local deformation without doubt causes a variety of trends elsewhere. The rocks are chemically altered and faulted to produce local areas of weak rock and fault gouge. In general, rocks of the Rampart Group are largely interbedded siltstone, shale, argillite, grit, chert, tuff, and volcanic flows and breccia. Local thin limestone beds containing fossils of Permian age are found at Point No Point on the Yukon River, 24 km below the crossing.

Bedrock beneath the Yukon River bridge consists of altered volcanic rocks (greenstone) for the most part, with some chert, tuff, and fine-grained sedimentary rocks. These rocks are highly fractured, which was incorporated into the design of the pier foundations. However, much of the center pier was found to be underlain by fault gouge, or a shear zone of soft material. Redesign of the pier and footings delayed construction 1 month and cost about $4,500,000 (Alaska Construction and Oil, 1975). The additional work to correct the foundation problems at the pier involved making 26 test borings and 50 jet probes to define the problem area, placing 61 12-m-long H-pilings in the gouge material beneath the pier, and pulling and rebuilding the caisson. The fault gouge is believed to be similar to that along faults elsewhere in rocks of the Rampart Group and to be unrelated to an active fault system.

The bedrock surface, highly weathered in some exposures, is overlain locally by gravel deposited by the Yukon River or one of its tributaries during early stages of canyon cutting. In most areas, however, the rock and the overlying gravel are concealed by eolian silt that is locally more than 12 m thick. The eolian silt is perennially frozen and is rich in ice, especially in large ice wedges like those exposed in 1969 along the Dalton Highway south of the Yukon River during construction. Thermal disturbance of the permafrost by road and other construction is likely to cause settlement, which will require maintenance for many years. The potential for thaw settlement of the frozen loess required building of the oil line above ground near the Yukon River.

The loess, consisting of silt and sandy silt, contains shells locally, notably gastropods at Pump Station 6. At a point 25 km upstream near Fort Hamlin, the eolian silt contains the air-breathing snail Succinea strigata Pfeiffer (Williams, 1962). The loess mantle can be traced for more than 320 km along the marginal upland south of the Yukon Flats above Fort Hamlin. It occurs also in the upland bordering the eastern margin of the Flats (fig. 51). Eolian silt and sand on the marginal upland north of the Yukon Flats were deposited by winds sweeping southward across broad outwash plains and alluvial fans in front of glaciers that extended from the central Brooks Range into the northern Yukon Flats in middle to late Pleistocene time (Williams, 1962). Local sand dunes on fluvial deposits within the Yukon Flats are mostly of late Pleistocene age, although the dunes immediately adjacent to the Yukon River are of Holocene age.

The origin of the broad incised meanders of the Yukon River within the Ramparts section, above and below the Yukon crossing, has been the subject of speculation since the early work of Spurr (1898), Eakin (1916), and Mertie (1937). The fact that the bedrock floor of the Yukon Flats, which is probably well below present sea level, is below the level of the bedrock threshold at the lower end of the Flats, where the Ramparts begin, suggests that differential crustal movement took place during Cenozoic time between the Yukon Flats and the surrounding highlands (Mertie, 1937). Although Spurr and Eakin both postulated that a Pleistocene lake had been formed in the Yukon Flats, Williams (1962) was unable to find any evidence in support of this thesis because of the thick cover of fluvial and eolian sediment of middle to late Pleistocene age. However, a well drilled at Fort Yukon (fig. 51) in 1954 in the center of the Yukon Flats encountered blue and gray silt and silty sand beneath Pleistocene fluvial and eolian deposits from a depth of 45 to 134 m. These fine-grained deposits may have been deposited in a large lake formed, perhaps, after Pliocene or earliest Pleistocene folding or faulting of Miocene and early Tertiary rocks around the margins of the Yukon Flats Cenozoic Basin (Williams, 1962, p. 303, 320-324). Such a lake may very well have sought an outlet at a low point in the highlands bordering the basin along the present Ramparts of the Yukon River between Fort Hamlin and Tanana. The outlet stream, or ancestral Yukon River, probably developed the broad meanders that would be expected of such a major stream, and later incised the meanders to present river grade. Terrace gravel left high above the river by subsequent downcutting was later covered by middle to late Pleistocene eolian deposits after the lake had drained and at the time the basin was being filled by fluvial deposits, which were in part outwash from glaciers of middle to late Pleistocene age.

D-56 : Yukon Crossing development area.

In 1980, the Bureau of Land Management published a land-use plan for the utility corridor from Washington Creek to Sagwon Bluffs. Preparation of the plan was closely coordinated with federal, state, and local agencies, with the public, and with Native corporations. The plan recognized the need to provide for future transportation and utility development along the highway and allow for the development of public service, support, maintenance, and residential facilities. To accommodate the latter in a manner that would not impede the future expansion of transportation and utility systems, a concept of localized or 'nodal' development was conceived. Six development areas were identified in the utility corridor. The Yukon Crossing is an area so designated. An elementary school, a highway maintenance station, a State Trooper post, commercial and recreational boat and barge landings, retail public-service facilities, and a public airport have either been established or are planned.

As part of early scientific investigations along the road north of the Yukon River, a series of vegetation maps (approximate scale, 1:6,000) were prepared (Brown and Berg, 1980). An aerial photograph and a vegetation map derived from a master map prepared in the manner of Everett and others (1978) and Walker and others (1978, 1980) depict the major or dominant vegetation (fig. 54).

Vegetation along the bars of the Yukon River is generally sparse; it becomes dense higher on the river banks. Immediately adjacent to the river, the important species include silverweed (Potentilla anserina), alpine milk vetch (Astragalus alpinus ssp. alpinus), and tansy (Tanacetum bipinnatum ssp. huronense). The upper portions of the river bank are covered by a few shrubs such as soapberry (Shepherdia canadensis), interior willow (Salix interior), and a few balsam poplar seedlings (Populus balsamifera ssp. balsamifera). The first river terrace is narrow and has small balsam poplar trees and a few aspen (Populus tremuloides ssp. tremuloides) with green alder (Alnus viridis ssp. crispa), cloudberry (Rubus chamaemorus), prickly rose (Rosa acicularis), meadow horsetail (Equisetum arvense), Chamerion platyphyllum, and tansy. The higher bluff (terrace) has stands of large white spruce (Picea glauca) mixed with paper birch (Betula papyrifera), green alder, and several species of willow, including the tall willows, Salix bebbiana and S. arbusculoides. The understory for the most part is dominated by lingenberry (Vaccinium vitis-

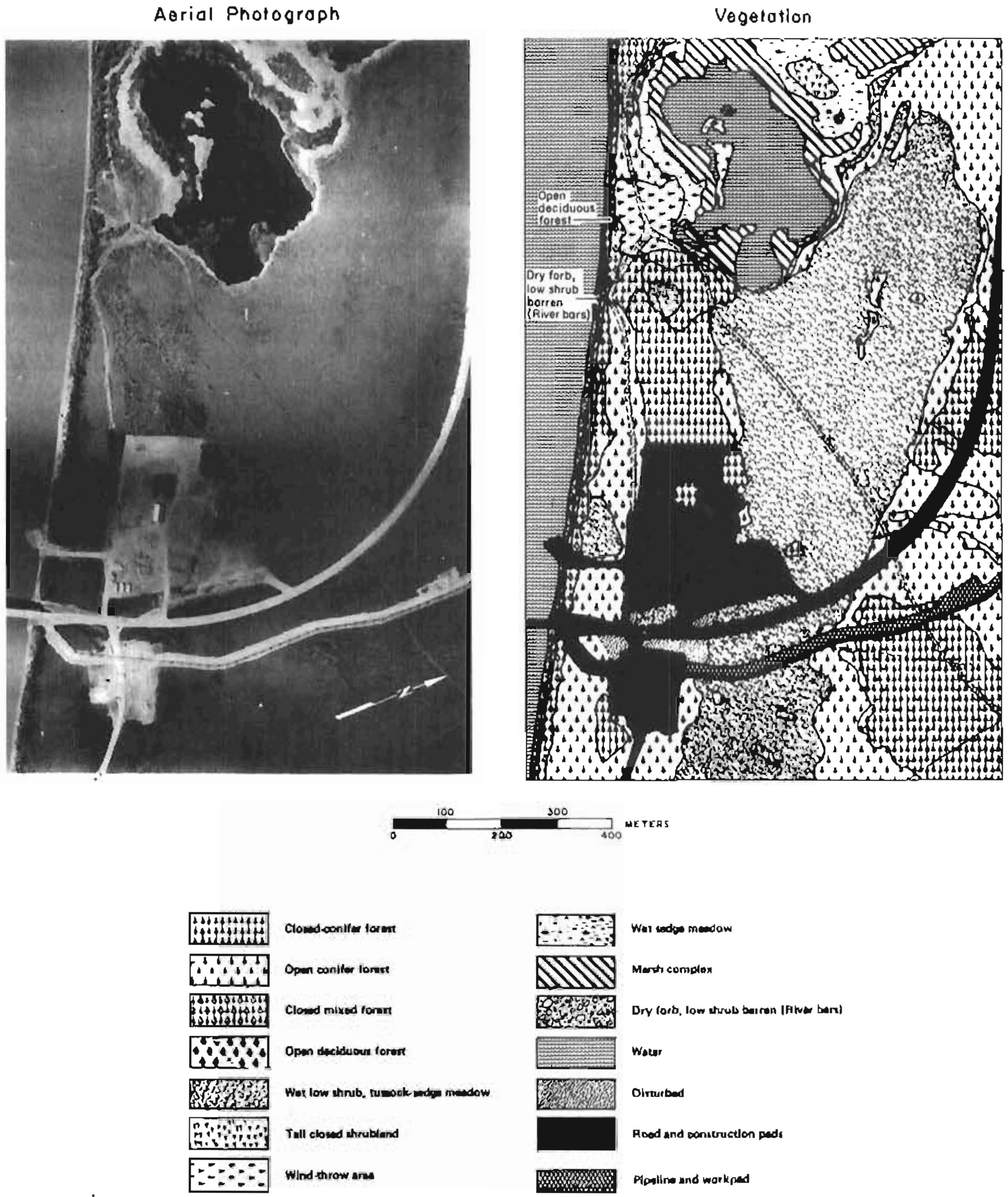
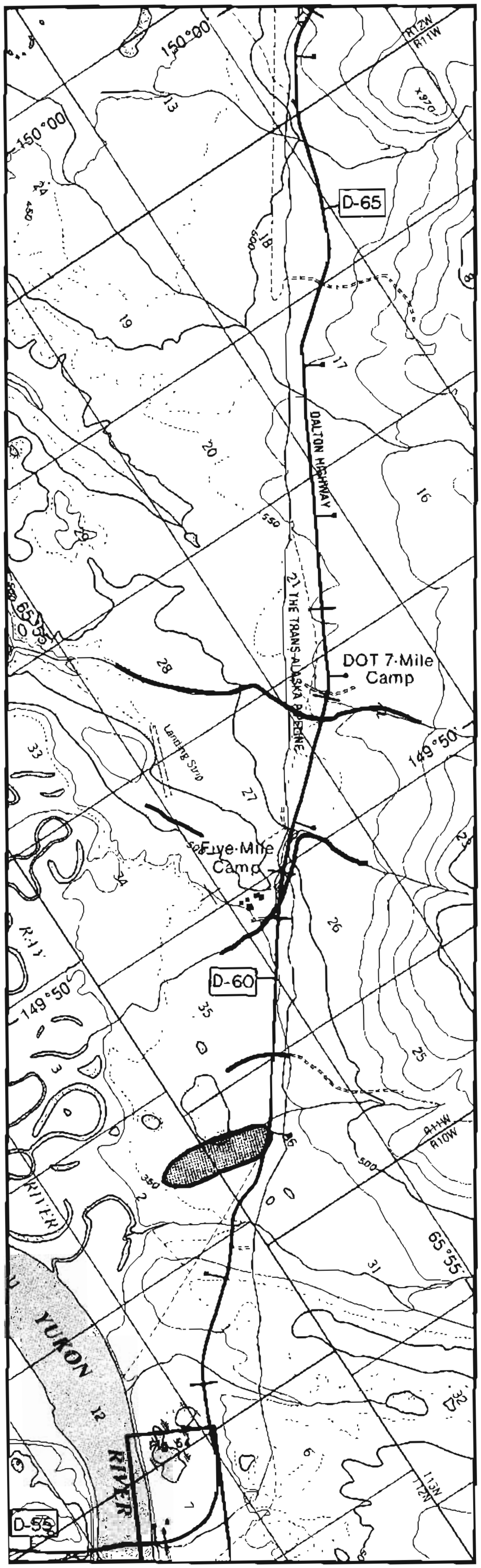


Figure 54. Vertical aerial photograph and vegetation map of an area adjacent to the north bank of the Yukon River (prepared by D.A. Walker).

idaea ssp. minus), blueberry (V. uliginosum), cloudberry, swamp wintergreen (Pyrola asarifolia var. purpurea), bluebell (Mertensia paniculata), and Hylocomium splendens.

Between the river and the road is a wet sedge meadow dominated by sedge (Carex lugens), resin birch (Betula glandulosa), willow (Salix planifolia ssp. pulchra) and Cassandra (Chamaedaphne calycullata). Dominant mosses are Hylocomium splendens and Aulacomnium palustre. Sphagnum is rare, probably because of the relatively high pH of the water. Areas adjacent to the meadow have small black spruce (Picea mariana). In slightly drier microsites, black spruce forests have an understory of Labrador tea (Ledum groenlandicum), blueberry, resin birch, and several lichen species. The forests contain occasional small stands of larger spruce trees that have understories of lingenberry, blueberry, Labrador tea, swamp wintergreen, and H. splendens.

The western part of the map (fig. 54) is dominated by a small lake and associated sedge meadow, which are prime habitats for several species of ducks, geese, hawks, owls, microtines, and muskrats. A large population of frogs also attracts sandhill cranes. The wettest areas bordering the lake have vegetation dominated by swamp horsetail (Equisetum fluviatile). Other areas are dominated by beaked sedge (Carex rostrata), water sedge (C. aquatilis), and marsh five finger (Comarum palustre). Surrounding the meadows are medium-height shrub communities dominated by willow (Salix planifolia ssp. pulchra) and tall cottongrass (Eriophorum angustifolium). These communities provide feed for moose and ptarmigan.



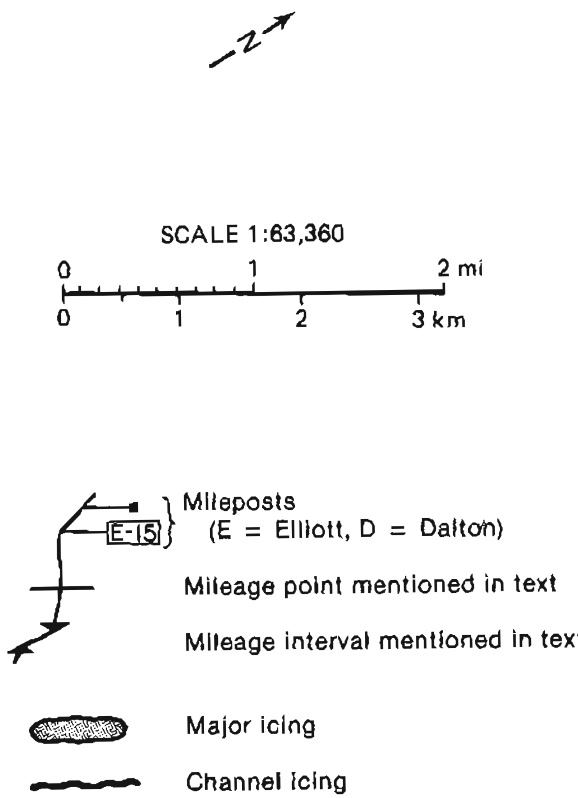


Figure 55. Route map, Mile D-55 to D-66.

D-57.3

Cuts 4-6 m high along both sides of the road expose horizontally bedded gray silt that contains occasional granules and snail shells and which is interbedded with clayey silt and organic silt layers. For the first 8 km or so north of the Yukon River, deciduous forest underlain by permafrost is common.

D-60.4 : Entrance to Five Mile Camp.

A cutbank 6-8 m high opposite the entrance exposes alluvial sand with a thin gravel layer near the top that is capped by a loess blanket 0.3 m thick.

D-60.7

The road crosses over the elevated pipeline. This special road crossing is in thaw-unstable soils (frozen silt and silty sand) up to 9 m deep. The insulated pipeline passes beneath the road embankment through a large culvert. A 1,200-m-long airstrip closely parallels the road.

D-61.8 : Entrance to Alaska Department of Transportation and Public Facilities (DOTPF) maintenance camp.

From inside the entrance to the DOTPF camp, Fort Hamlin Hills can be seen to the north. One peak rises to 960 m. In mid-July, snowbanks still persist in the alpine areas. During the Pleistocene, snowline was considerably lower, periglacial weathering and erosion were more intense, and cryoplanation terraces, which can be faintly observed on the Fort Hamlin Hills, were actively forming. An Alyeska communication tower is on the ridge line. This site and adjacent roadcuts afford an opportunity to examine soil development. A Subarctic Brown soil has developed in loess over weathered bedrock (diorite). These well-drained sites support a birch forest. Within a short distance is a black spruce forest developed on permafrost.

D-62.4

A stable cut as deep as 9 m through a ridge crest has exposed loess above rock rubble and bedrock. At its north end, on the east side, the exposure is 3 to 6 m high and exposes mainly colluvial silt, fine sand, and rock rubble.

D-66.3

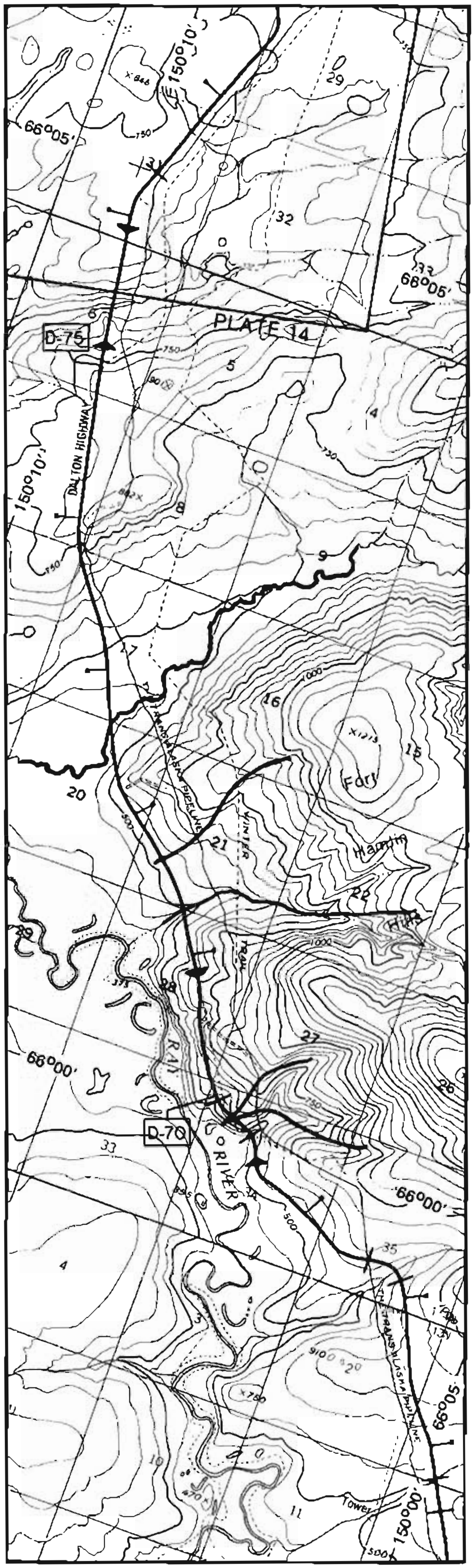
A 6- to 8-m-deep cut through a minor ridge crest exposes fluvial gravel with cobbles up to 10 cm in diameter above frost-shattered bedrock. The terrain consists of a dissected alluvial apron from the Fort Hamlin Hills. The black spruce forest is on a mantle of frozen loess and retransported silt or muck.

D-66.6

The road crosses a swale filled with organic sediments and immediately to the north cuts across a minor ridge crest where about 2 m of gravel is exposed above as much as 5 m of bedrock. The gravel is virtually unweathered, but a thick, red, clayey weathering horizon lies along the gravel-bedrock contact. The north flank of the ridge extends into a nearly horizontal terrace surface.

D-66.8

The swale provides an interesting example of road-induced modification of the vegetation. On the east side of the road are dead trees and shrubs (fig. 57). The bark has been stripped from many tree trunks. This phenomenon is



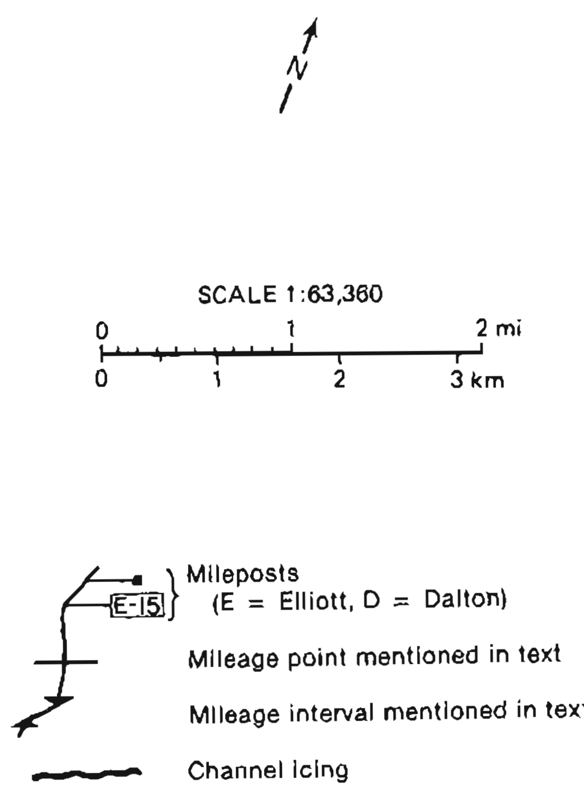


Figure 56. Route map, Mile D-67 to D-77. Plate 14 refers to illustration in Kreig and Reger (1982).

Figure 57. Dead trees resulting from winter icings (photograph taken by D. Cate on July 20, 1982).

observed elsewhere, and is caused by fluctuations of the impounded water level during the winter. As the culverts ice over, the water level rises and ice becomes attached to the tree trunks. Later, when the culverts begin to function and the waterline recedes, the ice collapses around the trees and breaks them or girdles their trunks, which ultimately kills them. Also, as the floating ice mass settles it crushes and breaks the shrubs and black spruce.

This particular location was also the site of a classic culvert failure. The extended upstream end of the original culvert was uplifted because of inadequate anchorage and sizing when excessive stream flow in the spring created a partial vacuum.

D-68.1

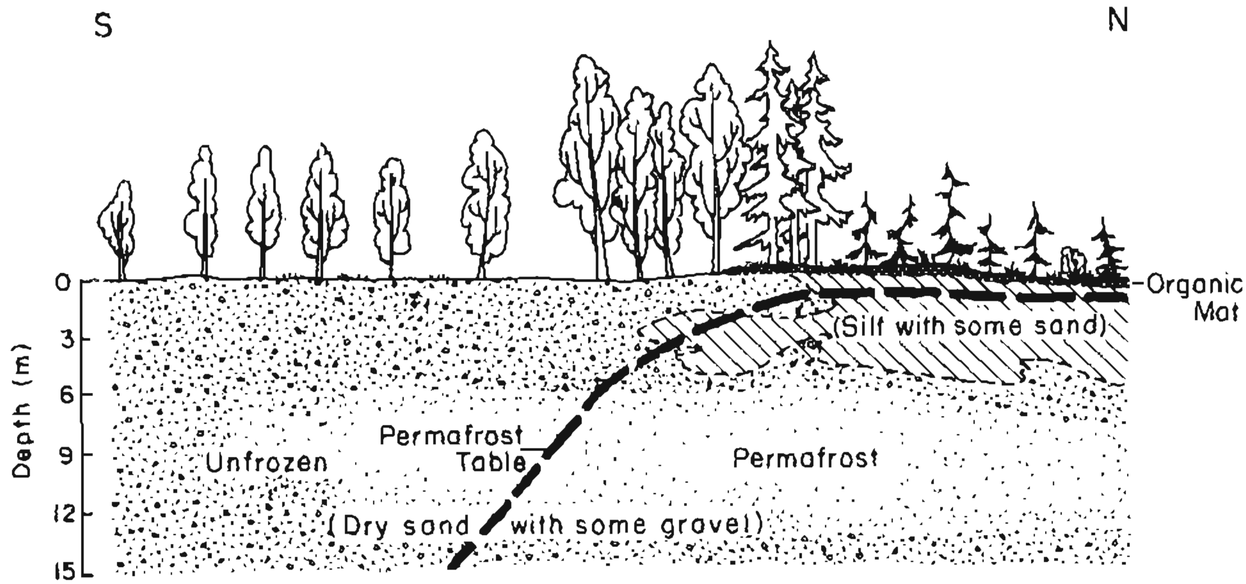
A cut through a minor ridge crest exposes argillite bedrock with no overlying gravel.

D-68.4

The road crosses over the buried pipeline.

D-69.5 to D-70.9

Cuts through ridge crests expose highly shattered argillite with a thin loess cap. The colluvium-filled swale between these ridges is exposed in a 3-m-high cut.



Trees	Scattered 7½-m aspen	Vigorous, dense 10–12 m aspen	Tall, thick spruce	Stunted and deformed 3½ – 4½ m black spruce
Ground cover	Absent or thin (less than 5 cm thick) lichen (*Cladonia*)	15 cm *Sphagnum* moss and tussocks over 20 cm black peat		
Permafrost	3 – 4 m +	1 – 2 m		½ m
Comments	Deep permafrost table and granular materials limit moisture availability for trees	Permafrost is deep enough for root development, and moisture perched over frost table is within reach of roots		Shallow permafrost restricts vegetation

Figure 58. Vegetation and soil conditions across permafrost boundary in high-level terraces south of No Name Creek (modified from Kreig and Reger, 1982, fig. 10).

D-69.7

One of the very few sections of the elevated pipeline without VSM's can be seen in the valley to the east. Thaw-unstable soils (frozen silty gravel) up to 9 m deep were encountered there during construction. These soils were too deep to allow pipeline burial in the underlying argillite bedrock. The short, fully restrained, elevated pipeline provided a low-cost, innovative solution to this limited area of unsuitable soils.

D-70.0

This overview of the Ray River is another example of the vegetation-permafrost development bordering youthful unvegetated point bars like that at

Hess Creek (fig. 46). The river is actively eroding the frozen cutbanks opposite the point bars.

D-75.1 to D-75.9

Tertiary basalt is exposed on both sides of the road in a series of cuts. The origin of the overlying sand and gravel is not clear. It may be a residual weathering product or an ancient alluvial deposit. In places, these deposits appear to interfinger with the basalt. Large anthills up to 1 m in diameter can be seen on the dry forest floor.

D-75.9

In this area, contrary to the normal situation, the taller and most vigorously growing trees (aspen and white spruce) are growing at the permafrost boundary rather than in the deepest unfrozen terrain (Fig. 50). Presumably, the more favorable moisture regime at the boundary is responsible for the greater growth. The excessive drainage of the deeply thawed substrate on the well-drained high-level terraces results in open stands of white spruce and depauperate quaking aspen with a dominant ground cover of reindeer lichen (Kreig and Reger, 1982, pl. 14).

D-76.3

The road crosses an unusual bog, which is unfrozen. Test holes encountered 3.3 m of thawed organic material and organic silt over 10 m of unfrozen sand. Ground-water flow may be preventing the establishment of permafrost.

D-78.2

The road reaches a high point that provides a good view of Caribou Mountain (970 m) and the valley to the north. Most of the landscape visible to the north is continuously frozen except for the steepest south-facing slopes on the distant mountains. Tertiary basalt is exposed in several roadcuts.

Much of the broad lowland between the Fort Hamlin Hills and the next upland to the north is underlain by high-level gravel of post-Miocene, perhaps late Tertiary to early Quaternary age. These fluvial deposits (Kachadoorian, 1971b) consist of pebbly to gravelly sand, gravel, and silt that have been mined for road and pipeline construction at several lowland material sites along the highway. The high-level gravel is underlain locally by vesicular lava flows of Tertiary age. These flows seem to be an extension of the andesitic flows mapped on the west side of the Ray River by Chapman and others (1975) and Kachadoorian (1971b). They are exposed only locally along the road in cuts adjacent to larger streams.

D-78.6

During construction of the road, an interesting subgrade failure occurred over permafrost about 0.8 km south of No Name Creek. The road was placed over the thaw bulb of an old tractor trail. The weight of the road fill displaced the underlying thawed silts, which emerged as mud boils, and on the slope overlooking No Name Creek the road fill flowed downslope into the woods bordering the road. The failures occurred in early August, when thaw depth was approaching its maximum (fig. 60).

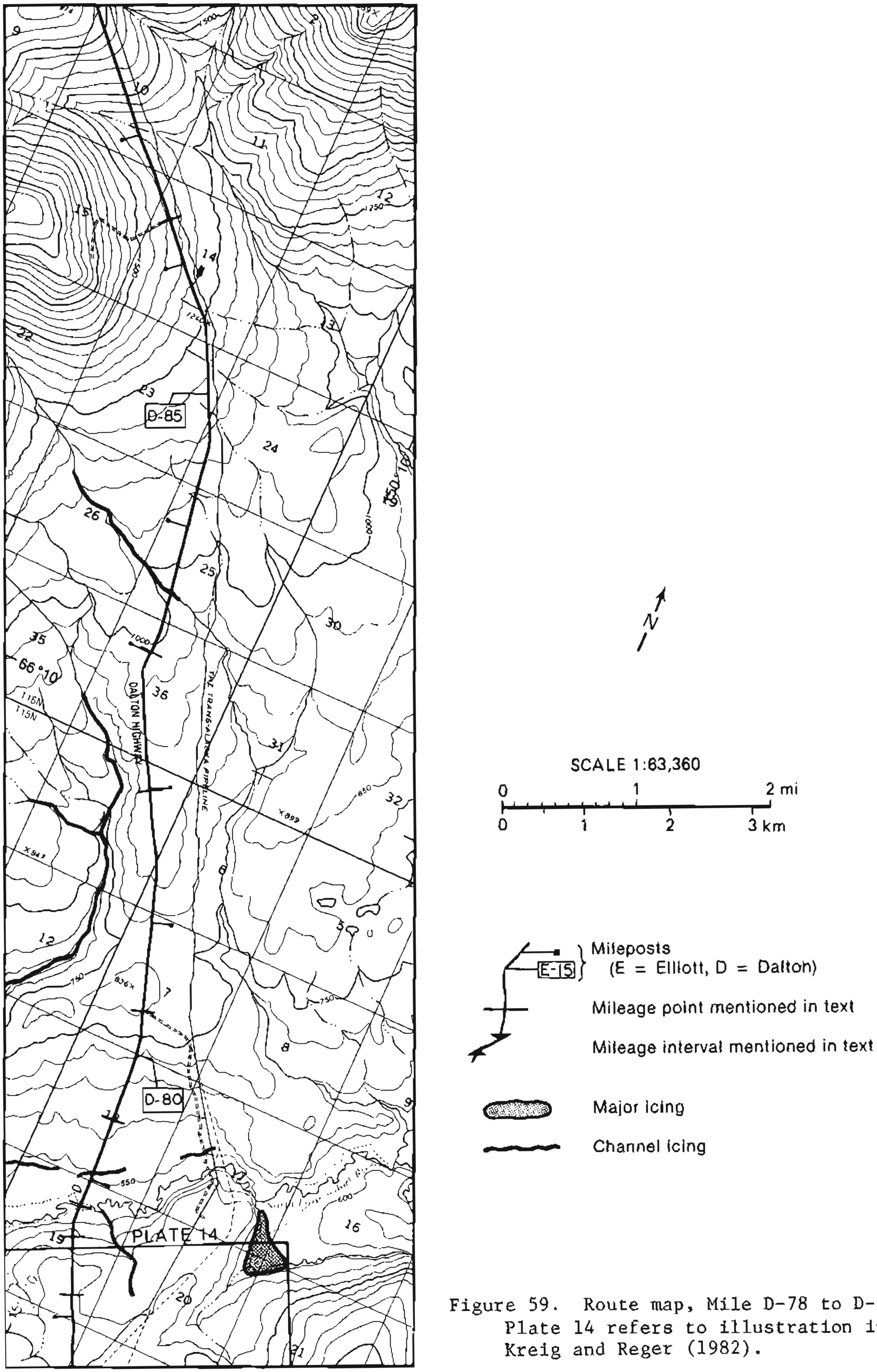


Figure 59. Route map, Mile D-78 to D-87. Plate 14 refers to illustration in Kreig and Reger (1982).

Figure 60. Displacement of underlying thawed silt through highway fill just south of No Name Creek (upper photograph APO 9126U; lower photograph APO 9126T, Alaska Pipeline Office, Anchorage, August 1974).

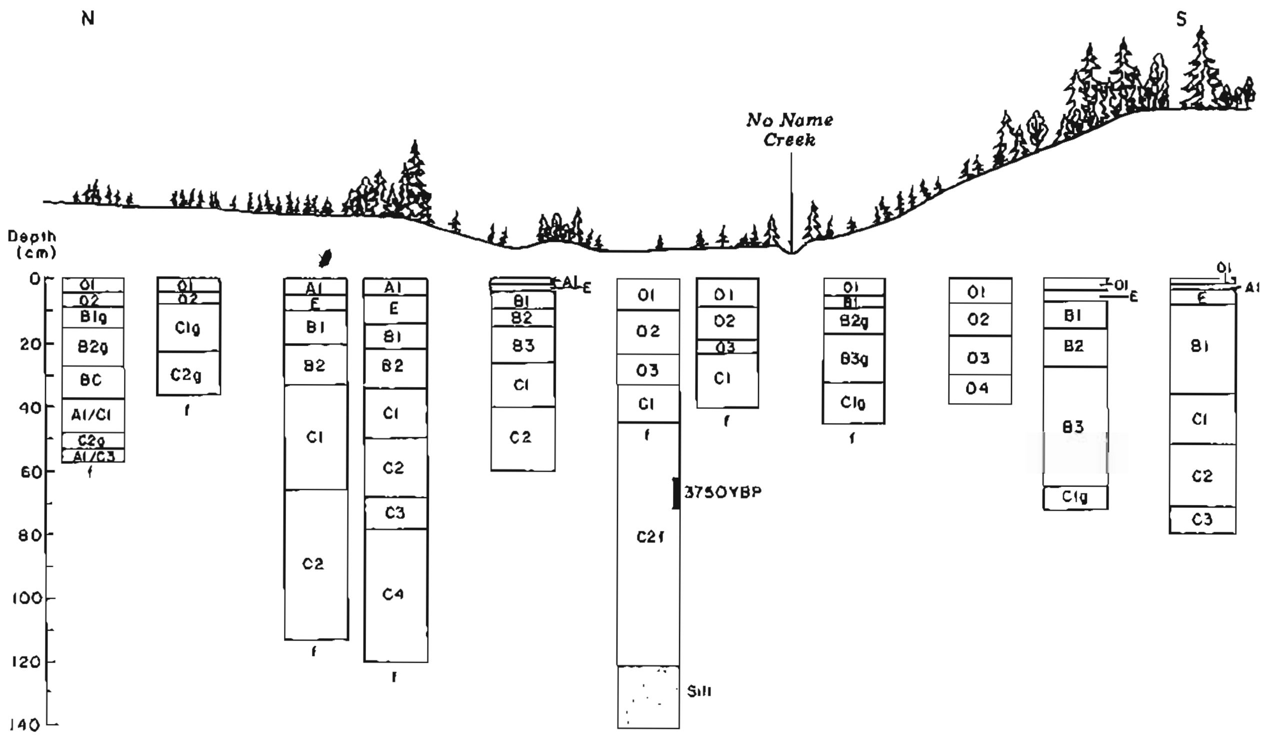


Figure 61. Idealized section showing relationship among soils, vegetation, and topography in vicinity of No Name Creek. See Appendix A for discussion of soil nomenclature. Horizontal distance is approximately 2.7 km. Maximum local relief is approximately 100 m (prepared by K.R. Everett).

D-78.8 : No Name Creek bridge (North Fork Ray River).

The No Name Creek site is one of several sites at which detailed soil studies have been undertaken (Brown and Berg, 1980; Everett, 1981)[10]. This site provides an example of the relationships between vegetation, topography, soil, and permafrost. The long, gentle, generally south-facing slopes are underlain by fine sand and silt which, in some cases, are incorporated with coarser sand and rounded quartz-rich gravel (Kachadoorian, 1971b) of the high-level terrace remnants that occur to at least 78 m above the creek. The broad (0.5 to 0.75 km), tussock-covered lowland on the north side of No Name Creek (fig. 61) is underlain by about 5 m of fine-grained organic materials over fluvial gravels. A radiocarbon date of 3,750 ± 150 yr B.P. (GX-5111) at 1 m was obtained in this section. There are several small, low, gravel terrace remnants adjacent to the lowland. The creek occupies a narrow meander belt on the south side of the broad valley.

The No Name Creek site is within the zone of discontinuous permafrost. Unfrozen areas are encountered under the dry, high terrace gravels. Permafrost probably exists throughout most of the remaining area. The principal plant communities and representative soils are shown in the idealized cross section in figure 61. On the long, spruce-covered, south-facing slopes, seasonal thaw ranges between 45 and 60 cm, with mineral soil stripes thawing more deeply. In well-drained areas covered by white spruce, thaw reaches 1.2 m.

[10] Based on Everett (1981).

Somewhat shallower thaw (45 cm) is probably characteristic of at least the wetter portions of north-facing slopes. Within the wet tussock meadows adjacent to the creek, permafrost containing a moderate amount of ice in thin lenses (1 to 2 mm) occurs 30 cm below the ground surface in intertussock areas. Within the organic soils of the filled oxbow ponds, thaw reaches 55 cm. Ice-wedge polygonal patterns are currently masked by vegetation in most of the area. The poorly expressed polygons that are visible on aerial photographs in the wet tussock meadows are difficult to detect on the ground.

Along the well-drained higher banks of No Name Creek is a narrow band of tall white spruce with an understory consisting mainly of horsetail. Along the edges of the stream are dense stands of willow and alder. Within a few meters on either side of the creek, the trees are much smaller and the understory changes to dwarf shrubs and cottongrass tussocks. To the north of the creek is a meadow of large cottongrass tussocks with a pond containing water lilies and other aquatic plants. Slightly better drained sites have a cover of *Sphagnum* bog and small-diameter black spruce. Farther north, a long, gentle slope is covered by a dense black spruce forest in which most of the trees are very small. The few better-drained sites are covered by larger trees. On the south side of the creek, plant communities range from 'drunken' black spruce forests with rich lichen understories to well-drained hillsides with birch and white spruce. From this point looking north, the first views of tors can be seen on the distant skyline.

D-79.5

On the west side of the road is an area that has been covered by silt, in some places to a depth of 0.5 m, by water flowing down the ditch from the north. As the ground thaws and is undercut by the flowing water, the water disappears and emerges several times beneath the roadbed and the opposite side of the ditch. About 0.75 km to the north, the vegetative mat, including the spruce trees, is slumping into the road ditch.

D-80.3

At this location there is an access road to the pipeline and a series of revegetated material sites that were mined for sand and gravel.

D-82.0 : Material site.

The first good view of cryoplanation terraces and tors to the north may be had from this site. The unnamed mountain to the east (unofficially called 'Castle Mountain') consists of schist and banded quartzite. Two sets of vertical joints perpendicular to each other break the exposed bedrock into well-defined columns and blocks, some of which form tors as high as 15 m that rise spectacularly from the cryoplanation surface. Some tors are separate and free standing, and others are part of the cryoplanation scarp (figs. 62 and 63).

D-83.0

The road-induced ponding and thermokarst on the west side of the road are presumably due to the melting of ground ice. The road is built on thick frozen loess that thins and ends about 1.5 km to the north.

D-86.3

Here is an access road to a quarry in hard metamorphic quartzite which breaks into blocky pieces when blasted. Most of the exposed bedrock west of the quarry is frost shattered and has been arranged by frost action into well-developed sorted stone nets and polygons. Some active sorted circles and

Figure 62. Large, blocky tor on 'Castle Mountain' consisting of horizontally foliated metamorphic rock (photograph taken by P.K. Bailey on June 24, 1982).

Figure 63. View from top of tor shown in figure 62 showing a cryoplanation scarp and small tors on the east end of the mountain (photograph taken by P.K. Bailey on June 24, 1982).

a few turf-banked steps occur on the east-facing slopes. This mountaintop supports cryoplanation terraces at several levels, but only a few tors.

D-88.6

The road crosses a broad, poorly drained valley floor. Morainelike mounds that stand up 20 m above the center of a basin filled with nonsorted gravel and silt are found within 2 km of the road on the west side. These mounds, described in Kreig and Reger (1982, pl. 15), are thought to be open-system pingos. Numerous irregular thaw ponds surround the mounds.

D-90.0

The road crosses a ridge crest and the cuts expose bedrock overlain by thin residual soil. Ice-wedge casts may be present. Further on, the road crosses a solifluction slope developed on weathered schist and phyllite. The elevated pipeline is next to the road. Black spruce are tilted from frost heaving and collapse as the ground thaws.

D-90.9

'Steam' pipes that run through the culverts are filled with antifreeze each winter. Prior to breakup, hot water or steam is circulated through the pipes, beginning melting of the ice and providing a 'tunnel' for the initial meltwater so that it does not overtop the road.

D-93.9

An access road to the west leads to a quarry in blocky schist and banded gneiss. There are good examples of sorted stone polygons, circles, and solifluction features on tundra-covered upland. The small, sorted circles appear to be active.

D-95.6

The bottom of this slope is the approximate contact between the metamorphic bedrock to the south and younger granitic rocks to the north. To the west, a large hill, the top of which is above treeline, exhibits several well-developed cryoplanation terraces on its south and east sides. Well-developed sorted polygons occur at the base of the cryoplanation scarps. In contrast to the granitic terrain to the north, this hill of finely jointed and foliated metamorphic rock does not have tors developed on it.

D-97.2 to D-99.5

The pipeline is buried adjacent to the east side of the road. Many small berms or water bars are placed across the buried pipe to control erosion, which can be severe during summer storms.

D-98.0 [11]

Finger Mountain is one of the more interesting summit areas on the road. The name is derived from one of the tors on the east side of the road that protrudes upward at an angle to resemble a pointing finger. The mountain was a landmark for early aviators, who used the tors---particularly Finger Rock---for navigation. To the north is Olson Lake and the Little Kanuti Flats, a broad valley covered by thaw basins and lakes ranging from rectangular to irregular form. Well-developed low- and high-center polygons and

[11] Based largely on Everett (1981).

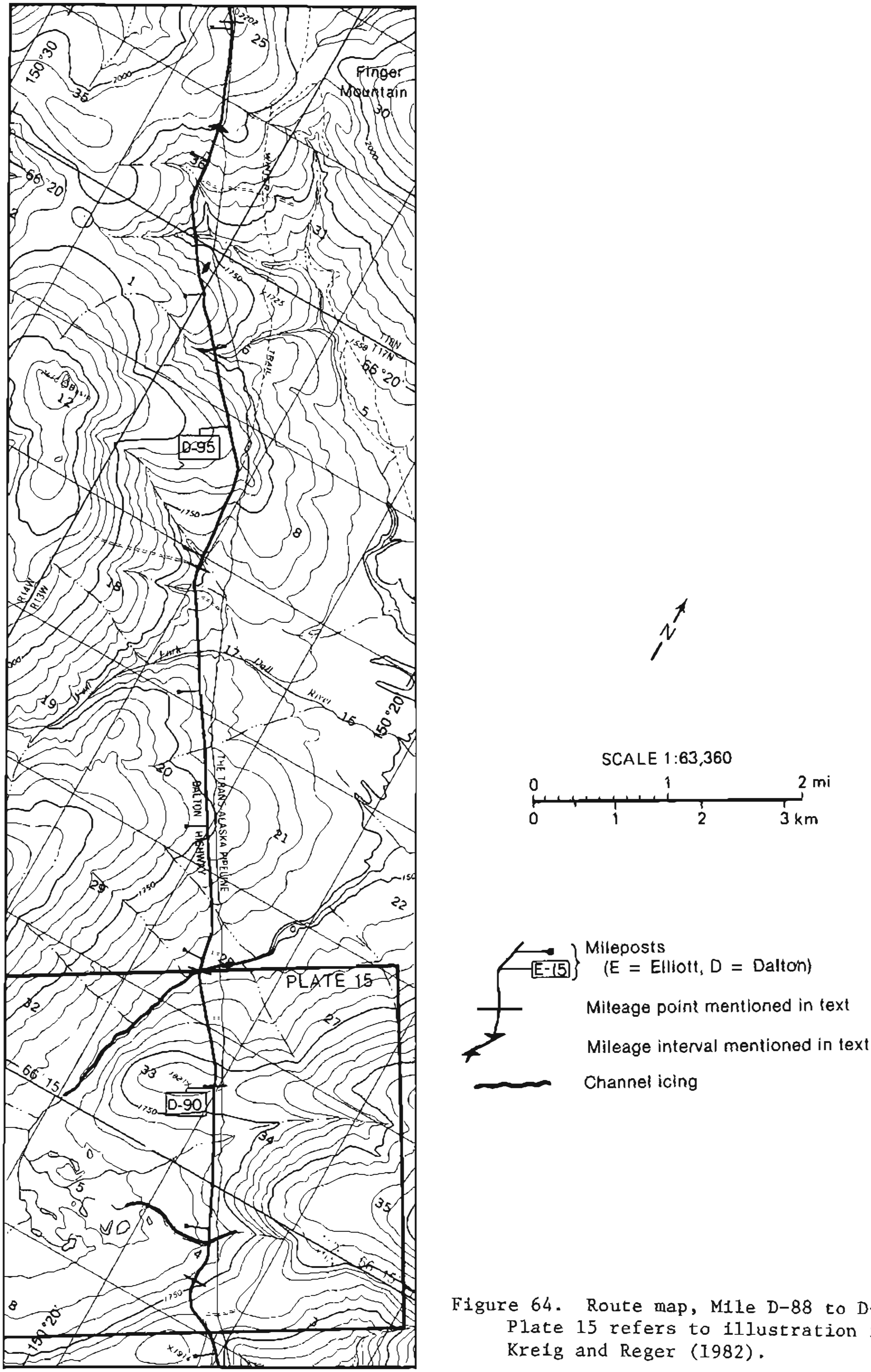


Figure 64. Route map, Mile D-88 to D-98. Plate 15 refers to illustration in Kreig and Reger (1982).

beaded drainage provide ample evidence of underlying ice wedges (Kreig and Reger, 1982, pl. 16). To the northwest is Caribou Mountain. Several cryoplanation terraces are visible in profile on its southwest side. Old Man Camp and airfield are on the far side of the Kanuti Flats along the road. The Finger Mountain uplands lie within the unglaciated Kokrine-Hodzana Highlands and are underlain by granitic rocks of probable late Cretaceous age (Kachadoorian, 1971b), which intrude a lower Paleozoic or Precambrian metasedimentary rock sequence that includes schist, phyllite, and greenstone.

The tors are products of deep weathering of long duration in the porphyritic granite. The spacing of the N-S/E-W joint sets in this bedrock may have contributed to their development (fig. 65). Joint geometry also controls the patterns in the thin mantle of coarse boulders or felsenmeer (fig. 66). In some areas, the patterned ground has been covered by vegetation. Large 8- to 10-m-diameter polygons, bordered by boulders and with small centers of fine mineral soil, form areas that are generally free of all vegetation except lichens. Other polygons have large mineral soil centers and considerable vegetation. As slope increases to about 9°, shallow drainage swales and poorly developed stone or vegetation stripes occur. The drainageways are generally wet, and in many cases contain solifluction features (hummocks and lobes). The wetter sites, together with solifluction microtopography (commonly <0.5 m in height), become extensive lower on the slopes. Also common to the middle and lower slopes, especially near drainage ways, are lichen-covered boulders that are surrounded or overgrown by thickets of alder or willow. These boulders commonly form a polygon pattern, but the area of fine-textured mineral soil in the polygon centers is either very small (1 m or less) or completely lacking. Relief within the polygons may exceed 1 m or more, and many of the boulders or slabs are loose or 'rocking.' Water can sometimes be heard running beneath the boulder surface.

Although the Finger Mountain area is included within the zone of discontinuous permafrost, most excavations within the area encountered frozen ground within 1 m of the surface. On felsenmeer slopes, permafrost is at 40 to 70 cm depth. Thickness of the active layer depends on the presence and thickness of Sphagnum peat. The permafrost table on the tussock - frost scar slope at the south end of the transect ranges between 30 and 70 cm (average of 47 cm), with the greater depths in the frost scars. In the well-drained gravelly soils, the depth to the permafrost table exceeds 80 cm and may reach more than 2 m. A late August temperature of 8°C at 80 cm was recorded in one site.

During the Wisconsin glaciation, the regional snowline was reduced to approximately 1,000 m above sea level (Péwé, 1975b). The Finger Mountain uplands would have been 300 m below this Wisconsin-age snowline. Thus, the area would have been subjected to a more rigorous climate than the present one, with lower summer temperatures, more extensive areas of late snow, and more frequent freeze-thaw events. The extensive block fields, together with their sorted large-diameter polygons, tors, and deeply frost-shattered bedrock, were probably produced during such a period. Climates more severe than at present and similar to or more severe than the Wisconsin climate affected the Finger Mountain area throughout the Pleistocene, and perhaps contributed as well to the present landscape features. Isolated flagged spruce and krummholz found on the upland surfaces attest to an alpine climate that may be sufficient to maintain the activity of these features.

Soils and vegetation characteristic of the Finger Mountain areas are shown schematically on the toposequence in figure 67. The poorly developed soils of the upland surfaces result from a combination of restricted drainage due to permafrost and site instability caused by frost heaving. Long, uniform

Figure 65. Granite tor on Finger Mountain uplands on south side of road. Note intersecting joints. Well-developed ground cover includes lichen and dwarf birch (photograph taken by R. Veazey on July 20, 1982).

Figure 66. Large, apparently stable stone nets outlined by lichen-covered blocks of granite in the vicinity of Mile 99 (photograph taken by K.R. Everett).

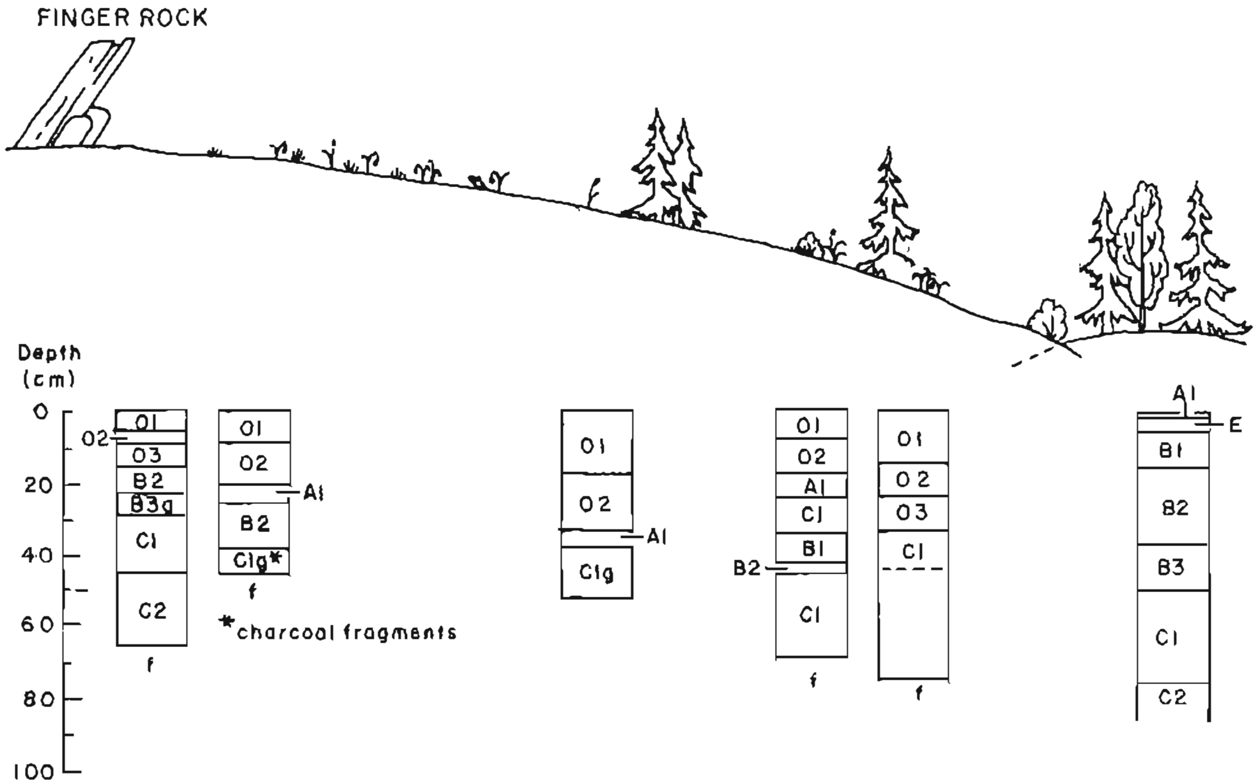


Figure 67. Idealized section of soils, vegetation, and landforms, Finger Mountain. Horizontal distance approximately 1.5 km. Prepared by K. R. Everett.

slopes have been modified by solifluction and creep in wet, sandy loams. Frost scars and discontinuous soil stripes are common on slopes. The seemingly regular spacing of alder shrubs on such slopes (as well as on the felsenmeer surfaces) may in some way be related to regular textural and moisture changes in the mineral substrate related to frost patterns. There is no indication that extensive forest has covered these slopes in recent time. The charcoal fragments in mineral soil horizons appear to have been derived from shrub roots. On lower slopes, below the alpine and subalpine zones, are dense stands of black spruce interspersed with paper birch. Few solifluction forms are found. Some forested slopes have many nearly parallel drainages and soils finer in texture than upslope. A radiocarbon date of 525 ± 120 yr B.P. (GX-5110) obtained from a buried soil surface on such a slope suggests an influx of sediments associated with erosion possibly triggered by fire.

D-100.3
An access road goes off to the west. The granite in this quarry is much finer grained than on Finger Mountain and it lacks large feldspar phenocrysts. However, near the quarry are surfaces which are nearly totally covered with large feldspar crystals.

D-100.6
The pipeline crosses under the road.

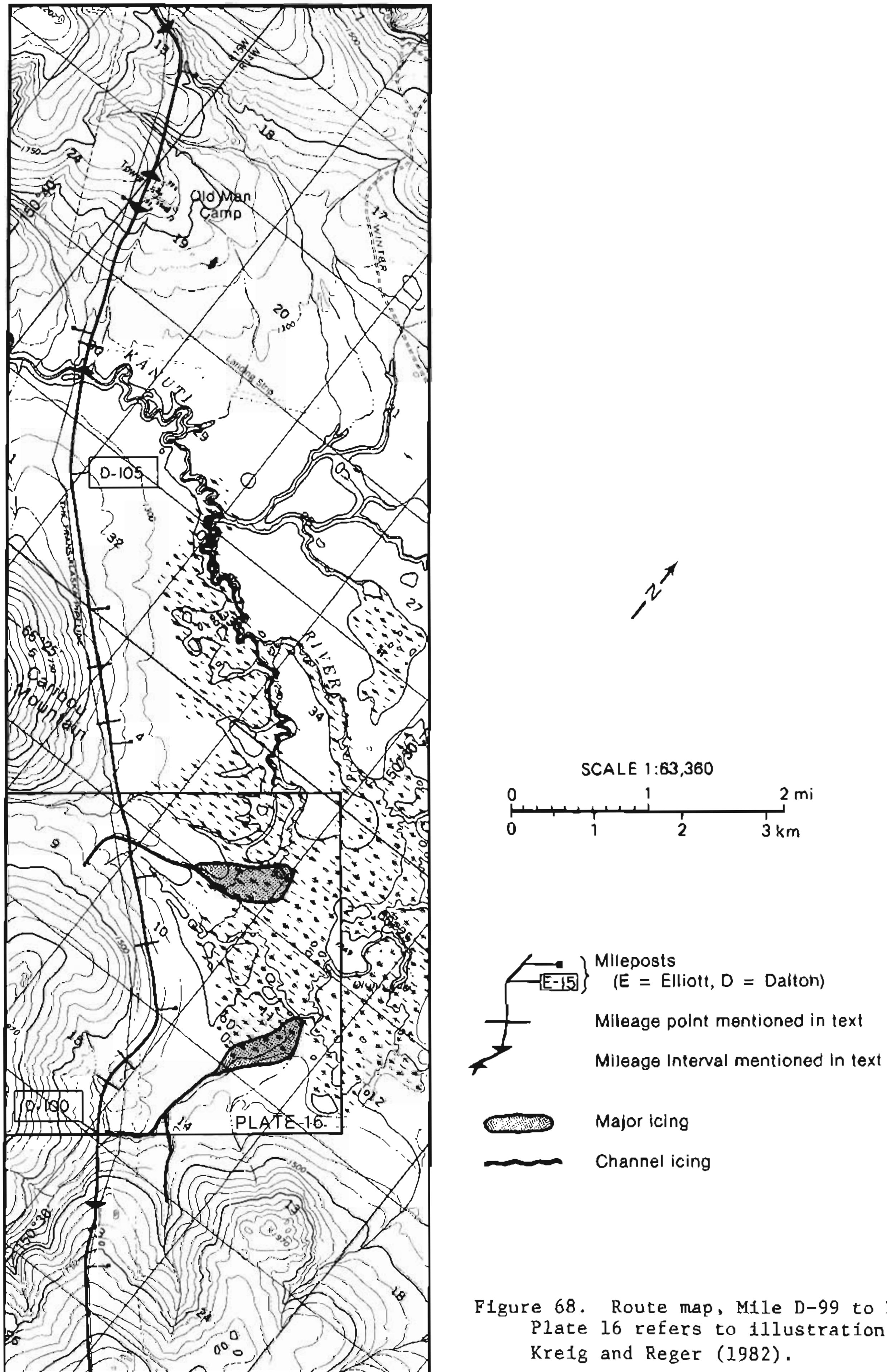


Figure 68. Route map, Mile D-99 to D-108. Plate 16 refers to illustration in Kreig and Reger (1982).

D-101.5

The road crosses slopes with well-defined striped patterned ground. There is a good view of Little Kanuti Flat, with Olson Lake and numerous small thermokarst lakes. Small mounds may be observed at the base of the slope to the east of the nearest lakes and extending to the southeast. They are about 100 m long and are covered with shrubs, which cause them to appear higher than the actual 1 to 2 m. Shallow excavations encountered the water table at 85 cm in a sandy substrate. The adjacent areas were frozen at 25 cm in peat or silts. These mounds appear to be sand dunes, but an ice-cored origin cannot be ruled out until they are actually drilled (Kreig and Reger, 1982, see pl. 16).

D-103.2

Probable solifluction occurs in a moist drainage swale with permafrost at 50 cm depth. Summer 1974 measurements at 3-wk intervals recorded net downslope movement at the surface of 0.5 to 2.8 cm, with movement at some points continuing into August (T.D. Hamilton, pers. commun.). Unfortunately, measurements have not been made over a number of years, and any conclusions about the degree of present solifluction activity here or at sites farther north are not definite.

D-103.6

The road cut exposes 3 to 4 m of rock rubble. Caribou Mountain and lower ridges are on the west side. The bedrock is mafic and ultramafic intrusive rock. Good examples of nivation hollows can be observed on the flanks of the closest ridge. The higher slopes of Caribou Mountain have cryoplanation terraces. Sorted stripes and polygons are common above treeline.

D-105.7 : Kanuti River crossing.

Metagabbro crops out in the stream bottom at the pipeline crossing. Mafic igneous rock is also exposed in the material site on the west side of the road and south of the bridge.

D-105.7 to D-107.0

The small pipeline on the east side of the highway is an insulated freshwater supply line leading from water wells near Kanuti River to Old Man Camp. The contact between older mafic igneous rock to the south and granite to the north occurs approximately 600 m north of Kanuti River on the pipeline right-of-way.

D 105.9 : Old Man airfield.

Little Kanuti Flats, which lies southeast of Old Man Camp, contains many forms of ground ice. Sediments beneath the Flats are probably fine-grained fluvial or lake deposits. The airfield and its access road are built over polygonal ground (fig. 70). Subsidence of parts of the road and airfield resulted from the melting of ice wedges that was induced by placement of the thin gravel overlay. Ice-cored relief occurs at the northern end of the runway. Lenses of horizontal ice 50 cm or more thick were observed in raised-relief forms along the north edge of the runway. Some of this ice may have formed after the runway was built as a result of blocked local drainage. The ice is similar to that observed in seasonal icing mounds, and presumably developed at the base of the active layer during winter freezeup. Low, oval-shaped mounds are also observed in this bog.

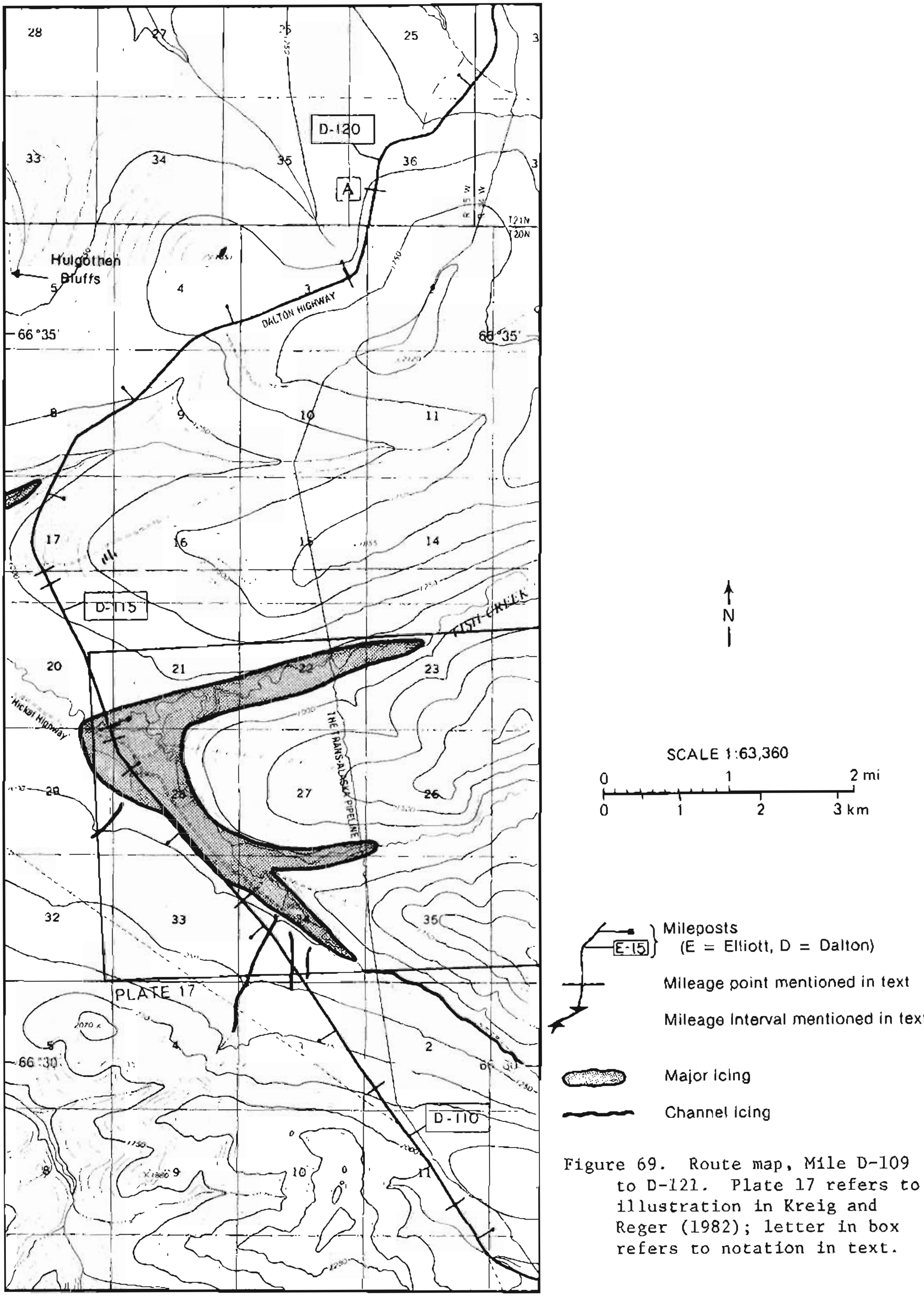


Figure 69. Route map, Mile D-109 to D-121. Plate 17 refers to illustration in Kreig and Reger (1982); letter in box refers to notation in text.

Figure 70. Low-angle aerial photograph from east end of Old Man runway. Ice-wedge polygons visible in the foreground. Ice-cored relief occurs on the upslope side of the runway (photograph taken by D. Atwood on July 19, 1982).

D-107.0 : Old Man Camp.

The quarry on the west side of the road is in a weathered pink granite with large feldspar crystals.

D-107.2 to D-108.3

Roadcuts 3 to 5 m high expose grus above granite. The overlying thin soils thicken into retransported aprons on the ridge flanks.

D-108.3

The highway crosses the buried pipeline. Against the hillside to the north are 'water bars' constructed to prevent gullying above the buried pipeline.

D-109.3

Cuts 6 m deep along both sides of the road expose grus over granite. To the east are numerous outcrops of weathered granite. In this vicinity, the road is intercepting runoff, which has deposited sediment in the shallow road ditches. At the crest of this hill is an access road to the pipeline and a contact between granitic bedrock to the southwest and mafic bedrock to the northeast. West of the road on the hilltops are numerous outcrops of weathered porphyritic granite.

D-110.5

A long, steep hill to the north is locally known as the Beaver Slide because of its extreme slipperiness when wet. To the west are well-developed solifluction slopes.

D-112.3

The access road to the pipeline encountered severe icing problems where it crosses the South Fork Fish Creek. Much of the valley is covered by icings each winter, many of which form from perennial springs in schist on the south side. The access road crosses the old bladed winter trail (Hickel Highway). On the far side of the stream are several degrading ice-cored mounds similar to those formed at Mile 126.5. (The latter are adjacent to the road and can be viewed more conveniently.)

D-113.6

An access road leads to the east, crossing a tributary of Fish Creek and continuing around a ridge and up to the pipeline. The north-facing slope of the ridge has well-developed solifluction or turf-banked lobes over 1.5 m high on slopes of 12° to 14°. Radiocarbon analyses of buried organic layers on one lobe yielded dates of 2,075 to 2,670 yr B.P. (Kreig and Reger, 1982, fig. 11). These dates suggest a downslope advance of about 2 m since then. However, the lobes may now be relatively stable, even though seasonal movement of 1.5 to 2.0 cm along lobe axes and about 1 cm along lobe margins was noted along a survey line in the summer of 1974. The motion continued into late July, but ceased as the site became drier in midsummer compared to the solifluction site (D-103.1; T.D. Hamilton, pers. commun.). To the east along this ridge are several small tors formed in metamorphic rock.

D-113.9

The 'Hickel Highway,' visible along Fish Creek, crosses the Dalton Highway immediately south of the bridge.

D-114.0 : Fish Creek bridge.

Fish Creek is the southernmost stream along the Dalton Highway north of the Yukon River to have been mined for gold.

D-115.2

Phyllitic bedrock with a thin rubble mantle is exposed in the 6-m-deep cut. The rubble cover includes igneous rock, which also occurs in stone nets on the ground surface. The igneous rock fragments are probably derived from a contact upslope between igneous and metamorphic rocks.

D-115.3 : Arctic Circle (66°33'24.9"N).

This is a good photo point with views to the south and west. There is an excellent view of cryoplanation terraces on a mountain 8 km to the southwest. A campground with facilities is located beyond the Arctic Circle sign. A prominent tor of greenstone and several other tors are found along the access road beyond the campground. One joint plane forms the 5-m vertical east face of one such dramatic feature.

D-119.0

Solifluction lobes are present on the slope on the southeast side of the road. Long, smooth slopes typical of very old periglacial landscapes are visible on both sides of the road from here to Bonanza Creek.

In this vicinity two segments of the road built from the Old Man and Prospect Creek construction camps were joined here (sign on the east side of the road). Stunted birch and aspen cover lower slopes. A regrowth of black spruce that followed a fire can be seen. Widely spaced alder shrubs grow near the treeline in what appears to be a regularly spaced pattern.

D-119.8

[A][12] The Koyukuk basin (to the west) was glaciated, probably during late Tertiary and early Quaternary times (fig. 9). The oldest recognizable

[12] [ ] refers to location on glacial geology maps (figs. 71, 86, 125 and 129).

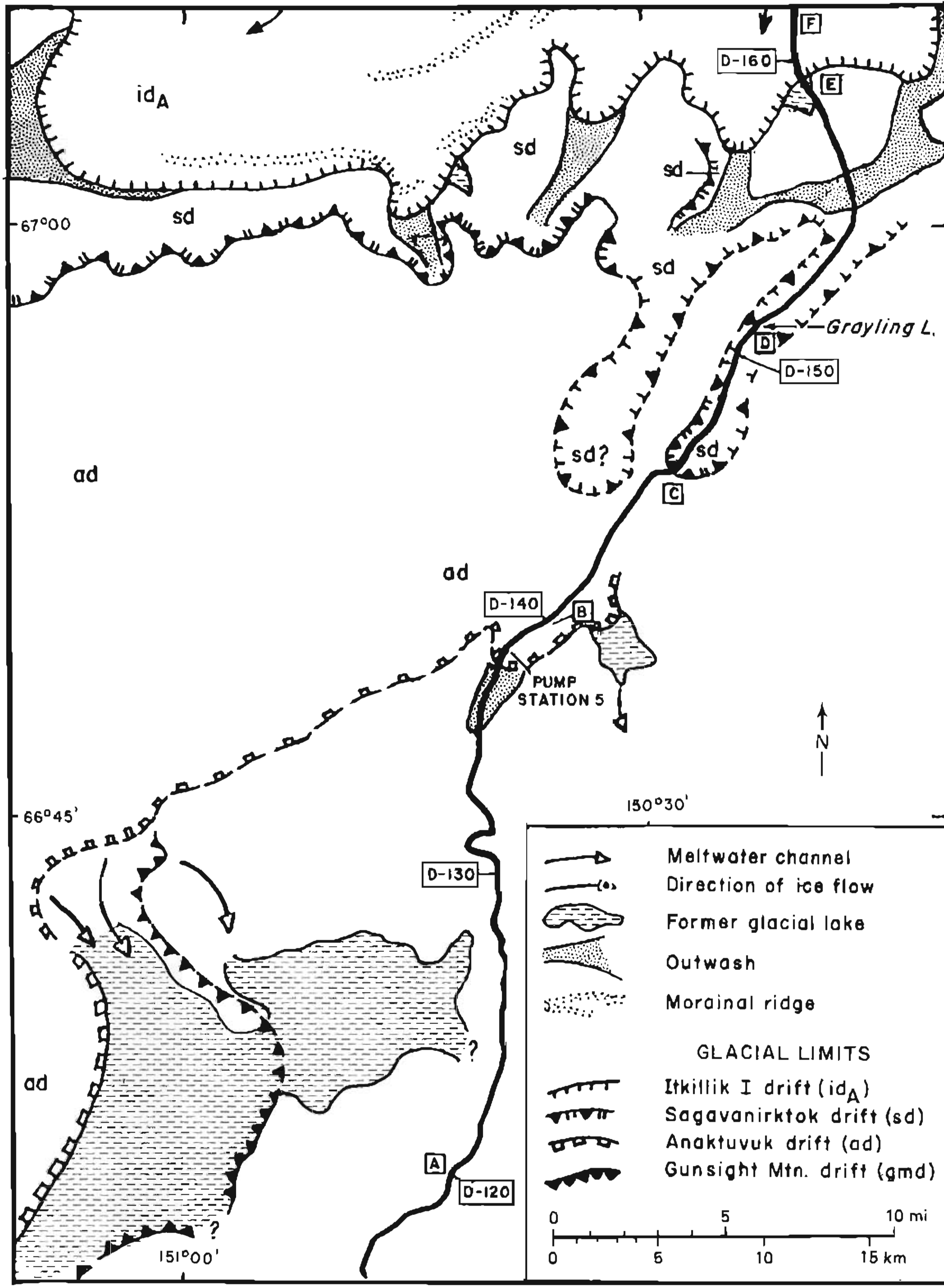
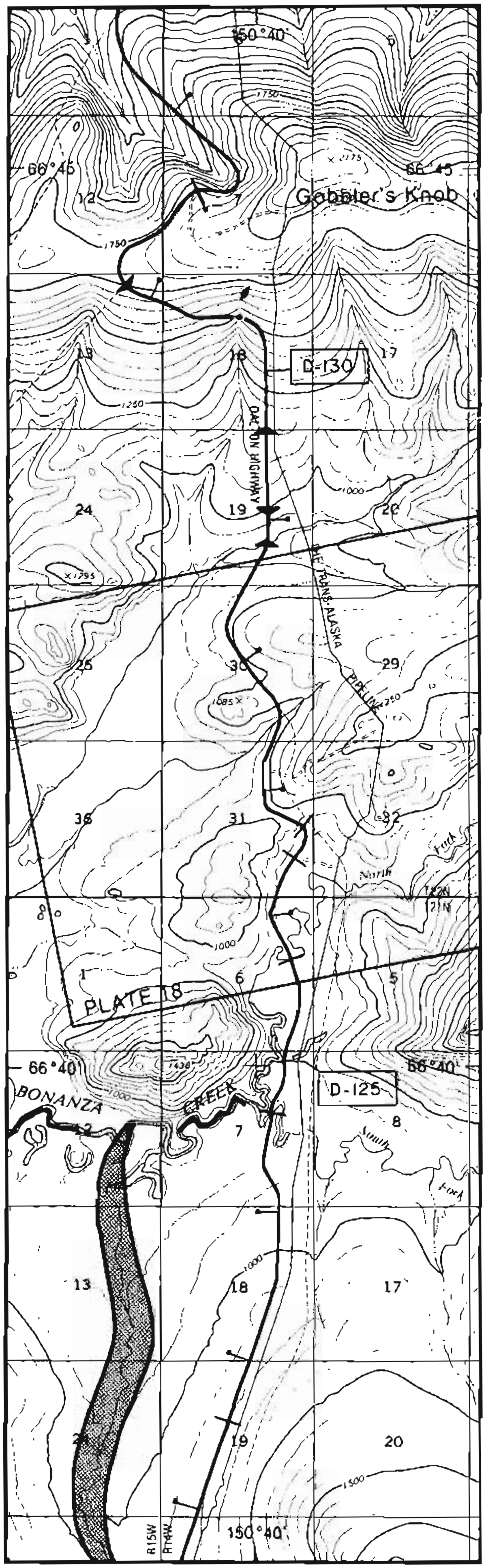


Figure 71. Glacial geology of the area between the Arctic Circle and Cathedral Mountain (map scale 1:250,000). The letters in boxes refer to notations in text.



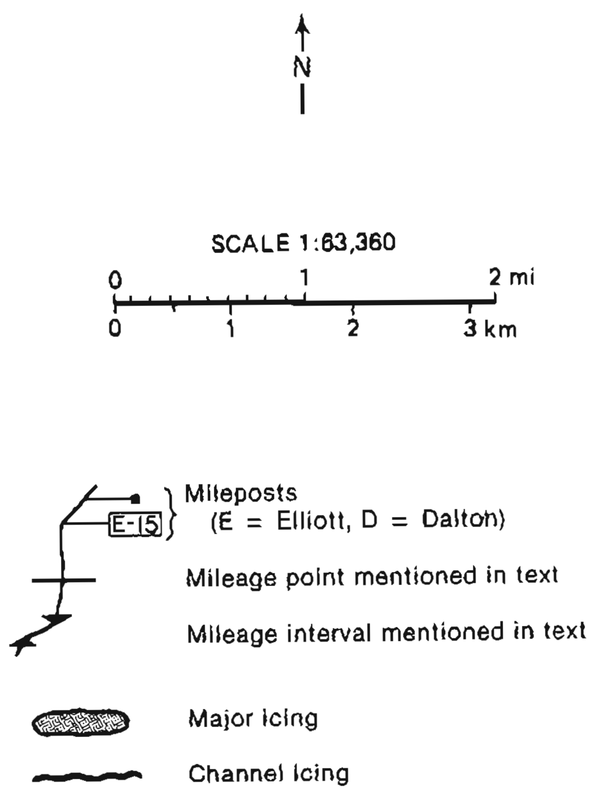


Figure 72. Route map, Mile D-122 to D-133. Plate 18 refers to illustration in Kreig and Reger (1982).

advance is correlated with the Gunsight Mountain glacial phase of the north-central Brooks Range (fig. 71). It is marked by low, broad, featureless drift bodies, and by streams deflected into ice-marginal courses. A younger glacial advance, correlated with the Anaktuvuk River Glaciation of the northern Brooks Range, extended southeast across the Koyukuk basin to the position of Hulgothen Bluffs. The bluffs stand 40 m high, exposing two till layers separated by 2 m of organic silt containing layers and lenses of woody peat. The glacier dammed a proglacial lake (ap, fig. 71) that filled the valley of Bonanza Creek to about 250 to 275 m elevation (at or slightly above the 800-ft contour). The lake was fed by the drainage systems of Fish and Bonanza Creeks and by meltwater streams that issued from the ice front. It extended southeast up the valley of Fish Creek an unknown distance and eastward to positions along the haul road in the headwaters of Bonanza Creek. Any proglacial lake sediments that existed along the road section have either been deeply eroded or removed entirely by subsequent channel cutting (T.D. Hamilton, pers. commun.).

D-122.6

Across the valley is an area of discolored vegetation (orange and black) that has persisted for many years. Its cause is unknown (R.A. Kreig, pers. commun.). Along the east side of the road (by APL 89-1) are tussock-birch-heath polygons similar to those described on the Seward Peninsula (Hopkins and Sigafoos, 1951; Sigafoos and Hopkins, 1952). The area is dominated by alder-birch shrub vegetation. Low peat or tussock ridges surround irregular to circular centers of mineral soils. These features, best observed on aerial photographs, are common on these nonforested slopes.

D-124.7 : South Fork Bonanza Creek.

Tors are seen on hilltops to both the east and west. Along Bonanza Creek a relatively tall forest of balsam poplar and spruce shows the lateral extent of the thaw bulb in gravelly alluvium as established by test borings to 15 m. These trees do not grow on the adjacent, generally frozen and tussock-covered abandoned flood-plain deposits (Kreig and Reger, 1982, pl. 18).

D-125.8 : North Fork Bonanza Creek.

Tors and dikes are seen along the road.

D-126.5

There is an area of ice-cored mounds immediately upslope from the road (fig. 73). These mounds are underlain by 50 cm or more of pure ice that has arched the organic-rich sediments into mounds 3 to 10 m across. Where the mounds have ruptured, ice layers are exposed. During summer, the ice in many of the mounds melts completely, leaving behind clumps of upturned peat. Mounding has apparently been induced by blocked drainage caused by rapid deep freezing beneath the road. Tension cracks are seen crossing the mounds and adjacent areas. These mounds are seldom found downslope of the road. Larger and more permanent mounds unrelated to the road will be examined farther north, at Sukakpak Mountain.

D-126.7

The terrain is granitic with grus cover. The open forest floor is covered by a thick growth of reindeer lichen (Cladonia rangerifera) (fig. 74). There are tors on hilltops east and west of the road (Kreig and Reger,

Figure 73. Ice-cored mounds in various stages of degradation (photograph taken by P.K. Bailey on June 26, 1982).

Figure 74. Open forest covered with a thick growth of reindeer lichen overlying granitic grus (photograph taken by P.K. Bailey on June 26, 1982).

1982, pl. 18). Within 500 m southwest of the road is a group of tors composed of porphyritic granite. The elevation of 330 m is well below the local treeline of about 600 m and a dense mixed forest surrounds the tors. The tors are deeply weathered and are surrounded by a thick cover of decomposed granite. Another group of tors is located on the opposite side of the road near the pipeline.

D-128.9 to D-129.1
The road crosses a tributary of Bonanza Creek with a willow-covered flood plain subject to aufeis formation. This upland is underlain by generally well-drained soil with occasional granitic tors. The roadcut exhibits 3 m of granite and grus overlain by up to 0.5 m of residual soil.

D-129.6 to D-131.2
The road ascends to the north from the valley of a tributary to Bonanza Creek. A cut up to 3 m deep along the east side of the road exposes loess over occasional bedrock on the lower part of the slope and solifluction rubble above fractured metamorphic rock higher up. The valley occupied by the Bonanza Creek tributary is cut in granite, whereas the upland to the north (on which Gobbler's Knob stands) is a ridge of metamorphic rocks. The valley to the southwest illustrates a willow-covered flood plain, probably subject to aufeis.

D-132.0
Gobbler's Knob is located at the crest of a steep hill (elevation 460 m) on a point overlooking Jim River and Prospect Creek to the north. Prospect Camp, Pump Station No. 5, and the airport are visible. The mean annual temperature at this treeline elevation is approximately -3°C (Haugen, 1982). The lowest temperature ever recorded in Alaska (-62°C) was measured in the valley bottom at Prospect Creek Camp on January 13, 1971. The road descends into the valley of Prospect Creek. Cuts up to 4 m deep along the east side of the road expose thin (0.5 m) colluvial cover above highly fractured phyllitic rock.

D-135.2 : Prospect Creek.
The Prospect Creek pipeline crossing is elevated because of the presence of frozen silt containing stones, possibly till or stony glaciolacustrine deposits.

D-135.6
Thin colluvial cover over bedrock is seen in a cut up to 5 m deep through the ridge crest. No glacial erratics are evident. The colluvial and frost-churned cover becomes thicker and more organic near the north end of the exposure.

D-135.8 : Prospect Creek Camp access road.
This is the eastern terminus of the winter road from Bettles and the proposed starting point for the road to the Ambler mining district and Nome. The planned Bureau of Land Management Prospect Development Area extends from near Prospect Creek north to the northernmost Jim River crossing.

D-137.2 : Pump Station 5 and airport.
The state-operated airport is located east of the pump station. The pump station, on a refrigerated foundation, is constructed on a ridge of cemented gravel flanked by ice-rich organic silt. During construction of the Prospect

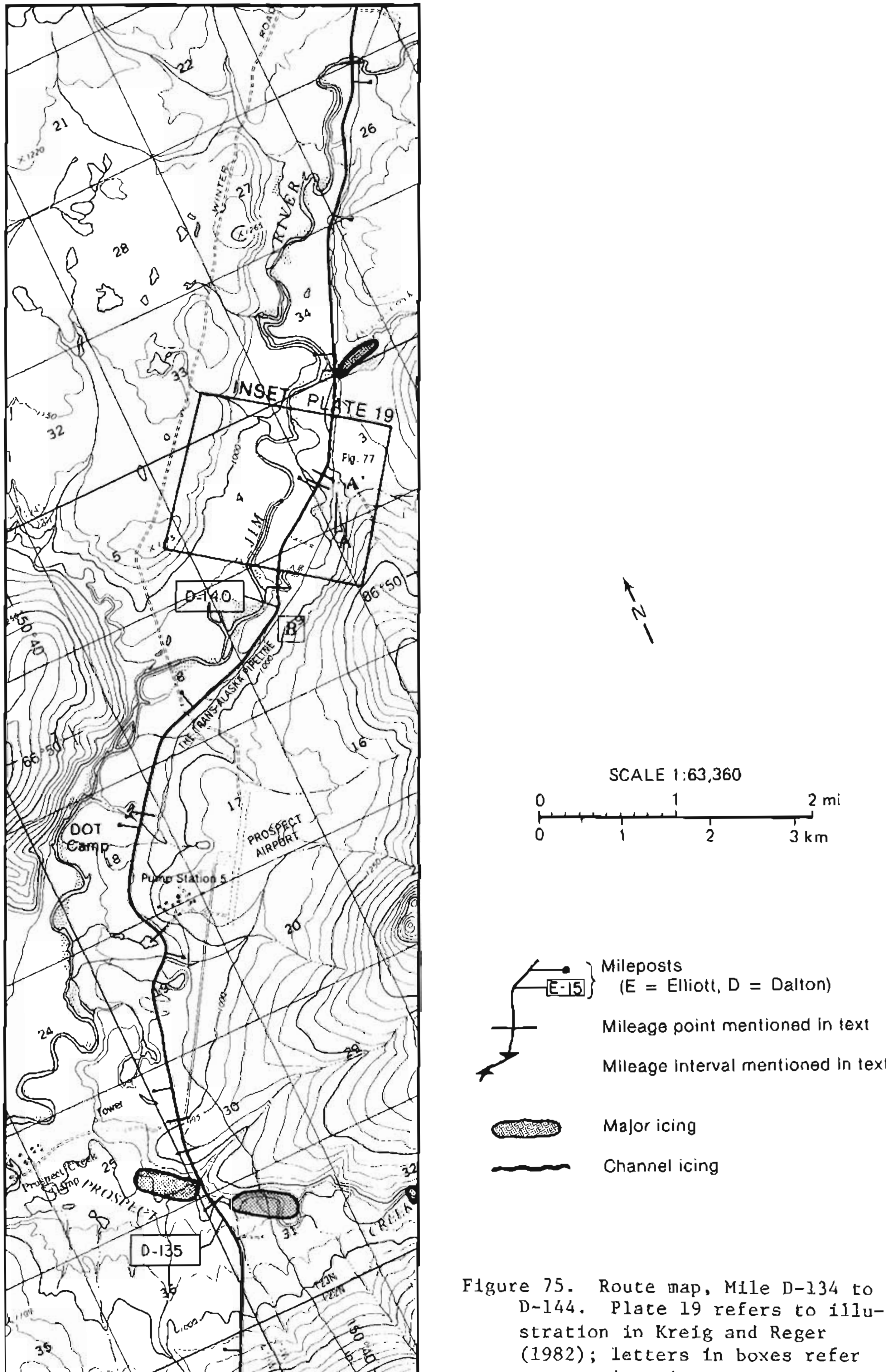


Figure 75. Route map, Mile D-134 to D-144. Plate 19 refers to illustration in Kreig and Reger (1982); letters in boxes refer to notations in text.

Creek airport in 1974, drainage problems developed with the thawing of ice-rich silts. Fill was not placed directly on the undisturbed terrain to preserve the permafrost; instead, the central segment of the runway was stripped and backfilled with a thin gravel overlay. Soft spots and mud boils developed over the stripped areas as the permafrost thawed during the summer of 1974. Drainage trenches were then excavated along the margin and beneath the runway to remove water from the thawing sediment.

D-138.1 : Jim River Alaska Department of Transportation and Public Facilities Camp.

D-140.1 : Jim River Crossing 1.
[B] The drift limit correlated with the Anaktuvuk River glacial advance crosses the valley center near this point (fig. 71). A probable remnant of its former outwash train extends south toward Prospect Creek. The drift has been deeply eroded by Jim River, and its exact former limits are not known. A remnant of a correlative end moraine a few kilometers northeast dams a proglacial lake south of Douglas Creek (fig. 71). An outlet stream from the lake crossed the present drainage divide and flowed south into Prospect Creek. Farther downstream, Jim River was deflected into a probable ice-marginal course along the north flank of a bedrock ridge, into which it eroded its present deep and narrow canyon (T.D. Hamilton, pers. commun.).

D-141.0 : Jim River Crossing 2.

D-141.1 : Access road to pipeline.
The irregular 'hummock and ridge' topography here is similar to topography in an area 50 km to the north along the Middle Fork Koyukuk River (Kreig and Reger, 1982, pl. 19). The maximum relief is 3 to 5 m, with irregularly shaped lakes and ponds. Borings encountered ground water below 2 to 15 m of permafrost. The volume of positive relief is accounted for by the volume of ground ice observed in borings (fig. 77).

D-141.8 : Douglas Creek.
This creek bed has a thaw bulb. The bridge was constructed in 1982 to replace culverts. Icings have formed on the east side of the road in the broad valley. The elevated pipe is raised above the level of the icings. The lack of trees in the valley results from recurrent natural icings, which were noted prior to road construction.

D-144.2 : Jim River Crossing 3.

D-145.2
[C] The road ascends and crosses a probable moraine front that is covered by black spruce (fig. 71). This drift limit is continuous with end moraines of Sagavanirktok River age mapped farther north and northeast in both the Koyukuk and Chandalar valleys (Hamilton, 1978a,b). Drifts assigned to glacial advances of Sagavanirktok River age are believed to be of middle Quaternary age. They are morphologically much fresher than glacial deposits of Anaktuvuk River age, with steeper flanks and more primary relief. They typically occupy valley-floor positions, whereas Anaktuvuk River drift has almost always been eroded from the centers of modern valleys (Hamilton, 1979d).

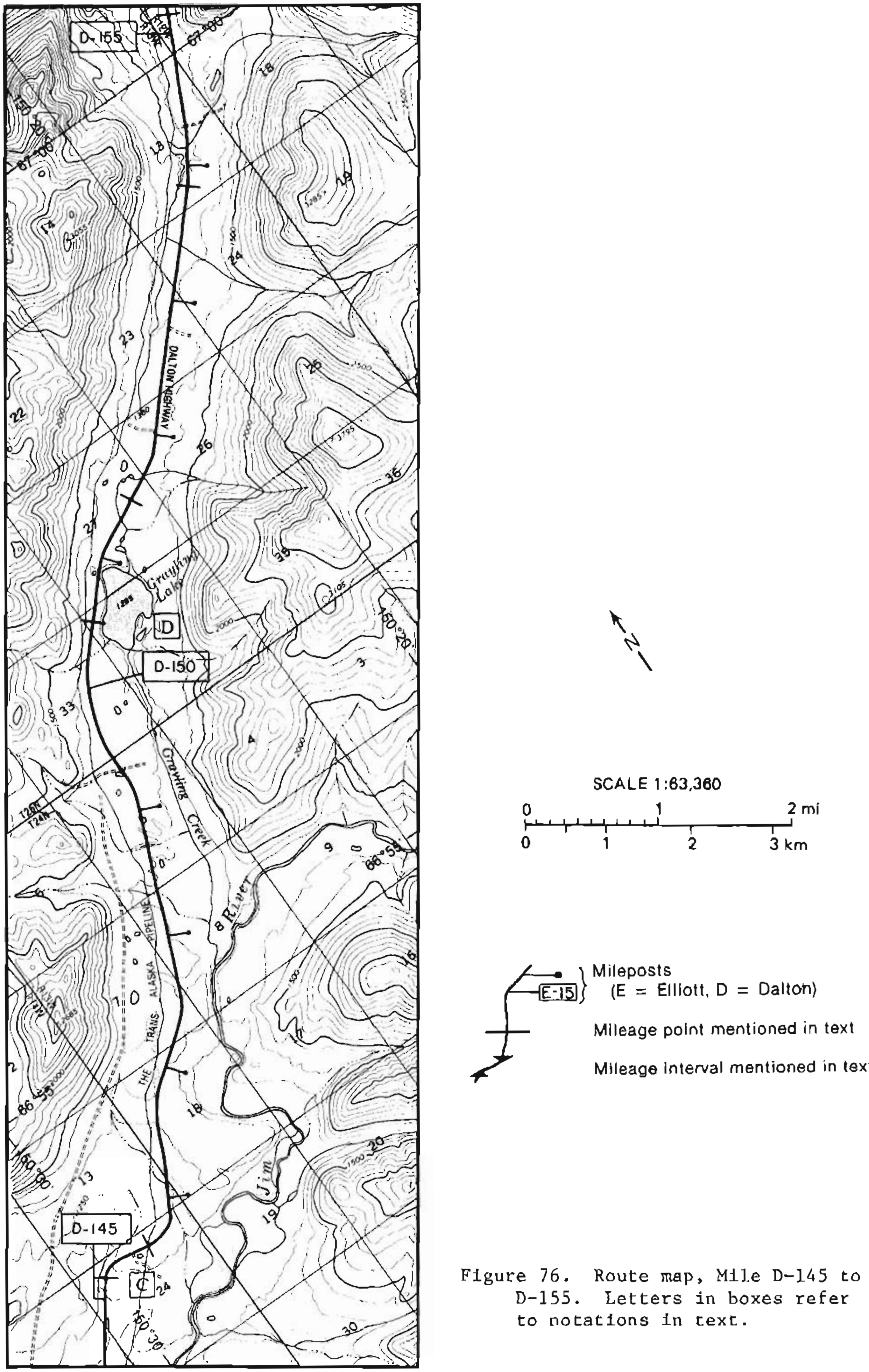


Figure 76. Route map, Mile D-145 to D-155. Letters in boxes refer to notations in text.

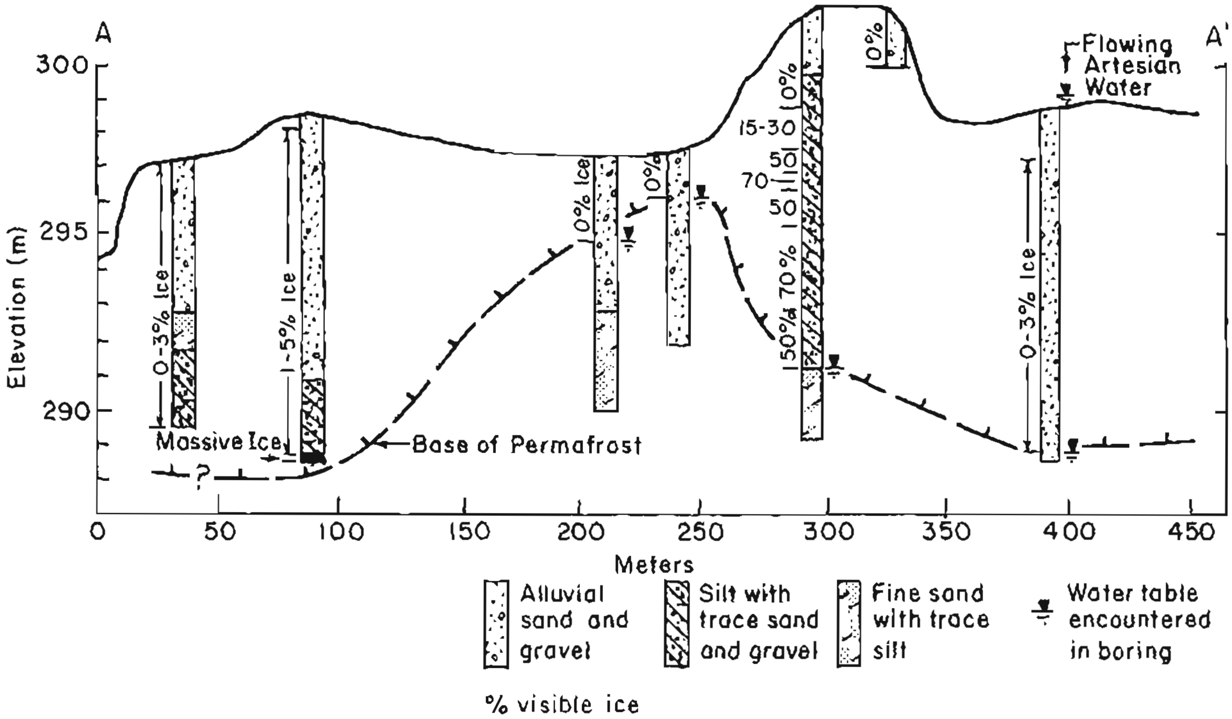


Figure 77. Cross section through a perennially frozen 'hummock' on the flood plain of the Jim River. Logs are from Alyeska Pipeline Service Company (modified from Kreig and Reger, 1982, pl. 19, fig. 12).

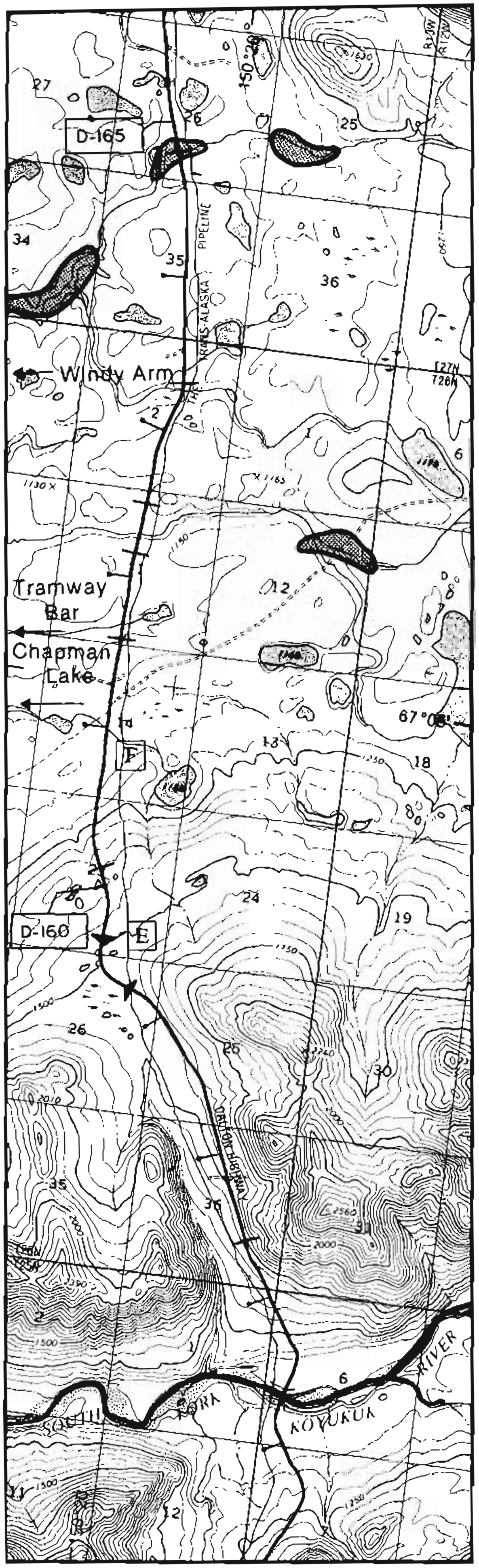
D-145.6

The road crosses the pipeline and the foothills of the Brooks Range come into view for the first time.

D-150.5 : Grayling Lake.

[D] The U-shaped trough scoured by the glacier of Sagavanirktok River age is much older than glacial valleys formed by late Pleistocene ice advances within the Brooks Range. It has been greatly modified by postglacial weathering and erosion, but traces of lateral moraines or kame terraces are still evident near the base of the eastern valley wall. They are largely mantled by blocky granite talus that forms most of the lower slopes, in contrast to the sandstone of the west side of the valley. Talus aprons, a rock glacier, and most of the alluvial fans along the bases of nearby valley walls are inactive features with weathered and vegetated surfaces (T.D. Hamilton, pers. commun.).

Grayling Lake is not a primary kettle, but rather is a shallow water body that probably formed as a thaw lake within older lacustrine sediments that filled the valley floor at this locality. A series of radiocarbon dates and pollen analyses have been obtained from sections from the peat banks adjacent to the lake. Several basal wood and organic samples from 1.2 to 1.4 m below the surface range between 8,700 and 9,400 yr B.P. (K.R. Everett, pers. commun.). Pollen analyses indicate that a shrub tussock tundra existed at Grayling Lake from approximately 9,000 to 7,500 yr B.P. About 8,000 yr B.P., alder migrated into the area, followed by spruce a few centuries later. From 7,500 yr B.P. to the present, an open spruce woodland, much like today's, is postulated. The late Holocene pollen record is less distinct here than at the peat island site at Mile 163.3 (S.A. Baker, pers. commun.).



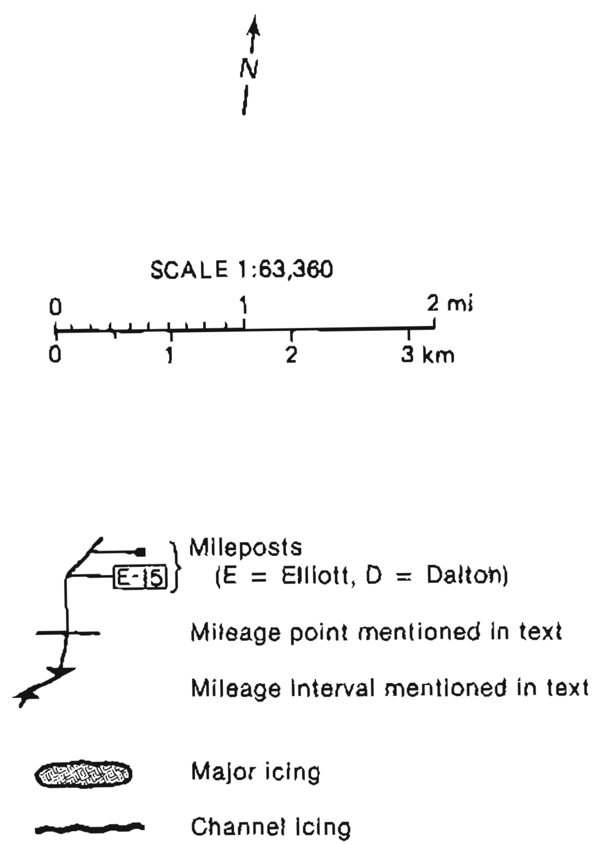


Figure 78. Route map, Mile D-156 to D-165. Letters in boxes refer to notations in text.

D-151.5
The road crosses a recessional moraine that separates the Jim River drainage from tributaries to the South Fork Koyukuk River.

D-153.8
Melting of ice wedges can be observed downslope from the culverts. Steep talus cones are seen on the east side of the road.

D-155.2 : South Fork Koyukuk River valley.
To the east, on the north-facing slope of a 1,000-m-high hill, are large contraction cracks in talus. These unusual cracks are best viewed looking back from the hill on the north side of the river (fig. 79).

D 156.3 : South Fork Koyukuk River.
This large river is a tributary of the Koyukuk River, which flows past the villages of Bettles, Allakaket, Alatna, Hughes, and Huslia before finally draining into the Yukon River near the village of Koyukuk. This is the point at which the final connection of the haul road was made on September 27, 1974 (fig. 79). The two mountains to the north are Twelve Mile Mountain (970 m) to the west and Cathedral Mountain (915 m) to the east. Because some of the glaciolacustrine deposits that lie beneath the flood-plain gravel are frozen, the pipeline crossing was elevated. The bridge has extensive rock armor for erosion protection.

D-157.4
Shallow roadcuts at the crest of the north valley wall of the South Fork expose till above conglomeratic sandstone.

D-159.3
The elevated pipeline crosses under the road.

D-159.3 to D-159.6
[E] The road crosses bog deposits with ice-wedge polygonal features and thermokarst ponds in a former small proglacial lake. It then crosses end moraines of the Itkillik Glaciation (at the gravel pits) and enters a drift complex of Itkillik age (fig. 71). The Itkillik Glaciation, the last major series of ice advances in the Brooks Range, is represented by three principal drifts within the valley systems of the South, Middle and North Forks of the Koyukuk River. The outermost drift (id_A on fig. 71) was deposited by large piedmont lobes that formed when valley glaciers coalesced in lowlands just beyond the south flank of the range. Outwash terraces extended southwestward down the Middle and South Forks of the Koyukuk River, and lakes were dammed behind each of the moraines as the glaciers receded. The outermost Itkillik drift is older than the maximum range of radiocarbon dating. A set of younger moraines (id_B, fig. 71) has sharper relief than the outermost Itkillik drift, but also is too old to date by radiocarbon. Ice tongues in both the North and Middle Forks evidently terminated within the moraine-dammed lakes that formed during the earlier Itkillik advance. A probable correlative drift sheet along the South Fork is marked by a conspicuous outwash train and extensive moraine-dammed lake. The youngest substage of the Itkillik is termed the Walker Lake advance (wld, fig. 86) and is well dated by radiocarbon as between 24,500 and 11,800 yr B.P. (fig. 10). Glaciers of Walker Lake age flowed sluggishly as 'underfit' ice streams through broad troughs carved by much larger glaciers of the older Itkillik substages; they generally terminated

Figure 79. View looking south of final linkup of the haul road, which took place on September 27, 1974, at the South Fork Koyukuk River. Possible large contraction cracks have been observed in talus above the turn in the road (photograph courtesy of Alyeska Pipeline Service Company).

15-30 km inside the range. Moraine-dammed lakes of Walker Lake age are still present in some valleys, but elsewhere glacial lakes either did not form or were drained early and have been filled by later alluviation on the valley floors (T.D. Hamilton, pers. commun.).

D-160.1

[F] The road crosses a probable recessional moraine. Till with abundant faceted and striated clasts is exposed in the 3-m-high cut through the moraine crest. To the west near Tramway Bar on the Middle Fork of the Koyukuk River, a 3-m-thick bed of nearly pure coal has been reported. At Tramway Bar, a deposit of gold-bearing stream gravel on a bend cut into conglomerate and sandstone 30 m above the Middle Fork has been mined sporadically for many years (Mulligan, 1974).

D-161.6

Ice-rich, thaw-unstable soils and massive ice occur near the surface in many places throughout this lowland from here to the Koyukuk River. Mitigative pipeline designs include insulation placed around the VSM's to limit the long-term depth of thaw. Those VSM's with insulation can be identified by the mounds of gravel that cover the polystyrene insulation around their bases (visible along the pipeline east of the road). The original workpad in this area was 0.6 to 0.9 m thick. Subsequent thaw settlement due to thermal disturbance beneath the workpad has caused the gravel to subside in some places to the original level of the ground. Differential settlement of the workpad can be observed.

D-162.2

Drill records show buried ice masses 10 to 15 m thick at about 12 to 20 m depth within the drift along the pipeline on the terrace 125 m east of the road. Actively forming kettles and other indicators of relict glacial ice have been reported on drift of Itkillik age elsewhere in the Brooks Range, and buried ice in these borings could also be of glacial origin. Development as segregation ice in permafrost is a possible alternative, but this is considered less likely because the buried ice is found within glacial deposits. There is no evidence of a subsurface unconformity below which ice could have become segregated by processes acting near a former permafrost table (T.D. Hamilton, pers. commun.).

D-162.5

A cut 7 m into a kame exposes water-washed sand and gravel up to cobble size. Frost churning has created a mixed silty gravel zone as much as 1 m deep.

D-163.3 [13]

The site on the west side of the road illustrates the development of peat islands associated with sedge fens (fig. 80). Much of the surrounding area consists of narrow, often discontinuous gravel ridges that rise 10 m or more above the surrounding fens. Small kettle lakes and ponds occur between or are surrounded by the ridges. Most of the fens are crossed by narrow streams, some of which are 1 m or more deep. Occasionally, nearly circular thermokarst ponds interrupt a drainage and reach depths greater than 2 m. Peat islands

[13] Prepared by K.R. Everett and S.A. Baker.

Figure 80. Acidic Sphagnum peat (left) rises 1 m above adjacent alkaline sedge fen. An area of well-drained outwash gravels can be seen in extreme upper left (photograph taken by K.R. Everett).

are common features of the sedge fen, with the larger islands reaching several hectares and rising 1 m above the surrounding fen.

The area lies in the discontinuous permafrost zone, very near the southern margin of the region of continuous permafrost previously indicated on the map by Ferrians (1965). The relatively warm continental summers south of the Brooks Range permit thawing to 1.5 m or more in gravelly soils on south-facing ridge slopes. Mid-August temperatures of 7°C at 90 cm are not uncommon. On slopes, thaw reaches 40 cm under a few centimeters of organic material at the surface and 23 cm in adjacent swales with thick organic horizons. In the fen, depth to permafrost is variable, depending on moisture conditions and the amount of organic soil. On peat islands, ice-rich permafrost was encountered in August at 40 cm and massive segregation ice in some cases below 1.5 m. In the adjacent sedge fen, permafrost may be 60 cm or more deep. Permafrost is being maintained and is probably aggrading in areas of rapid peat accumulation.

Other manifestations of ice-rich permafrost include ice-wedge polygons apparent in some localities and isolated thermokarst ponds or beads. Some depressions are water filled and others are simply wet. They are interpreted as thermokarst features that have formed in response to the melting of relict ground ice.

An area surrounding the gravel ridges, and to some extent on steep, south-facing slopes below the ridges, supports an open stand of paper birch, quaking aspen, and scattered white spruce. Alder and prickly rose are common understory species. The ground cover is a mat of lichen (Cladonia alpestris),

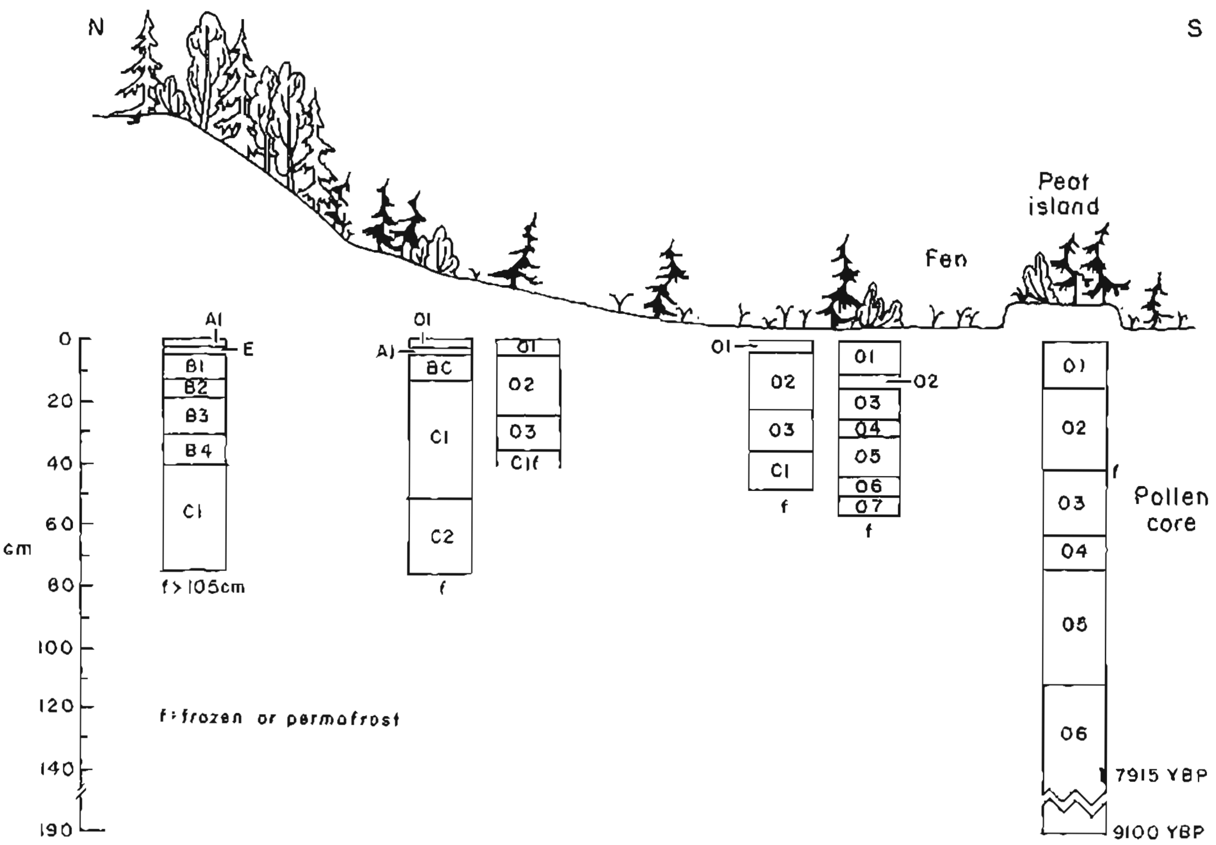


Figure 81. Schematic section of soils, vegetation, and landforms at Mile 163.3 looking west. Horizontal distance approximately 0.3 km; vertical scale 10 m (prepared by K.R. Everett).

lingenberry (Vaccinium vitis-idaea), crowberry (Empetrum eamesii), and cottongrass (Eriophorum vaginatum). Tall alder shrubs occur as widely spaced individuals on several long, southwest-facing slopes dominated by tussocks. Black spruce occurs in bog meadows as scattered individuals or groups of trees surrounded by sedges (Carex aquatilis and other Carex spp.) or in cottongrass tussock meadows with birch (Betula spp.), Labrador tea (Ledum palustre), blueberry (Vaccinium uliginosum), crowberry, and scattered species of willow. Peat islands are raised above the general level of the fen and support thin stands of black spruce with an understory of willow, birch, and Sphagnum (fig. 81).

The oldest radiocarbon date, 9,105 ± 585 yr B.P. (GX-8387), is from a fibrous sedge peat at a depth of 1.74 to 1.84 m in a peat island. Charcoal fragments record at least one burn, although many others undoubtedly occurred. The increasing amount of Sphagnum, especially in the active layer, suggests that this particular peat island may have been elevated with respect to the adjoining fen rather recently. Its relative elevation with respect to the surrounding alkaline surface waters permitted the rapid accretion of moss and set the stage for the development of a peat island. Peat islands are probably transitory features. Some sites may undergo several cycles from sedge fens to Sphagnum-forest peat islands followed by collapse of the island.

A 1.98-m-long peat core recovered from the peat island (fig. 81) revealed a pollen record (S.A. Baker, pers. commun.) in which four site-specific assemblage zones are recognized, based on both the relative (percentage) (fig. 82) and absolute (concentration) diagrams.

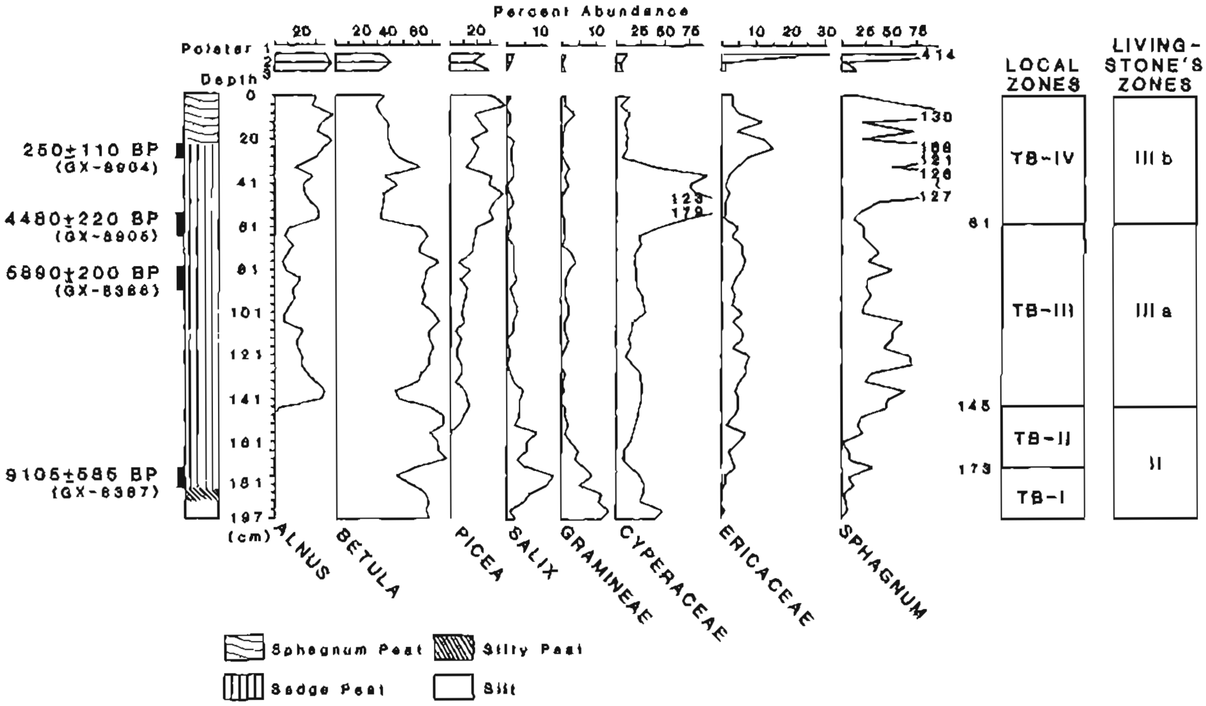


Figure 82. Pollen abundance from the peat island core at Mile 163.3. Sum excludes Cyperaceae, Ericaceae, Sphagnum, and unidentifiable pollen (modified from S.A. Baker, in prep.).

Zone I (1.97-1.73 m, pre-9,000 to 9,000 yr B.P.) is dominated by Betula, Cyperaceae, and Gramineae in the relative diagram. Salix and herb taxa such as the Umbelliferae and Rosaceae are important. This zone corresponds approximately to the silt and silty peat units at the base of the core.

Zone II (1.73 to 1.45 m, 9,000 to 8,000 yr B.P.) is dominated by Betula. Cyperaceae and Gramineae decrease slightly in importance in the relative diagram, but remain important in the concentration diagram. Salix, gramineae and herb taxa reach their maximum absolute values in this zone. Overall, a shrub tussock tundra environment is indicated for this zone.

Zone III (1.45 to 0.61 m, 8,000 to 4,480 yr B.P.) is dominated by Betula, Alnus, and Picea. Picea becomes more important, rising to 10-15 percent. Other taxa of importance include Cyperaceae, Ericaceae, and Sphagnum. Such an assemblage suggests an open spruce woodland.

Zone IV (0.61 m to surface, 4,480 yr B.P. to present) is also dominated by Betula, Picea, and Alnus. Picea reaches its maximum percentages and concentrations in this zone, suggesting an expansion of the forest to present conditions.

From this radiocarbon-dated pollen record, a shrub-tussock tundra environment is thought to have existed in the area from at least 9,000 to approximately 7,500 yr ago. About 8,000 yr ago, spruce and alder appeared in the area. Finally, around 4,500 yr ago, the forest underwent a second expansion to approach present conditions. Changes in the last half of the Holocene are difficult to interpret because of slow accumulation rates.

Until recently, the major pollen work in the central Brooks Range and vicinity consisted almost entirely of Livingstone's early work (1955, 1957), which established the three-zone pollen sequence for the late Wisconsin and

Holocene. The oldest of these, Zone I, is characterized by herbaceous taxa and Cyperaceae, and is thought to represent a tundra environment comparable to the modern tundra of the Barrow area. Zone II is dominated by Betula, with smaller amounts of Cyperaceae and Gramineae, and is thought to represent a birch-dominated shrub tundra environment. Finally, Zone III is characterized by Alnus, with smaller amounts of Betula. Zone III is further divided into substages when applicable, based on alder maxima and subsequent decline. Spruce, in some cases, is more abundant in Zone III as well. Livingstone attempted to document the Hypsithermal either by alder maxima or, in some cases, spruce maxima, in the uppermost parts of the cores. Overall, Zone III vegetation was interpreted as modern---either open spruce woodland or an alder-birch shrub tundra environment, depending on the modern vegetation of the site in question.

Because radiocarbon control was not available for these zones as originally defined by Livingstone, his Zone I was tentatively considered late glacial (late Wisconsin); Zone II, early Holocene; and Zone III, late Holocene. Dates of approximately 8,000 and 6,000 yr B.P. were later obtained for the base of Zones II and III, respectively, at a site near Umiat (Livingstone, 1957). However, many problems exist in extending this chronology south of the Brooks Range. Because of the time-transgressive nature of species migrations, vegetational changes north of the Brooks Range are probably not contemporaneous with those on the south side; however, their vegetational equivalence is almost certain. The approximate correlations of Livingstone's zones and the present site are indicated in figure 82.

D-164.8

Several special sections of elevated and buried pipeline were constructed to accommodate animal crossings. A short section of buried pipe was spaced to facilitate caribou crossings. Here the pipe is in thaw-unstable materials. Insulation and heat pipes were used to prevent deepening of the active layer and thawing of perennially frozen ground with a silt content greater than 6 percent. An arched, elevated section is located just north of the small lake. The added clearance presumably enables animals to pass beneath the pipe more easily.

D-166.4

A cut extends about 50 m along the road at the edge of the highest alluvial terrace of the Middle Fork Koyukuk River, which probably dates from the younger Itkillik (id_B) readvance (fig. 71). The cut exposes as much as 10 m of sand and gravel beneath a surface cap of peat. The peat thickens to 2 m near the north end of the cut, where it fills a depression in the surface of the gravel. At this locality, willow wood and poorly preserved wood fragments of either spruce or larch have been dated at 7,990 ± 130 yr B.P. (I-10,501). This date places a minimum limiting age of early Holocene expansion of boreal forest into the area (Hamilton, 1980, 1982). It supports the date of about 8,000 yr B.P. for replacement of herbaceous tundra by spruce forest observed in the pollen record at the peat-island site (fig. 82). At this point the road enters the central Brooks Range proper. The first mountain to the east is Cathderal Mountain and to the west is Twelve Mile Mountain. Both are composed of Mesozoic mafic igneous rock. Rock types to the north to the Atigun River drainage are primarily Devonian sediments that have been subjected to various degrees of thrust faulting and metamorphism. Schist, phyllite and marble predominate in the south and progressively less metamorphism is displayed farther north, where siltstone, limestone, conglomerate, and slate predominate.

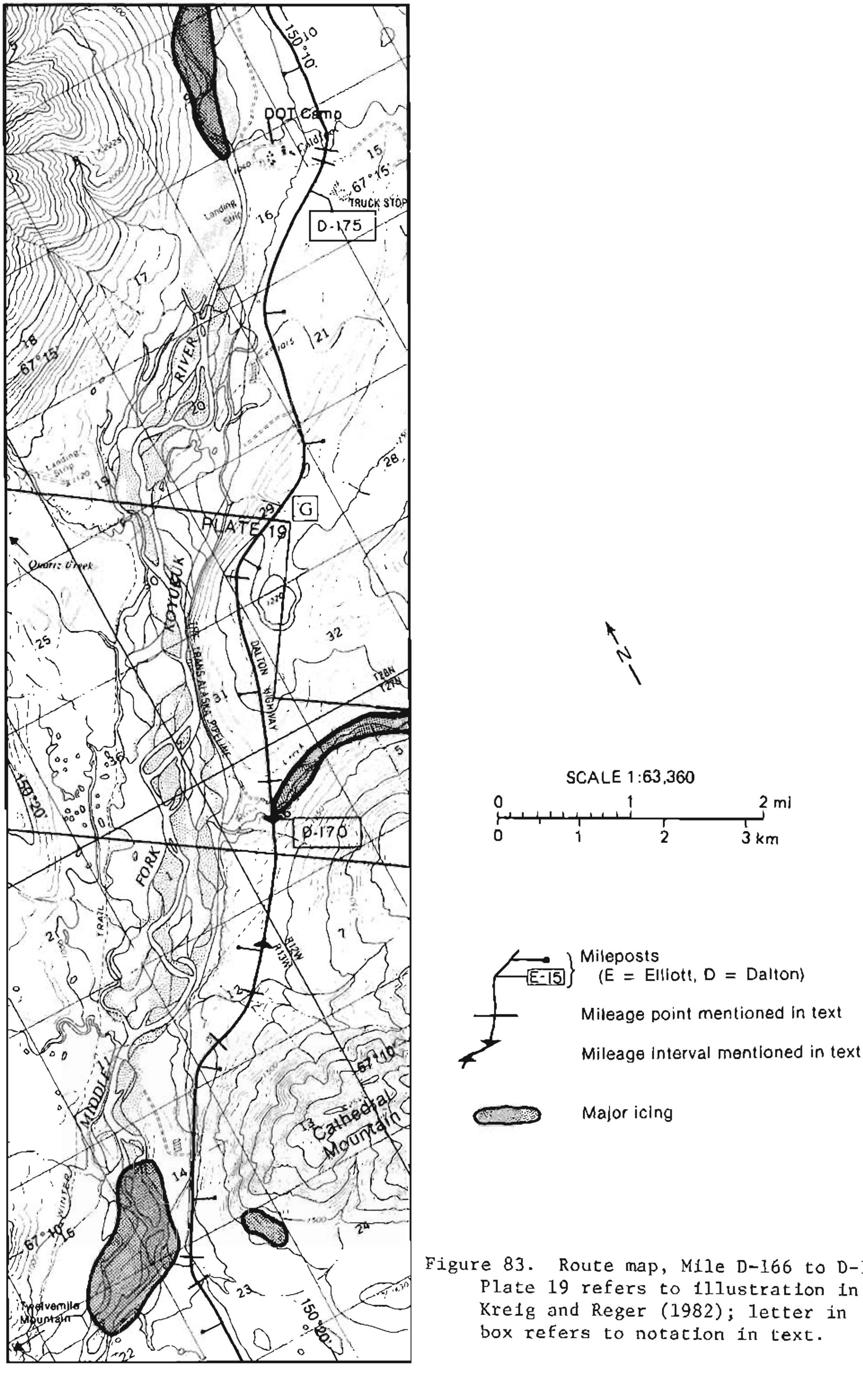


Figure 83. Route map, Mile D-166 to D-176. Plate 19 refers to illustration in Kreig and Reger (1982); letter in box refers to notation in text.

The terrain crossed by the road and pipeline in the next 2-km stretch in the flood plain is discontinuously frozen under stunted black spruce and sporadically frozen under more vigorous-growing white spruce. The terrain under the road where it ascends the side of the valley is underlain by continuous permafrost for the next 10 km (R.A. Kreig, pers. commun.).

D-166.6
The pipeline crosses under the road. It is buried for a short distance and then elevated on high terraces of the Middle Fork Koyukuk River.

D-168.2
The road ascends from the flood plain to an upland surface of glacial drift. Sandy alluvium underlies 5 to 8 m of glacial drift, which consists of till west of the road and ice-marginal stream gravel to the east. Till forms a ridge that probably is an end moraine; gravel occupies a channellike depression that later filled with colluvium and organic matter.

D-168.7
Roadcuts 12 to 15 m high expose probable alluvial-fan deposits. Clasts are poorly bedded and sorted, but most are angular, of local lithology, and range from pebbles to very small boulders. No striated or faceted clasts are evident.

D-169.1 to D-170.0
The road crosses poorly drained upland, which appears to be ground moraine. Solifluction appears to be widespread.

D-170.0 : Rosie Creek.
Excavation of the roadcut on the south side of Rosie Creek exposed ice wedges (fig. 84) that began to melt almost immediately on exposure and, although covered by slump materials, were still melting in August 1978. On the southwest side of the creek are a thermokarst pond and small hummocks, which are called 'cemetery mounds' or 'baydzherakhi,' after similar features in Siberia. They are formed from the melting of ice wedges and ice-rich sediment (fig. 85), possibly initiated at this location by forest fires.

D-170.3
A cut extends along the west side of the road into the alluvial fan of Rosie Creek. Exposed sediments consist of sand and silty fine sand with undisturbed bedding overlain by fan gravel that contains ice-wedge casts, involutions, and frost-churned stones with vertical fabric. Although obscured by a debris apron, the sand or similar fine-grained deposits must extend to at least the level of the roadway. Small twigs just below the base of the fan deposits have been dated at 28,450 ± 950 yr B.P. (I-10,816), providing a maximum age on alluviation of the fan. Fan building evidently took place under a severe frost climate and seems to have corresponded in time to the Walker Lake glacial phase, as dated elsewhere in the Koyukuk drainage system (Hamilton, 1979c, 1980, 1982).

In the southern Brooks Range, permafrost is generally absent beneath flood plains that are either unvegetated or vegetated by balsam poplar. Flood plains vegetated by white spruce are underlain by isolated masses of permafrost. Aspen and birch grow on dissected, well-drained slopes with a deep permafrost table. In this reach of the Middle Fork Koyukuk River, a 3-m-thick layer of Holocene alluvium covers glaciofluvial or lacustrine sandy silt and

Figure 84. Exposure of ice wedges on the south side of Rosie Creek (Brown and Berg, 1980, fig. 19; photograph taken by R.L. Berg on May 30, 1975).

Figure 85. Siberian cemetery mounds, or baydzherakhi, downslope from exposed ice-wedge cut shown in figure 84. Mounds are erosional remnants left after ice wedges have melted (photograph taken by R. Veazey on July 20, 1982).

silty sand. Coalescing fans of fine-grained, retransported deposits have locally buried flood-plain alluvium and are frozen. Mudflows occur on steep slopes of clayey Itkillik Till that overlies schistose sandstone, phyllite, and slate (Kreig and Reger, 1982, pl. 19).

Across the river from Rosie Creek, the relatively old flood-plain surface has unusual, irregular hummocks and ridges that are composed of fluvial sand and gravel and have a maximum relief of 3 to 4.5 m. Interspersed between the hummocks and ridges are numerous irregular flood-plain lakes and ponds, which have anomalous forms compared to other flood-plain lakes along this branch of the Koyukuk River. Hummock surfaces are rounded, and adjacent mounds or ridges do not have accordant summits.

The lack of summit accordance indicates that the hummocks and ridges are not terrace remnants, even though they are composed of coarse alluvium. Variation in height and the irregular forms of the ridges and mounds could be explained by differential settlement as ice-rich permafrost thaws. But the irregular form of the intervening lakes and ponds is analogous to the outlines of ponds developed by aggrading ice-rich permafrost, and is different from the typical rounded or scalloped form of thaw lakes. These hummocky flood-plain surfaces are probably the result of the aggradation of ice-rich permafrost (Kreig and Reger, 1982, pl. 19). Ground water under hydrostatic stress in thawed sand beneath the downward-growing permafrost probably promoted the local growth of massive ground ice at depth, causing differential surface uplift.

D-171.9

[G] The road follows a moraine of the second Itkillik advance (id_B, fig. 86), which evidently terminated in a lake that formed behind the outermost Itkillik end-moraine belt. A large, fresh landslide in the basin of Quartz Creek on the west side of the valley is visible from this point. The slide occurred in the early 1970's. Across the river in Porcupine Creek, coarse gold has been recovered from gravel 6 m deep. Recently, it has been mined by bulldozer and hydraulic methods. Some drift mining in deep frozen gravels has also been used (Mulligan, 1974).

D-175.2 : Coldfoot.

The settlement of Coldfoot was founded in 1899 at the mouth of Slate Creek, when prospectors first discovered gold on Slate, Myrtle, Clara, Emma, Gold, Porcupine, and other nearby creeks. Over 1,000 persons are reported to have taken steamers up the Koyukuk River in search of gold in the upper drainage. Most were soon discouraged by the absence of bonanzas and by the remote, inhospitable country. According to Marshall (1933), only 200 people wintered in the upper Koyukuk drainage that year in the instant towns of Arctic City, Bergmann, and Peavy, and in camps along the South Fork. When travel permitted in the spring of 1899, more left the Koyukuk district. Those who stayed were the more seasoned propectors, and their persistence quickly paid off when new strikes were made later that year on Slate Creek and Myrtle Creek, tributaries of the Middle Fork. Two new towns were founded: Slate Creek (later Coldfoot) at that creek's confluence with the Middle Fork, and Bettles, just below the John River confluence.

In 1900, Bettles largely replaced the downstream town of Bergman as the major supply point for upriver placer mines. The town of Slate Creek became known as Coldfoot, named after a 'cheechako' or newcomer who, on reaching the Slate Creek diggings, got cold feet and turned back. The old cemetery still exists. In the early 1900's, Pickarts, Bettles, and Pickarts (distributors

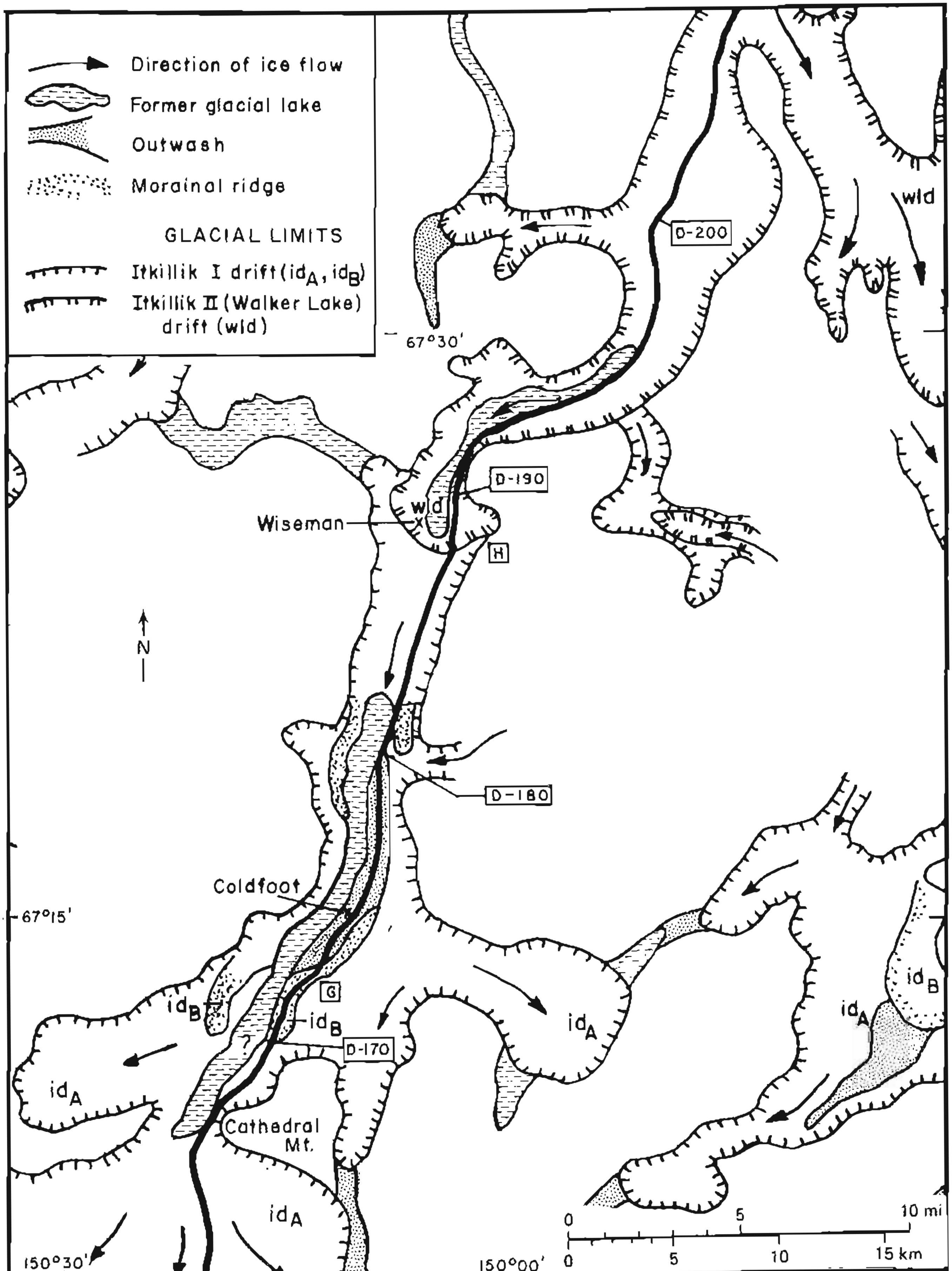


Figure 86. Glacial geology of the area between Cathedral Mountain and Sukakpak Mountain (map scale 1:250,000). Letters in boxes refer to notations in text.

for the Alaska Commercial Company) established a store in the new mining town. Coldfoot was also the office of the U.S. commissioner, probate judge, coroner, and recorder. By 1904, the settlement consisted of about 80 well-built cabins. The place was practically deserted during the summer, but about 60 prospectors, trappers, and Natives resided there during the winter. In 1902, the Alaska Commercial Company abandoned its store, which was soon replaced with that of Stevens & Plummer. The community received its supplies from Bettles by boat and sled. Mail was delivered to the town by dog team from Fort Yukon once a month. About 1908, the town was eclipsed by Wiseman. The Coldfoot post office, established in 1900, was closed in 1912. This area includes the Coldfoot Development Area, which has been 'permitted' by BLM.

The creeks to the north have been and are sites of gold-placer mining. Some mining was done along Clara Creek in 1901 and also in 1934. On Emma Creek, a rich gold deposit was formed by a steep gradient stream flowing through a narrow, boulder-laden gulch. Considerable prospecting was done in Marion Creek and some gold was found in coarse gravels on Sawyer Creek (Maddren, 1913; Mulligan, 1974).

Emma Dome (1730 m) is visible to the west. The northern limit of aspen (Populus tremuloides) along the road corridor occurs near Coldfoot.

D-175.3 : Slate Creek.

For the next 11 km north of Coldfoot, the road follows alluvial terraces flanked to the east by possible solifluction slopes, which occasionally extend to the road edge.

D-177.0

Several rock slides can be seen on the higher slopes to the east in Clara Creek valley and in the small drainage 2.3 km north of Clara Creek.

D-**179.9** : Marion Creek.

The bridge was installed in 1982.

D-180.4 : Marion Creek campground.

A large rock slide is located 2.4 km upstream from the road. Open stands of white spruce have formed on river terraces, especially south and east of the campground. The excellent internal drainage provided by the gravel is expressed by widely spaced trees and the rich carpet of lichens on the forest floor.

The road descends to a terrace of the Middle Fork Koyukuk River for the next 1.9 km. Although much of the stretch is covered by stunted spruce, it is discontinuously frozen, possibly because of ground-water flow moving down-valley in the coarse-grained alluvium at depth (R.A. Kreig, pers. commun.).

D-181.9

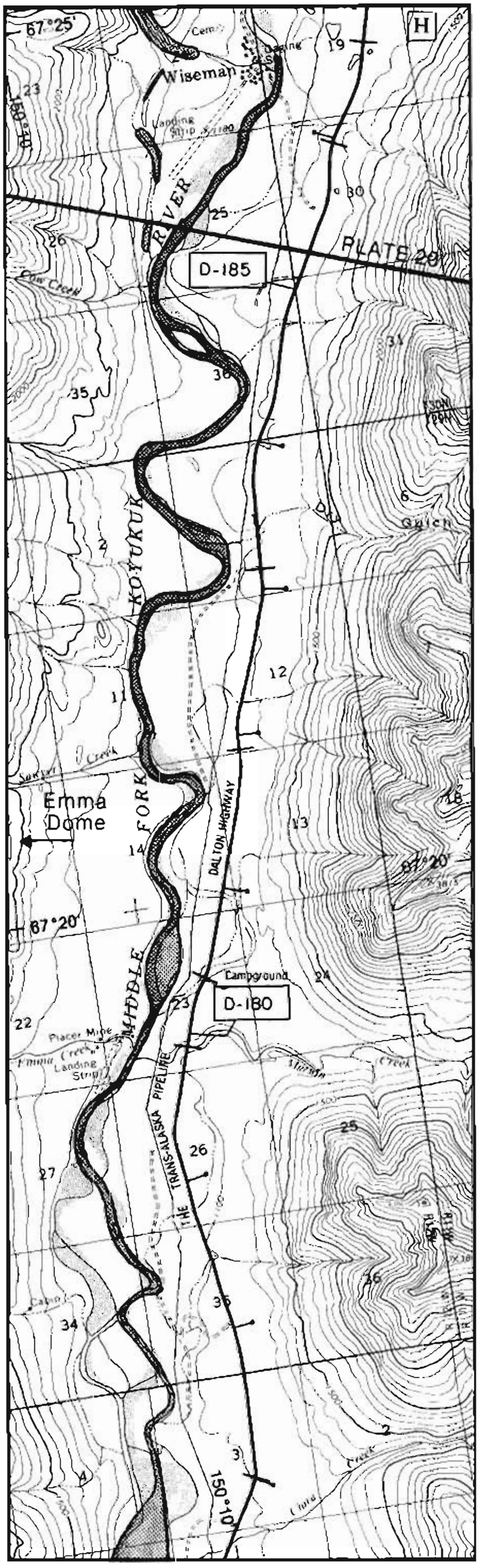
The road ascends to a surface of higher alluvial terrace. A 7-m-deep cut at the terrace edge reveals fluvial gravel with minor sand beds beneath a thin (0.5-m) loess cap. The road follows the terrace surface for the next 4 km.

D-183.1

A recent rock slide is visible on the upper slopes on the west side of the Koyukuk River valley.

D-186.0 : Wiseman area.

An overview of the valley is gained from a rock quarry on a protruding ridge of gneiss. The historic mining community of Wiseman can be seen across



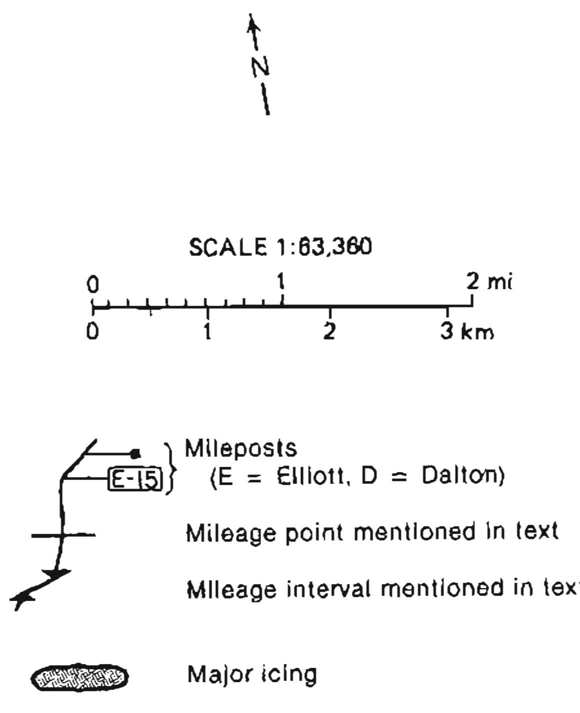


Figure 87. Route map, Mile D-177 to D-186. Plate 20 refers to illustration in Kreig and Reger (1982); letter in box refers to notation in text.

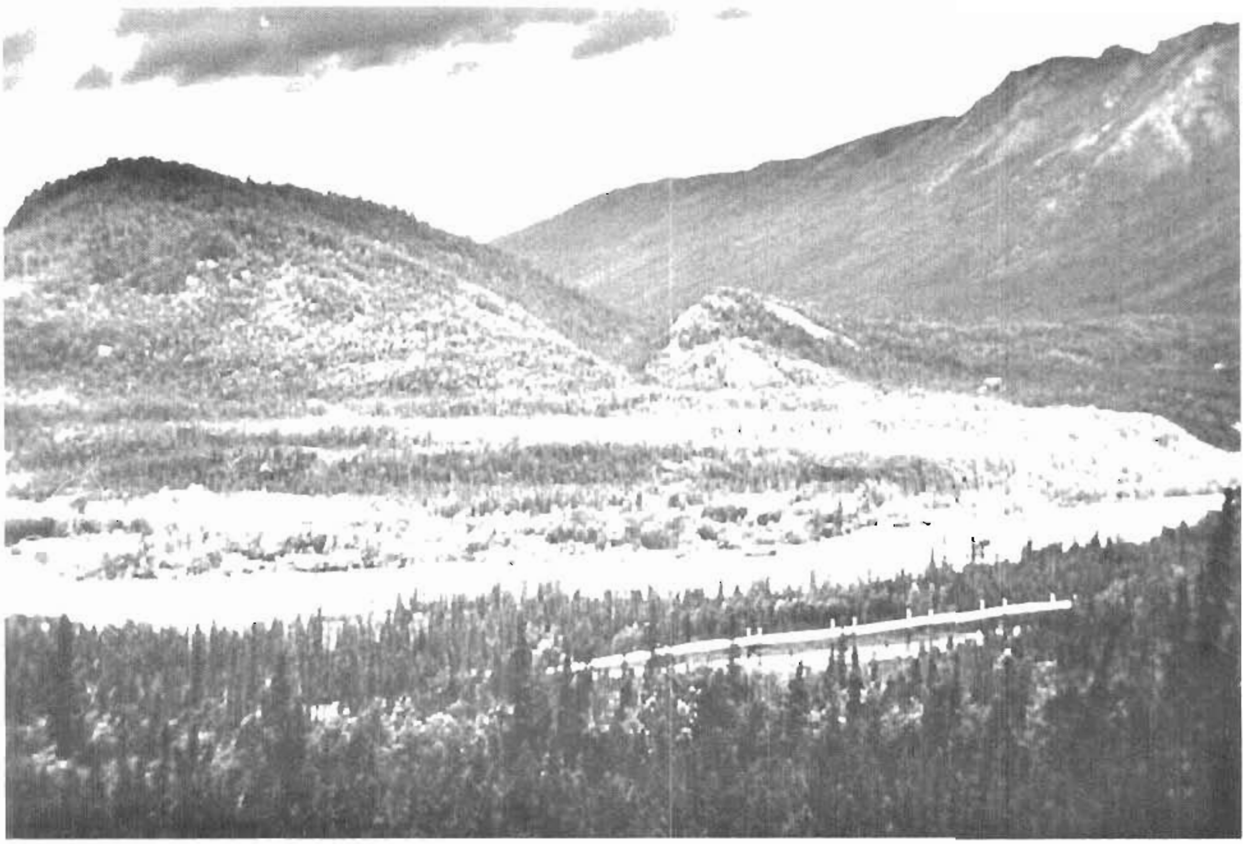
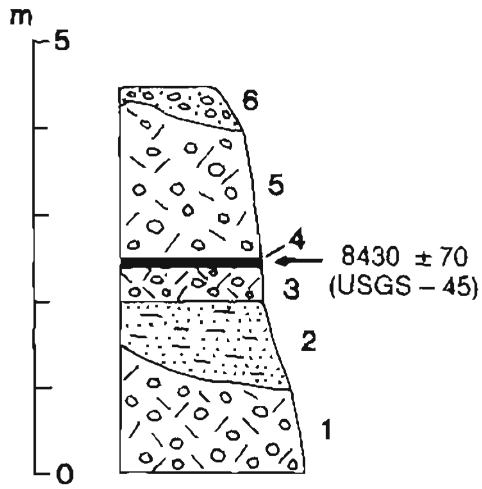


Figure 88. View across the Middle Fork Koyukuk River to Wiseman and the glacially sculptured valley wall (photograph taken by R. Veazey on July 21, 1982).

the Middle Fork Koyukuk River west of the road (fig. 88). Wiseman was established about 1908 as a supply point for mining operations on Wiseman, Mascot, and Nolan Creeks, and on the Hammond River. It was originally called Nolan and a post office was established there in 1909. The town was located at the head of navigation for shallow-draft scows and poling boats. There are many buildings still standing at Wiseman, whose heyday came in about 1910, after the gold rushers abandoned Coldfoot, 16 km south. In 1930, about 103 people resided in the vicinity of the town, which was by then largely served by airplane. Life in Wiseman was vividly described by Marshall (1933). An airfield was built there in 1926-27 and served as the major stopover between Fairbanks and Barrow. The post office was closed in 1956. About 12 year-round residents still live there. An early mining community (now called Nolan) was located on Nolan Creek, about 10 km northwest of Wiseman. A mine shaft on Wiseman Creek was dug and drilled through 110 m of permafrost (Maddren, 1913).

This area is typical of the central and southern Brooks Range. Glacially scoured valleys walled by 1,800-m-high ridges of limestone, shale, sandstone, phyllite, and schist contain glaciofluvial deposits, alluvium, and till. Flood-plain deposits are commonly underlain by glaciofluvial or lacustrine silt and sand. Alluvial fans built by tributary streams and colluvial aprons extend from the lower valley walls towards the flood plain of the Middle Fork. This terrain is generally frozen, except for the active tributary flood plain and riparian zones of balsam poplar and white spruce (Kreig and Reger, 1982, pl. 20).



Unit	Thickness and description
6	**Sandy gravel** (0 – 0.5 m). Caps erosional surface.
5	**Diamicton** (1.5 – 2.0 m). Unsorted, nonstratified pebbles and cobbles in matrix of silty sand.
4	**Paleosol** (0.1 m). Black to dark reddish brown (5 YR 2/2) peaty muck. Overlain by 0.5 cm white calcareous marl(?).
3	**Diamicton** (0.4 m). Unsorted, nonstratified pebbles in brown sandy matrix.
2	**Sand** (0.5 – 1.0 m). Gleyed and locally organic silty fine sand. Fills depression on surface of Unit 1.
1	**Diamicton** (1.0 – 1.5 m). As in Unit 5.

Figure 89. Roadcut in Walker Lake moraine (wld, fig. 86) on east side of Middle Fork Koyukuk River 1 km south of Minnie Creek. A diamicton is an unsorted till-like deposit (Hamilton, 1980, fig. 18).

Lacustrine deposits underlying 4-5 m of Holocene alluvium of the Middle Fork Koyukuk River were laid down in a lake behind an end moraine of Walker Lake age (Hamilton, 1980) that formerly blocked the late glacial and early postglacial drainage. Lacustrine deposits are rarely exposed.

The lower course of Wiseman Creek formerly flowed through a valley that was subsequently filled with drift. It was diverted along an ice margin where it cut a side-glacial canyon into quartz-mica schist.

D-186.7

[H] A cut about 4 to 5 m deep extends 100 m along the west side of the road where it crosses an end moraine of Walker Lake age (fig. 89). In the exposure, upper and lower diamictons (units 1 and 5 in figure 89) are separated by sand, diamicton, and organic soil (units 2-4) that fill a kettlelike depression in the lower diamicton. Sand and gravel overlap the upper diamicton and cover its eroded north and south flanks. The buried soil, a peaty muck within the depression, grades laterally into lenses of organic silt that separate units 1 and 5; it has a radiocarbon age of 8,430 ± 70 yr B.P. (USGS-45). If the date is correct, it indicates that the upper diamicton is too young to have been emplaced by a glacial readvance within the valley of the Middle Fork. It must have been deposited as flowtill during downwastage of relict ice within the end moraine. Deposition of a diamicton by a landslide from the valley wall is less likely because the sandy, pebbly, boulder-free upper diamicton contains no rubble from the valley side and is nearly identical to the basal diamicton (unit 1) at this locality (Hamilton, 1980). A kettle lake is located between the road and the river.

D-187.1

A cut 5 to 7 m deep along the west side of the road exposes till that contains a deep kettle fill of silt and organic material.

D-187.3

The road drops through a long cut from the moraine surface down to the fan of Minnie Creek. The south end of the cut exposes water-washed ice-contact drift from two kames. The north end of the cut exposes up to 10 m of stratified ice-contact deposits associated with a third kame.

D-187.4 : Minnie Creek.

Considerable prospecting has taken place along the creek. Coarse gold was recovered in places, but the presence of water in unfrozen material above bedrock discouraged drift mining (Maddren, 1913; Mulligan, 1974).

D-187.7

A cut 4 m deep along the east side of the road exposes the gravel of the old, dissected Minnie Creek fan. Boulders as large as 50 cm in diameter are common, with clasts occasionally as large as 70 cm. Minnie Creek may have reworked older glacial deposits, because nearly all large clasts are subrounded rather than angular to subangular.

D-187.9 to D-188.4

A probable solifluction slope impinges on the road from the east. Silt and organic silt were exposed in a cut 2 m deep where the road begins to drop onto the active flood plain of the Middle Fork Koyukuk River.

D-188.7

The road crosses the Middle Fork Koyukuk River (Crossing 1) and follows its flood plain northward. The pipeline crosses under the river downstream from the road.

D-189.7

The Alaska Natural Gas Transportation System chilled-pipe test site is located 50 m west of the road in unfrozen alluvial deposits that mantle 30-60 m of fine-grained lake deposits. The site, near a pond, has the high water table needed for testing maximum frost heave in these deposits. In this vicinity, the terrace deposits have an irregular surface with small thermokarst(?) ponds and positive relief features. Deposits under the ridges have a high ice content. Isolated potholes are thawed at least to a depth of 15 m. The base of permafrost is below a depth of 50 m in places (R.A. Kreig, pers. commun.). These hummocks appear to be similar to those discussed by Kreig and Reger (1982, pl. 19).

Occasional cuts expose fluvial sand and gravel in banks up to 2 m high. The numerous river-training structures along the east side of the road are designed to prevent erosion of the road and to protect the pipeline during flooding by the Koyukuk River. Dikes are spaced at distances less than the length of the river meanders. Settlement of these dikes has resulted from thawing of ice-rich lacustrine deposits.

D-190.7 : Hammond River.

Bridge test borings indicate that the rapidly shifting river has failed to thaw frozen ground in places beneath its channel. Deeply buried, frozen, gold-bearing gravel was mined by drift methods near the mouth of the Hammond River, but in many places these operations were hindered by water in thawed gravel above bedrock. The paystreak extended into the Middle Fork valley. Coarse gold and nuggets were recovered from this paystreak. Bench gravel upstream from the mouth of the river was worked by open-cut methods and also yielded coarse gold (Mulligan, 1974).

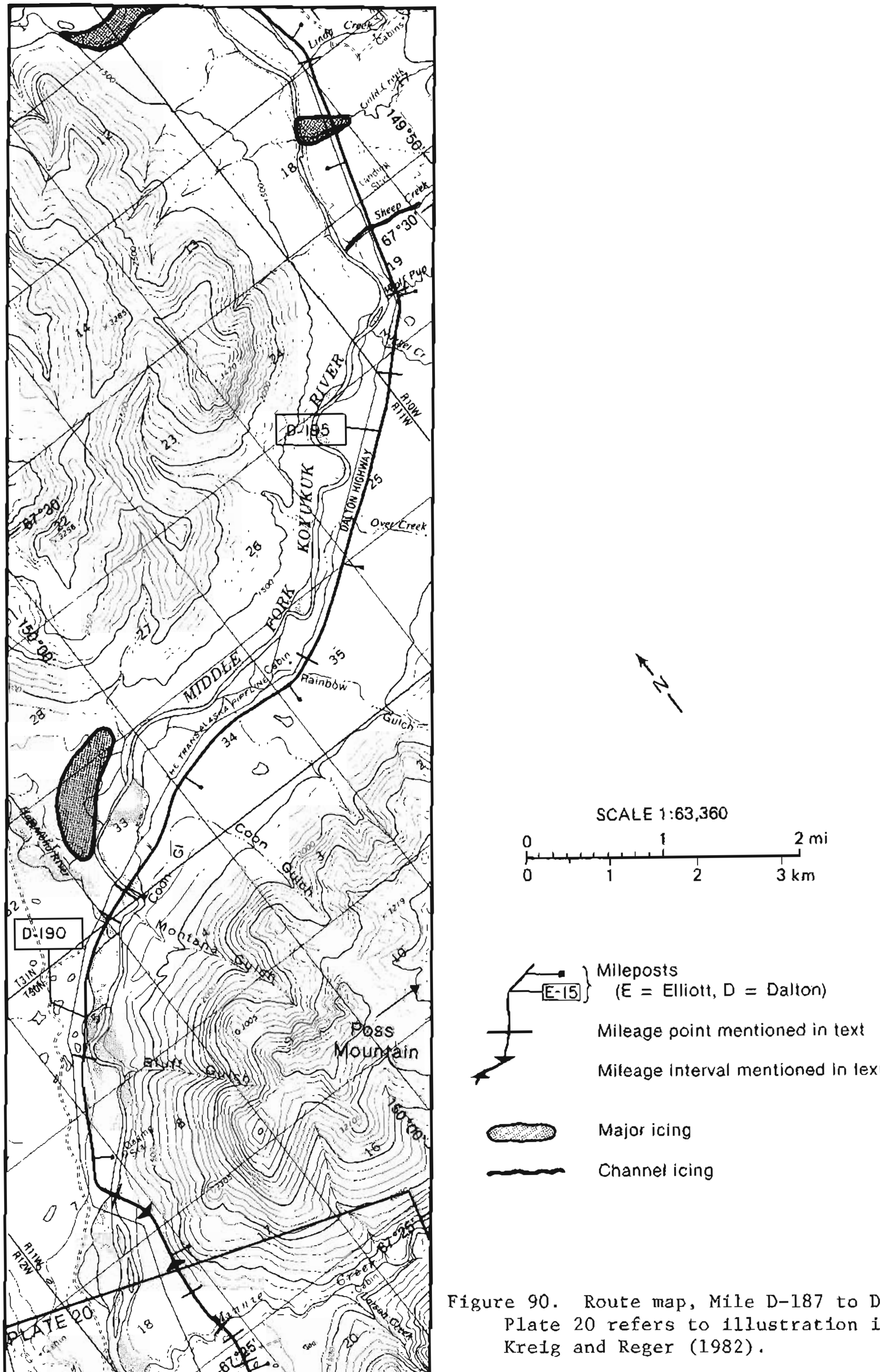


Figure 90. Route map, Mile D-187 to D-198. Plate 20 refers to illustration in Kreig and Reger (1982).

D-191.0 : Middle Fork Koyukuk River (Crossing 2).

The soft silt underlying this river section required deep VSM's for the pipeline. No permafrost was encountered. There is a good view of a pipeline bridge. Piles were driven deeper than 30 m. Extensive riprap has been placed on the river banks to protect them from erosion.

D-193.3

Sukakpak Mountain (1,220 m), 16 km to the north, comes into view for the first time. Wiehl Mountain (1,220 m) is east of Sukakpak. The high mountain just to the west of the road is unnamed.

A road sign indicates that the road sections linked here at noon, September 7, 1974.

D-195.4

An old cabin built in the mid-1930's is located just west of the road on the Arctic John Etalook Native Allotment. Except for a small lot in Wiseman, this land is the only private patented land north of Livengood. It occupies 65 ha on both sides of the road.

D-196.0

A remotely operated pipeline valve and related control building used in pipeline operation can be seen. Propane fuel tanks used to power the facility are buried in the frozen ground.

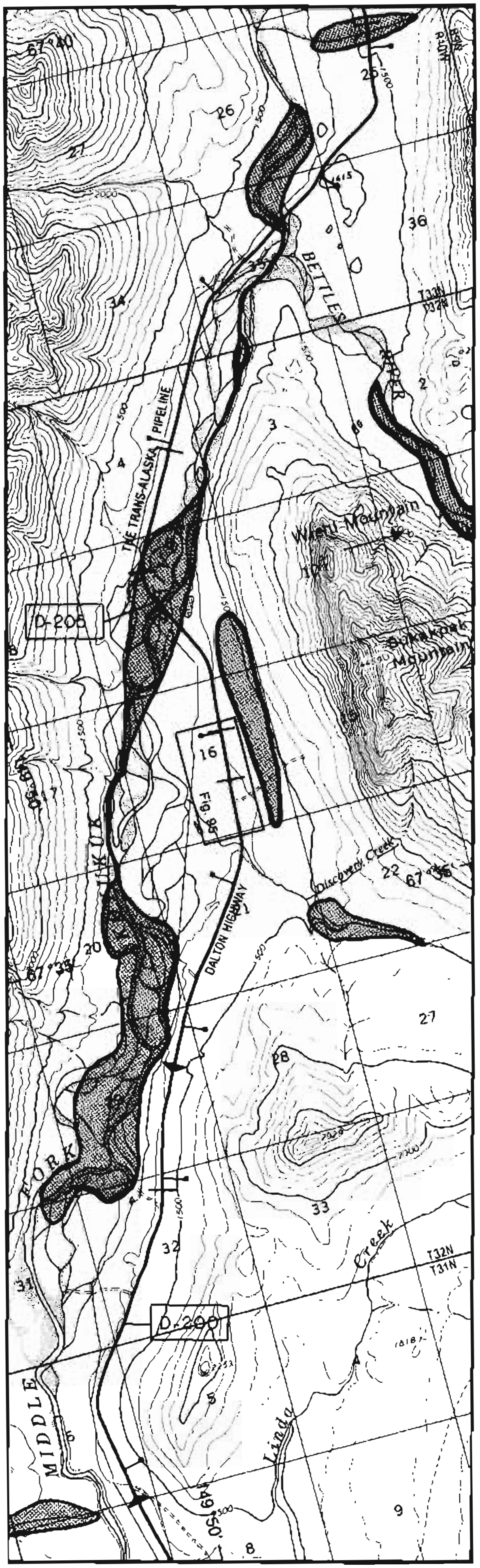
The road follows the U-shaped trough that was scoured and deepened by successive late Pleistocene glaciers flowing south from source areas near the Continental Divide. The valley floor is covered by coarse-grained alluvium that, for at least 40 km upvalley from the Walker Lake end moraine at Wiseman (fig. 86), overlies finer grained sediments. For the first 15 km south of Linda Creek, these sediments were formed within a moraine-dammed lake. Large alluvial fans encroach the flood plain from both valley walls. Each winter much of the Dietrich River valley from 8 to 30 km north of Sukakpak Mountain is buried by aufeis supplied by water discharged from alluvial-fan deposits or by creek underflow (Sloan and others, 1976). Landslides and rock glaciers are evident in places on both valley walls, but the most common forms of mass wastage are solifluction and flow slides. Solifluction forms widespread sheets and aprons on lower valley walls, especially where the local bedrock is shale, phyllite, or siltstone. Several solifluction localities are described by Hamilton (1979a). The flow slides are lobate bodies of rock rubble in a matrix of finer debris that moves by slow (and probably continuous) flow. These features are most common on schist, but also are present locally on slate, limestone, and hornfels. Flow-slide deposits generally contain abundant ice, and the ice-rich, perennially frozen matrix may be essential for development of these lobate features.

D-197.3

The road crosses Gold Creek. A new bridge with treated timbers and metal piers has recently been constructed. A miner's cabin is located on the west side of the road. Alluvial-fan sand and gravel are exposed in cuts 3 to 4 m deep where the road drops to the floor of Gold Creek valley. There is an active mine to the east beside the road.

D-197.8 : Linda Creek.

Gold-bearing stream-washed gravel was discovered at a depth of about 5 m in 1901 and is currently being mined (Mulligan, 1974).



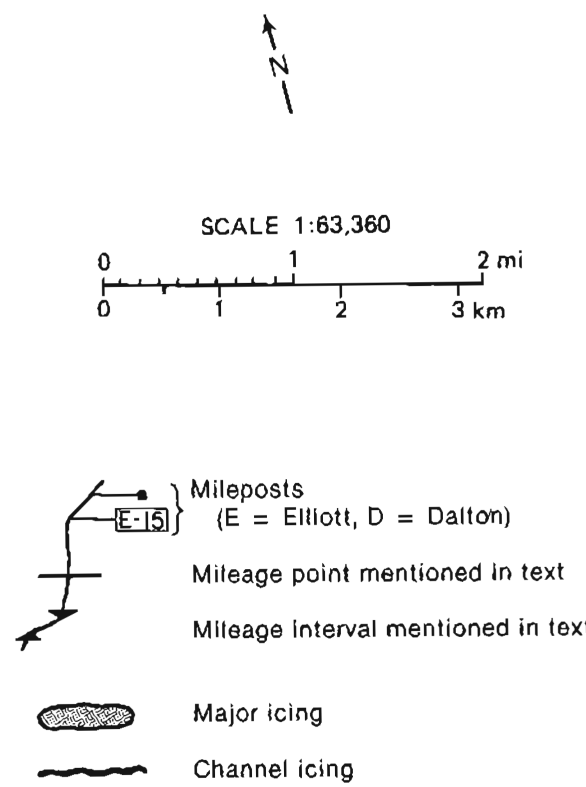


Figure 91. Route map, Mile D-199 to D-209.

D-198.8 to D-201.8

A probable solifluction slope extends from the valley side to the east edge of the road. The slope steepens to 7° at Mile 200.9, where solifluction appears especially active.

One of the most striking problems associated with drainage along this section of the road was thaw degradation and thermal erosion downslope from the roadway. Vegetation here consists of tussocks and black spruce, and the permafrost table is within 0.5 m of the surface. These ice-rich slopes consist of retransported silt that covers till. Ice masses 3 to 15 m thick have been reported. Prior to road construction, runoff occurred as sheet flow across the entire slope. Drainage waters concentrated by discharge through culverts created deep gullies on the downslope side of the road as the ice-rich permafrost was thermally and hydraulically eroded. These gullies threatened to undermine the road through headward erosion. A series of six culverts located between miles 200 and 203 demonstrates remedial measures taken to arrest erosion. The remedial measures consisted of backfilling the gullies with coarse rock fill. Several gullies were insulated and sealed with plastic liners before the backfill was placed. Half-culverts were placed over one filled gully to carry the runoff downslope (fig. 92). On similar slopes in other nearby areas, these problems were not observed, as drainage was apparently directed into existing drainage channels.

D-203.7

A deposit of active(?) protalus material from an old slide or rock glacier is located 1.2 km west of the road. The Middle Fork Koyukuk River is an example of a typical braided river whose streambed frequently changes position during high water.

D-204.0

Sukakpak Mountain is composed of marble and dolomite overlying graphitic and calcareous quartz schists intruded by metabasite dikes (Dillon and others, 1981; Dillon, 1982). The marble is apparently the core of an anticline that is overturned to the west. A high-angle fault truncates this fold at its northern end. At the structural base of the marbles are interlayers of quartzite and graphitic schist. Both lode and placer gold deposits occur at the south base of the mountain along 'Discovery Creek.'

Coarse limestone rubble forms bouldery talus aprons at the base of the mountain. The older, vegetated talus deposits have moved by flowage as in a rock glacier. Movement is still active, as shown by cracks in the surface of the spruce-covered hummocky deposits. During early pipeline construction, a pit was briefly opened in the active, unvegetated talus deposits. The site and access road have since been revegetated to restore the area to its original scenic appearance (Johnson, 1981). Transplanted spruce trees can be seen on the access road in the southern portion of the map area.

Numerous low mounds occur on the slope from the base of the mountain to the river terrace (fig. 93). Many of the spruce trees on them are tilted or J-shaped because of upheaval of the original ground surface. Layers of pure ice as thick as 50 cm are observed in some mounds as they crack and newly exposed ice begins to melt (fig. 94). Many of these mounds are unrelated to the presence of the road; they existed before it was built. But their morphology and formation have much in common with mounds that formed adjacent to the road because of blocked drainage (for example at D-126.5). Similar road-induced mounding is also observed on the upslope side of the road here at the Sukakpak location (upslope from culvert 2420+38). In this case the snow-free roadbed,

Figure 92. Half sections of corrugated metal pipe (CMP) used to channel water downslope from culvert. The CMP sections were over granular fill placed in a gully caused by thermal erosion (Brown and Berg, 1980, fig. 59; photograph taken by G.L. Guymon, May 1978).

Figure 93. Ice-cored mounds on slope below Sukakpak Mountain (photograph taken by R. Veazey on July 21, 1982).

Figure 94. Ruptured mound showing arched ice layer and cavity (photograph taken by R. Veazey on July 21, 1982).

which very likely freezes before deep freezing takes place in the snow-covered slope, presumably forms a 'frost dam,' which stores ground water upslope in the active layer between seasonal frost and the permafrost table. This additional water supply enhances the heaving of the seasonal frost layer, which is under local hydrostatic pressure. Heaving is probably due to a combination of the hydrostatic pressure of the stored ground water and cryostatic pressure caused when the water freezes. Expansion cracks are observed in and adjacent to the mounds.

More detailed characteristics and proposed origins of these particular mounds are being reported separately (Brown and others, in press). Their origin has similarities to frost blisters and mounds in northwestern Canada described by Van Everdingen (1982). The same conditions necessary for formation exist here: a) perennial discharge of water, b) an underlying layer of low permeability (permafrost in this case), and c) long, cold winters. Water is supplied from the bedrock and coarse-rubble-covered upper slopes. The water is trapped between the deeper underlying permafrost and the thin seasonal frost layer. As the water begins to freeze, upwarping or heave occurs, and the mounds are elevated, probably in a single winter. Water also seeps to the surface during fall and winter from the base of mounds and along drainage courses. This water freezes both as overflows on the surface and under the snow, forming surface icings that engulf the mounds. The road now intercepts the natural drainage, and icings develop on the road, particularly in spring.

In April 1982, three mounds and adjacent areas were augered and cored to determine distribution of ice and free water. Massive ice 35 cm thick was encountered within one elevated section. A second mound, 1 m high, was underlain by ice and water under low pressure. Water rose to within 50 cm of the surface. Several holes were drilled adjacent to this mound. A pure ice layer

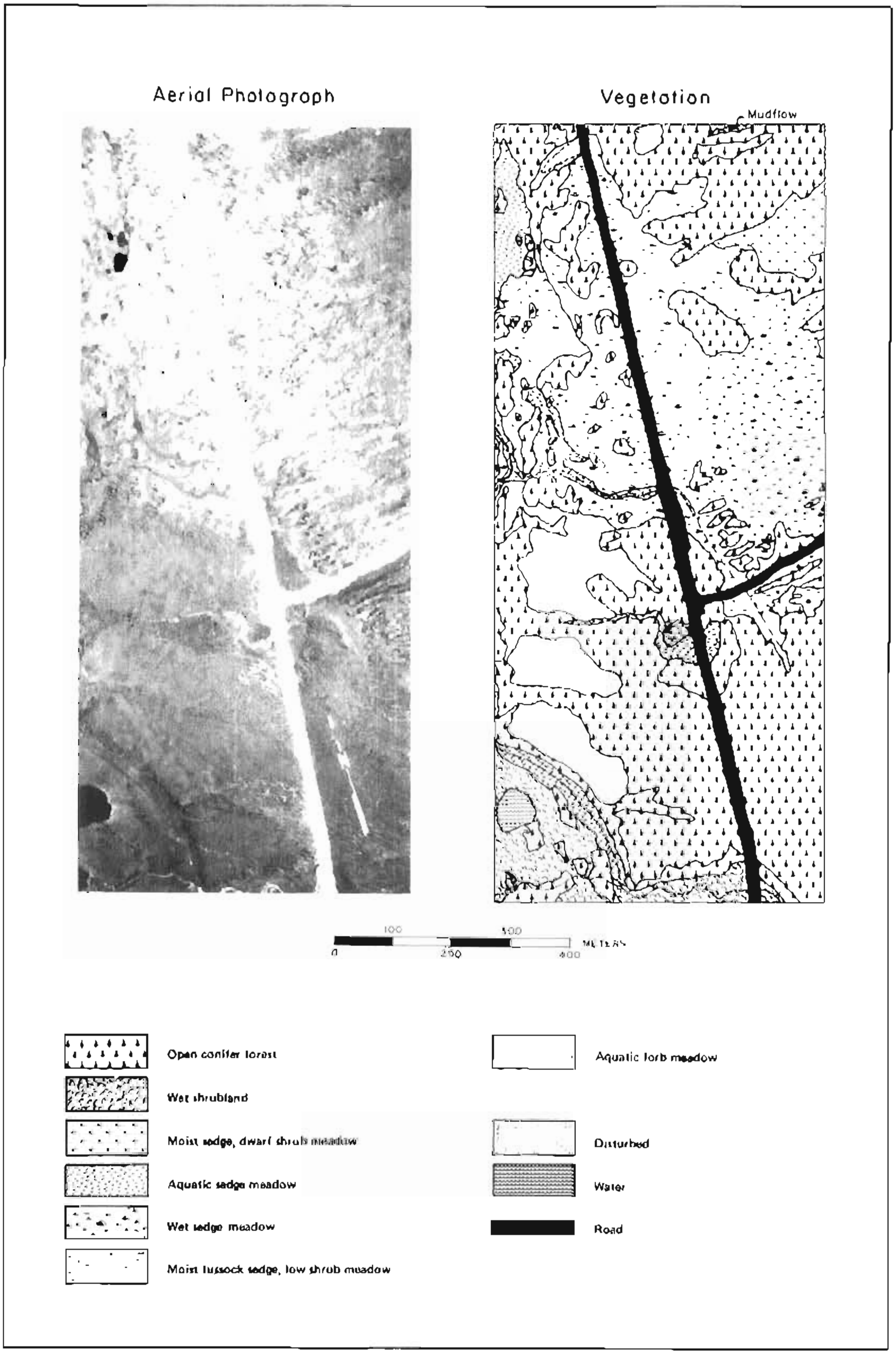


Figure 95. Vertical aerial photograph and vegetation map of Sukakpak Mountain slope (prepared by D.A. Walker).

50 cm thick was encountered under 60 cm of frozen peaty soil. More than 50 cm of water was encountered under the ice. Water flowed for over 1 hr with a 15-cm head from the core hole, which was then plugged with the trunk of a dead spruce tree. An adjacent cored hole yielded 20 cm of clear ice containing fresh-appearing roots under 45 cm of frozen soil. A third mound, 3 m high, was partially augered. A pure ice layer was encountered near the base of the mound, which was underlain by ice-rich sediment. An unfrozen, saturated fine sand was encountered at 1.5 m depth adjacent to the mound. No free water was encountered at this location.

The vegetation of this area is shown in figure 95. Mounds on the uphill (east) side of the road appear more disturbed than those on the lower slope, with large cracks and other evidence of recent surface upheaval. Many of the mounds have medium-sized white spruce (Picea glauca), which have been tilted in all directions by the mounds. Vegetation on the larger, more stable mounds usually consists of white spruce and resin birch (Betula glandulosa), lanate willow (Salix lanata), shrubby cinquefoil (Potentilla fruticosa), Labrador tea (Ledum groenlandicum), and white mountain avens (Dryas integrifolia). Some smaller mounds lack trees but usually have dwarf birch and other shrubs.

Between the mounds, calcareous fens support a rich flora that is distinct from the mounds or the forest. This difference is due not only to the moisture but also to the soil being highly charged with carbonates extracted from the limestone of Sukakpak Mountain. Much of the area below the talus deposits consists of moist to wet meadows with tufted clubrush (Baeothryon caespitosum), marsh arrowgrass (Triglochin palustre), maritime arrow (T. maritima), Kobresia simpliciuscula, Juncus triglumis, Carex atrofusca, Drepanocladus revolvens, and Catascopium nigritum. More mesic calcareous microsites have mountain avens, bog rosemary (Andromeda polifolia), K. simpliciuscula, shrubby cinquefoil, northern anemone (Anemone parviflora), net-leafed willow (Salix reticulata), Scottish asphodel (Tofieldia pusilla), Tomenthypnum nitens, and D. revolvens.

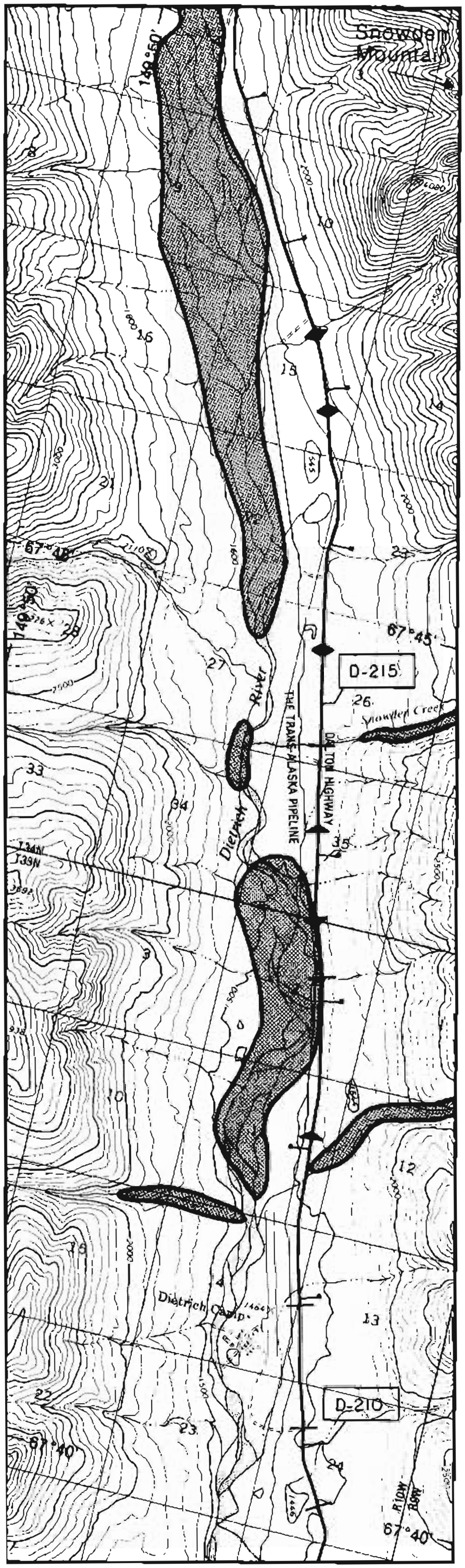
In forested areas, the understory is often somewhat dry and consists of mountain avens, sedge (Carex scirpoidea), fescue grass (Festuca altaica), shrubby cinquefoil, alpine bearberry (Arctous alpina ssp. rubra), bog blueberry (Vaccinium uliginosum), net-leafed willow, and many species of lichens, including Cetraria cucullata, C. richardsonii, and Cladonia species.

Very wet meadows on the west side of the road have sedges (Carex aquatilis and C. rotundata), buckbean (Menyanthes trifoliata), flat-leaf bladderwort (Utricularia intermedia), and Scorpidium scorpioides.

In the southern portion of the map area, where soils are apparently more acidic, are extensive cottongrass tussock - resin birch meadows. This vegetation type is also the principal understory in white spruce forests in the southern portion. A small stream crosses near the southern boundary, where vegetation along the creek consists primarily of sedges (Carex aquatilis, C. rotundata) and lanate willow. Extensive shrub meadows adjacent to the creek are mainly of lanate willow and resin birch. On the sloping banks adjacent to the creek bottom are medium-sized white spruce with an understory of alpine blueberry and mountain cranberry (Vaccinium vitis-idaea), resin birch, Hylocomium splendens, Rhytidium rugosum, and Cladoniaceae.

The black patches on rock faces of Sukakpak Mountain are the endemic moss Andreaeobryum macrosporum. Restricted to only a few localities in northwestern North America, it is locally common here where seeps flow over limestone. It also occurs on Wiehl Mountain to the east and on 'Mt. Hultén' near Galbraith Lake (Murray and others, 1980).

D-204.9 : Middle Fork Koyukuk River (Crossing 3).



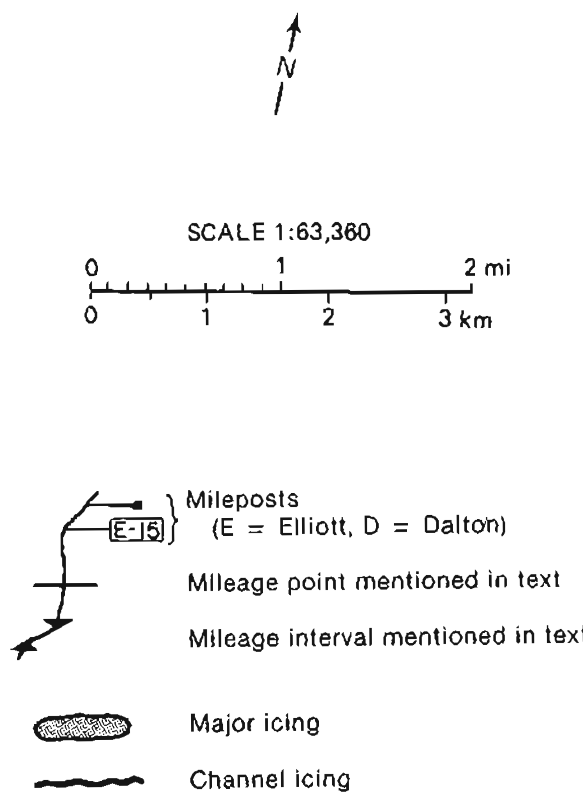


Figure 96. Route map, Mile D-210 to D-219.

D-205.2 : Middle Fork Koyukuk River (Crossing 4).

D-206.0
There is a good view of Snowden Mountain (1,760 m) 16 km to the northeast. The road crosses a frozen terrace of the Middle Fork Koyukuk River; this terrace is covered by retransported silt fans at the base of the slope to the west.

D-207.6 : Dietrich River crossing.
The road here lies in the valley of the Dietrich River which, with the Bettles River, forms the Middle Fork Koyukuk River.

D-209.2
A cut 4 m deep runs through a ridge of fan gravel.

D-209.6
A small, unnamed lake is seen on the west side of the road and there is a good view of Sukakpak Mountain to the south.

D-210.1 : Dietrich Camp.
The northern limit of paper birch (Betula papyrifera) along the road corridor occurs just north of the camp.

D-211.0 : Disaster Creek.
This has been the northern limit of public access to the road. Beyond this point road-use permits have been required. A stabilized debris slide or rock glacier tongue can be seen in the bottom of the tributary valley 1.1 km east of the road.

D-212.1 to D-213.6
Slopes are covered by frozen, retransported silt over till. Black spruce, many of which are tilted, is the common plant cover.

D-213.2
A debris slide or a rock glacier tongue is 1.2 km east of the road in the bottom of the tributary valley.

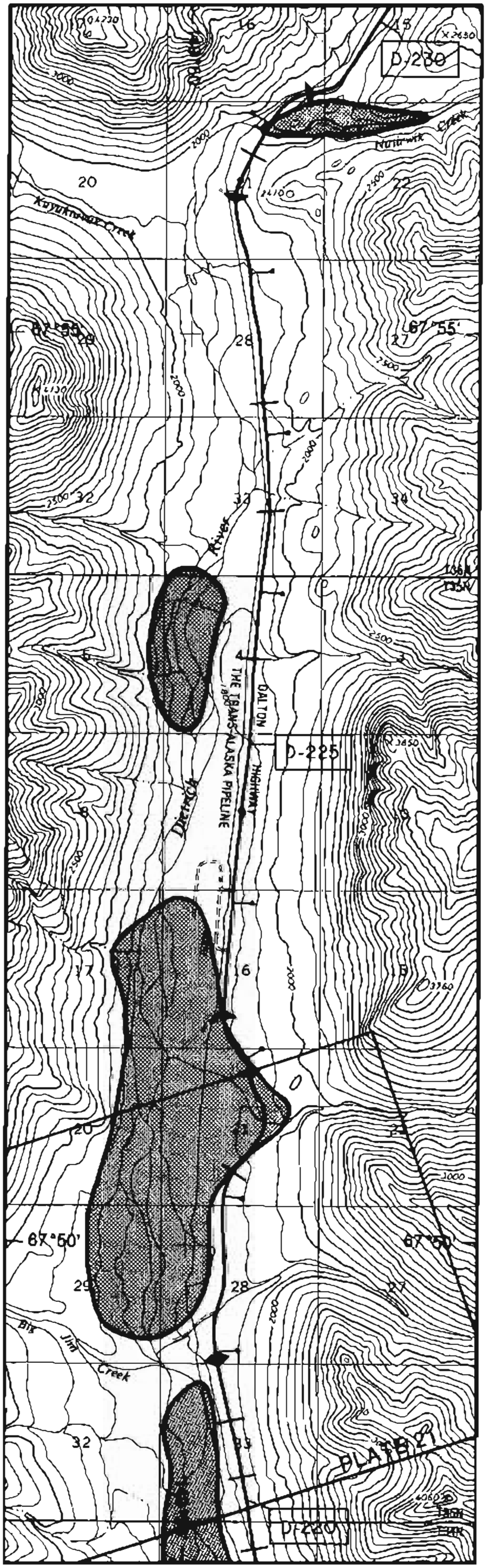
D-214.2 to D-215.4
The road crosses a large alluvial fan of Snowden Creek (D-214.7). This fan is predominantly frozen, except for thawed ground near the active creek channel.

D-215.4 to D-216.8
The road crosses alluvial fans and retransported silt over till slopes.

D-216.8
A debris slide or a rock-glacier tongue is 0.8 km east of the road in the bottom of a tributary valley.

D-216.8 to D-217.4
The road crosses a fine-grained alluvial fan from a low-discharge tributary stream.

D-217.4 to D-221.0
There are scenic views of the Brooks Range and the Dietrich River. The road crosses till and retransported silt over bedrock slopes. Possible



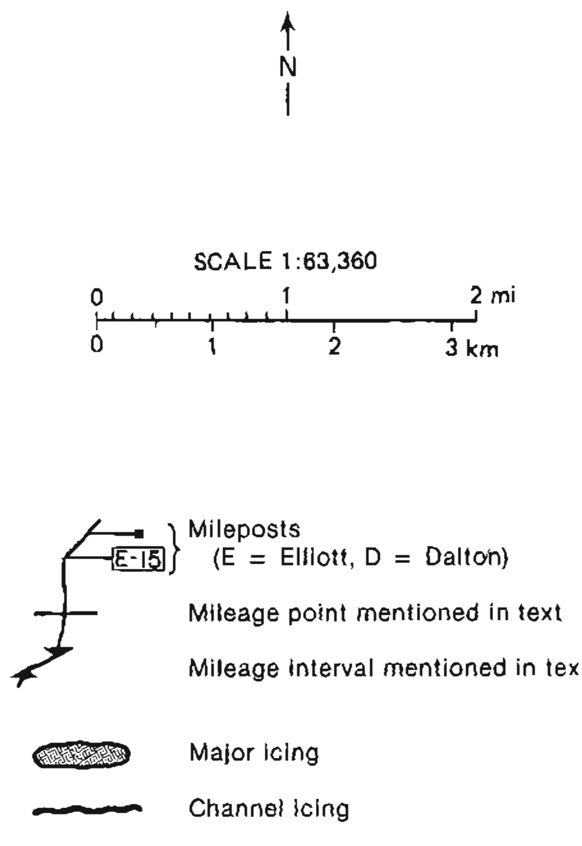


Figure 97. Route map, Mile D-220 to D-230. Plate 21 refers to illustration in Kreig and Reger (1982).

solifluction slopes flank the road to the east (Hamilton, 1979a). Several debris slides or rock glaciers lie east of the road. One is tree-covered and completely stabilized at Mile 219.7. An unvegetated front of one of these is close to the road at Mile 220.1. A third lies east of the road at Mile 220.5.

D-222.9 to D-223.0

The upper Koyukuk - Dietrich River system has a steeper gradient and is more extensively braided than the middle reach of the Middle Fork Koyukuk River (Kreig and Reger, 1982, pl. 21). The unvegetated and braided flood-plain surface is the site of seasonal icing sheets (aufeis) as thick as 5 m. Tributaries have built large coarse-grained alluvial fans over the margins of the flood plain and over glacial deposits. These alluvial fans are now discontinuously frozen. Frozen till blankets valley slopes of Late Devonian slate, phyllite, siltstone, sandstone, and limestone. Although surface polygons and thermokarst features are not visible, polygonal ice-wedge networks are probably present throughout the upper part of the till. Numerous mass-movement features are visible on steep slopes, including rock glaciers, debris slides, and mudflows. Tongue-shaped rock glaciers are composed of angular rock fragments and silt. Once talus accumulating at the bases of steep walls in the valleys and cirques reaches a critical thickness, temperatures at depth remain below freezing throughout the year. Water, derived primarily from precipitation but also including water vapor, ground water and overland flow, enters the cold talus and freezes in interstitial openings. The ice-cemented rubble mass moves by viscous flow of the interstitial ice if the rate of talus accumulation is sufficient. The dense vegetation cover, including trees, the irregular upper surface with longitudinal gullies, the rounded margins, and the dissected termini indicate that these rock glaciers are no longer active. Debris slides are released on steep slopes by saturation of the thin active layer of organic material, till, and colluvium over bedrock during intense summer storms. They change downslope into mudflows bounded by natural levees (Rapp and Nyberg, 1981). Sorted stripes occur on poorly sorted deposits such as till (Kreig and Reger, 1982, pl. 21).

D-222.2

The road begins to cross the upper margin of the alluvial fan of an unnamed tributary system.

D-223.3 to D-228.5

In a rock quarry on the east side of the road, shallow ice wedges were exposed in the overburden. The road follows the flood plain of the Dietrich River and crosses an alluvial fan at Mile 225.6. Cuts 3 m deep in a small fan at Mile 226.5 expose alluvial gravel; cuts at Miles 227.2 and 228.5 expose bedrock beneath thin (<0.5 m) colluvial cover. There are many high, unnamed peaks in this area. The numerous white spires to the east consist of Devonian Skajit Limestone.

D-228.8

Retransported materials extend from the east valley slope to the edge of the road.

D-229.0 : Nutirwik Creek.

River-training structures on the east side of the road protect the buried pipe.

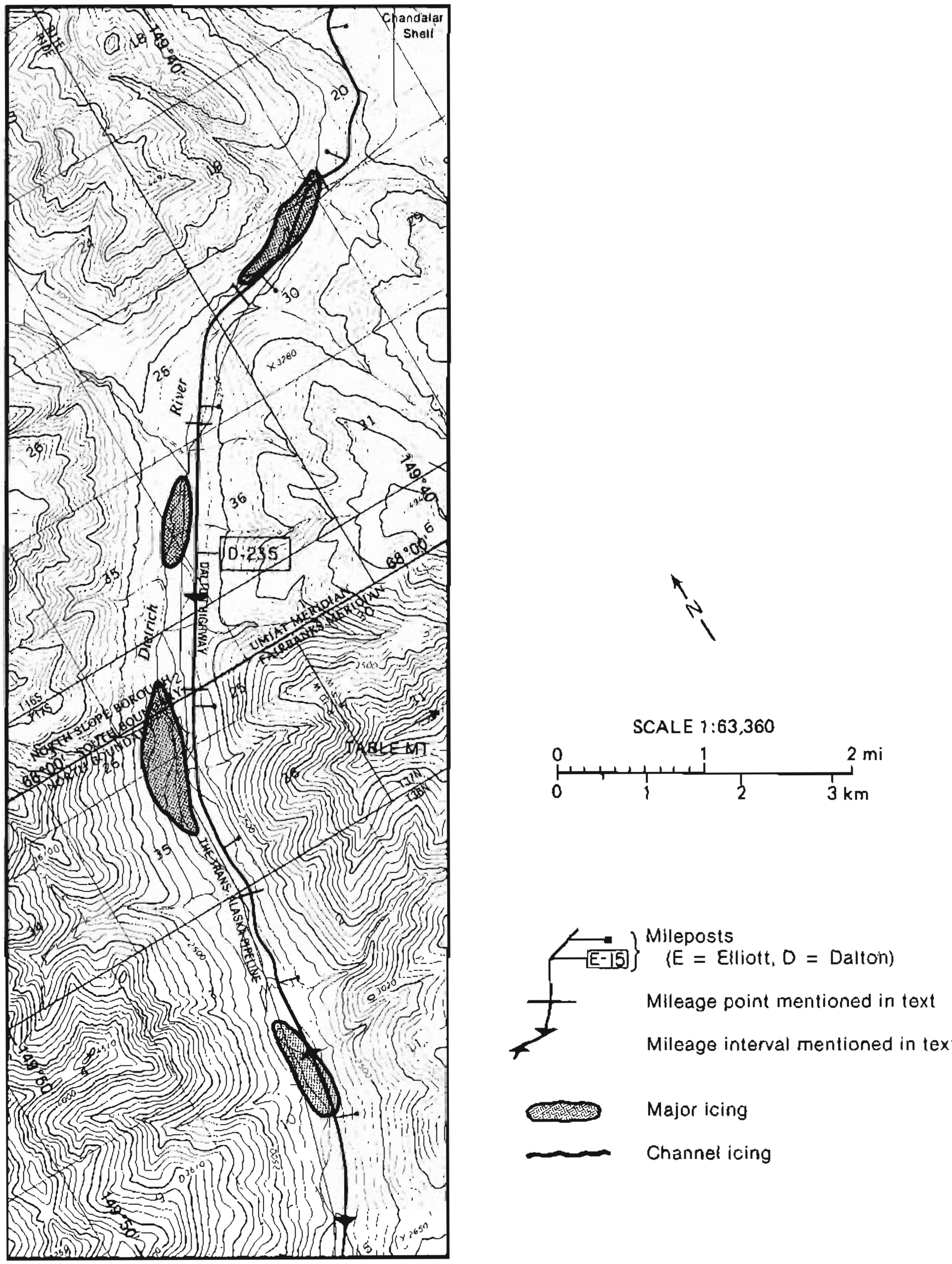


Figure 98. Route map, Mile D-231 to D-239.

D-229.3 to D-230.3

Devonian slate and phyllite are exposed in a series of cuts up to 10 m deep along the east side of the road.

D-231.5 to D-234.8

The road crosses a series of alluvial fans. Fan gravel is exposed in some cuts up to 5 m high along the east side of the road.

D-232.6

A small debris slide or rock glacier is located 300 m east of the road. No rock glaciers are found on the west side of the valley, but several kilometers to the north and on the north side of the Continental Divide rock glaciers are found on both the east and west sides.

D-234.1 : North Slope Borough boundary.

D-234.8

Alluvial fans are seen on the west side of the valley, some of which display mud boils. On the east side are solifluction or debris-slide materials and fans. The lower slopes are tussock covered and have ice-wedge polygons.

D-235.9

Turf-banked solifluction lobes are visible on the upper slopes ahead and east of the road. Patterned ground (sorted nets and stripes) can be seen on the ridge; a revegetated material site is across the river to the west.

D-236.8 : Base of Chandalar Shelf.

This location marks the northern limit of treeline. This northernmost stand of white spruce along the pipeline has been established as an ecological reserve to preserve it as a site for study of the vegetation and forest dynamics (Densmore, 1980). The treeline has been relatively stable in the area for several centuries; 30 percent of the trees are over 200 yr old and some are at least 400 yr old. Under present climatic conditions, regeneration by white spruce seedlings is adequate to replace the stand and even increase stand density. There is some evidence of extension of treeline on alluvial sites beyond the present line. Of special interest was the discovery of vegetative reproduction in the white spruce by layering: the production of new trees from the tips of branches growing along the moss surface. Although both black spruce and white spruce are represented at treeline at many sites in Alaska, at this site only white spruce is present. Willow, aspen, and a few balsam poplar are found immediately north of the white spruce limit. Balsam poplar reappears as groves in certain sheltered sites and at springs on the Arctic Slope, occasionally well beyond the mountain front (Murray, 1980). Although this stand is likely to be disturbed further during future construction, this northernmost treeline stand should be preserved for future detailed studies of treeline dynamics.

D-237.8

This point marks the base of the Chandalar Shelf, where the road begins the long, steep (9°) grade to the top of the shelf. Nearly continuous bedrock cuts 10-30 m high border the road to the east as it climbs to the shelf, exposing shale beneath colluvium, which thickens across the floors of swales. There is a view of the upper Dietrich River valley to the south and west.

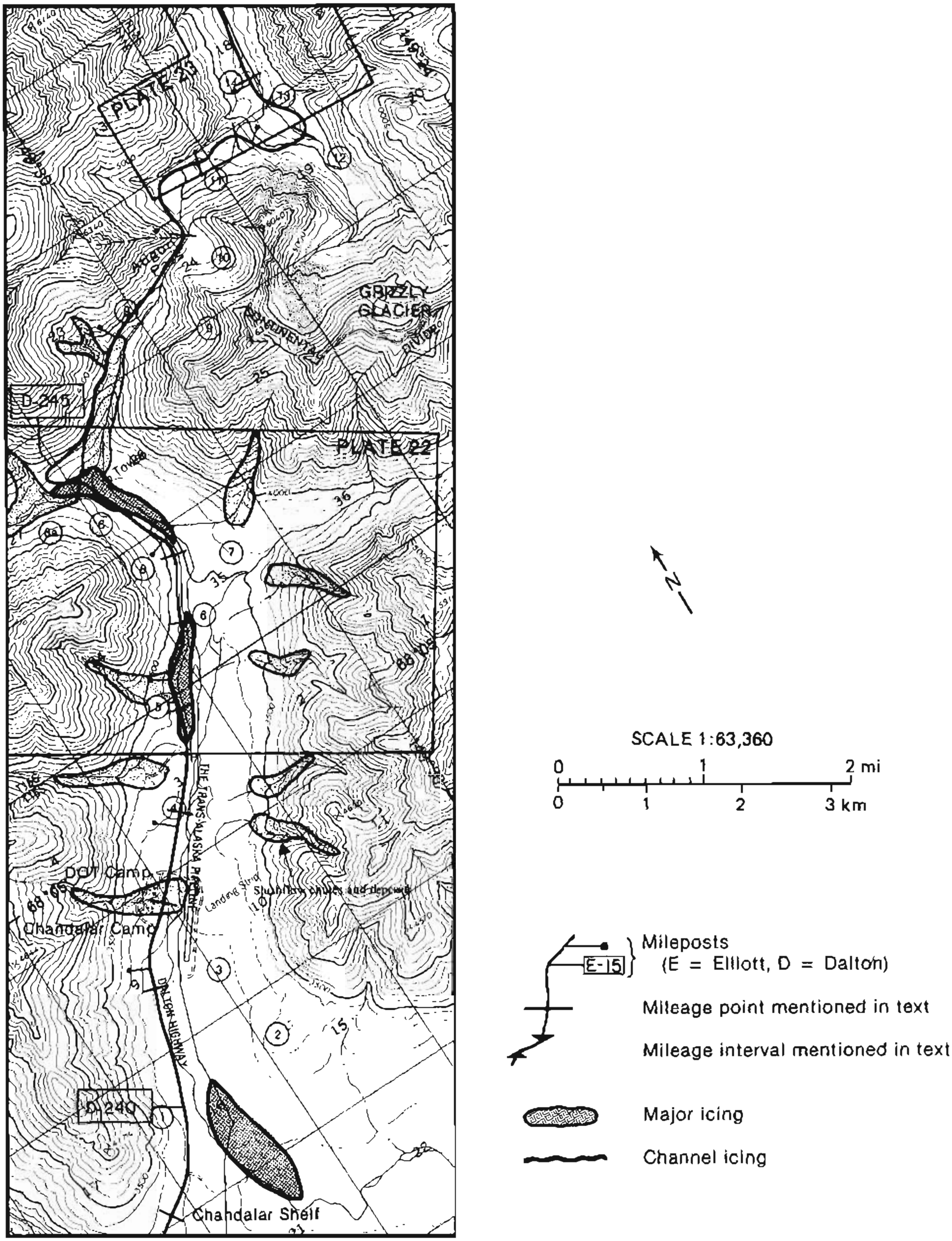


Figure 99. Route map, Mile D-240 to D-249. Plates 22 and 23 refer to illustrations in Kreig and Reger (1982). Circled numbers refer to notations in text.

D-239.2

The road levels out on the drift-covered floor of a broad, southeast-trending, glaciated western tributary valley to the North Fork Chandalar River. The main Chandalar River flows southeastward into the Yukon River. The terrain traversed by the road for the next 1.5 km is continuously frozen. The North Fork tributary is graded to a base level higher than that of the Dietrich River and its tributaries on the Koyukuk drainage system. Mountain valleys of the Koyukuk River system are consequently developed at generally lower altitudes, and have pirated adjoining parts of the North Fork Chandalar drainage. Glacier ice was diverted westward from the North Fork Chandalar system into the Dietrich River valley in the area around Chandalar Shelf.

A slope failure occurred on the west side of the road in early August 1977 following heavy rains (fig. 99, loc. 1)[14]. The base of the active layer provided the glide plane. These slope failures are a common form of mass wasting.

Across the Chandalar Shelf is a large ridge trending west-southwest that is of late Pleistocene age (fig. 99, loc. 2). It was deposited by the latest valley glaciation as a medial(?) moraine or east-lateral moraine of the glacier tongue that flowed southwestward over the Chandalar Shelf and down into Dietrich River valley. A ring of cobbles (abandoned campfire?) along the crest of the ridge can be dated by lichen-growth rates at about 1,500 ± 300 yr B.P. (Calkin and Ellis, 1980).

D-240.8

Across the willow-covered Chandalar Shelf is an extensive area abandoned by the river that is composed of well-rounded gravel and cobbles (fig. 99, loc. 3). These stones have been sorted into circles about 1.5 m in diameter. Lichen growth on the stones indicates that this periglacial sorting is now inactive and has been so for at least several thousand years.

D-241.5 : Chandalar Camp and Airport.

The camp is located on a fan with recently formed slushflow deposits. A diversion dike was built across the fan to divert flows away from the camp. Grizzly bears are frequently seen between Chandalar Shelf and Pump Station 4.

D-242.1

A pingo-shaped feature (fig. 99, loc. 4) may be seen on the west side of the road. A crack across its surface appears to trend north-south. The slope and position of the feature suggest it is an open-system pingo (but drilling is needed to ascertain the presence of pingo ice in its center). A stream cut on the east side of the road exposes a vertical section of well-drained glacial drift.

D-242.8

The debris cone (fig. 99, loc. 5) has a convex profile due to slushflow deposition in the recent past (Kreig and Reger, 1982, pl. 22). Reconnaissance lichenometric mapping indicates a washed zone near the apex, with no lichens on stones, and zones downslope that suggest discrete events about 30, 40, 80, and 170 yr ago (±20 percent age reliability). Near the road, large lichens and more weathering on stones suggest no slushflow deposition for at least several thousand years.

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[14] Numbers in parentheses refer to locations on strip maps. Many of the observations are by J.M. Ellis and P.E. Calkin.

Figure 100. Slope failure adjacent to west tributary of North Fork Chandalar River. Slide occurred in August 1977. Road sign is in foreground (photograph taken by J.M. Ellis).

D-243.4

Along the west valley wall, three inactive lobate rock glaciers can be seen over the next kilometer (fig. 99, loc. 6). To the east, thin (washed) ground moraine covers a bedrock rise. The pipeline is elevated atop this bedrock-cored ridge for about 2 km. There has been recent failure (fig. 99, loc. 6a) of the north-facing slope (fig. 100).

A landslide from the west valley wall extended eastward into the center of the valley. This very hummocky deposit is typical of landslides in upper valleys near the Continental Divide that occurred either during or immediately after deglaciation. Valley walls were oversteepened by glacial scour, and commonly failed as lateral support of glacial ice was removed during downwastage. Some slides were deposited on the surfaces of stagnant glaciers and developed conspicuous kame and kettle features as the ice wasted. Slightly younger slides crossed ice-free valley floors, but have been terraced by episodic stream incision that began immediately after deglaciation (T.D. Hamilton, pers. commun.; Hamilton, 1979c).

D-243.9

A debris cone (fig. 99, loc. 7) downslope of the southwest-facing drainage basin has a convex profile and exhibits evidence of episodic slushflow deposition. It was active in 1969 and 1976 (Kreig and Reger, 1982, pl. 22). The vegetation pattern downslope of the cone's apex, which can be seen from the road, suggests different ages of deposition. The cone could be built on a medial moraine deposit, formed when valley ice from the tributaries on both sides of this site flowed together and continued down the shelf in a southwesterly direction. The profile may reflect this glacial origin.

D-244.7

Along the steep climb toward Atigun Pass there is a view of the western tributary of North Fork Chandalar River to the south and Atigun Pass to the north. The west tributary to the North Fork Chandalar River has an inactive tongue-shaped rock glacier along the south wall, 3 km west of the road. The relatively low altitude (<1,500 m) may have prevented rejuvenation of its headward glacier core in late Holocene time when it became colder. Its upper surface stabilized by early Holocene time. Equally old, lobate rock glaciers line the valley across and upslope from this tongue-shaped deposit.

An almost-continuous series of roadcuts were made into colluvium flanking the northwest side of the road. The lower cuts are relatively low (3 to 5 m) and expose mainly solifluction rubble; farther up the slope they are talus. Close to the pass, many of the cuts are as deep as 20 m and several expose bedrock at their bases. Exposed strata dip directly downslope toward the road in only one locality. Active slushflow chutes exist on both sides of the valley.

An active lobate rock glacier is located southeast of and above the road at about 1,700 m (fig. 99, loc. 9). The road here is at about 1,350 m and is built on the toe of an inactive, lobate rock glacier.

D-246.8 : Continental Divide (1,447 m) at Atigun Pass.

Many peaks in the area exceed 2,100 m elevation. Talus and bedrock are exposed in cuts up to 20 m along the west side of the road. The fresh, frozen bedrock (sandstone and conglomerate) cut on the west side of the road in Atigun Pass exposed ground ice filling fractures and joints in the rock. Considerable spalling of the cut occurred during the first summer.

The empty cirque to the southeast is of late Pleistocene age (fig. 99, loc. 10). Insufficient mass wasting during valley deglaciation prevented preservation of late Pleistocene - incipient early Holocene glacial ice underneath a rock glacier deposit. The ice disappeared and this cirque was too low to form glaciers during late Holocene climatic deteriorations. The floor of this cirque is well shaded by both the surrounding cirque cliffs and mountainous terrain; less than 80 percent of the direct-radiation energy available on July 24 reaches the floor. The pipeline was relocated eastward at the mouth of the cirque to avoid frozen lacustrine sediments.

The pipeline is buried through Atigun Pass because of potential avalanche, slushflow, and rock-fall hazards and to minimize its impact on wildlife. As a result of a very detailed drilling program, it was discovered that in two sections---one on each side of the summit---the pipe could not be buried in thaw-stable soils or on competent bedrock. Construction in these two sections was complicated and expensive, and special conditions were imposed, including width of work pad, length of time the trench could be left open, and disposal of the spoil to a site in the Atigun River valley. In these sections a 28-cm-thick concrete slab was poured in the bottom of the trench and the pipe was then placed in a box made of 53-cm-thick, specially fabricated high-strength Styrofoam insulation. The box was enclosed in plywood before being covered and was backfilled with permeable gravel to allow upward dissipation of heat through a maximum cover thickness of 1.2 m. During summer 1979, a leak developed in the uninsulated buried section at the bottom of the steep grade below the summit on the north side of the pass. Failure

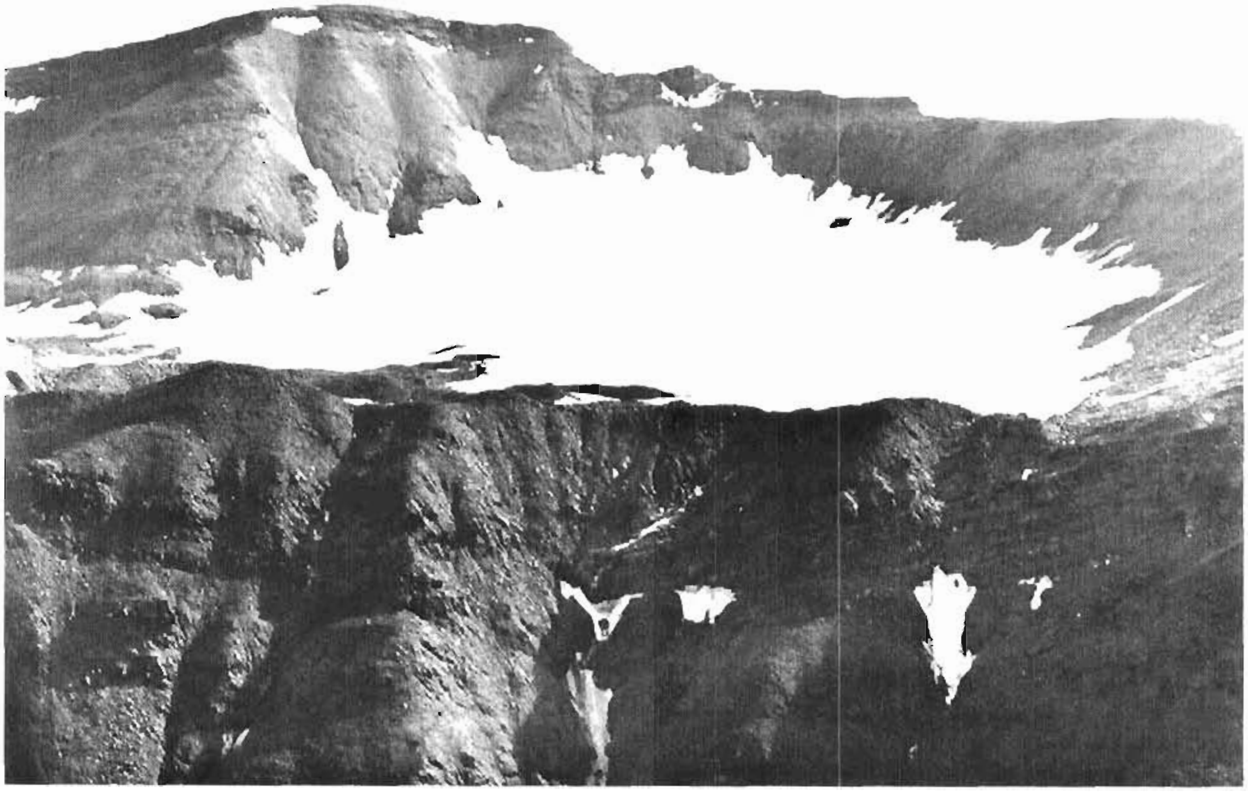


Figure 101. View looking south to Grizzly Glacier (photograph taken by D. Atwood on July 19, 1982).

evidently was caused by settlement due to melting of ice in the fractured bedrock. Expensive repairs were made and stabilization accomplished.

A 120-m-long segment of the insulated, buried box carrying the pipe on the south side of the pass settled in 1979. The primary cause was thawing of the permafrost caused by ground-water flow. During summer and fall 1980, a stabilization program was undertaken, which included grouting, drainage modification, and artificial ground freezing (Thomas and others, 1982). The remaining heat pipes over both sections of the insulated pipe are designed to maintain the frozen-ground conditions.

Cirque Glaciation and Processes in the Atigun Pass Area[15]

A cirque glacier and two glacier-cored rock glaciers occur at the headwaters of the Atigun River southeast of the pass (figs. 101 and 102). The region was just high enough to support cirque glaciation during the past 4,500 yr (fig. 103). More than 95 percent of these 'Neoglacial' ice masses are north of the Continental Divide (Ellis and Calkin, 1979). South of the Divide, higher summer temperatures associated with the continental climate of Alaska's interior apparently prevented Holocene glacier formation in cirques

[15] Prepared by J.M. Ellis and P.E. Calkin.

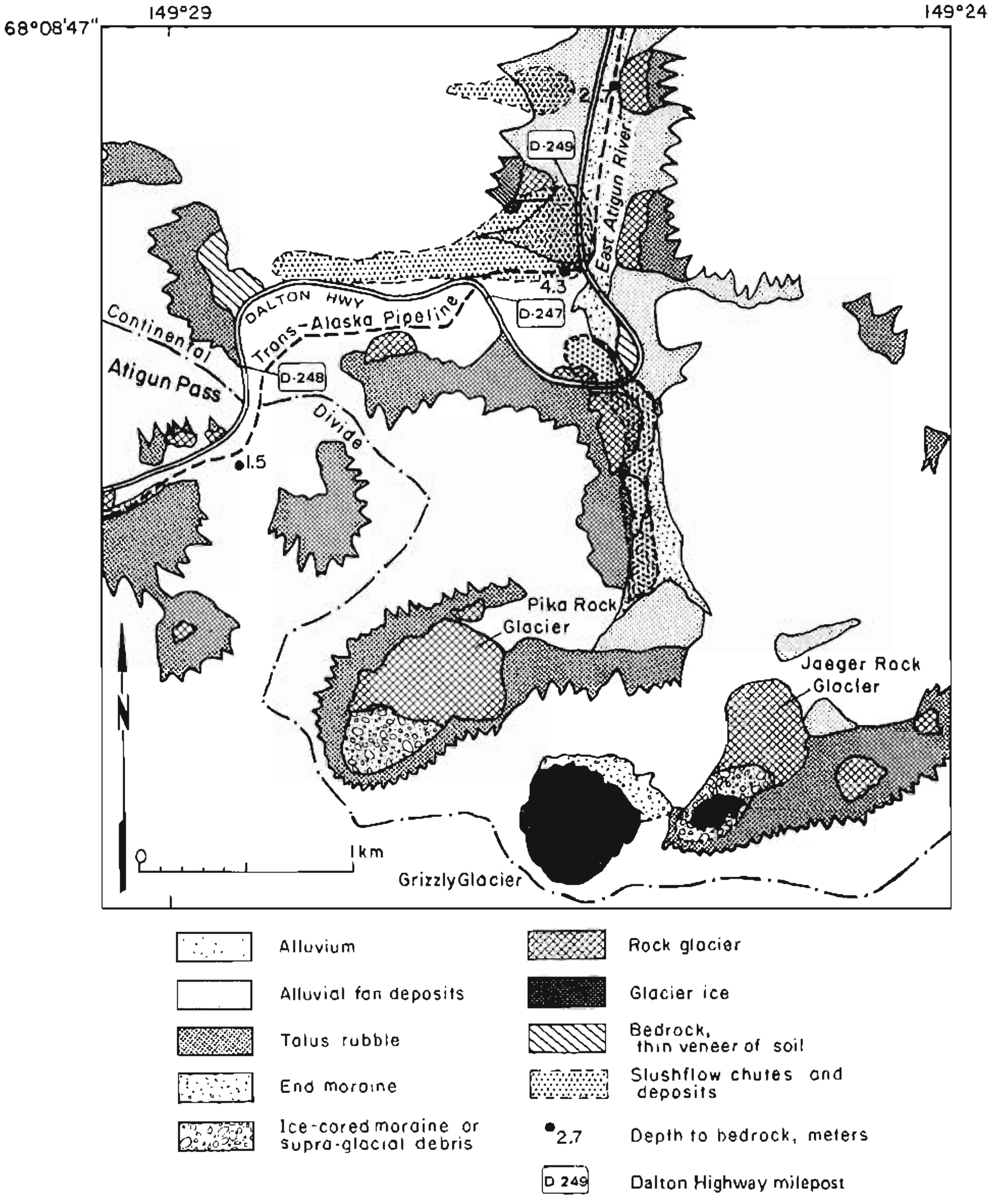


Figure 102. Surficial deposits of the Atigun Pass area. Hikes to the Pika Rock Glacier and Grizzly Glacier are part of the field excursion (modified from Bruen, 1980).

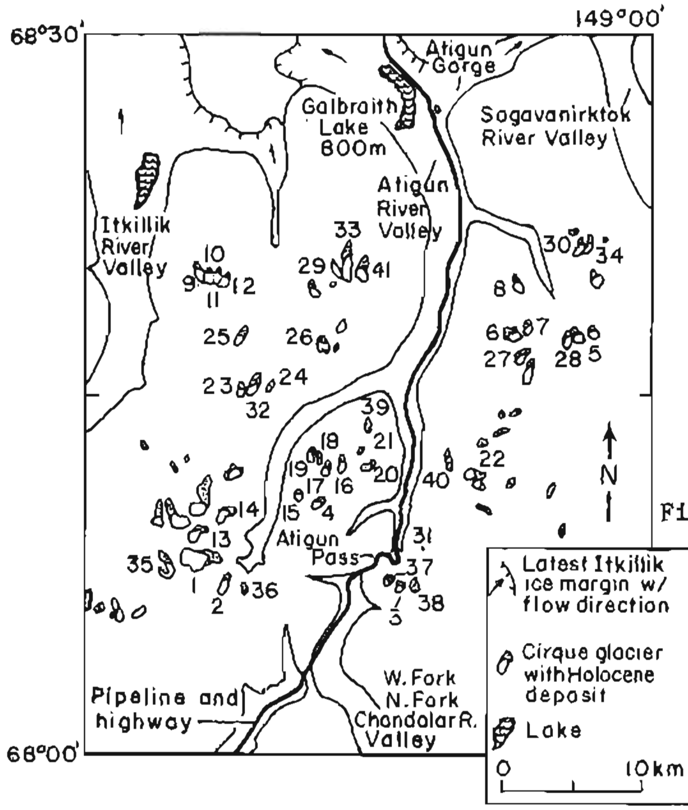


Figure 103. Map of the Atigun Pass area, east-central Brooks Range. Glaciers 1-12 have Neoglacial moraines, largely without ice cores; 13-33 have moraines with cores of glacier ice; and 35-41 have Neoglacial moraines superimposed upslope from an older rock glacier tongue (modified from Ellis, 1982, fig. 2).

at these altitudes. The glaciers are all above 1,500 m elevation and their lower limits rise northward across the range, reflecting orographic depletion of snow and predominance of southerly moisture sources such as the Gulf of Alaska and Bering Sea for the central Brooks Range (Ellis and others, 1981). Snow pits and rain-gauge measurements made from 1977 to 1982 indicate that at least 600 to 720 mm of precipitation falls on the glaciers annually at about 1,750 m. Atigun Pass (1,447 m) probably receives from 400 to 700 mm annually, of which about half is snow.

Varying cirque environments promote formation of three types of Neoglacial moraines (Ellis, 1982; Ellis and Calkin, in press; fig. 103). Those moraines without cores of ice were formed in cirques with relatively low headwalls and sidewalls, resulting in minimum shading, low supply of supraglacial debris from cirque cliffs, and minimum insulating debris on the glacial ice. However, three of four moraines are cored with glacial ice in this continuous permafrost environment (Ellis and Calkin, 1981). Most of these moraines are fairly stable, and their headward glaciers occur at elevations similar to those fronted by moraines without ice cores. Some glacier-cored moraines are superimposed on older rock glacier tongues; their associated glaciers tend to be about 100 m lower in elevation than ice masses fronted by morainal deposits alone (fig. 104). These downslope rock glacier tongues (fig. 102) are of early Holocene age and probably contain late Pleistocene or incipient early Holocene glacier cores. The headward portions of these ice cores were high enough ($\geq$1,500 m) to respond to climatic deteriorations; they built Neoglacial moraines but were unable to overrun and completely incorporate their downslope rock-glacier tongues.

Cirques occupied by glacial ice are oriented toward the north, strongly minimizing insolation (Ellis and Calkin, 1979). This orientation contrasts

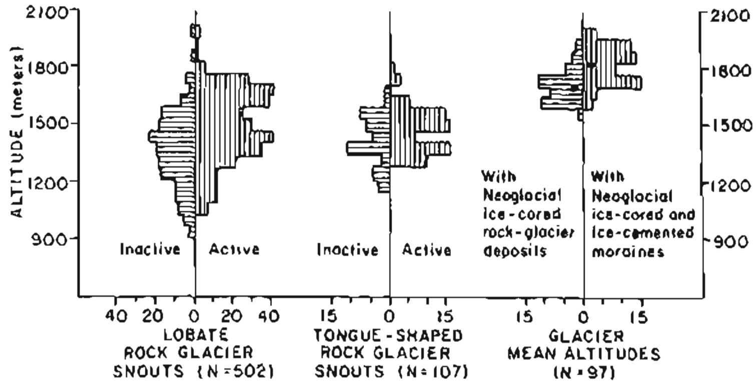


Figure 104. Summary of altitudinal distribution of glaciers and rock glaciers (Ellis and Calkin, 1979, fig. 6).

markedly with the widely dispersed pattern of empty cirques and nivation hollows of Pleistocene age, which show strong structural control.

All active tongue-shaped rock glaciers are probably cored with glacial ice. Those without exposed ice cores are less sensitive to insolation than those with visible glaciers. This pattern may occur because increased debris cover protects the core from ablation and stagnation. Inactive tongue-shaped rock glaciers may have lost much of their ice core. However, they are similar in elevation to active ones (fig. 104). Inactive snouts are rounded and covered by vegetation; they tend to have more southerly aspects. Only 30 percent of the tongues south of the Divide are active, with only 9 percent of these showing exposed ice cores. North of the Divide, 76 percent are active and 46 percent have exposed ice cores. The lower limit of tongue-shaped rock-glacier snouts is about 1,200 m.

Lobate rock glaciers are broader than they are long (downslope) and develop below talus along valley walls, including cirque walls. More than 500 were mapped in a 4,000-km^2 area around Atigun Pass. They occur in a 500-m-thick elevation zone that persists from 68°N. latitude to the foothills of the Brooks Range. These lobate forms occur over a greater elevation and geographical range and they have a more variable orientation than tongue-shaped forms (fig. 104). Their internal composition is not known. Their distinctly lower elevation limit of 950 m suggests development without temperature-sensitive cores of glacier ice. The orientation patterns suggest insensitivity to insolation; this may reflect a lower interstitial ice content relative to debris. However, there are many lobate forms with large, spoon-shaped depressions between the rock glacier and the headward cliff. These depressions may represent significant cores of ice or ice-rich debris in various stages of deterioration (Kreig and Reger, 1982, pl. 23).

Only 50 percent of the lobate rock glaciers south of the Divide are active; to the north 70 percent are active. The more active state of rock glaciers north of the Divide is probably related to the unfavorable effects of the interior-Alaska summer climate. The activity of rock glaciers depends most on the availability of debris from headwall cliffs, not on elevation, bedrock, or shading from solar radiation by a surrounding mountainous terrain (Ellis, 1982). In contrast to the Alaska Range, a substantial part of the debris source area for rock glaciers in the Brooks Range is platy siltstone, shale, and phyllite. Lobate rock glaciers and talus cones commonly occur in close association on lower valley walls. However, lobate forms are localized

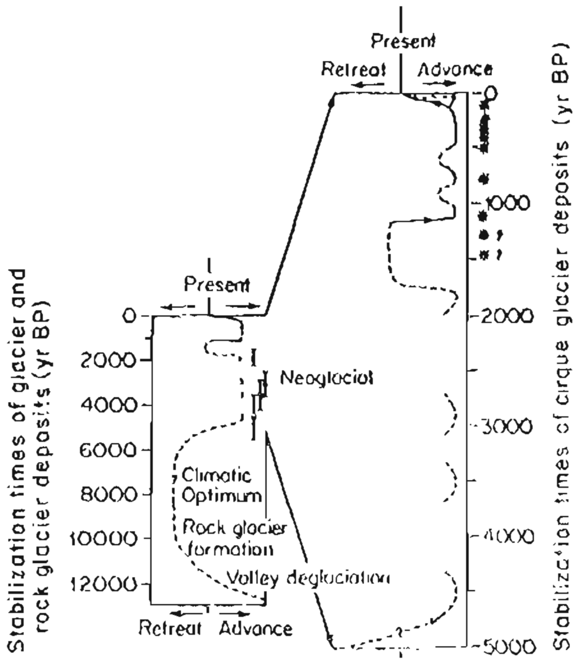


Figure 105. Holocene glacier - rock glacier chronology for the central Brooks Range, based on lichenometric and radiocargon ages, and showing seven periods of cirque glacier expansion followed by moraine stabilization. The four vertical error bars parallel to the time line on the left (5,000-1,500 yr B.P.) are assumed age-reliability ranges of ±20 percent for lichenometric ages. Radiocarbon ages are depicted by asterisks; all were interpreted to be related more to glacial advances than retreats. Two radiocarbon ages of 320 ±10 and 1,120 ±180 yr B.P. are exceptionally reliable as indicators of glacial expansions (Calkin and Ellis 1982, fig. 6).

directly beneath steep, truncated bedrock spurs where there is a minimum of fluvial activity in the debris source area.

Rock glaciers were formed beneath valley and cirque cliffs. Their upper surfaces stabilized by early Holocene time, based on lichen, soil, and boulder-weathering criteria (fig. 105). A relatively warm period from early to middle Holocene time is suggested by a lack of cirque-glacier deposits and the stabilization of rock glaciers. About 4,400 ± 1,000 yr B.P., climatic conditions deteriorated and cirque glaciers were formed or rejuvenated in higher, north-facing cirques of the central Brooks Range (Hamilton and others, 1982).

Lichenometric mapping (Calkin and Ellis, 1980; in press) on moraines downslope from more than 50 cirque glaciers and five radiocarbon dates associated directly with Neoglacial moraines define seven major expansions of similar magnitude since this middle Holocene climatic deterioration (Calkin and Ellis, 1981a, 1982; fig. 105). For the past 1,100 yr, cirque glaciers were continually in more advanced positions than they are under the present climatic regime (Calkin and Ellis, 1981b). Three of the seven major expansions occurred during this interval. The last expansion is dated at 1410 to 1600 A.D. Initial recession from this advanced position was slow; ice margins remained close to their maximum extents until 1640 to 1750 A.D. Retreat was most rapid after 1870 A.D. and decelerated after the mid-1900's. Recession since this most recent Neoglacial expansion has covered 150 to 700 m and continues today. A temperature lapse rate of 0.6°/100 m was used to reconstruct temperature changes that may have accompanied snowline fluctuations from about 450 yr ago to the present (Ellis and Calkin, 1981). This method was applied to more than 50 cirque glaciers and indicated that a change of only about 1°C in average temperature could account for the major Neoglacial expansions and retreats.

During the late 1970's, when annual snowline was above glacier surfaces in the central Brooks Range, as much as 3 m of ice ablated from glacier snouts (Ellis and Calkin, 1982; fig. 106). Correlation with meteorological records (A. James Wagner, NOAA - National Weather Service, written commun., 1981)

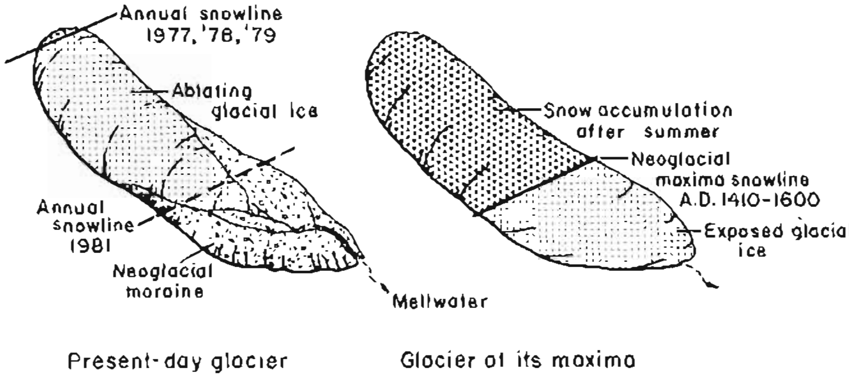


Figure 106. Sketches of a cirque glacier in its present configuration and during its maximum expansion phase. Approximate altitudes of snowline (equilibrium-line altitudes) are depicted for 1977-79 and 1981 and for 1410-1600 A.D. Snowlines rise northward across the central Brooks Range at about 5 m/km (Ellis and Calkin, 1981).

indicates that stronger-than-normal ridges of high pressure near or over northern Alaska caused less cloudiness and generally sunnier, warmer, and drier conditions during the late 1970's. In contrast, the annual snowline in 1981 was at the elevation averaged during the last major expansion of 1410 to 1600 A.D.; little snow melted and ice ablation was minimal. That summer a much deeper than normal low developed over the Arctic Ocean just north of Alaska during the last week of June and persisted the rest of the summer. This situation resulted in colder, cloudier, and wetter weather. From 1977 to 1981, monthly summer temperatures at the glaciers dropped 3°-4°C (extrapolated from data provided by R.K. Haugen, written commun., 1982) and snowline was depressed about 250 m. This measured temperature drop is greater than suggested by lapse-rate calculations; 3-4°C may be a better estimate of summer temperature changes that accompanied middle to late Holocene snowline fluctuations.

Slushflow Activity in the Atigun Pass Area[16]

Flows of water-saturated snow, called slushflows, are common in stream courses in this alpine terrain. Slushflows are a type of wet-snow avalanche, primarily occurring in arctic and subarctic mountainous regions, that is initiated by rapid spring melting of the seasonal snow cover (Washburn and Goldthwait, 1958). Slushflows are very powerful geomorphic agents and their engineering ramifications cannot be overlooked (Reger, 1979). Colluvial deposits at the mouths of slushflow chutes have a characteristic proximal hump that commonly diverts drainage. Slushflow deposits are unsorted and till-like, and consist of large blocks and small rock fragments, fine-grained material, and occasional shredded plant remains (Kreig and Reger, 1982, pl. 22).

Slushflows are common in the Atigun Pass area. Approximately 30 individual events were observed between 1977 and 1980. Slushflows are closely

[16] Prepared by L.J. Onesti.

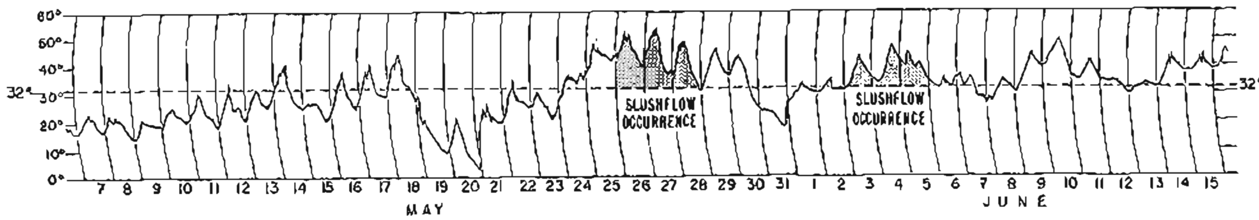


Figure 107. Periods of slushflow activity during May and June 1980, Atigun Pass (prepared by L.J. Onesti).

linked to meteorological conditions, and some evidence suggests a periodicity associated with climatic fluctuations. The slushflow season corresponds with spring breakup, which in the Atigun Pass area normally occurs sometime between mid-May and early June and lasts only a few days. Slushflows are caused by a very rapid buildup of free water in the snowpack due to the accelerated rate at which the arctic-alpine snowpack melts. At Atigun Pass, air temperature normally remains below or just slightly above freezing during the early spring, with 'nighttime' temperatures remaining below freezing (fig. 107); this allows the bulk of the snowpack to remain intact. However, as the days get longer, radiation becomes stronger, warm-air masses penetrate the Brooks Range, and regional air temperatures remain above freezing for 2 to 3 days at a time. These conditions trigger slushflow events and the start of the spring breakup. The slushflow process is extremely sensitive to diurnal fluctuations in air temperature. For example, if the air temperature rises rapidly on clear, sunny days, rapid melting causes free water to accumulate in the snowpack. Free water is shown by the appearance of light blue patches in the trough of a chute, and indicates the potential for slushflow activity. However, if the air temperature begins to fall in late afternoon, or if early evening melting is inhibited, the snowpack will drain, terminating the potential for slushflow activity. Rainfall has also been linked with slushflow activity, but at no time during 4 yr of observation did rain fall during the slushflow season.

Slushflows in the Atigun Pass area are grouped in two categories, depending on the rate at which they move. High-velocity flows, estimated to move at tens of meters per second, are associated with relatively steep (12° to 18°), confined alpine chutes. Low-velocity slushflows move at a few meters per second and occur exclusively in stream channels or on broad, open flood plains with slopes of about 2°.

Observation of slushflow tracks in steep chutes suggests that high-velocity flows move at supercritical rates. When a slushflow encounters a change in chute alignment or a constriction, it superelevates on the outside of bends and is diverted diagonally, deflecting back and forth across the chute (fig. 108).

The morphology and surficial characteristics of slushflow deposits assume a low-relief drumlinoid or whaleback form, which develops at the mouths of steep alpine chutes and which may be attributed to the slushflow process (see strip map for locations). Observation again indicates that the whaleback form develops through repeated deposition of relatively thin layers of material. Large blocks weighing several tons have been moved, but they compose only a small portion of the material exposed at the surface. Material transported by slushflows is naturally a function of what is available in the chute, which in turn depends on a variety of other conditions related to periglacial processes.

Figure 108. Superelevation of slushflow on outside of bends in chute (photograph by L.J. Onesti).

Geomorphic evidence suggests that deposition of slushflow material follows predictable patterns. Normally the alignment of the main whaleback deposit extends away from and follows along the long axis of the chute that produces the flow. This orientation and whaleback configuration remain constant until enough material accumulates and the form attains a size where the force of flows being produced at that time is not adequate to carry up the proximal slope of the whaleback. At this time the flow is diverted to one side or the other of the whaleback, depending on the influence of the predominant local slope. A new whaleback deposit can then begin to develop adjacent to the old form, and multiple whaleback features are commonly found at the outlets of chutes. Or, if the divergence of the flow is not too drastic, the original whaleback can begin to develop asymmetry.

Lichenometric mapping of the surfaces of slushflow deposits indicates that great differences in age exist in different areas of a deposit. However, the difference in age is most explicit when multiple whalebacks are present at the outlet of the chute. Examination of several slushflow-runout zones indicates that deposition either terminated or was diverted away from the main whaleback approximately 4,500 yr ago. There also appears to be a high frequency of depositional surfaces with ages ranging from 2,000 to 3,500 yr, and of very young surfaces formed in the last 30 yr.

Field observation indicates that over the past 5 yr many slushflows have occurred annually in Atigun Pass. One slushflow chute near the south side of the Continental Divide in Atigun Pass has reportedly produced at least one slushflow each year between 1971 and 1975 (Reger, 1979). However, between 1977 and 1981, only two flows were observed at this site. The Alaska Department of Highways (1971), using dendrochronological evidence, suggested that slushflow chutes in the immediate vicinity of Atigun Pass have produced at least one slushflow every 3 to 11 years during the past 50 yr.

ATIGUN VALLEY[17] - PRUDHOE BAY

The road follows the east fork of the upper Atigun River. The valley is typical of many of the larger north-trending valleys in the Endicott Mountain segment of the Brooks Range. Throughout most of its length it cuts into faulted and folded, well-indurated conglomerate, fissile shale, chert, and sandstone of Devonian and Mississippian to Permian age (fig. 8; Ferrians, 1971b; Beikman, 1978; Brosgé and others, 1979). Differential erosion has rendered the broader structural characteristics of the units quite visible. Mississippian limestone and conglomerate and Devonian conglomerate and shale form the valley walls to the north. Near its mouth, Atigun Valley passes through a narrow (2 to 3 km) band of hard Mississippian to Permian limestone and abruptly turns northeastward, following a probable fault through Atigun Gorge until it joins the Sagavanirktok River. These rocks are succeeded to the north by Cretaceous sedimentary rocks (Brosge and others, 1979).

Atigun Valley displays the classic U-shaped form of glaciated mountain valleys (fig. 109). Mass-wasting deposits are abundant and of varied

Figure 109. Glaciated, U-shaped Atigun Valley looking north (photograph taken by D. Atwood on July 19, 1982).

[17] General description of Atigun Valley prepared by K.R. Everett. See Kreig and Reger (1982, pl. 23-25) for additional information.

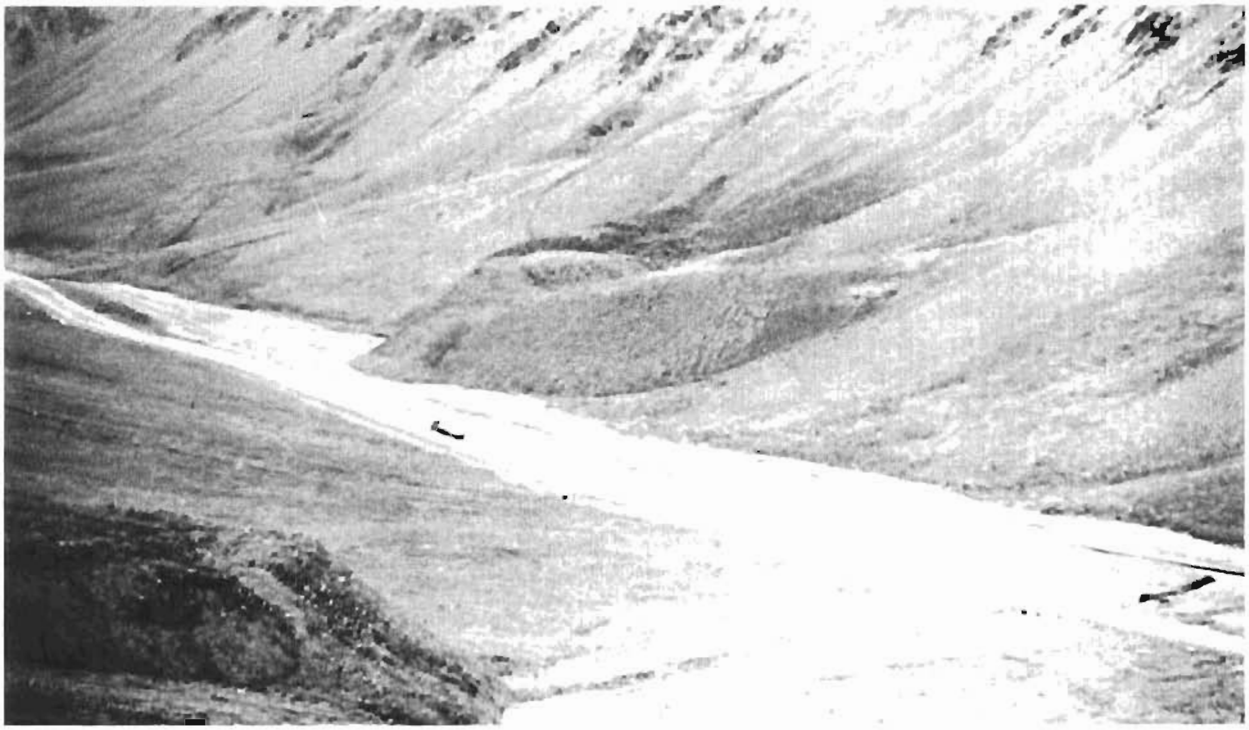


Figure 110. Lobate rock glacier with a curved bouldery rampart on east side of Atigun Valley. Pipeline is buried in the river. The slope is the foreground has slushflow channels and proximal hump deposits characteristic of slushflow features (photograph taken by R.K. Fahnestock).

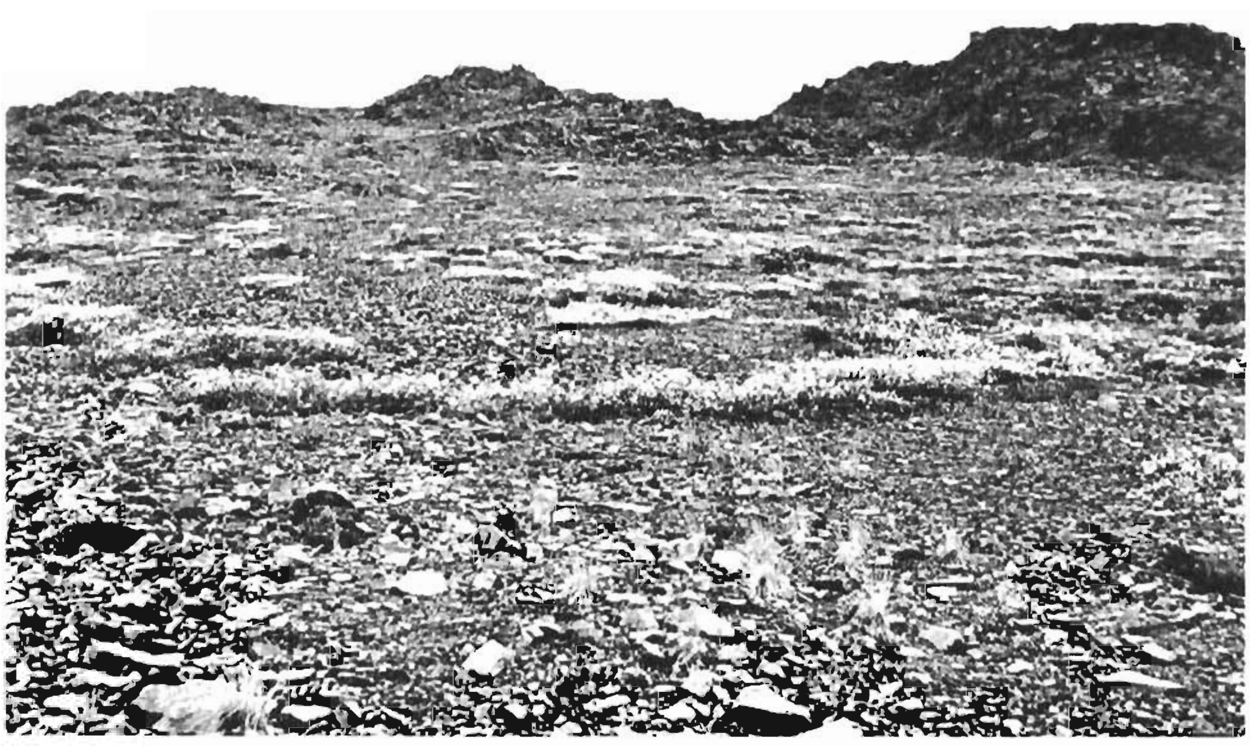


Figure 111. Steep talus slope (50°) with partially vegetated steps and stripes consisting of *Dryas octopetala* and willows (photograph taken by K.R. Everett).

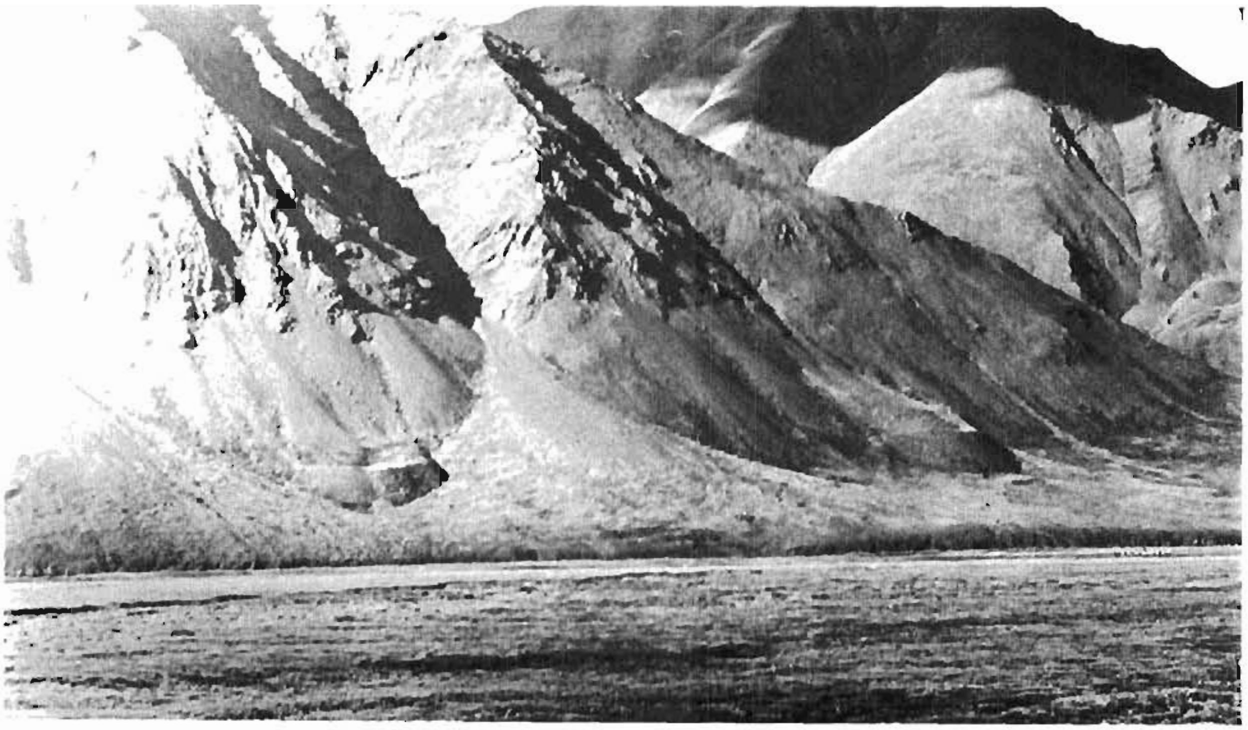


Figure 112. Several debris cones developed from shaly bedrock. These steep cones (22°) exhibit active debris flows. Note lobate rock glaciers at base of faceted spurs (photograph taken by K.R. Everett).

character on the valley walls. In the upper third of the valley and especially near its head are steep-fronted (27°+), curved, bouldery ramparts or rock glaciers (fig. 110; Ellis and Calkin, 1979; Bruen, 1980). The downslope face of these features is composed of angular boulders and rises to a height of 10 m or more. Behind the rampart is a platform or tread that slopes as much as 6° downward toward the valley wall. Commonly there is a depression in this surface, which is the site of snow accumulation and a pond (or former pond). In some cases, the rampart is breached by a V-shaped trough leading to the depression. Slopes above the tread area are composed of talus cones or talus sheets that terminate on the tread. The origin and significance of the ramparts are not completely understood. Fines have been removed from the boulder face of the rampart by entrainment and snowbank sapping. At least one of the larger forms displays a group of nested, curved protalus ramparts developed on the tread. These have been formed by rock fragments loosened by freeze-thaw sliding over large snowbanks to the tread. The number of protalus ramparts suggests either a progressive thinning or recession of the seasonal snowbank (indicating a warming climate) or seasonal variability in the extent of the snowbank (no climatic significance).

Narrow rockfall chutes commonly terminate in talus sheets or steep talus cones. Typically, these features have temporarily stabilized areas of willows and mountain avens (Dryas octopetala) in the form of discontinuous stripes parallel to the slope (fig. 111). Rockfall and creep are the principal processes of accumulation and movement. Talus cones (fig. 112) have relatively small material source areas and high slope angles, and are composed mostly of large angular boulders with relatively few fines. Fine materials increase in abundance near the apex and in the shallow subsurface. Water and

Figure 113. Mudflow or debris cone on east wall of Atigun Valley (photograph 55-18 taken by R.A. Kreig in 1974).

Figure 114. Alluvial fan (slope 13°) displaying characteristics intermediate between those of the debris cone (far right) and the broad, low-angle (4.5°) fan that emanates from a larger source area (photograph taken by K.R. Everett).

slushflow transport appear to be less of a factor in their formation than rockfalls and snow avalanches.

More deeply incised chutes with larger source areas produce steep debris cones (fig. 113). These cones are intermediate in volume and slope angle between talus cones and alluvial fans. The geometry of this form reflects the dimensions of the material source areas and the type of transport mechanism, that is, the amount of water or slush and the gravity component. Debris cones are composed of materials of all sizes, but angular and subangular boulders dominate at the surface. Surface water flow tends to be confined to early summer. Some of these forms are 0.5 km or more across at their bases. They are characterized by numerous active and formerly active slushflow or mudflow channels and levees. Many of the surfaces support vegetation.

Numerous steep (11° or more) alluvial fans line the valley walls (fig. 114). These features, composed of a wide range of particle and fragment sizes, are the products of debris flows. Their surfaces commonly show many distributary channels. Such fans are intermediate in form between the talus cones and the broad (2-3 km), low-angle (4 to 6°) alluvial fans (fig. 109). They form by a combination of fluvial and colluvial processes. The large fans have extensive source areas and are crossed by one or more perennial distributary stream. The fans have a long history of shifting channel movement, deposition, and erosion, and are composed of materials of nearly all sizes. Large, subrounded boulders are most common at the apex area and fine sand and silt are more important near the toe.

Kames, kame moraines, or lateral moraines probably occur as remnants of more extensive deposits formed against valley walls by downwasting glacier ice. They have mostly been destroyed by slope failure, erosion by running water, or burial by alluvial cones and fans. They are composed of a wide variety of materials ranging from angular boulders through rounded and subrounded gravel to sand and silt. In some cases, steep-fronted (38°) lateral-moraine remnants have undergone or are undergoing destruction by slope failure (fig. 116). At lower elevations on slopes and in some cases adjacent to the river are remnants of kames composed of poorly stratified sand and gravel.

Between alluvial fans and debris cones and below talus or colluvial slopes or lateral moraines are wet solifluction slopes (12° to 16°) that are characterized by solifluction lobes, hummocks and swales, ponds, and frost scars. Drier, coarser textured colluvial slopes commonly occur below talus slopes.

All valley-wall deposits postdate deglaciation of the Atigun Valley and are therefore probably less than 12,000 yr old (Hamilton and Porter, 1975).

The depth to permafrost ranges widely in Atigun Valley. On dry, bouldery colluvial slopes, debris cones, and alluvial fans it may be over 2 m. On wetter, finer textured colluvial and solifluction slopes, permafrost is generally encountered between 40 and 60 cm and occasionally as shallow as 20 cm; in strangmoor it is between 60 and 65 cm.

D-247.5

A lobate rock glacier (fig. 115, loc. 11) is on the north-facing wall upslope of the buried pipeline.

D-247.8 : Buried pipeline crossing.

At this point the road starts a steep descent into Atigun Valley. Good opportunities exist during the next few kilometers to view dall sheep, which use this area for lambing.

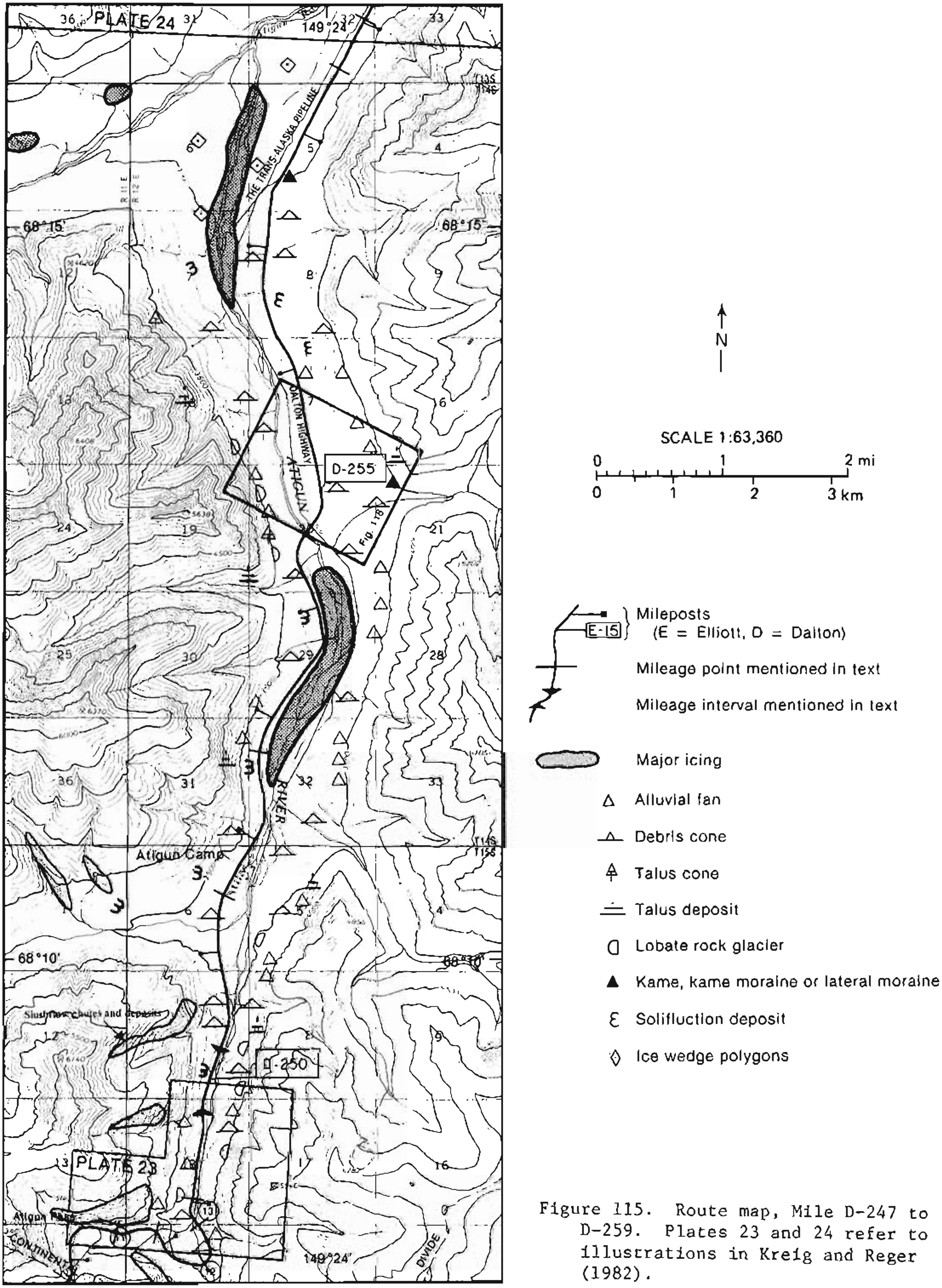


Figure 115. Route map, Mile D-247 to D-259. Plates 23 and 24 refer to illustrations in Kreig and Reger (1982).

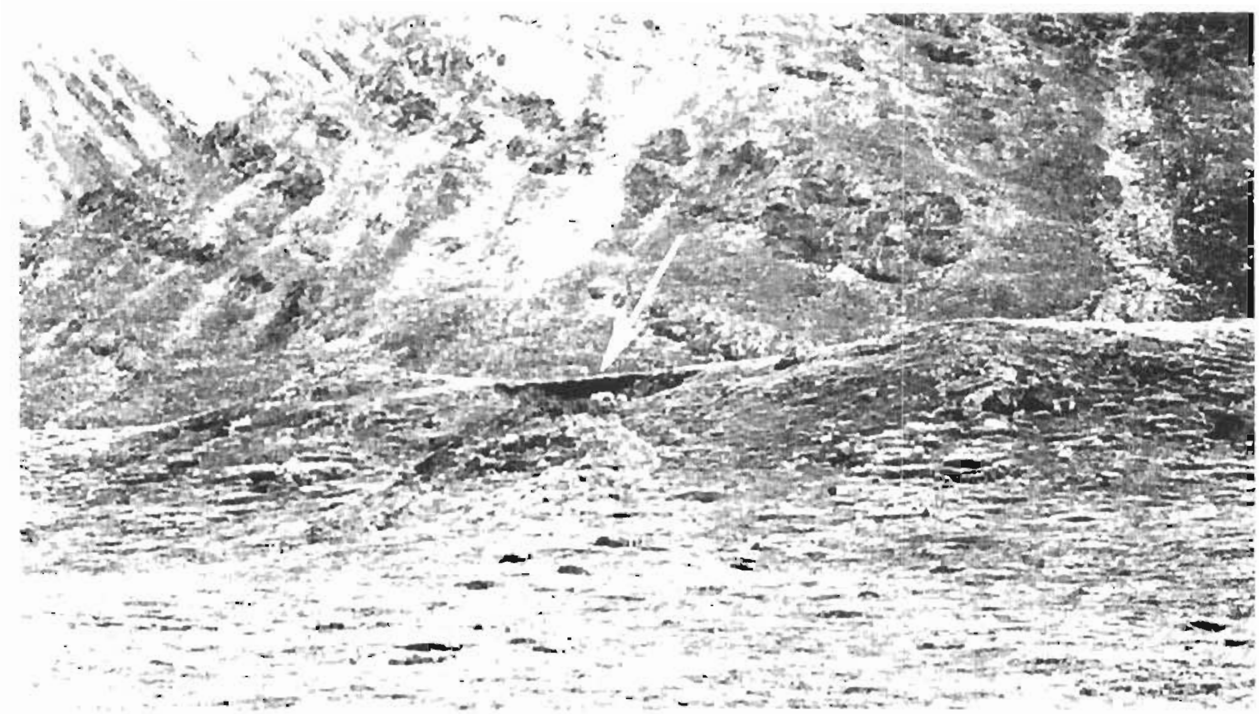


Figure 116. Slope failure (arrow) in colluvium and kame-terrace material on the east side of Atigun valley. Flow occurred September 3, 1979 (photograph taken by K.R. Everett).

D-248.4

Atigun River passes under the road. Several lobate rock glaciers occur on the west side of the east branch of Atigun River. A 3-hr hike up to Grizzly Glacier and Jaeger Rock Glacier (a climb of almost 600 m) or an alternative hike to Pika Rock Glacier (300 m) are part of the field trip (fig. 115, loc. 12; fig. 102). The cut east of the road was made in ice-rich permafrost. In the alluvial fan east of the hairpin turn, a peat layer preserved 95 cm below the present surface dates the last aggradation event at 800 ± 90 yr B.P. (BGS-548).

D-248.8 : Atigun River and buried pipeline crossing.

The lobate rock glacier (fig. 115, loc. 13) along the east wall had four deep trenches dug into its upper surface by a backhoe. The internal fabric of the rock-glacier deposit demonstrated downslope creep of the landform. In the excavations, platy stones were aligned with their short axes vertical and their long axes tilted away from the valley sidewalls. Stones were embedded in a matrix of 70 percent ice. Larger boulders were concentrated at the upper surface of the deposit; stone sizes decreased.

D-249.0

The road intersects a steep fan that bears fresh levees and boulder litter indicative of repeated slushflows. Most of the boulders are weathered, but some lack weathering and lichen cover and may have been deposited recently. There are many active slushflow chutes between here and Atigun River bridge 1. A lobate rock glacier is observed at locality 14 in figure 115.

Figure 117. Exposed ice at base of fan opposite road from Atigun Camp (photograph taken by R. Veazey on July 22, 1982).

D-249.7 to D-250.2

Cuts 6 m and 10 m deep along the west side of the road expose gray slate overlain by thin (less than 0.2 m) colluvial cover. The pullout is adjacent to a borrow pit on the roadcut. Across the valley on the east side, two alluvial fans border a series of lobate rock glaciers and a talus cone. At this point the west side of the valley is glacially scoured bedrock with very little till.

D-251.4 : Atigun Camp.

D-252.7

On the north side of the fan, blocked drainage produced temporary large ice-cored mounds with over 1 m of ice exposed in a small ice cave (fig. 117).

D-254.6 : Atigun River bridge 1 crossing.

Atigun Valley becomes relatively broad and gentle from here north, and evidence of slushflow activity diminishes greatly. Debris or mudflow cones are dominant along the east side of the valley to Pump Station 4. In Atigun Valley, VSM logs revealed the presence of massive ice in the unconsolidated materials. At the bridge, argillite bedrock can be found within 15 m of the surface.

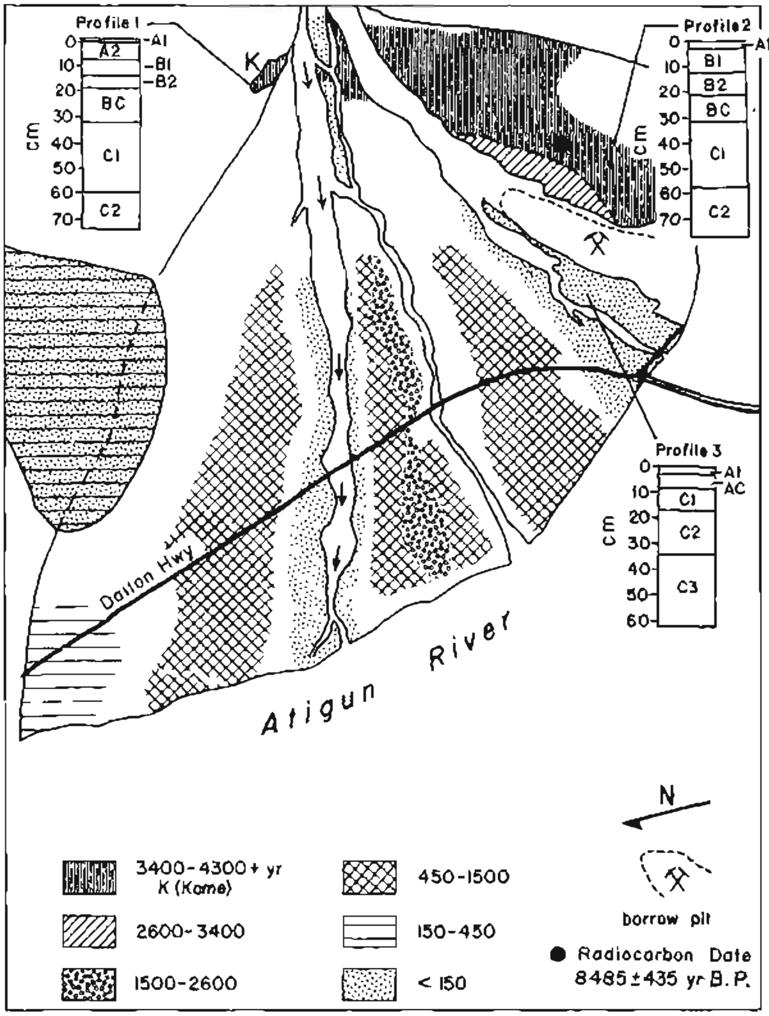


Figure 118. Estimated surface ages of alluvial fan in Atigun Valley near Mile 254.6, Dalton Highway, based on lichenometric dating. Soil profiles show degree of development in different age deposits (prepared by K.R. Everett).

A radiocarbon date of 8,485 ± 435 yr B.P. (GX-5113) from the large alluvial fan (fig. 118) demonstrates that Atigun Valley and similar valleys were free of late-Itkillik II ice by or near the beginning of Holocene time (Everett, 1981). At present, meltwater is supplied to this fan from a small cirque glacier about 2.5 km from its apex. The glacier, at an elevation of 1375 m, probably advanced into Atigun Valley during Itkillik II time, and removed most if not all of the alluvial deposits. Very likely some of the water-washed (kame) deposits near the head of the fan as well as those near Atigun River are products of ice stagnation near the close of Itkillik time. Lateral moraines and kame deposits higher on valley walls date from earlier phases of Itkillik Glaciation. The present form of the alluvial cones and fans was probably developed quickly on final melting of the valley ice. In all cases, large alluvial fans were developed rapidly from outwash as tributary glaciers retreated to their cirque basins. Atigun River has removed the distal end of the large fans.

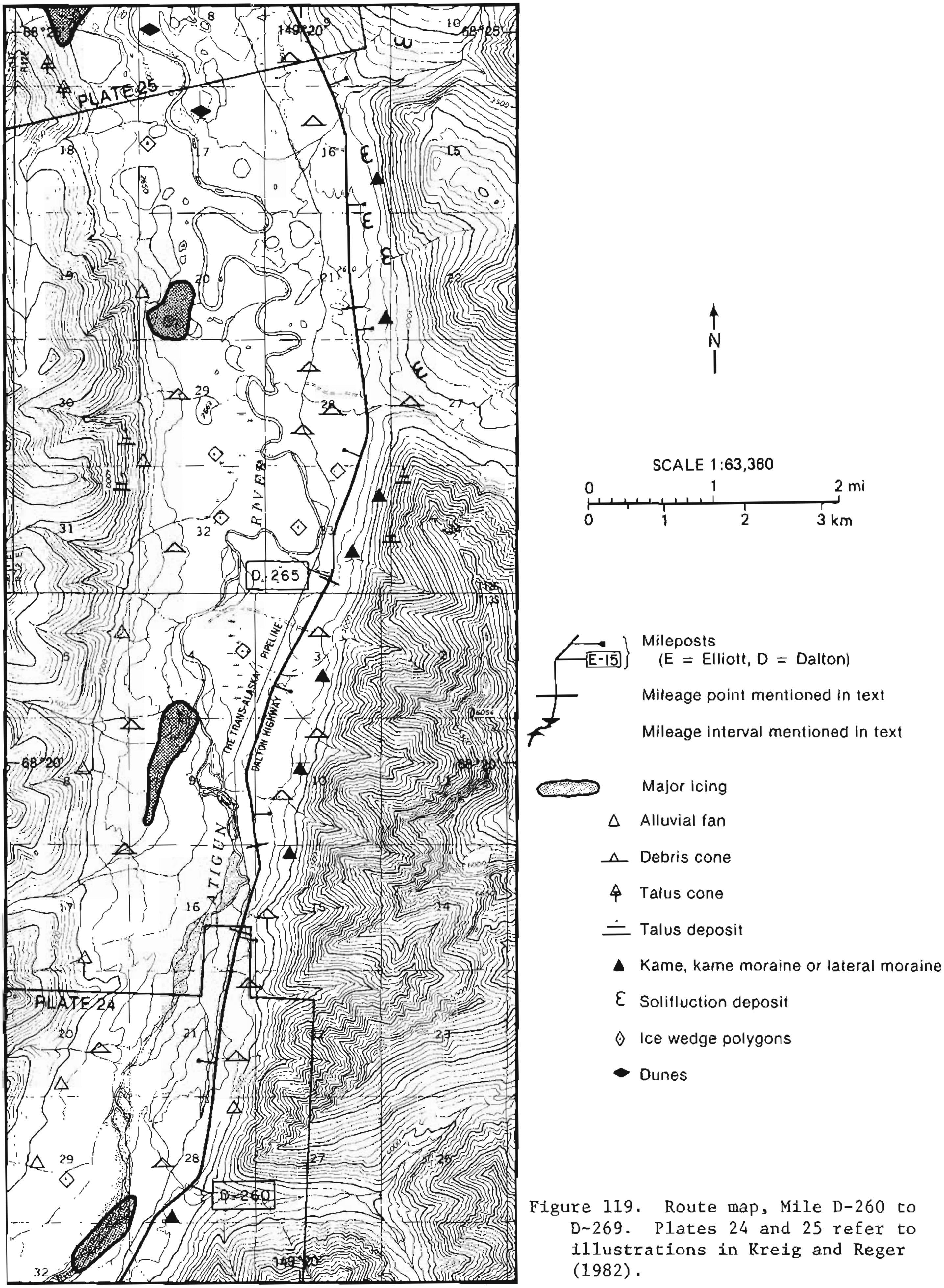


Figure 119. Route map, Mile D-260 to D-269. Plates 24 and 25 refer to illustrations in Kreig and Reger (1982).

The ages of lower fan surfaces range widely. Lichenometric dating using Rhizocarpon geographicum suggests that the surface of the fan ranges in age from less than 150 yr in some channel areas to as much as 3,400 yr between channels. The range of 450 to 1,500 yr appears most common. A radiocarbon date of 495 ± 155 yr B.P. (GX-5114) was obtained from the A1 horizon buried 28 to 34 cm deep in an area with a surface lichen age between 450 and 1,500 yr. The oldest part of this alluvial fan is north of the main active channel and borrow pit.

Lichen dates in this section indicate surface stability between 2,000 and 4,500 yr ago, using the growth curve of Calkin and Ellis (1980). The antiquity of this surface is supported by a radiocarbon date of 8,485 ± 435 yr B.P. (GX-5113), which was obtained for wood fragments at a depth of 158 cm. The soils of this surface show some of the strongest profile characterization of the Cryorthents.

Among the oldest and most stable surfaces associated with the fan are kame or kame-moraine terraces. Subsequent to ice retreat, these features have for the most part been buried or engulfed by alluvial-fan deposits. It is within kame deposits that significant soil-profile development has taken place. Kame surfaces and certain areas of the large alluvial fans appear to have remained stable for periods of 3,500 to 6,000 yr. Most other surfaces in the valleys are much younger. Water-washed (kame) deposits near the head of the fan as well as those deposits near the Atigun Valley may be products of the retreat of the last major ice. This is probably true also of some lateral or kame moraine deposits higher on the valley walls, but other, higher lateral moraines are older.

D-258.6

Steep debris cones with active levee-bordered flow channels extend to within 100 m of the road.

D-259.0

Across the river, north of the confluence of the west and east branches of the Atigun River, is an extensive wet area characterized by a mixed assemblage of high- and low-center polygons and thermokarst ponds (Kreig and Reger, 1982, pl. 24).

D-262.1

A road runs east to a rock quarry in Devonian Kanayut Conglomerate on a low ridge.

D-262.7

A slope failure in a reddish bouldery substrate occurred on the east side of the valley wall 250 m from the road. When it was freshly exposed in 1979, massive ice, possibly of glacial origin, was observed (fig. 116).

D-265.0

Atigun Valley was dammed by a large compound end moraine north of Galbraith Lake, forming a water body that may have extended south for as much as 30 km. This area at present is a broad, poorly drained sandy plain with abundant ice-wedge polygons, strangmoor, and thaw lakes. Test borings and natural bluff exposures show deep fill of lacustrine silt and clay grading southward into predominantly deltaic sand with some fine gravel. At this point, Atigun River leaves its gravel bed and enters the lacustrine and deltaic deposits. It changes from a braided channel in the gravel deposits to a meandering or braided channel in the finer deposits to the north. Tributary

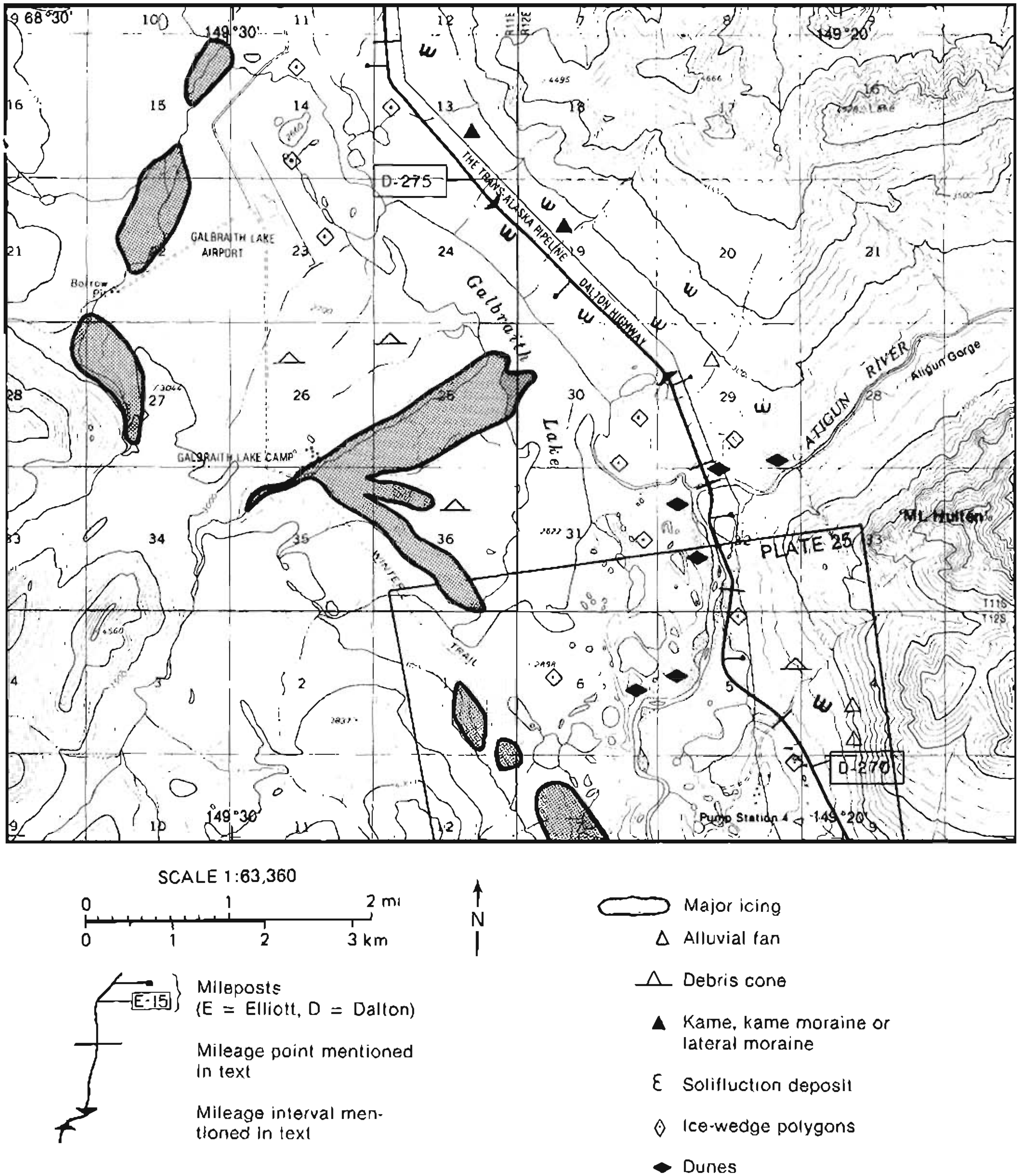


Figure 120. Route map, Mile D-270 to D-276. Plate 25 refers to illustration in Kreig and Reger (1982).

streams that entered the lake basin from both valley sides deposited fan deltas that grade from gravelly fan deposits near their apices into sandy deltaic beds toward the valley center. The basin later filled largely with alluvial sand, which is exposed along Atigun River as channel, flood-plain, and reworked eolian deposits in bluffs as high as 22 m. Radiocarbon dates from a bluff 6 km south of Galbraith Lake indicate that Atigun River alluviated to a height of 15 m above its modern level between 4,800 and 4,630 yr B.P. (Hamilton, 1979b).

D-267.2

Kames are present immediately east of the road.

D-270.4

Pump Station 4 is built on limestone of the Lisburne group on an unrefrigerated foundation. Water wells drilled there in bedrock to 245 m depth were unsuccessful and apparently did not reach the bottom of permafrost. This pump station and the three to the north are powered by natural gas carried in a 20- to 25-cm-diameter fuel-gas line buried beside the road or beside the oil-pipeline workpad. North of the crest of the Brooks Range, the pipeline workpad proximate to elevated sections was constructed with polystyrene board insulation. The use of insulation substantially reduced the amount of gravel required for the workpad and also made it possible to reduce the length of the VSM's, since the insulation reduces the depth of thaw. In this portion of the Brooks Range and immediately north, boards of 7.6- to 11.4-cm-thick polystyrene were used (Metz and others, 1982). North of Pump Station 3, 7.6- to 10.2-cm-thick boards were used, and beyond Pump Station 2 on the coastal plain, boards 3.8 to 7.6 cm thick were used. Thickness of the insulation was based on ground temperatures---the lower the temperature, the less insulation. On level ground, only 50 to 56 cm of gravel was required over insulation. Because of low permafrost temperatures north of Atigun Pass, most VSM's do not require heat pipes or radiators. But, wherever VSM's are in massive ice, heat pipes are required.

Glacial and glaciofluvial sediments underlie lacustrine, fluvial, and eolian deposits beneath the floor of this broad, glaciated valley just south of Galbraith Lake (Kreig and Reger, 1982, pl. 25). Lacustrine silt and clay commonly have 25 to 95 percent visible ice. Fluvial silt and sand that cover clayey lake deposits typically contain as much as 15 percent visible ice. Thermokarst-pitted topography developing in these ice-rich deposits has become quasi-stabilized. The topography is irregular because of numerous thermokarst lakes with receding shorelines and bimodal slope failures (fig. 121). These are best observed on the west side of the Atigun River, although an example can be observed along the shore of the small lake at the northwestern edge of Pump Station 4.

Linear eolian deposits are conspicuous along the margins of the Atigun River flood plain and parallel the dominant downvalley wind direction. Blowout troughs 15 to 20 m deep are separated by sharp-crested ridges (yardangs). Sand removed by wind from the troughs is deposited downwind as longitudinal dunes and sand blankets 0.6 to 8 m thick. In this area, the bedload of the Atigun River is sand. Sandy flood-plain deposits 1.2 to 2.4 m thick overlie lacustrine clay and silt (Kreig and Reger, 1982, pl. 25).

The panorama across Atigun Valley looking to the north from Pump Station 4 illustrates landforms and vegetation of this glaciated valley (fig. 122)[18]. The plant cover is discontinuous and is predominantly of cushion and mat-forming types that form closed communities only at sites of surface

[18] Description by D.M. Murray.

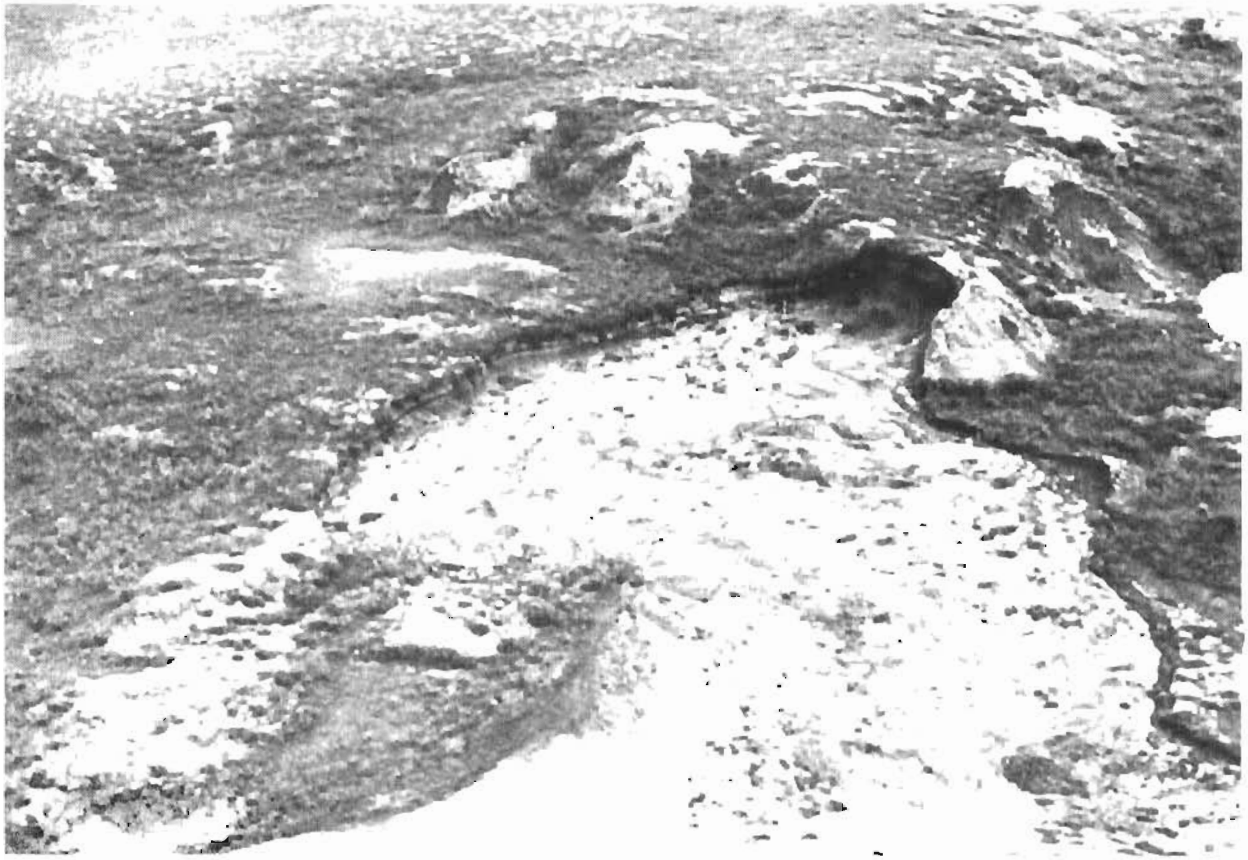


Figure 121. Bimodal slope failure 60 m wide at the head face and 100 m long adjacent to shore of the lake near Pump Station 4 (photograph 55-2 taken by R.A. Kreig).

Figure 122. Panoramic sketch of Atigun Valley looking north from Pump Station 4 (sketch by Eleanor Huke).

stability. The barren talus supports several species, including a fern that emerges from the interstices of blocky rubble. The alpine meadows of the middle slopes are continuous except for areas of local disturbance by mass wasting. In these meadows are mosaics of sedges, grasses, forbs, and prostrate shrubs, the composition of which varies along a gradient from topographic prominences to depressions. Dry and exposed high areas have fell fields and dry meadows, whereas moist, sheltered depressions have rich sedge fens and moist meadows. Further variation results from changes related to slope and aspect. North-facing slopes are cool and moist, with long-lying snow where heaths are prominent. South-facing slopes are warm and dry, and are free of snow in the spring, even before the valley bottoms.

Lower slopes have a conspicuous shrub component where even minor depressions offer stability, shelter, and moist soils. Habitats are more uniformly moist in the transition from slope to valley floor, and there sedge tussock meadows are common but are not as well developed as beyond the mountain front in the foothills. Wet sedge meadows are extensive on the valley floor, where drainage is poor. These meadows are patterned by weakly developed, low-center ice-wedge polygons or by low peat ridges (strangmoor). Meadows are interrupted by riparian stands along Atigun River and where the sediments have been reworked and sculptured by wind.

Talus cones are common on steepest portions of the valley wall and debris cones and large alluvial fans between remnants of lateral moraines have formed at the mouths of V-shaped tributary valleys. These cones have floras similar to those of fell fields and talus, and the fans are largely dry meadows with riparian shrub (willow) thickets along deeply incised distributaries.

'Mt. Hultén' and the mountain directly to the north across Atigun River are topographically similar, yet share only about 60 percent of their plant species. Differences in flora reflect differences in the lithology of these mountains from the Pennsylvanian and Mississippian Lisburne Limestone (Mt. Hultén) to the Cretaceous Fortress Mountain Conglomerate and associated sediment (Brosgé and others, 1979). Similarly, there are some species more or less restricted to local outcrops of shale. Additional information on this area is available in reports by the North Slope Borough (1979a,b).

D-271.5

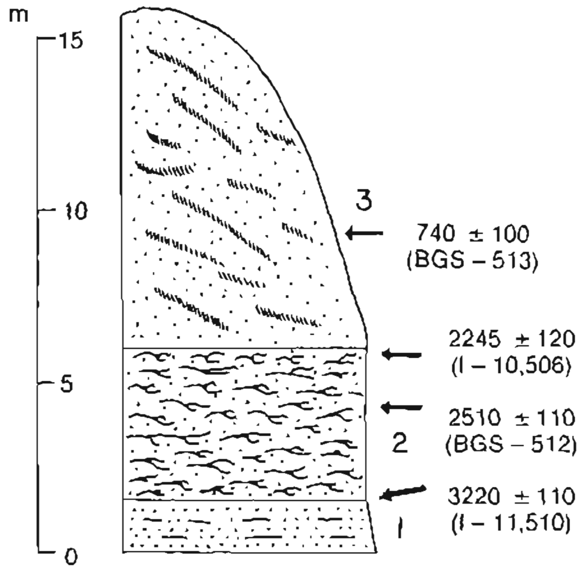
Cuts 3 m deep along both sides of the road expose fluvial sand above glaciolacustrine sand. The sand is bedded and contains buried organic matter.

D-272.3 : Atigun River crossing.

Only a shallow (1.2 to 2.4 m) thaw bulb occurs under the river. Borings made in the river near the south bank, on a point bar, and in the center of the active channel near the pipeline bridge revealed that up to 18 m of glaciolacustrine clay and silt contain layers that are 50 to 95 percent ice under 1.5 to 3 m of silt and silty sand. VSM's have heat pipes to keep the ice-rich clayey sediment frozen. The Arctic National Wildlife Refuge boundary is located 5 km east in the Atigun Gorge. The gorge, a fault valley, is bounded to the south by Mississippian to Permian limestone and lower Triassic to early Permian siltstone, shale, and some limestone and to the north by north-dipping Cretaceous sedimentary rocks (Brosgé and others, 1979).

D-272.4

A 15-m-deep exposure along the north bank of Atigun River exhibits dune sand above peat and sandy alluvium (fig. 123). Basal sediments (unit 1) represent filling of the moraine-dammed Atigun basin by a sluggishly flowing water body. The overlying peat (unit 2) dates an interval, between 2,250 and



Unit	Thickness and description
3	**Dune sand** (5 – 10 m). Dominantly medium sand to granules, with shale chips abundant in coarse sand to granule range. Upper 2 m mainly peaty fine to medium sand. Irregular upper surface has dune morphology.
2	**Peat** (4.5 m). Sandy bryophytic peat with scattered twigs; loose texture; oxide-stained. Sharp near-horizontal upper contact; gradational lower contact.
1	**Sand** (1.5 m). Sand and silty fine sand with some lenses of granule-sized shale chips. Horizontal beds, generally 1 – 2 cm thick; maximum thickness 4 cm.

Figure 123. Exposure along north bank of Atigun River 0.5 km east of Galbraith Lake outlet stream. Height above river ranges from 11 to 16 m, depending on local thickness of unit 3 (Hamilton, 1979b, fig. 10).

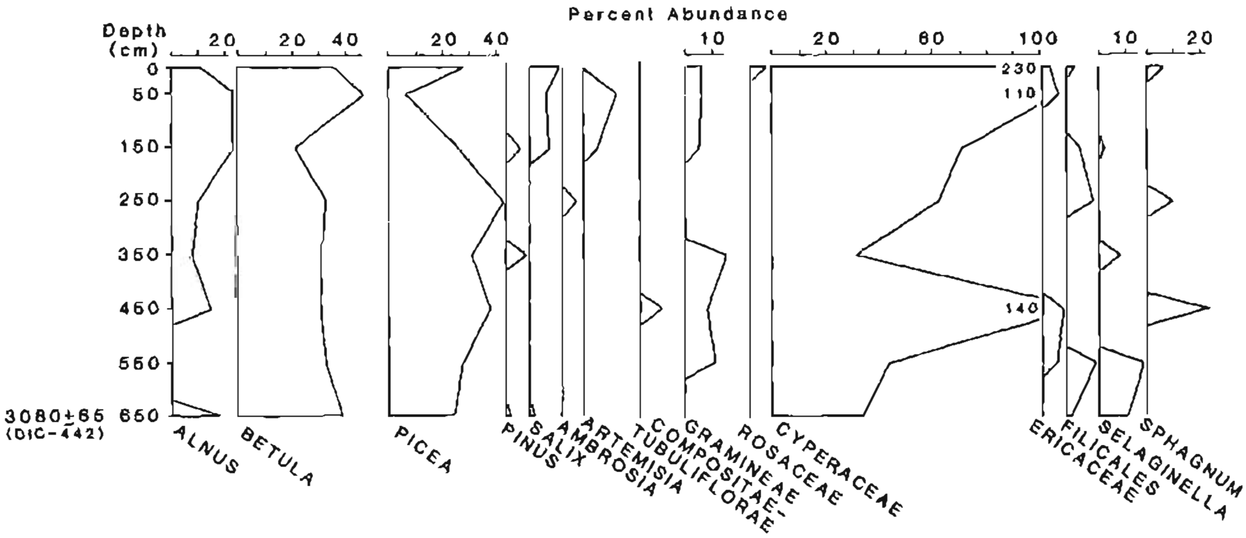


Figure 124. Pollen diagram from Atigun River cut (pollen sum excludes Cyperaceae, Ericaceae and Sphagnum) (modified from Walker and others, 1981, fig. 11).

3,200 yr ago, when Atigun River and the lacustrine plain around the south end of Galbraith Lake may have remained at a nearly constant level. Dune sand (unit 3) evidently began accumulating more than 750 yr ago and sand continues to be scoured and redeposited by strong downvalley winds (Hamilton, 1979b).

Samples for pollen analysis were obtained from the road section on the north side of the Atigun River crossing at 50- and 100-cm intervals, representing sample intervals of 250 to 500 yr each (Walker and others, 1981). A radiocarbon date of 3,080 ± 65 yr B.P. (DIC-442) was obtained from a sample of in-situ willow twigs, with bark intact, from a depth of 6.5 m (Walker and others, 1981). The relative pollen diagram is similar to those from Prudhoe Bay, with 30 to 40 percent birch and 10 to 20 percent alder (fig. 124).

Cyperaceae pollen occasionally reaches high percentages but in this section is generally less than 60 percent. Gramineae is present but in low percentages. Tree pollen is dominated by spruce, with up to 40%, although values decrease near the top of the section. These large values contrast with modern pollen records in the region (S.K. Short, pers. commun.).

The 'absolute' pollen assemblage suggests a very general threefold division of the data. At the base, the accumulation of spruce, alder, and birch pollen is relatively high. Between 5.5 and 2.5 m, Cyperaceae pollen is present in moderate quantities, but at 1.5 m and upward the section is dominated by Cyperaceae. The broad changes in amount of sedge pollen and in the amount of exotic shrub and tree pollen possibly reflect regional changes in climate.

D-274.8 to D-275.0

The road crosses a smoothly graded 7° to 8° solifluction-modified slope on the flank of a lateral moraine. Frost hummocks are abundant on the slope, but solifluction lobes are absent. Slope measurements in July and August 1974 showed small movements, including apparent retrograde movement along drier parts of the slope, suggesting partial recovery from frost-creep displacement of the previous winter. In the drainage swale, small net downslope displacements (0.4 to 0.8 cm) occurred, suggesting that some solifluction could be taking place where the ground remains moist through the summer (T.D. Hamilton, pers. commun.). Ice-wedge polygons are found on lower slopes and in swales. Material excavated from roadcuts was dumped along the edge of the road in several locations between here and the entrance to Galbraith Lake Camp. Thaw subsidence occurred under the sandy detritus in the ice-rich slope deposits and these materials are now at ground level.

The Galbraith Lake construction camp and airport are located on the large alluvial fan that borders the west side of the lake. Archaeological evidence found near here during pipeline construction indicates that the area had been used by humans for thousands of years (see also North Slope Borough, 1979b).

D-276.2 : Road access to Galbraith Airport.

North of the Galbraith Camp entrance road, the road crosses a solifluction-modified slope on a lateral moraine along the base of the east valley wall. Borings from the pipeline to the east encountered extensive ice-rich soils and massive ice to depths of 17 m.

D-277.5 to D-284.5

The road crosses a series of recessional moraines of the Itkillik II Glaciation. Boulders are abundant on the drift surface, as are kamelike sand and gravel deposits.

D-285.6 : Entrance to Toolik Camp.

Toolik Lake is a large compound kettle in glacial deposits of Itkillik II age that marks the position of a persistent block of stagnant glacier ice during deglaciation. The hillside to the east is covered with mass-movement features. North of the Toolik Lake turnoff, the road ascends the outer moraines of Itkillik I age. Swales between moraines show slight thermokarst formation along the road. Itkillik II moraines associated with Toolik Lake have many sorted bouldery features.

Sediments in Toolik Lake span a time from about 13,000 yr B.P. to the present. The pollen record from Toolik Lake (Bergstrom, 1982) supports the three-zone stratigraphy of Livingstone (1955). An initial herb tundra of

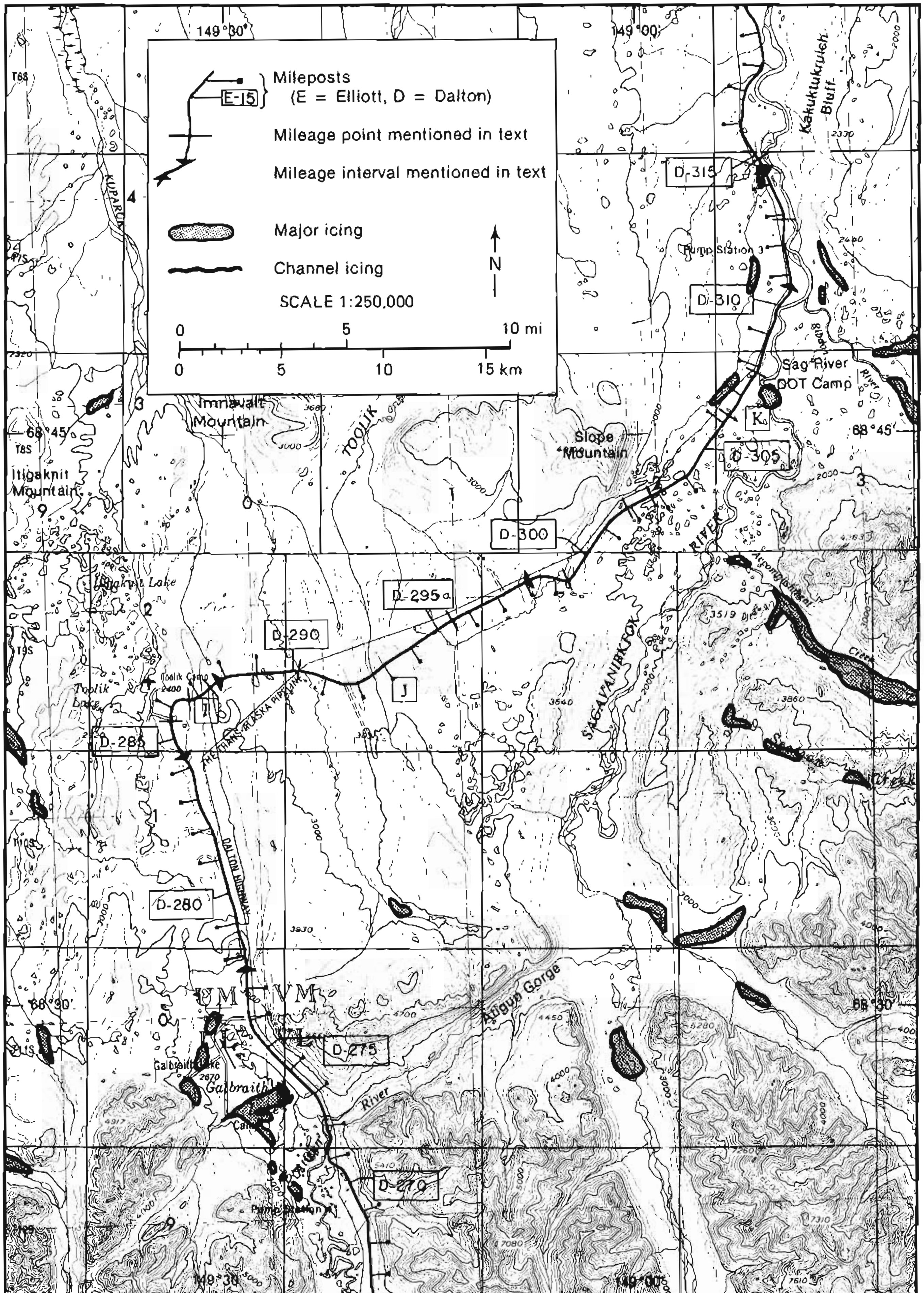


Figure 125A. Route map of area between Galbraith Lake and Sag River Camp (scale 1:250,000). Letters in boxes refer to notations in text.

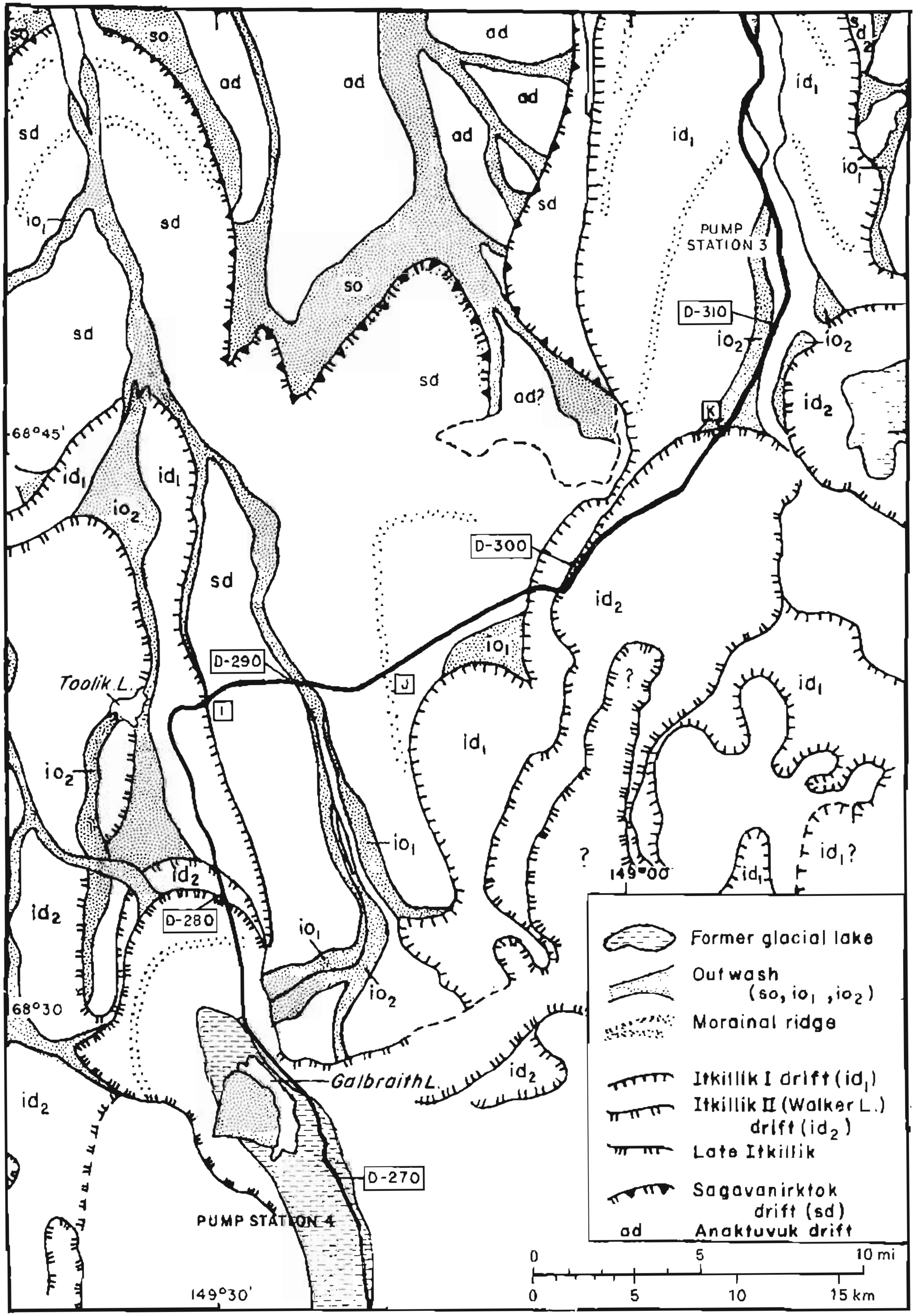


Figure 125B. Glacial geology map of area between Galbraith Lake and Sag River Camp (scale 1:250,000). Letters in boxes refer to notations in text.

sedge and grass was replaced by a birch-dominated shrub tundra about 12,000 yr B.P. An increase of alder pollen at about 9,500 yr B.P. marks the establishment of that shrub on the Arctic Slope. Radiocarbon dates from the Sagavanirktok River valley and elsewhere in the north-central Brooks Range also indicate that peat-forming plants and woody shrubs became relatively widespread during this interval, probably because of abrupt climatic warming (Hamilton, 1982). Several dated pollen profiles along the route of the road, both north and south of the Continental Divide, suggest that the arrival of spruce was nearly synchronous, at about 7,000 yr B.P.

Toolik Lake has been the site of a scientific base camp operated by the University of Alaska since 1975. Detailed limnological studies of lakes and streams and studies of soils and vegetation were supported by a number of government agencies.

D-286.5

[I] The road crosses the crest and outer limit of a lateral moraine of Itkillik age (fig. 125). The outer margin of the Itkillik drift sheet generally is sharply defined by abrupt contrasts in soils, vegetation, drainage, and relief. To the east, the broad, rolling, tussock-covered ridges of Sagavanirktok age contrast sharply with the steeper, drier, more irregular, bouldery moraines at the Itkillik ice limit. The front of the double moraine of Itkillik II age that encloses Galbraith Lake is visible (Hamilton, 1978b).

D-287.6

This high point on the road offers a scenic view of the Brooks Range to the south and east. A kettlelike feature filled with up to 1 m of peat on the east side of the road yielded a radiocarbon date of 10,375 ± 265 yr B.P. (GX-5108) at a depth of 0.7 m (K.R. Everett, pers. commun.).

D-287.8 to D-298.2

[J] The road crosses the surface of Sagavanirktok-age drift, which is appreciably older and more subdued morphologically than Itkillik I drift. More continuous tussock cover suggests finer and moister soils than on the Itkillik I drift. Swales have well-developed ice wedge polygons in presumably more organic-rich sediments than those on adjacent uplands.

On a smooth west-facing slope inclined 3°, moist swales form a dark-toned 'horsetail drainage' pattern. Net slope motion between June and August 1974 was 0.1 to 0.5 cm downslope in the swales. Retrograde movements of 0.3 to 0.5 cm were measured on the drier ridges between the swales (T.D. Hamilton, pers. commun.).

D-290.1 : Kuparuk River crossing.

D-290.2

The pipeline crosses beneath the road through a large culvert. The work pad here has 11.4 cm of insulation. A sign indicates that it is 126 mi along the pipeline route to Pump Station 1 at Prudhoe Bay. At many points along the road between Galbraith Lake and Prudhoe Bay, traces of the buried 20- to 25-cm-diameter fuel-gas line can be observed immediately adjacent to the road. The fuel-gas line was designed to operate at ambient temperatures and was buried in a trench 0.5 to 1 m deep. Insulation was placed over the line to prevent settlement due to thawing of the permafrost. However, settlement and erosion over and across the trench created maintenance problems (Brown and Berg, 1980). Above ground, fenced gas-line valves and the milepost markers for the fuel-gas line are seen along the road.

D-295.5

The short buried section of pipeline is called a 'sag-bend game crossing.' An 8-km-long experimental snow pad was used here as a workpad for construction of the elevated pipeline (Johnson and Collins, 1980). Settlement of the bouldery access road can be observed. This road was originally 1 m above the tundra surface.

D-298.2

The road intersects the outer Itkillik drift limit at the west margin of the Sagavanirktok River valley. Soils are generally granular and firm within this limit, with only minor silty, organic, swale fillings.

D-299.4

The Sagavanirktok River valley is first seen from this promontory.

D-302.0 : Entrance to Slope Mountain material pit.

Slope Mountain is composed of Cretaceous sedimentary rocks ranging from the fluvial and shallow-marine conglomerate, sandstone, shale, and siltstone of the Nanushik Group capping the mountain to the marine shale and siltstone of the Torok Formation at its base (Brosgé and others, 1979). Dall sheep and raptors are frequently observed on the uppermost slopes. The base of the mountain was mined for rock during pipeline construction and has since been restored. A series of ice-cored mounds less than 1 m high have formed in the marshy drainage east of the pipeline (Nelson and Outcalt, 1982; Brown and others, in press). The underlying upwarped ice is clearly visible in most blisters or mounds (figs. 126 and 127). In April 1982, several mounds were cored. One was a pure ice mound that had formed in the gravelly streambed. A total of 1.75 m of ice was augered and cored before the frozen streambed was reached. A mound completely buried by snow on the west bank of the stream was also cored. Over 1 m of buried ground ice was encountered 70 cm below the surface of the mound. Water under slight pressure was encountered at about 1.8 m, approximately the same depth as the bottom of an adjacent ice mound in the stream. This occurrence of free water within the continuous zone of permafrost at such a shallow depth is unusual. It is assumed that this mound and adjacent ones had been present for several years. Several of these mounds have collapsed (fig. 127). However, others are still preserved; presumably, new ones are still forming.

D-302.8

The pipeline is above ground near Slope Mountain as it crosses end and ground moraines. Sediments here are largely of glacial origin. Gallagher Flint Station, one of the oldest known archaeological sites in northern Alaska, occupies a large kame north of the road. The site was excavated in 1970 and 1971 by E.J. Dixon, Jr., of the University of Alaska (Dixon, 1975). Charcoal within loess at 20 to 25 cm depth was dated as 10,540 ± 150 yr B.P. (SI-974). Several other radiocarbon dates between 2,600 and 3,200 yr B.P. were obtained on charcoal at shallower levels near the base of the surface organic mat. Archaeological remains found at this site suggest that the inhabitants may have been the bearers of a technological tradition from which both Inuit and Aleut material cultures derived.

D-306.4

[K] The road crosses the front of a moraine of Itkillik II age and follows the outwash terrace that issues from it (fig. 125). Much of the

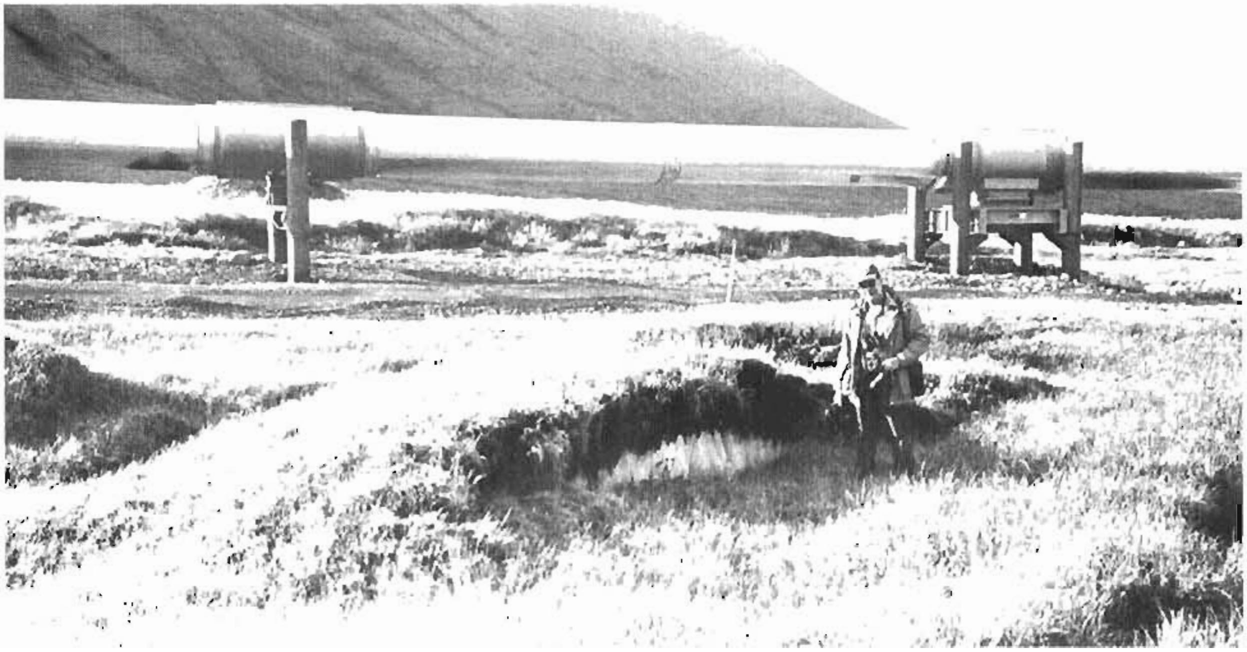


Figure 126. Ice-cored mounds at base of Slope Mountain (photograph taken by J. Brown July 15, 1981).

Figure 127. Remains of a mound immediately adjacent to those in figure 126. The ice was gone by the following week (photograph taken by R. Veazey on July 22, 1982).

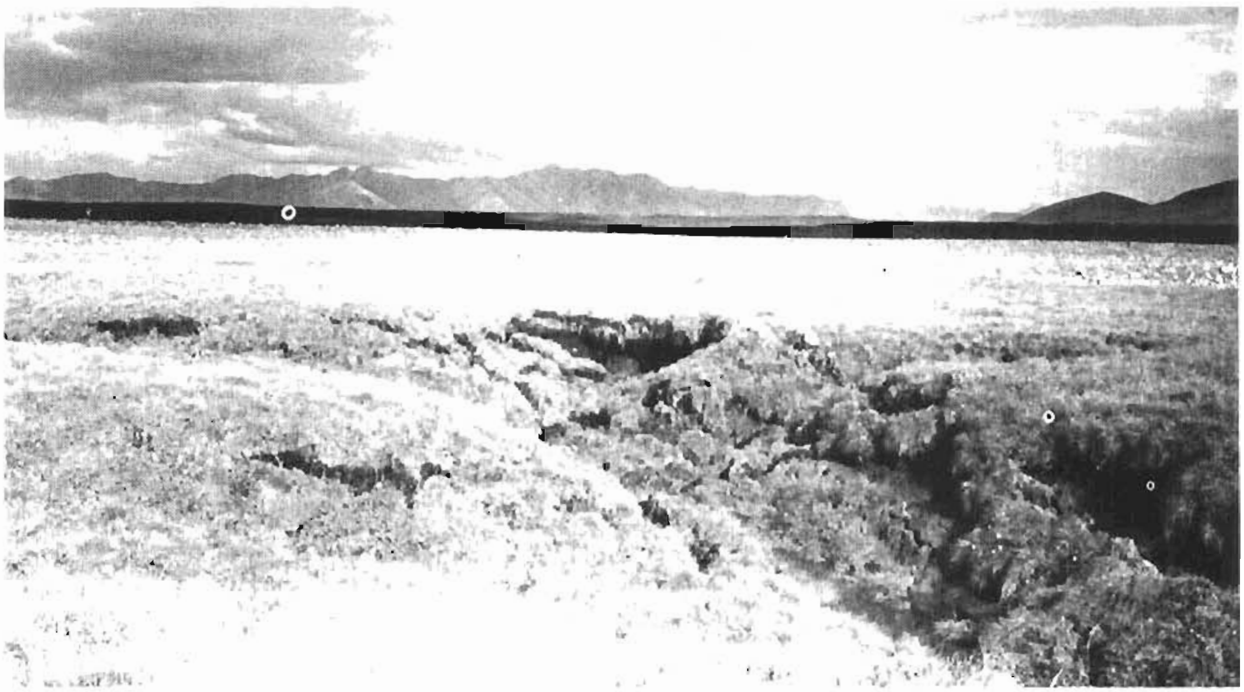


Figure 128. Ice-wedge meltout adjacent to road (photograph taken by J. Brown on July 5, 1981).

regional drift sequence is visible from this sector of the valley. The 300-m-high ridge that flanks the valley to the west is a buttress against which a compound lateral moraine was built by superimposed drifts of Sagavanirktok and Itkillik age. A corresponding lateral moraine east of the valley is visible a few kilometers farther north. Steep-fronted moraines of Itkillik II age in the Ribdon and Sagavanirktok River valleys must have been in contact at one time, but were eroded by meltwater streams and by postglacial river cutting. A younger readvance of Itkillik II age (double-hachure pattern on fig. 125) is widespread through this part of the northern Brooks Range. Ice readvanced to a position north of Galbraith Lake and flowed east through Atigun Gorge to block the upper course of Sagavanirktok River. Radiocarbon dates from the Sagavanirktok and Anaktuvuk River valleys indicate that the readvance culminated between about 13,000 and 12,500 yr B.P. (Hamilton, 1979b).

D-307.8

Ice-wedge meltout has occurred adjacent to both the road and the buried pipe on the west side of the road. However, the deeply incised meltout and troughs appear to be stabilized (fig. 128).

D-310.6

The road begins its descent to the flood plain of Sagavanirktok River. A cut along the west side of the road exposes 7 m of gray outwash gravel consisting of rounded stones up to cobble size in a sandy matrix. Low, wet areas contain ice-wedge polygons and string bog or strangmoor.

D-310.6 to D-314.5

The road follows the flood plain and terraces of Sagavanirktok River.

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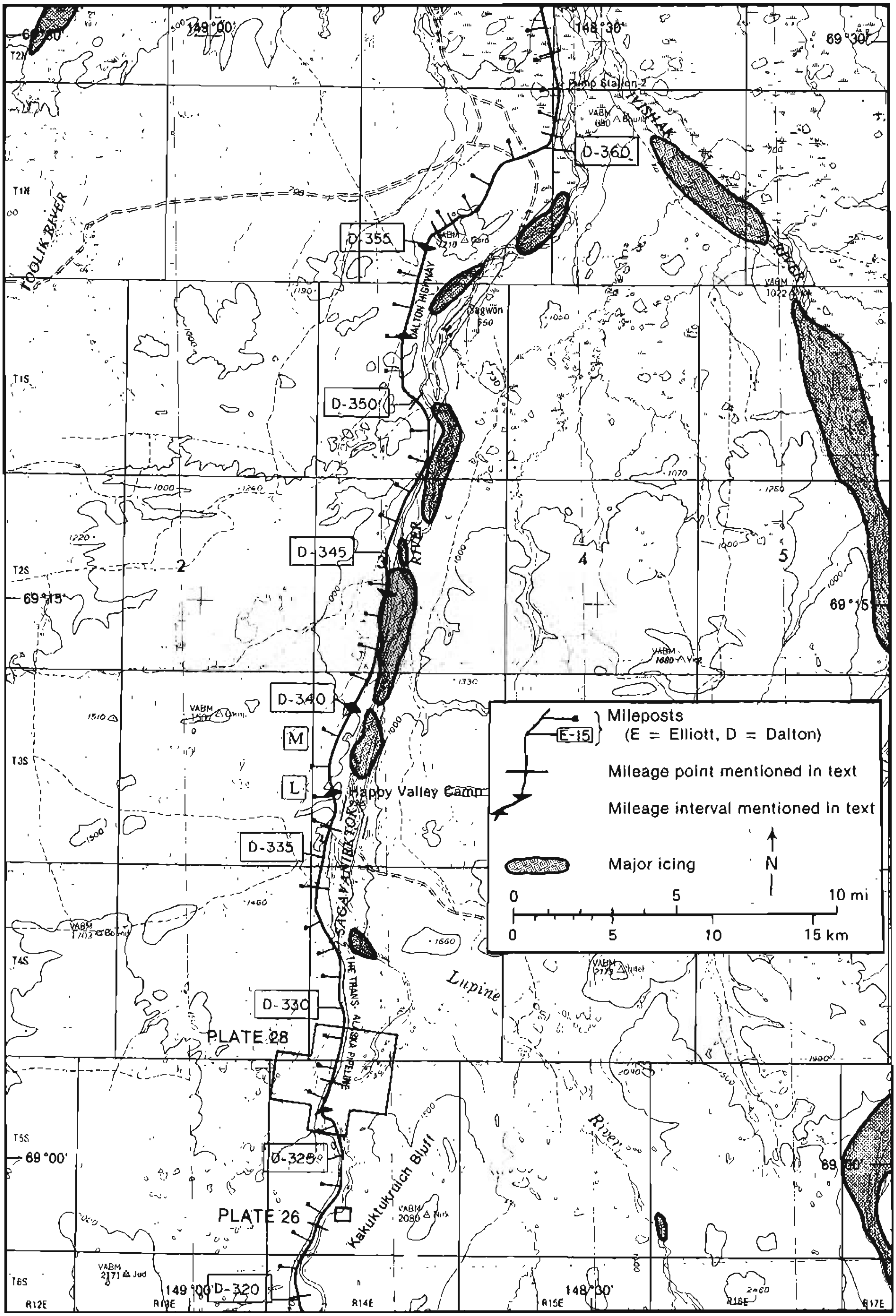


Figure 129A. Route map of the area between Galbraith Lake and Sag River Camp. (scale 1:250,000). Letters in boxes refer to notations in text.

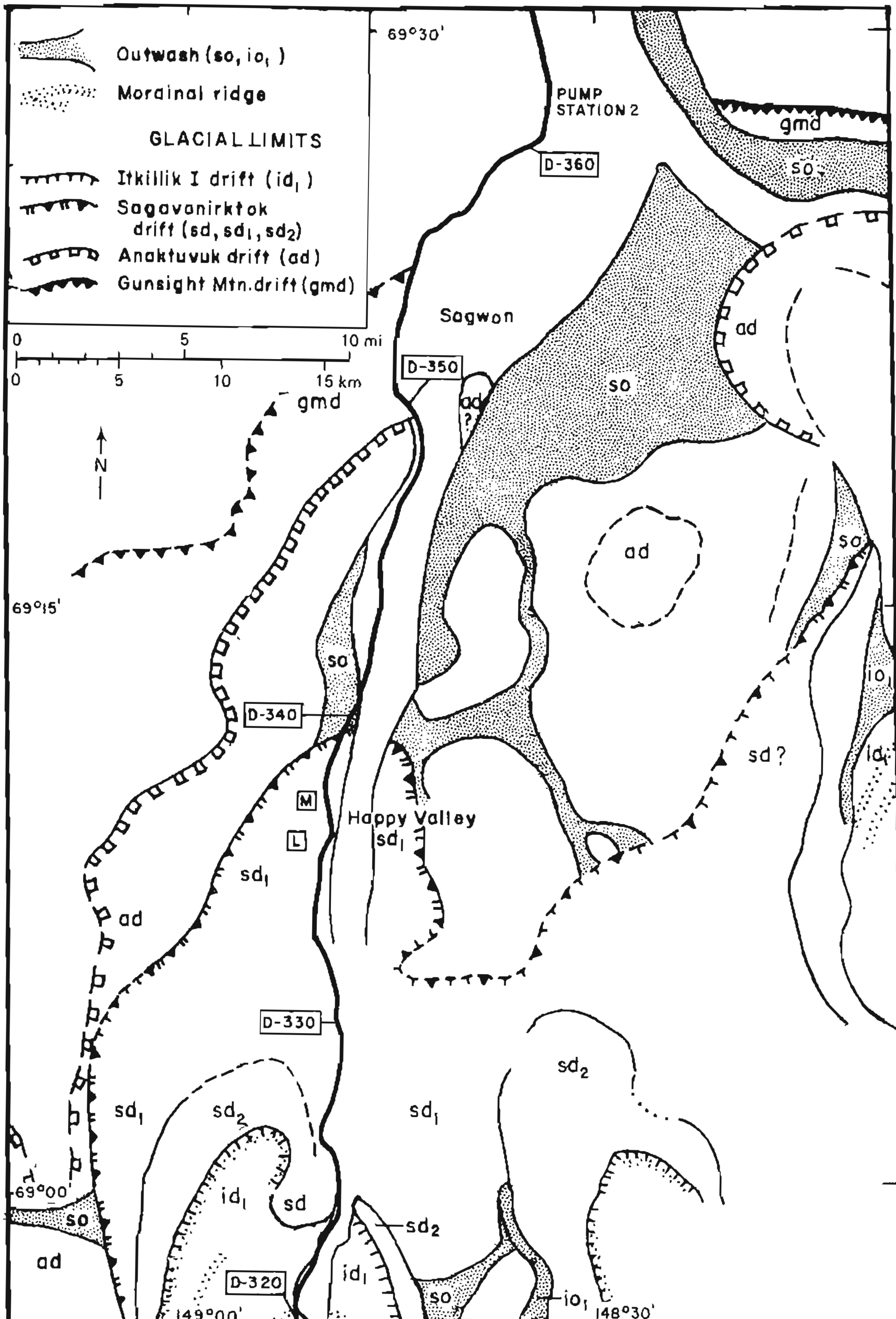


Figure 129B. Glacial geology map of the area between Galbraith Lake and Sag River Camp (scale 1:250,000). Letters in boxes refer to notations in text.

The Sag River Camp of the Alaska Department of Transportation and Public Facilities is located on the outwash plain to the east.

D-312.6 : Pump Station 3.

Refrigerated foundations are used here to prevent thawing of permafrost. Remnants of several ice-cored mounds have been observed just to the north on the west side of the road, where drainage was impeded and ice developed under the tundra surface.

D-314.5 to D-355

The road crosses nested end moraines of Itkillik age until approximately Mile 320. It then continues north past the northern drift limits of the Sagavanirktok River (Mile 340), the Anaktuvuk River (approximately Mile 350), and Gunsight Mountain (?) (approximately Mile 355) ice advances (fig. 129). North of the Philip Smith Mountains Quadrangle these drifts have been mapped primarily by airphoto interpretation. Consequently, details of their composition and distribution are poorly known (T.D. Hamilton, pers. commun.). Pipeline and road-test borings have not yet confirmed the presence of till north of the Sagavanirktok ice advance limit at Mile 340 (R.A. Kreig, pers. commun.).

D-315.0

The elevated pipeline to the west encountered extensive massive ice. Borings encountered over 12 m of clear ice beneath 0.5 to 1 m of organic mat. The long range of hills east of the road is the Kakuktukruich Bluff.

D-320.0

This section of the Itkillik till sheet has numerous heat pipes in the VSM's, an indication of its high ice content. The road ahead descends to the Sagavanirktok River terraces and flood plain.

D-322.6

Solifluction and strangmoor (string bogs) occur on wet terraces. The strangmoor occurs here on a thin active layer and forms on very gently sloping to flat surfaces covered with slowly moving shallow water. They are oriented normal to the direction of water movement, and each ridge functions as a low dike separating grassy fens at slightly different elevations (Kreig and Reger, 1982, pl. 26).

Coarse flood-plain alluvium is discontinuously frozen adjacent to the active channel of the Sagavanirktok River, where silty cover deposits are thin or absent and the flood plain is bare or vegetated, with low willow shrubs and a ground cover of lichens and mosses. Alluvium beneath the remainder of the flood plain is continuously frozen and the surficial silt layer is up to 1.5 m thick. Infrequent flooding permits development of an insulating mat of _Sphagnum_ moss and sedge tussocks (Kreig and Reger, 1982, pl. 29).

Rounded uplands of till and ice-contact gravel are perennially frozen and covered by tussocks. Within the seasonally thawed surface layer, colluvium is flowing down a terrace scarp to form solifluction cones that are building over the low fluvial terrace of the Sagavanirktok River. These solifluction cones have a thick organic mat of _Sphagnum_ moss, sedge tussocks, and willow shrubs that stand 0.3 to 0.6 m high.

D-326.5 : Happy Valley roadcut.

The road leaves the flood plain of the Sagavanirktok River and ascends

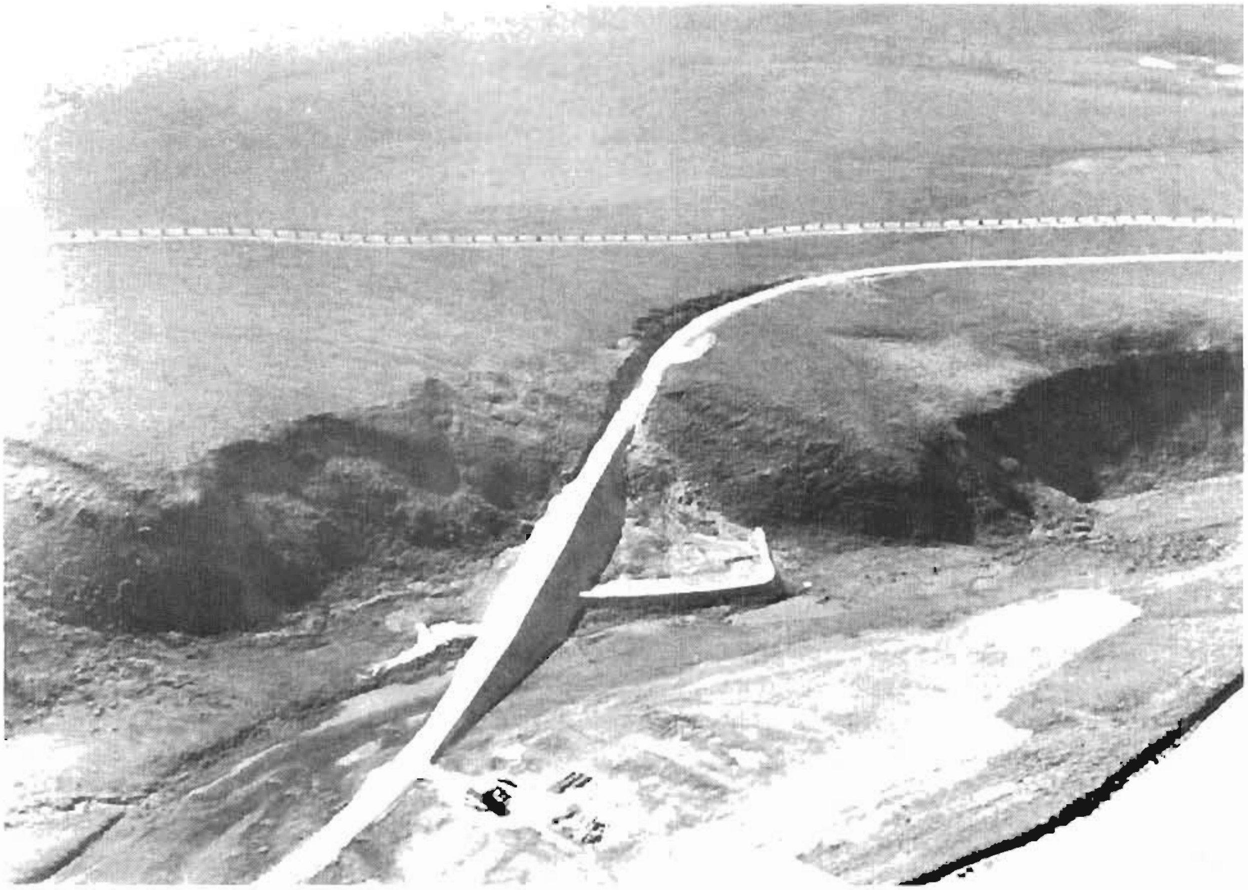


Figure 130. Aerial oblique photograph of Happy Valley roadcut (photograph taken by D. Atwood on July 19, 1982).

about 50 m up a steep grade to an upland surface underlain by bedrock and glacial deposits (fig. 130). In 1974, roadcuts exposed muck and peat with ice wedges and other massive ground ice above a lens of till resting on bedrock (figs. 131 and 132).

Ice content of the till is partly related to its antiquity. In general, old till contains more massive ground ice than young till because older till is generally finer grained and more time has been available for epigenetic ice growth (assuming that ground ice did not melt deeply during interglaciations). Till in the Happy Valley area was deposited during the Sagavanirktok Glaciation of middle Pleistocene age. Borings and observations of the roadcut indicate that the upper 7.5 to 13 m of till is volumetrically composed of up to 75 percent massive ice. Till between large ice wedges in the fresh road cut had uniformly disseminated visible ice in the form of lenses, pods, and coatings around clasts that composed up to 50 percent by volume of the frozen till. Soon after construction of the cut, bimodal failures developed in the southern half of it, where disseminated ice occurred in till. Winter installation of an insulating gravel blanket stabilized this section (McPhail and others, 1975). In contrast, the rest of the cut, which contained extensive wedge ice, was self stabilizing. Meltwater from ablating massive ice apparently did not produce the elevated pore-water pressures needed to generate mudflow tongues at the base of the ablating face of the cut (Kreig and Reger, 1982, pl. 28).

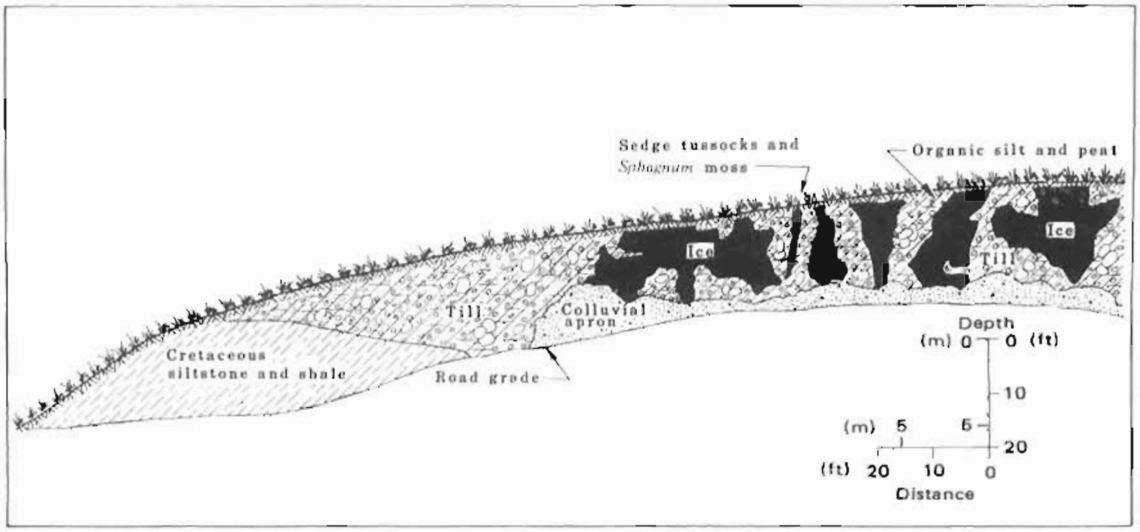


Figure 131. Geologic section exposed in southwest wall of Happy Valley roadcut. Till composition is silt with some sand, gravel, and clay, and scattered to numerous cobbles and boulders. A radiocarbon date of >49,000 yr B.P. (USGS-56) was obtained from a peat lens near the base of a 5-m-thick surficial gray silt layer that occurs above the till to the right of the section illustrated here (T.D. Hamilton, pers. commun.) (modified from Kreig and Reger, 1982, fig. 13).

Figure 132. Ice wedges exposed in Happy Valley cut, June 1974 (photograph taken by R&M Consultants, Inc.).

Figure 133. Gully erosion exposing large ice wedge just north of the Happy Valley cut (photograph taken by R. Veazey on July 22, 1982).

By July 1975, massive ground ice was no longer visible in roadcuts, but it continued melting and caused slope retreat by slump and flowage. The slope has gradually receded as ice continues to melt. Ample evidence of ice-wedge polygons in the area is seen on close inspection of aerial photographs. About 0.5 km north of here and on the east side of the road, gully erosion has exposed large ice wedges (fig. 133). The gully is forming from the erosive forces of drainage water collected by the road and channeled through a culvert. Although headward erosion toward the road was still quite active in summer 1982, the lower portion of the gully is stabilizing naturally.

D-326.5 to D-340.0

The road crosses ground moraine and end moraines of the Sagavanirktok Glaciation. This terrain is typical of the Arctic Foothills. Ice-rich till derived locally and from sedimentary rocks in the Brooks Range to the south covers a tilted sequence of interbedded shale, siltstone, and sandstone of Cretaceous age (Kreig and Reger, 1982, pl. 28). Slope processes have greatly modified the original morainal topography, lowering and rounding high areas and filling depressions, and surface streams have become well integrated. The conspicuous flat-floored upland depressions, which are partially filled with ice-rich peat, organic-rich slopewash deposits, and colluvium at least 1.5 m thick, may be partially filled kettles or thaw ponds and basins developed through local deep thawing of ice-rich sediments. An example of such a depression is crossed by the road at Mile 334. Similar features occur in many

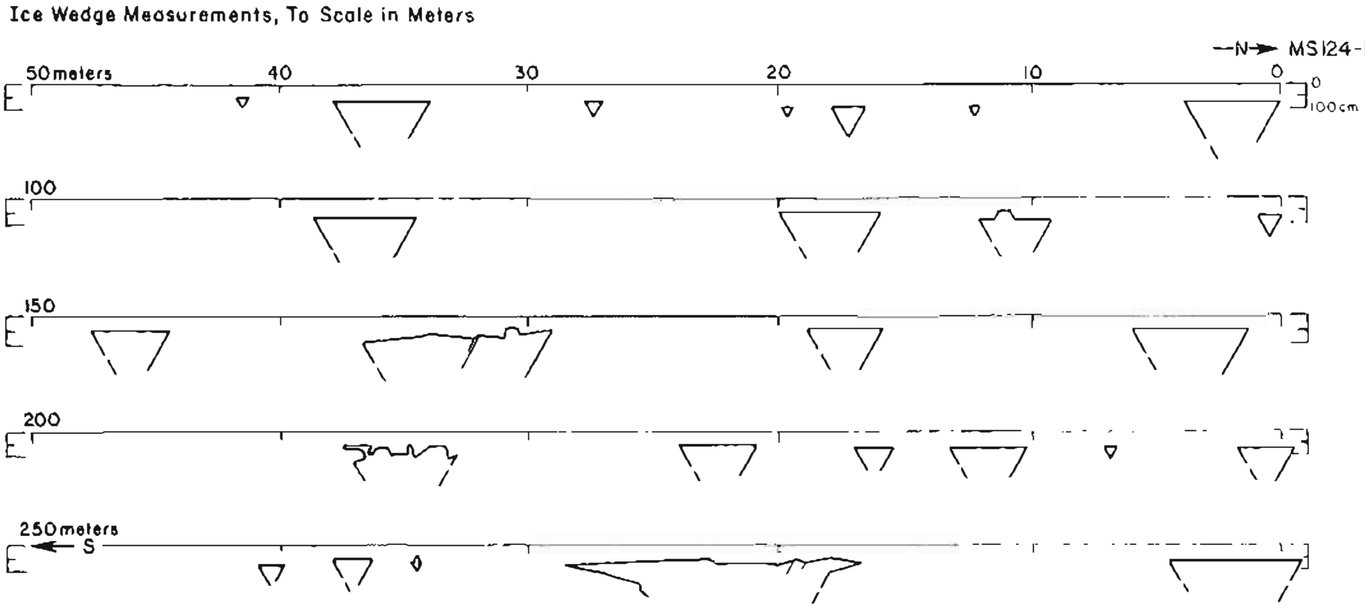


Figure 134. Idealized cross sections of fuel-gas line trench immediately south of the access road to Material Site 124-1. Tops of wedges are to horizontal scale, but shapes are idealized and not to vertical scale (Brown and Berg, 1980, fig. 25; observed by Jerry Brown in 1976).

areas beyond the known limits of glaciation. Most basin floors display the well-developed polygonal surface pattern of ice wedges. High-centered polygons indicate local degradation of ice wedges.

D-327.6
The elevated pipeline crosses under the road.

D-334.0
The road crosses numerous drainages that contain well-developed ice-wedge polygons like those observed both north and south of Happy Valley Camp. Occasional exposed ice wedges may be seen melting. In a drained lake basin immediately south of the access road to the east (Material Site 124-1), the fuel-gas line trench exposed a 1-km-long section of ice wedges (fig. 134). The irregular distribution of the tops of these wedges indicates that they were formed and modified by several cycles of development and degradation. Many VSM logs of this area show large amounts of massive ice. Kovacs and Morey (1978) were able to detect the top and bottom of massive ground ice along the elevated section of the pipeline by using an impulse radar system.

D-336.0 : Happy Valley Camp.
[L] This area is the type locality for the Sagavanirktok Glaciation of Detterman and others (1958) (fig. 129). Beaded drainage, resulting from the melting of ice wedges, occurs on either side of the road throughout these uplands.

D-337.0 to D-340.0
[M] Immediately north of Happy Valley Camp, the road cuts across several more basins and drainages that contain ice-wedge polygons (fig. 129). These basins are filled with organic-rich silt and sand. A thaw lake adjacent to

the road is actively eroding into an ice-rich, peaty bluff. The road crosses broad, smoothly sloping, tussock-covered moraines of Sagavanirktok age, then descends the moraine front to follow the relatively smooth surface of the associated outwash terrace and the flood plain of the Sagavanirktok River, which it follows nearly to Sagwon Bluff.

D-340.0 to D-343.8

Rivercut exposures of 30-m-thick outwash terrace of Sagavanirktok age are visible along the east side of the flood plain. Oxidized outwash gravel overlies till of Anaktuvuk age that is underlain by bedrock in some places. Outwash occurs directly above bedrock in a few exposures, with scattered erratic boulders forming a residual deposit along the bedrock surface.

D-350.0

The road ascends onto the Sagwon uplands. This marks the northern limit of alder (Alnus viridis) along the road corridor. Sagwon Bluffs may be seen to the north. There is a solifluction slope on the west side of the road. Several old and largely vegetated earth-flow scarps are present. This point marks the northernmost advance of the Anaktuvuk Glaciation.

D-352.0

Bladed 'cat' trails cut across from the west and parallel the road. The Sagwon uplands area was heavily impacted by winter and summer tractor trains in the 1960's. Disturbance of the surface vegetation triggered melting of the underlying wedges and other forms of ground ice in the fine-grained loess and colluvium. A number of thermokarst ponds are present. Pond depths, indicating loss of volume due to ground ice melting, ranged between 38 and 67 cm and averaged 50 cm in 13 ponds measured. Radiocarbon dates in swales range between 4,900 and 6,000 yr B.P. (K.R. Everett, pers. commun.; fig. 135).

D-352.0 to D-355.0

These steeply rolling uplands may have been covered by the Gunsight Mountain Glaciation. Poorly cemented sandstone and conglomerates of the Sagavanirktok Formation of Tertiary age crop out at right angles to the road. Ice wedges are occasionally exposed in gullies eroded along the edge of the road (fig. 136). Beaded drainage in valley bottoms indicates the extent of ice-wedge formation and melt.

D-355.6

A probably active solifluction slope impinges on the road from the east. Bluffs to the east (not visible) have active mudflows, oil-soaked sands, and coal beds in Tertiary deposits. On these river terraces is an Alaskan endemic population of Muir's fleabane daisy (Erigeron muiri). No ground or air access is permitted around the bluffs because this is also an endangered raptor habitat.

D-356.3 : Material Site 127-2.1B.

Large cracks are visible in weathered Tertiary sand and gravel (fig. 137). Thermokarst pits, caused by melting of buried ice wedges, are also present in the gravelly upland material site. This location offers an excellent panorama of the Arctic Coastal Plain and the rolling foothills.

D-360.4 : Pump Station 2.

The road descends onto the terraces of the Sagavanirktok River and the

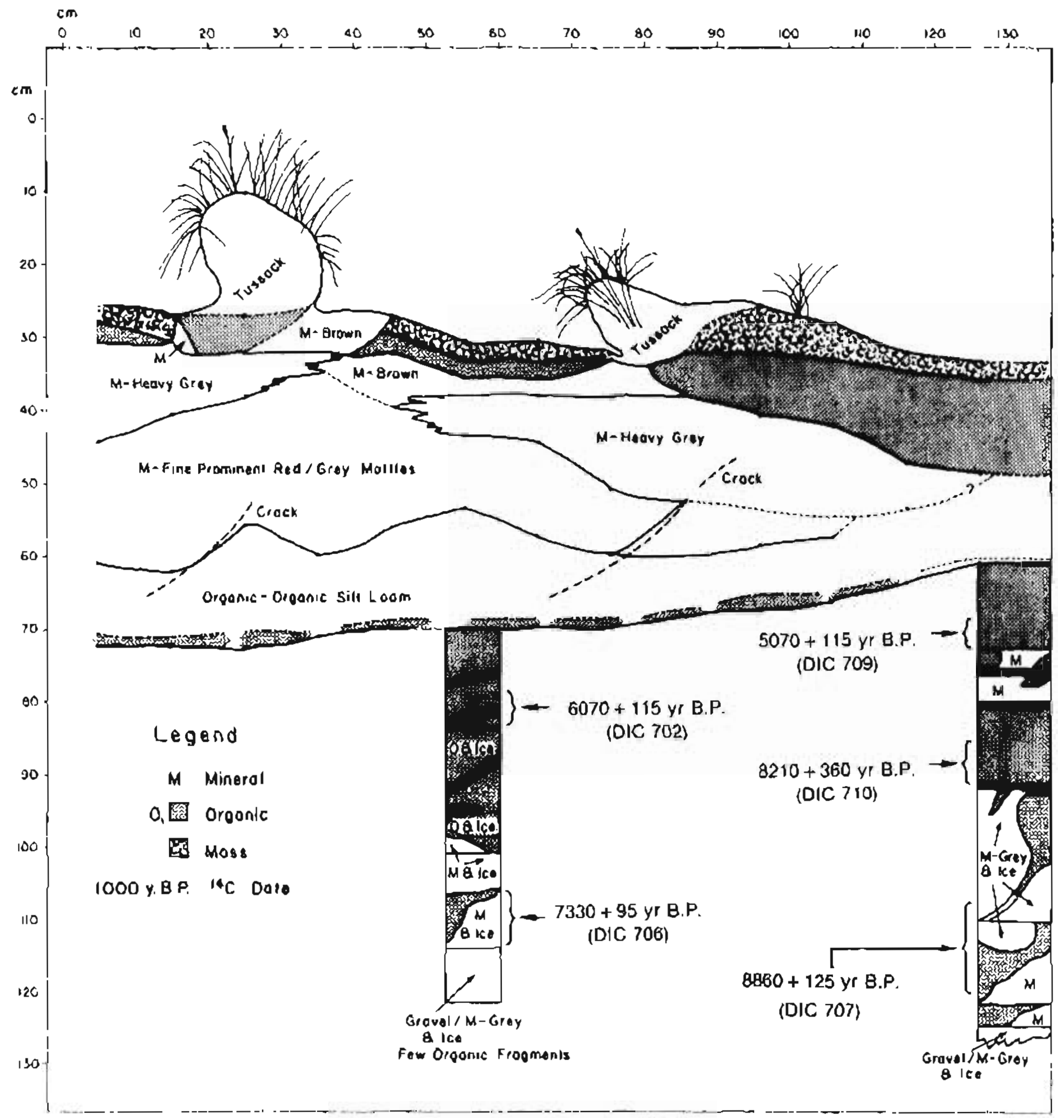


Figure 135. Section of upland (tussock-frost scar) tundra soil (Pergelic Cryaquepts) in the Sagwon area. The processes that incorporate organic material within the soil have operated over a considerable span of time. Discontinuous and interrupted soil horizons are typical of tundra (frost-disturbed) (modified from Everett and Brown, 1982, fig. 8).

Arctic Coastal Plain. The elevation of the Arctic Coastal Plain at this point is 170 m. It begins a gentle descent to Prudhoe Bay some 100 km north. The northern limit of dwarf birch (Betula nana) along the road corridor occurs at the base of the slope opposite Pump Station 2 (to the east). The pipe is elevated in this area because the overburden of 5 m of ice-rich silt was too thick to trench so that the pipe could be buried in the underlying thaw-stable ground. This is the northern boundary of the utility corridor and of federal lands under control of the Bureau of Land Management. Land north of this point is owned by the state.

Figure 136. Gully erosion adjacent to east side of road on Sagwon upland exposed ice-rich sediment and small ice wedge (next to shovel) (photograph taken by J. Brown on July 5, 1981).

Figure 137. Large contraction cracks (foreground) were exposed during extraction of poorly cemented gravel of Tertiary age for road construction at Material Site 127-2.1B. Interconnecting ice wedges have since melted to form thermokarst troughs (photograph taken by J. Brown on July 15, 1981).

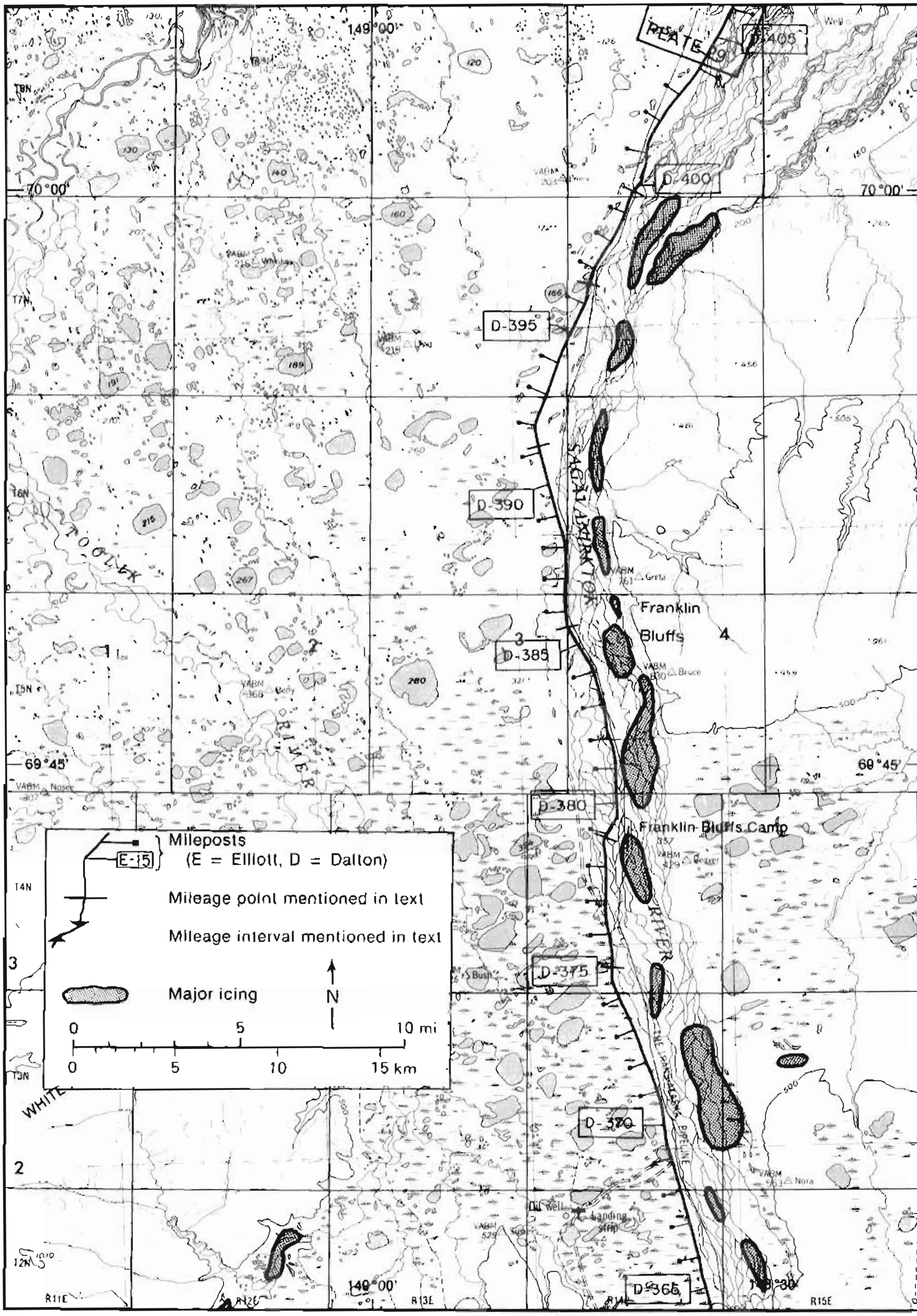


Figure 138. Route map between Pump Station 2 and just south of Deadhorse (scale 1:250,000). Plate 29 refers to illustration in Kreig and Reger (1982).

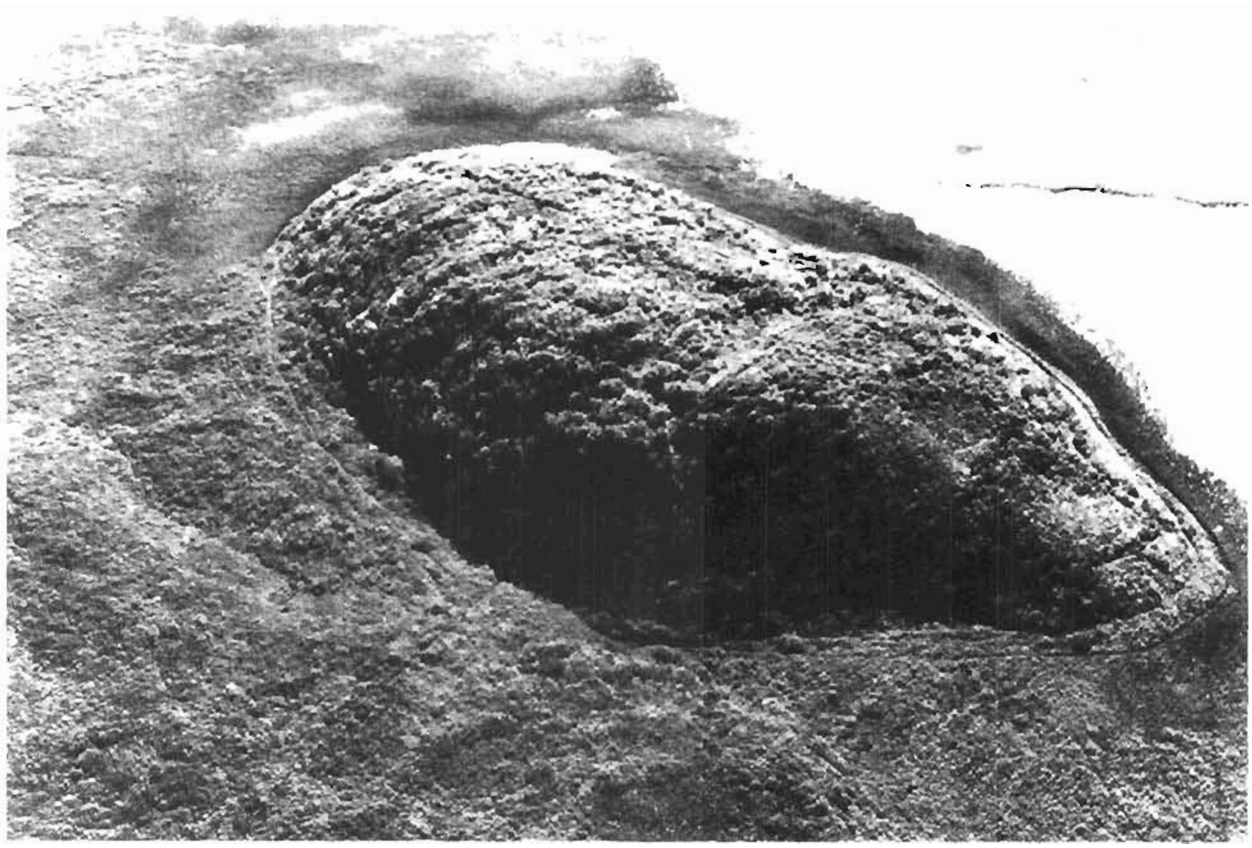


Figure 139. A relatively small pingo in the Toolik River pingo field. Such features are generally less than 5 m in height, and willows are the principal shrub on them. Note polygonal troughs on right end (photograph taken by K.R. Everett).

D-363.0

The line of low cliffs bordering low hills to the north marks Franklin Bluffs. Late snowbeds may be seen in July. East of the road, the Ivishak River empties into the Sagavanirktok River. The pipeline to the east is buried in frozen thaw-stable gravels under thaw-unstable fine-grained soils. The Brooks Range can be seen to the southeast, and the foothills and White Hills to the southwest and west, respectively. A thaw lake is observed adjacent to the road. The road passes over a series of low ridges composed of ice-rich silt of unknown origin.

D-375.0

The small hill about 8 km west of the road is one of many pingos in the Toolik River pingo field. This field occupies an area of the lake-dotted flat terrain typical of the Teshekpuk Lake section of the Arctic Coastal Plain that projects south between segments of the White Hills. This area serves as a corridor for the present Sagavanirktok, Putuligayuk, and Toolik rivers. Regional elevation ranges between 60 and 75 m, and relative relief, excluding the pingos, ranges between 3 and 6 m. The pingos are numerous, and the concentration is probably the greatest on the North Slope. In plan, most pingos in the area are ovoid and their long axes range from 50 to over 130 m (fig. 139). There is also a considerable range in height from a few meters for

Figure 140. Percy Pingo, one of the largest pingos in the Toolik River pingo area, located approximately 5 km west of the road (photograph taken by D. Atwood on July 19, 1982).

frost blisters to nearly 20 m. The pingo shown in figure 140 is one of the largest in the region. It is generally assumed that pingos represent a localized upward bulging of frozen near-surface sediments that was caused by hydrostatic forces associated with the formation of an ice core. The formation of pingos and their locations have been closely tied to the thaw-lake cycle (see Prudhoe Bay section). They may form in recently drained thaw lakes that were deep enough to have had thaw windows or deep thaw bulbs beneath them and where unfrozen sediments had suitable permeability. Numerous examples of this association between pingos and thaw-lake basins can be found on the Arctic Coastal Plain. There are relatively few examples of pingos in thaw-lake basins and it is probable that their development is tied to hydrostatic forces associated with the freezing of taliks developed beneath former channels of the Toolik and Putuligayuk Rivers.[19]

Pingos provide a botanical contrast on the Arctic Coastal Plain with the thaw lakes and wet sedge meadows. The steep sides provide such good drainage that the plant cover is very similar to if not essentially the same as the rich sedge-grass-forb meadows of alpine slopes in the Brooks Range to the south. South-facing exposures and the summits provide habitats for species quite "out of place" on the Arctic Coastal Plain (Koranda, 1960).

[19] Based on material provided by K.R. Everett.

Figure 141. Franklin Bluffs with late snowbeds in July. Lower beds are siltstone, sandstone, and pebble conglomerate. Upper beds are quartz pebble conglomerate (photograph taken by G. Johns on July 15, 1981).

Figure 142. Upper section of eroding Franklin Bluffs showing deposition in alluvial fans (photograph taken by P. Spatt).

D-379.0 : Franklin Bluffs Camp.

To the west-northwest can be seen pingo Berry, and the White Hills of the Tertiary Sagavanirktok Formation are visible to the southwest.

D-385.5

Franklin Bluffs may be seen to the east and a pingo to the west. Franklin Bluffs is a remnant of lower Tertiary claystone, siltstone, sandstone, and conglomerate beds (fig. 141). These units compose the lower part of the Sagavanirktok Formation. Through much of their extent, the bluffs are being actively eroded by the east branch of the Sagavanirktok River. The orange coloration of the lower part of the bluffs reflects ferruginous, weakly indurated siltstones interbedded with relatively thin (several meters), strongly indurated gritty sandstones and pebble conglomerates. The cementing material is intensely colored by oxidized iron. These beds are undergoing badlands erosion (fig. 142). The upper part of the high bluffs is composed of a very bright, white quartz pebble conglomerate. These materials are exposed at various other locations on the bluffs and on upland positions on the foothills east of Toolik River. Their color lends the name White Hills to this physiographic section of the Arctic Coastal Plain.

Deeper valleys are sites of long-lying to semipermanent snow. Semipermanent snow is characteristic of the entire lower bluff line extending south from the Franklin Bluffs camp area. The vegetation (Koranda, 1960) and the geomorphology and developmental stages of the alluvial fans and their upland drainages (Anderson and Hussey, 1962; Reckendorf and Hussey, 1962) are of interest. Growth of the fans along the base of the bluffs (fig. 141) is initiated as colluvial cones. Equilibrium is eventually reached when the slope angles of both the fans and drainage area are about equal. Melting of deep areas of drifted snow and the ice-rich nature of the ice-cemented gravels adds to the critical instability of the slopes.

Small groups of caribou are frequently observed along the road. During the summer, a cloud bank or fog bank is common between Franklin Bluffs and Prudhoe Bay, particularly in the morning. The low clouds coincide with the cool arctic air mass, which oscillates across the Arctic Coastal Plain (Haugen and Brown, 1980).

D-391.2 : Franklin Bluffs.

Late snowbeds are visible. A ponded area on the east side of the road at Material Site 133-3 was caused when the access road blocked drainage. Many of the vascular plants have died because of the extended periods of inundation.

D-396.7

River-training structures built to protect the pipeline from river erosion allow for a more shallow burial of the pipe in the river than otherwise would be required to place the pipeline below the depth of scour.

D-399.8

Percy Pingo may be seen from Material Site 134-3. A good opportunity exists here for photographing Franklin Bluffs. Low-center ice-wedge polygons are located beside the road. The buried pipeline crosses under the road for the last time as it heads toward Pump Station 1.

D-404.4

Immediately south of the access road to Material Site 135-A,B,C, erosion of ice-rich permafrost nearly undercut the road (fig. 143). Snowmelt runoff water apparently became concentrated in a shallow depression caused by a Rolligon trail along the east side of the road. During early summer 1976, this concentrated flow initiated erosion of massive ice lying within 0.5 m of the surface. Deep gullying resulted and moved headward toward and parallel to the road. The gullies appear to form polygons, which suggests melting of ice wedges; however, inspection of the gullies during the erosion period revealed some horizontally bedded ice that may have been buried river ice or icings. The erosion was finally arrested by building a shallow gravel dam upslope from it and diverting the flow through a half culvert.

Figure 143. Erosion channels caused by melting of ice-rich permafrost adjacent to road at Material Site 135-A,B,C. Although the pattern resembles polygonal ground, some horizontally bedded massive ice was observed in the exposed cut (from Brown and Berg, 1980, fig. 31, photograph taken by J. Brown on June 24, 1976).

Irregular thaw lakes are localized along former stream channels. These lakes postdate the channels with which they are associated. Relatively deep, anastomosing former stream channels are visible in sand and gravel beneath the younger, shallow thaw lakes. Accelerated thawing of ice-rich overbank deposits has produced scalloped lake banks (Kreig and Reger, 1982, pl. 29).

D-408.0

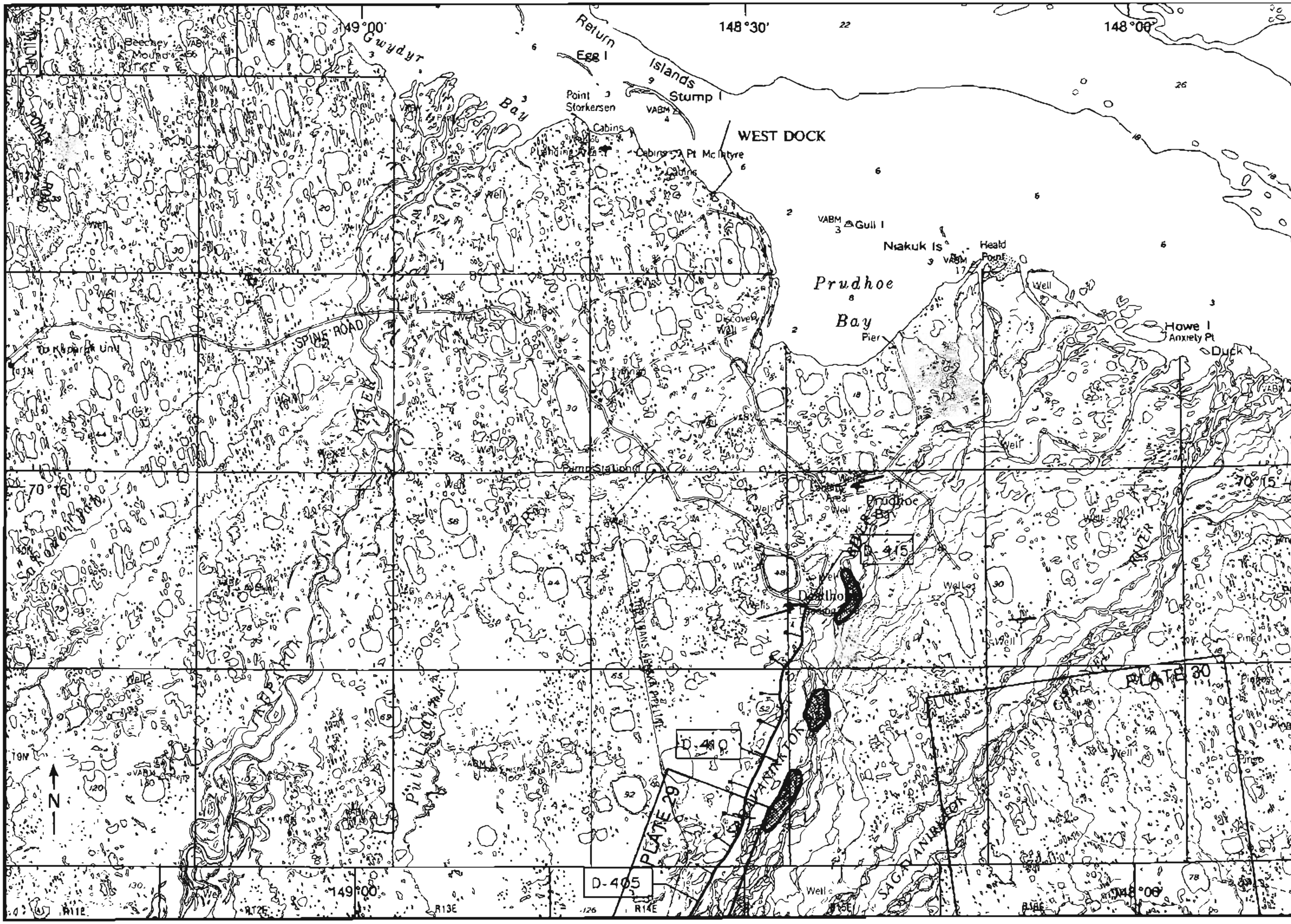
In summer 1982, the Sagavanirktok River shifted channels to the west to flow across a vegetated part of the flood plain. Presumably this channel will remain occupied, and westward erosion of the terrace toward the road will continue if left unchecked.

D-410.0

The Prudhoe Bay oilfield is visible along the horizon. Shallow thaw lakes are a dominant aspect of the landscape.

D-414.9 : Northern limit of state-maintained highway.

A 1968 bulldozed summer track extends to the west. This is an example of one of the first trails made in the Prudhoe Bay area. It was constructed by



149°00'
148°30'
148°00'
Gwydyr
Bay
Return
Egg I
Islands
Stump I
Point
Storkersen
Cabins
Pt McIntyre
WEST DOCK
VABM
Gull I
Niakuk Is
Heald
Point
Prudhoe
Bay
Pier
Howe I
Anxiety Pt
Duck I
SPINE ROAD
To Kuparuk Unit
Discovery
Well
Pump Station
Well
Prudhoe
Bay
D-415
D-410
D-405
PLATE 29
PLATE 30
SAGAVANIRKTOK
RIVER
Putuligayuk
70°15'
T10N
T9N
R11E
R12E
R13E
R14E
R15E
R16E
N

stripping the surface organic and active layer to make an embankment or roadbed. Subsequent thawing of the underlying ice wedges made the temporary road impassable.

Unvegetated coarse alluvium of the braided Sagavanirktok River flood plain contains continuous permafrost, except for shallow thaw bulbs beneath deeper active channels. During most of the winter and spring the river is ice covered, and much of the flood-plain surface is blown nearly free of snow. Breakup in late May to middle June is the dominant hydrologic event of the year and is marked by an abrupt increase in discharge (Scott, 1978; Updike and Howland, 1979). During high breakup flows, channel deposits of the Sagavanirktok River are frozen and little change in channel form or location occurs in braided reaches. These changes happen during the rest of the summer runoff season after coarse bedload and bank deposits begin thawing and stream competence is sufficient to move coarse material (Scott, 1978). The perennially frozen, cohesive banks of the Sagavanirktok River are undercut and retreat, primarily by thermoerosional niching, which produces scalloped banks and tilted soil blocks that retard lateral erosion.

Anastomosing channel patterns cover the surface of the 1- to 2.6-m-high terraces of the Sagavanirktok River. Some of these channels are floored with sandy gravel; others are partially filled with as much as 2.6 m of frozen lowland loess and fluvial sandy silt. Between channels low terrace treads are capped by 0.3 to 2.6 m of continuously frozen fluvial sandy silt overlying sand and gravel (Kreig and Reger, 1982, pl. 29).

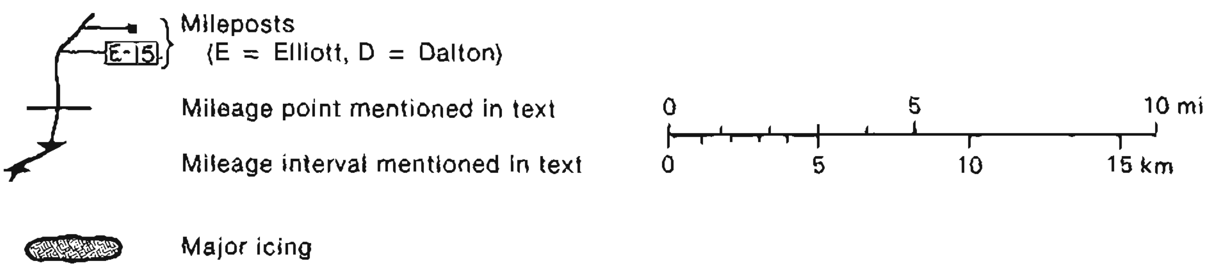
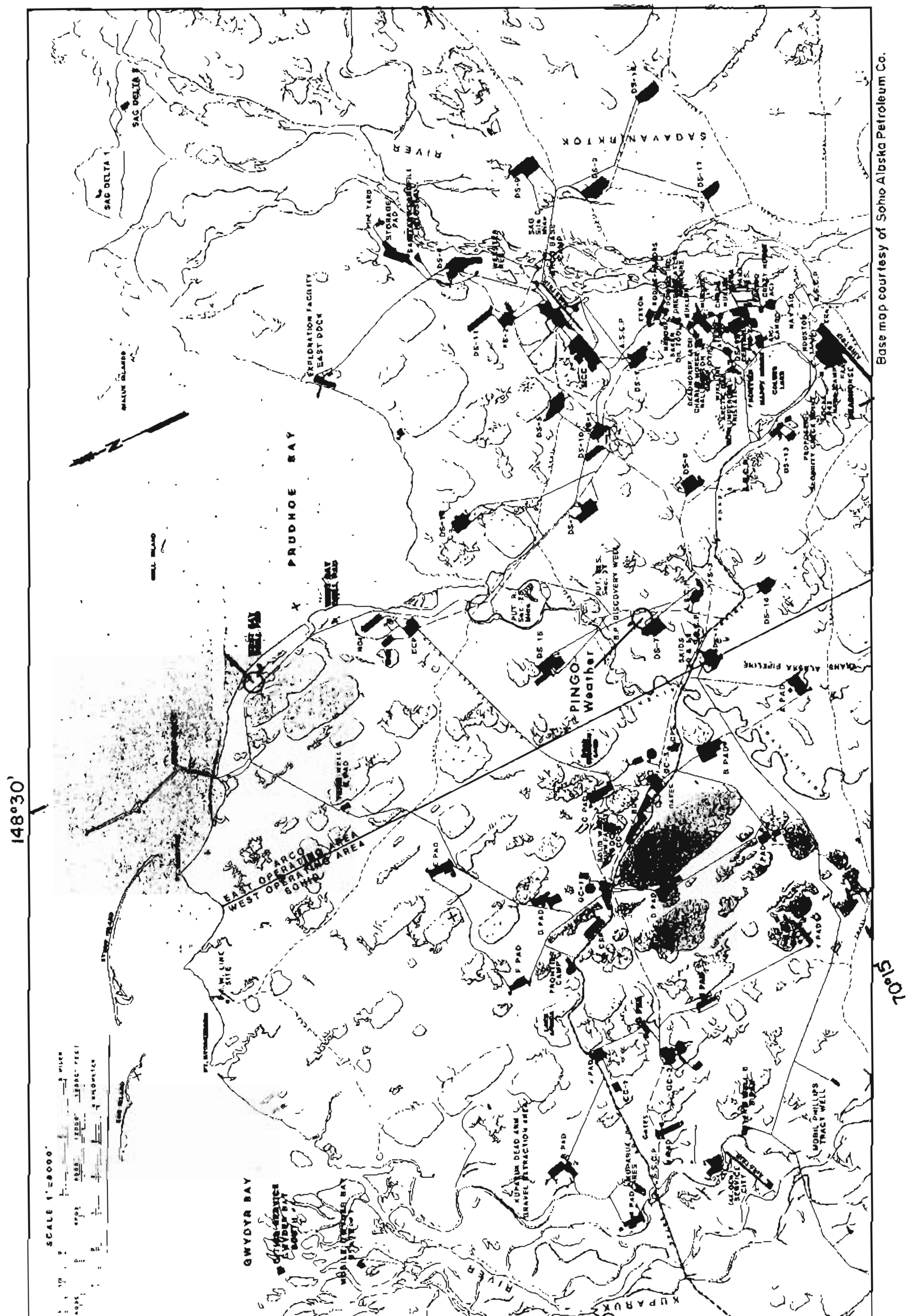


Figure 144. Map of the Deadhorse and Prudhoe Bay region (scale 1:250,000). Plates 29 and 30 refer to illustrations in Kreig and Reger (1982).



Base map courtesy of Sohio Alaska Petroleum Co.

Figure 145. Map of Prudhoe Bay oil field showing well pads, major facilities, the predominance of oriented lakes, and the location of two pingos mentioned in text.

THE PRUDHOE BAY REGION

The following sections, extracted from the Prudhoe Bay geobotanical atlas (Walker and others, 1980), provide some general landscape and geological background for this Arctic Coastal Plain environment. Additional details are found in the accompanying coastal guidebook (Rawlinson and others, 1983) and other publications (Walker and others, 1980; Walker, 1981). A series of Landsat-derived land cover maps of the Beechey Point Quadrangle and an accompanying report in preparation by Walker are based on techniques reported in Walker and others (1982) for a coastal area east of Prudhoe Bay.

Oil-field Development

The existence of large reservoirs of oil and gas at Prudhoe Bay was confirmed in early 1968 by two wells drilled by Atlantic Richfield (ARCO). British Petroleum (BP) began drilling its first well in November 1968. In the fall of 1969, following a $900-million lease sale by the State of Alaska, estimates of 9.6 billion barrels of recoverable oil and over 500 billion m^3 of salable gas were announced.

The oil and gas of the Prudhoe Bay field are contained in an area 72 km long and 29 km wide in the Sadlerochit Sandstone at depths below 2,400 m (Larminie, 1977). The field or unit is divided along a north-south line, with Sohio Petroleum Co. (formerly BP-Alaska) as operator of the western portion and ARCO of the eastern portion. A road net provides access to some 30 drill sites (fig. 145). Each site consists of a large gravel pad (2 m thick) from which initially 6 to 18 wells are directionally drilled to predetermined bottom-well locations. Approximately 150 wells were required for the initial stage of oil production. The oil passes through lines built on gravel pads or elevated on piles to gathering centers where the oil and the gas in solution are separated and the oil is cooled. The oil flows from these gathering centers to Alyeska Pipeline Service Company Pump Station No. 1, the northern terminus of the Trans-Alaska Pipeline System. The gas is piped to a central compressor plant on the ARCO side, compressed, and injected into the overlying gas cap to maintain the field pressure until gas transportation facilities are built.

Three major oil-industry facilities exist. The ARCO complex was the first to be built (1968). It was later expanded to house approximately 500 people in permanent facilities and about 2,600 more in temporary construction camps. In 1972, BP-Alaska began construction of its main camp, which provides accommodations for 250 in permanent facilities and 1,250 in temporary construction camps. In 1978, Sohio Petroleum Co. acquired all of BP-Alaska assets at Prudhoe Bay. Alyeska Pump Station 1, built on an artificially drained lake bed, was completed in 1977.

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

Geology

Prudhoe Bay is underlain by a major structural feature, the Barrow Arch, which consists of uplifted lower Paleozoic rocks (Carman and Hardwick, 1982). Above the arch is approximately 3,750 m of post-Devonian sedimentary rocks.

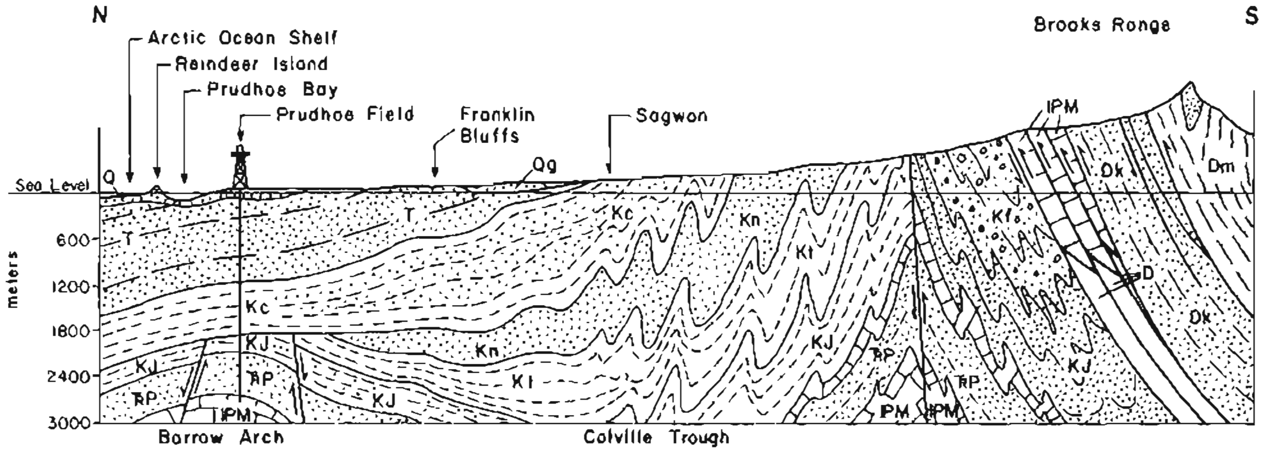


Figure 146. Geologic stratigraphic transect between Prudhoe Bay and the Brooks Range (modified from Bennison, 1974).

The thickness of these rocks increases southward toward the Colville Trough (fig. 146). Pre-Cretaceous sediments beneath Prudhoe Bay were derived from the Beaufort Uplift, a former source area north of the present coastline (Morgridge and Smith, 1972). Repeated uplift of the Barrow Arch, especially during Triassic and Jurassic time, resulted in a number of erosional unconformities. One of the most important of these breaks occurred near the end of the Jurassic, affecting not only Jurassic rocks but also older rocks. By early Cretaceous time the Barrow Arch and the northern sediment sources had begun to subside, and the source of sediments shifted to the south in response to the rising Brooks Range. An early Cretaceous marine shale deposited over the late Jurassic unconformity provided an impermeable seal beneath which hydrocarbons were trapped. The hydrocarbons are believed to be derived from the capping shale because nearly 2,500 m of marine and nonmarine sediments accumulated above it through the Mesozoic Period and into the Tertiary Period (Morgridge and Smith, 1972). A second oilfield, the Kuparuk, located to the west of the Prudhoe Bay field, is one of the largest in the U.S. (Carman and Hardwick, 1982).

The Prudhoe Bay region is situated on a thick section of unconsolidated Quaternary sediments, which lie unconformably on northward-dipping, weakly cemented sand, gravel, clay, and silt of the Tertiary Sagavanirktok Formation. Permafrost reaches depths of 660 m in the Prudhoe Bay region (Osterkamp and Payne, 1981; Lachenbruch and others, 1982). A profile of the depth of ice-bearing permafrost northward across the Arctic Coastal Plain in the proximity of the road is shown in figure 147 (Osterkamp and Payne, 1981). Most Quaternary deposits are unconsolidated sand and gravel composed of reworked Tertiary materials and materials derived from the Brooks Range to the south. They are similar to terrace and bed deposits of the present Sagavanirktok and Kuparuk rivers. Overlying these deposits are between 1.5 and 2.5 m of ice-rich silt with variable amounts of organic matter. The silt is probably equivalent to part of the Gubik Formation (Black, 1964). Juxtaposed with or immediately overlying the silt are deposits of loess 1 m or less thick that have been derived from the braided channels and deltas of the Sagavanirktok and Kuparuk Rivers. Surface organic deposits overlie the loess and, in many cases, are coextensive with underlying organic-rich sediments. Locally, sand dunes derived from the Sagavanirktok River cover the silt.

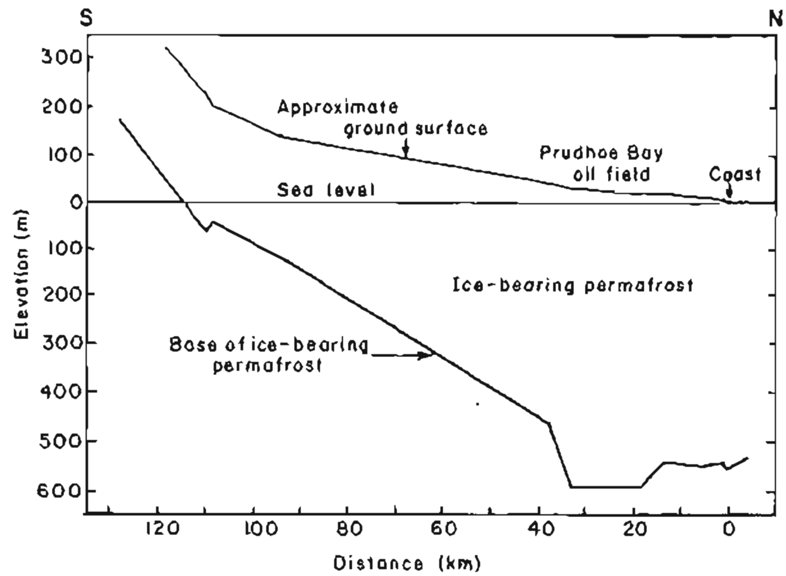


Figure 147. Profile of ice-bearing permafrost across the Arctic Coastal Plain in the vicinity of Prudhoe Bay (modified from Osterkamp and Payne, 1981, fig. 3).

Geomorphology, Soils, and Vegetation

The Prudhoe Bay region is essentially flat, with elevations rising gradually from about 3 m at the top of the sea bluffs to between 15 and 23 m some 20 km inland. The dominant geomorphic elements of the landscape, especially when it is viewed from the air or from maps, are the numerous elliptical lakes. Lakes occupy an estimated 25 to 30 percent of the landscape. Most of the larger lakes of the Arctic Coastal Plain and many of the smaller ones have a long-axis orientation of N15°W (Black and Barksdale, 1949). The vast majority of the lakes are shallow, 0.6 to 2 m deep, and are geologically short-lived features (Kreig and Reger, 1982, pl. 30).

The landscape between the lakes is characterized by a variety of patterned ground forms and associated ice wedges. The most common of these is the low-center polygon which, together with much less extensive areas of high-center polygons and transitional forms, constitutes the principal microrelief. Where best expressed, the microrelief contrast between polygon centers and troughs is 0.5 to 1 m, but extensive areas of polygonal ground patterns with microrelief contrast less than 0.5 m are common. Frost boils are also common. Other features include nonpatterned tundra; small (0.5 m diameter) polygons and hummocks along river banks; large-diameter, low relief (about 10 cm), high-center polygons on narrow interfluves and adjacent to most streams; pingos; and sand dunes near the mouth of the Sagavanirktok River.

Thaw lakes have modified the landscape over the last 10,000 yr through the combined processes of thermokarst and thermal erosion (Carson and Hussey, 1962; Everett and Parkinson, 1977). The initiation, expansion, and eventual drainage of these lakes constitute the principal elements of the thaw-lake cycle as originally defined by Britton (1967) (fig. 148). In a manner similar

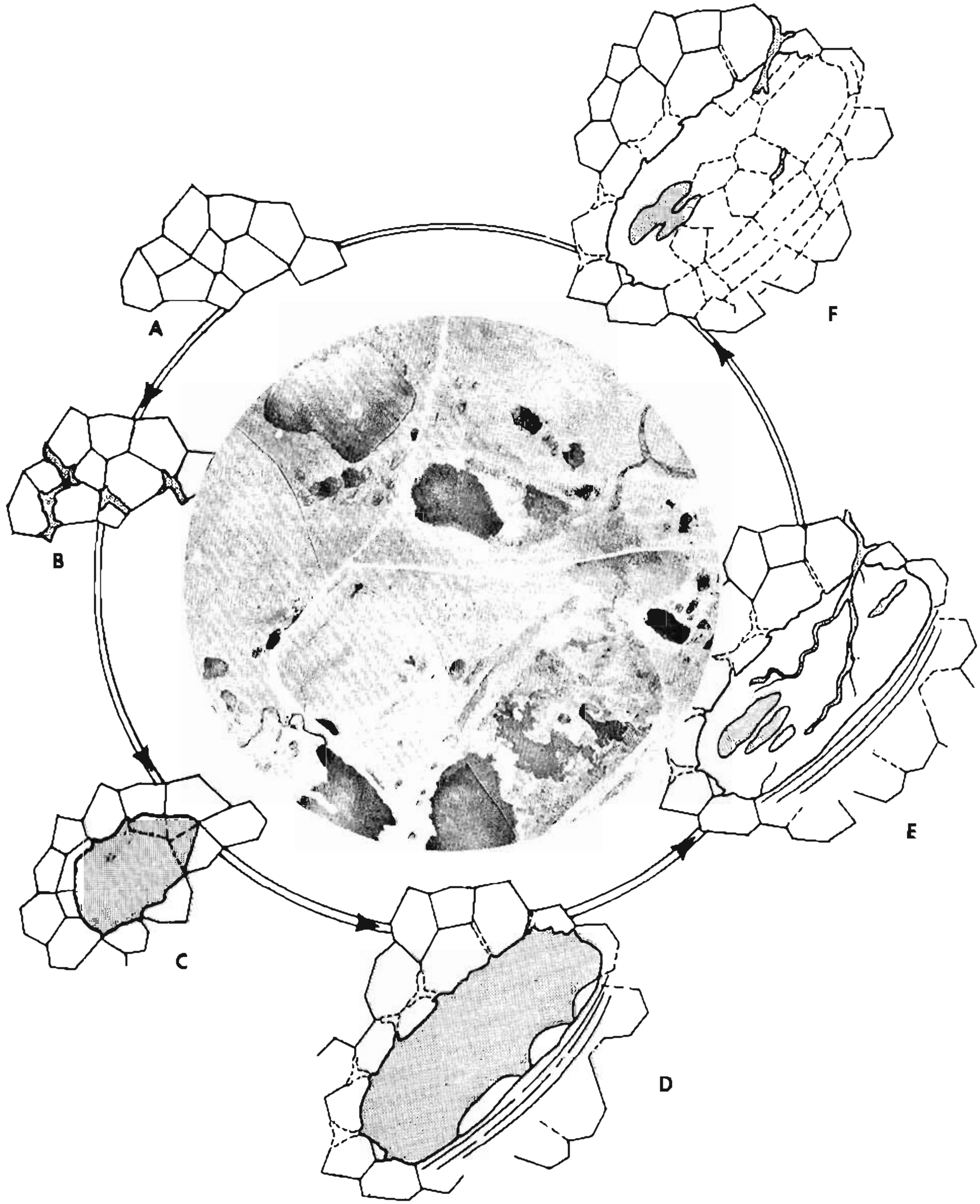


Figure 148. Stages of the thaw-lake cycle represented both schematically and photographically (Walker and others, 1980, fig. 28).

to that summarized by Brown and others (1980) for Barrow, the growth of the larger and deeper lakes has melted the ground ice contained in the permafrost and lowered the land surface in some areas, perhaps as much as several meters (see also Sellmann and others, 1975).

The initial polygonal outline develops in response to rapid, intense winter cooling and subsequent contraction of the fine-grained coastal-plain sediments (Lachenbruch, 1962). The narrow thermal-contraction cracks thus formed are subsequently filled by ice in the form of winter hoarfrost or water produced from melting of the snow cover. The process of cracking and filling, repeated over many centuries, results in the growth of vertical wedge-shaped masses of ice that penetrate many meters and may attain widths up to several tens of meters. The increase in volume caused by the expanding ice wedges commonly produces a buckling or heaving of the tundra on either side and parallel with them. The ridges or rims so produced, together with melting of the wedge tops, cause linear depressions or troughs to form immediately above the ice wedges that commonly define the polygonal surface pattern. A 242-m-long continuous subsurface section of the polygonal terrain was exposed during construction of the Arctic Gas Test Facility (fig. 149). Similar but less continuous exposures of ice wedges occur along the coastal bluffs and at the shorelines of some of the larger lakes, where mechanical and thermal erosion are especially active (for example, Lake Coleen at Deadhorse).

The development of an oriented thaw lake begins with climatic change or disruption of the vegetation and organic cover of the polygonized tundra (stage A in fig. 148). Thaw of the ice-rich, near-surface materials and melting of ice wedges can result in a pool of standing water and the development of a shallow pond that eventually becomes a thaw lake (stage B). If the pond is large enough, permafrost thaws beneath it and along its sides, resulting in expansion of the water body (stage C). Bank thaw proceeds most rapidly at and below water level, eroding the surrounding tundra and rapidly melting and truncating ice wedges to produce an irregular shoreline (stage D). Eventually, thawed and frozen blocks of tundra collapse into the growing lake. Their organic and mineral components are subsequently broken up and redistributed by wave and current action. Underwater shelves form where the tundra is eroded, usually along shorelines perpendicular to the dominant wind direction. Sediments and detritus are moved into the enlarging lake basin. The lake grows most rapidly along the axis perpendicular to the wind, partially because of the increased velocity and the seasonally higher temperatures of the water at the ends of the lake (Carson and Hussey, 1962).

Stream capture or the breaching of low divides between lakes may interrupt the expansive lake phase by partially or totally draining the lake. This process produces relatively broad, drained or partly drained basins (stage E). Even completely drained basins commonly remain very wet or have shallow standing water for protracted periods during the summer. On drainage, plants colonize the newly exposed lake sediments. With time, permafrost and ice wedges become reestablished in drained basins. If ice wedges were not completely removed in the lake portion of the cycle, they become active again and residual ice wedges may melt, forming deeper troughs. The result is the development of a surface polygonal pattern (stage F). In some cases large orthogonal polygons are established, sometimes in rows parallel to the margins of the lake basins.

The thaw-lake cycle and polygonized tundra, which is the product of ice-wedge growth or erosion, govern closely the distribution and composition of plant communities and soils. Although wet sites are certainly the most common, the tundra is actually composed of a wide variety of habitats, many of

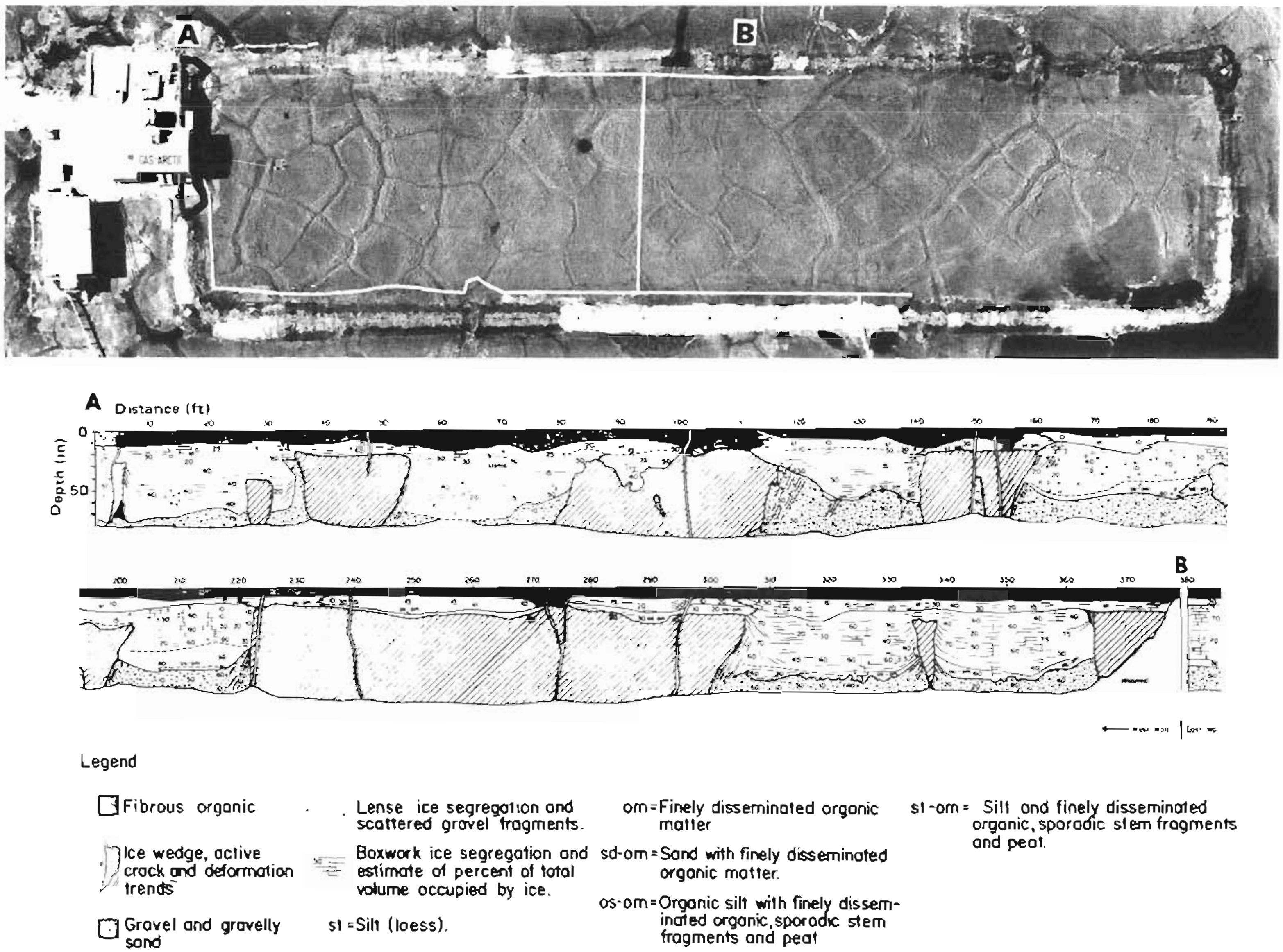


Figure 149. Air photo and cross section of ice wedges from a trench at the Gas Arctic Test Facility, Prudhoe Bay (Walker and others, 1980, fig. 16).

which are not wet. In low, marshy areas, such as the basins of low-center polygons and recently drained thaw lakes, sedge and moss communities are dominant. Often, pure stands of sedge or grass are rooted in lake sediments or inorganic deposits reworked during the lake phase. Organic matter production is high and conditions are ideal for its accumulation and preservation. The distribution of these conditions in a given basin is highly variable. Soils are most commonly Pergelic Cryaquepts. Continued organic accumulation in the situation just described will result in the development of Histic Pergelic Cryaquepts and in some cases an organic soil develops that may include, in the lower part, reworked organic materials from the former lake.

In the early stages of polygon development, microrelief contrasts are minor and soils and vegetation are little, if any, different from those of nonpatterned basins. In time, however, significant microrelief may develop between the polygon rims and centers as the polygon network becomes nonorthogonal. In the center, organic materials may continue to accumulate and Histic Pergelic Cryaquept soils develop. Slightly elevated sites such as polygon rims, high-center polygons, and sloping stream margins have more of an upland character, with sedges and mosses mixed with lichens, and low woody shrubs. On such sites with better drainage, the organic soils (Histic Pergelic Cryaquepts) are converted to highly decomposed humic types. Where inorganic lake sediments lie close to the organic surface horizon, the soil is gradually transformed from a Histic Pergelic Cryaquept to a Pergelic Cryaquoll.

The drainage of thaw lakes or the headward erosion of streams commonly convert formerly poorly drained environments such as lake basins and low-center polygon terrain into relatively well-drained areas. Thermokarst and thermal erosion processes quickly convert low-center polygons into high-center forms in which decomposition converts fibrous organic materials to highly humified states similar to those of polygon rims. If the substrate is mostly mineral, Histic Pergelic Cryaquepts are converted to Pergelic Cryaquolls or Pergelic Cryoborolls. Such sites, including pingos and river bluffs, have dry, alpinelike vegetation. Such areas are responsible for much of the botanical variety within the region. Smaller streams, such as the Putuligayuk and Little Putuligayuk Rivers, have willow- and sedge-covered banks. Bluffs, terraces, and steep slopes of pingos provide sufficient terrain relief for the formation of snow patches and their associated plant communities. Adjacent to such drainageways, and in particular the Putuligayuk River, reduction of the organic thickness by oxidation in response to better drainage contributes to an increase in frost heaving and consequently the deformation of frost boils. The frost-boil soils (Pergelic Cryaquepts) form a finely textured repetitious association with Pergelic Cryaquoll or Histic Pergelic Cryaquept soils that characterize frost-boil tundra.

Larger rivers have numerous braided channels with extensive gravel and sand bars. Cryorthent soils are most common on the bars and low terraces associated with the Sagavanirktok and Kuparuk Rivers.

Pingos are common to this coastal region. However, they do not commonly attain the large dimensions reported from the Mackenzie River region (Mackay, 1979). Figure 150 illustrates the major steps in formation of the closed-system pingos:

a) In lakes where the water depth exceeds 2 m, winter ice does not extend to the lake bottom and the underlying sediments. In the case of large lakes, the unfrozen zone may be very deep or permafrost may be absent.

b) Drainage of such lakes in the course of the thaw-lake cycle permits refreezing of the surface and progressive extension of frost into the subsurface. Freezeback from the sides of the thawed zone probably occurs as well.

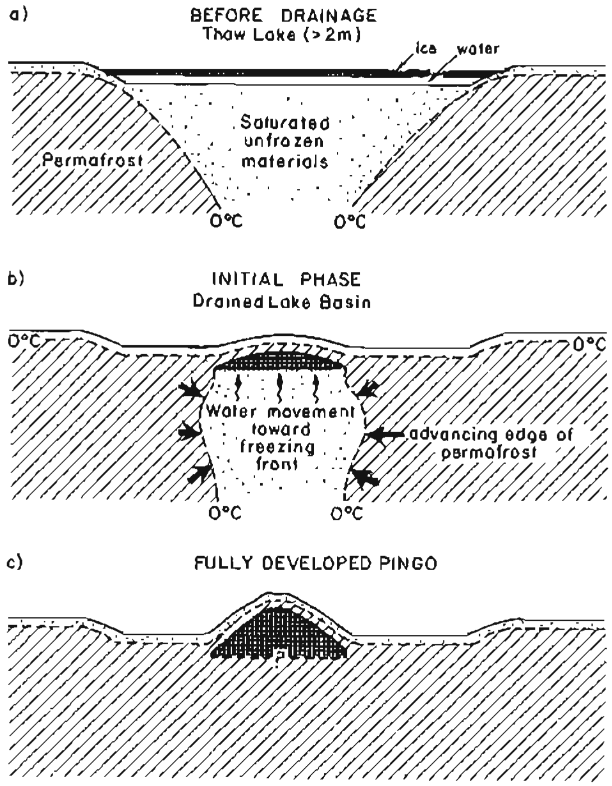


Figure 150. Schematic representation of closed-system pingo development (Walker and others, 1980, fig. 42).

A year-round supply of water is available to move toward the freezing front, where it freezes and becomes part of a growing ice mass that expands upward, forcing the surface to mound.

c) Growth of the pingo may continue for many centuries, as is the case of some of the very large pingos (60 m high) in the Mackenzie River Delta east of Prudhoe Bay. In the case of Prudhoe Bay pingos, the active-growth phase may have lasted only decades. Growth ceases when the ground-water source is cut off by the downward and lateral extension of permafrost or is depleted. The ice core may be maintained for long periods if the insulating organic materials and sediments remain undisturbed on its top and sides and regional climate does not warm appreciably.

Several small pingos in the Prudhoe Bay region were cored by CRREL in preparation for this conference field trip (fig. 145). 'Weather' pingo contains 12 m of ice under 1.1 m of sandy soil. 'Prudhoe Mound' contains 9 m of ice under 2.2 m of overburden. A third, large pingo west of Kuparuk River contains over 25 m of ice (Bruce Brockett, pers. commun.).

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APPENDIX A

SOIL TAXONOMY[20]

Five of the ten soil orders described in "Soil Taxonomy" (Soil Survey Staff, 1975) are recognized along the route between Fairbanks and Prudhoe Bay. Between Fairbanks and the Yukon River, soils belonging to the orders Inceptisols and Spodosols are most extensive. These are mineral soils that have only weakly differentiated soil horizons. The term Inceptisol refers to a soil showing only the inception of the soil-forming processes in the form of horizons. Principal among the Inceptisols are the Cryaquepts. Soils designated Aquepts are Inceptisols forming under an aquic (aqu), or reducing moisture environment. The prefix Cry indicates a mean annual temperature less than 8°C. Along much of the route, Cryaquept soils are designated Pergelic Cryaquepts, indicating the presence of permafrost within 1 m of the surface. North of the Continental Divide, the designation Pergelic precedes all soil names. A Pergelic Cryaquept, then, defines a cold, wet, poorly differentiated soil underlain by permafrost.

Organic carbon is unevenly distributed in the surface horizon of Pergelic Cryaquepts. Most such soils show some degree of mottling (iron oxidation) in the mineral horizon below the surface horizon. Mineral soils generally are gray, reflecting a saturated and reducing environment. In some cases an organic surface horizon more than 20 cm thick forms the epipedon (surface horizon), and the soils are termed Histic Pergelic Cryaquepts. Most Cryaquepts have some organic matter mixed in the subsurface horizons, commonly concentrated at or near the seasonal permafrost table. Many Pergelic Cryaquepts developed in silt, silt loam, or fine sandy loam display thixotropic characteristics and will flow spontaneously on vibration. Pergelic Cryaquepts are common components of soil complexes and, north of the Continental Divide, are often associated with Mollisols, particularly when they occur with frost scars. In such cases the complex is termed Ruptic (interrupted) Cryaqueptic Cryaquoll. The term Entic (Entisol) may replace Cryaqueptic if frost-scar soils show no horizon development.

Relatively well-drained and stable sites, especially on ridge crests, have Pergelic Cryumbrepts, which are Inceptisols with an umbric (dark-colored, base-poor) surface horizon underlain by an acidic horizon. Similar soils lacking the umbric surface horizon are usually designated Cryochrepts.

Spodosols include some of the soils termed podzols and soils with podzolic characteristics, for example the Subarctic Brown Forest soils. Spodosols are characterized by a subsurface horizon in which amorphous mixtures of humic materials and aluminum have accumulated. Iron may or may not be present. This horizon is commonly overlain by one in which iron and aluminum coatings have been removed from quartz grains through the action of organic acids. The horizon is designated as E, indicating that it has been eluviated (A_2 horizon of older soil descriptions). Eluviated clay may accumulate below the Spodic horizon.

Most Spodosols encountered along the route are more or less freely drained and have developed under coniferous vegetation or in alpine areas beneath evergreen dwarf and prostrate shrubs. They belong to the suborder Orthods and display characteristics typical (orthic) of the order.

Entisols are soils with no horizon development. They are common on unstable sites such as sand dunes, flood plains, and talus deposits. Cryopsamments are sandy Entisols that are subject to blowing and drifting.

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[20] For additional details, see Rieger, S., 1983, The genesis and classification of cold soils: New York, Academic Press.

Cryorthents are coarser and are composed of gravel and rock materials found in recent mudflows, glacial deposits, and stabilized river alluvium. Entisols may be found in association with any of the other soil orders, but along the route they occur most commonly with Inceptisols.

Soils belonging to the order Mollisols are extensive. They are found on all terrain types, particularly in the foothills and hilly coastal plain. Mollisols are dark-colored mineral soils. The dark color is a reflection of at least 2.5 percent organic carbon in the upper 18 cm of the profile. In addition to the dark color, Mollisols have a base saturation greater than 50 percent, that is, Mollisols are neutral or slightly alkaline in reaction (pH). Wet Mollisols are classified as Aquolls, aqu indicating an aquic (reducing) moisture regime and oll indicating the soil order Mollisols.

Following the nomenclature described above, a soil designated as a Pergelic Cryaquoll defines a cold, wet, dark-colored, base- and organic-rich mineral soil underlain by perennially frozen material. Pergelic Cryaquolls occurring in very wet areas may have a surface horizon with greater than 20 cm but less than 40 cm of organic material. These soils are designated as Histic Pergelic Cryaquolls (the term Histic indicates an organic surface horizon more than 20 cm thick). Mollisols on well-drained sites are termed Pergelic Cryoborolls.

Perhaps the least extensive and least predictable in occurrence are the organic soils (Histosols). These soils have a surface horizon composed of more than 40 cm of organic materials and generally more than 60 percent organic matter overlying gray, sometimes mottled, fine-textured mineral materials. Normally these soils are very wet (to the extent that the organic materials are buoyant or partially so). They occur on flat areas, either on ridge crests or on lowlands. Three taxa of cold Histosols are recognized: Pergelic Cryofibrists (fibrous, low-density organic matter), Pergelic Cryosaprists (nonfibrous, highly decomposed and dense organic matter), and Cryohemists (intermediate organic matter characteristics). Histosols may have any pH. South of the Continental Divide, mosses, especially *Sphagnum* spp., are a major component of these soils. North of the Divide, sedges are more important.

Soil profiles used in the text have been generalized and horizon designations simplified. Horizons designated O are organic (decomposition state symbols have been omitted). Surface horizons that are commonly organic rich are designated A. Subsurface horizons whose mineral component has been chemically altered or into which materials have been moved from surface horizons are designated as B. Mineral horizons which show little or no chemical alteration from the parent material are C horizons. In many cases soil profiles are composed of sequences of O or B or C horizons. These horizons are differentiated in the field on the basis of color, texture, or some other parameter and shown in the schematic profiles numerically from the surface down. Soils whose horizon descriptions are followed by the letter subscript g are gleyed, and those followed by f were frozen at the time the profile was described. In most cases, the f represents the bottom of the active layer.

APPENDIX B

LIST OF PLANTS

Latin name	Common name
Alnus tenuifolia	Thinleaf alder
Alnus viridis ssp. crispa	Green alder
Andromeda polifolia	Bog rosemary
Anemone parviflora	Northern anemone
Arctous (=Arctostaphylos) alpina ssp. rubra	Alpine bearberry
Arenaria chamissonis	Matted sandwort
Astragalus alpinus ssp. alpinus	Alpine milk vetch
Baeothryon (=Trichophorum) caespitosum	Tufted clubrush
Betula glandulosa	Shrub or resin birch
Betula nana	Dwarf birch
Betula papyrifera	Paper birch
Calamagrostis canadensis	Bent reed grass or Bluejoint
Carex albo-nigra	Sedge
C. aquatilis	Water sedge
C. aurea	Two-color sedge
C. concinna	Low northern sedge
C. lugens	Sedge
C. rostrata	Beaked sedge
C. rotundata	Sedge
C. scirpiodea	Sedge
Cassiope tetragona	Four-angled cassiope
Chamaedaphne calyculata	Leatherleaf
Comarum (=Pontentilla) palustre	March five finger
Draba cana	Draba or Rockcress
Draba macounii	Draba or Rockcress
Dryas integrifolia	White mountain avens
Dryas octopetala	Entire-leaf mountain avens
Empetrum eamsii	Crowberry
Empetrum nigrum	Crowberry
Equisetum arvense	Meadow horsetail
E. fluviatile	Swamp horsetail
E. pratense	Meadow horsetail
E. sylvaticum	Woodland horsetail
Erigeron grandiflorus	Fleabane
Erigeron muiri	Fleabane
Eriophorum angustifolium	Tall cottongrass
Eriophorum vaginatum	Tussock cottongrass
Festuca altaica	Fescue grass
Galium boreale	Northern bedstraw
Hippuris vulgaris	Mare's tail
Juncus triglumis	Rush
Kobresia simpliciuscula	Kobresia
Koenigia islandica	Koenigia
Larix laricina	Larch or tamarack
Ledum groenlandicum (=L. palustre)	Labrador tea
Ledum decumbens	Narrow-leaf labrador tea

Latin name	Common name
Linnaea borealis	Twinflower
Loiseleuria procumbens	Alpine azalea
Mertensia paniculata	Bluebell or lungwort
Menyanthes trifoliata	Buckbean or bogbean
Montia bostockii	Spring beauty
Oxytropis scammaniana	Scamman oxytrope
Pentaphylloides floribunda (=Potentilla fruticosa)	Shrubby cinquefoil
Picea glauca	White spruce
Picea mariana	Black spruce
Polygonum bistorta	Bistort
Populus balsamifera	Balsam poplar
Populus tremuloides	Aspen
Potentilla anserina	Silverweed
Pyrola asarifolia var. purpurea	Swamp wintergreen
Rosa acicularis	Prickly rose
Rubus chamaemorus	Cloudberry
Rubus idaeus	Raspberry
Salix arbusculoides	Little tree willow
S. bebbiana	Bebb willow
S. interior	Interior willow
Salix lanata	Lanate willow
Salix planifolia ssp. pulchra	Diamond-leaf willow
Salix reticulata	Netleaf willow
Saxifraga oppositifolia	Purple saxifrage
Shepherdia canadensis	Soapberry
Silene acaulis	Moss campion
Spiraea beauverdiana	Spirea
Stellaria umbellata	Chickweed
Tanacetum bipinnatum spp. huronense	Tansy
Thalaspi arcticum	Pennycress
Tofieldia pusilla	Scottish asphodel
Triglochin maritima	Martime arrow
Triglochin palustre	Marsh arrowgrass
Utricularia intermedia	Flat-leaf bladderwort
Vaccinium oxycoccus	Bog cranberry
Vaccinium uliginosum	Bog blueberry
Vaccinium vitis-idaea	Lingenberry or mountain cranberry
Viburnum edule	High bushcranberry