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AIR-PHOTO ANALYSIS AND SUMMARY OF LANDFORM SOIL PROPERTIES ALONG THE ROUTE OF THE TRANS-ALASKA PIPELINE SYSTEM

By
Raymond A. Kreig and Richard D. Reger

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STATE OF ALASKA

Bill Sheffield, *Governor*

Esther Wunnicke, *Commissioner, Dept. of Natural Resources*

Ross G. Schaff, *State Geologist*

Cover photo: *View northeast of route of Trans-Alaska Pipeline System in valley of Middle Fork Koyukuk River, Chandalar Quadrangle. Sukakpak Mountain in right background (Alyeska Pipeline Service Company photograph).*

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AIR-PHOTO ANALYSIS AND SUMMARY OF LANDFORM SOIL PROPERTIES ALONG THE ROUTE OF THE TRANS-ALASKA PIPELINE SYSTEM

By
Raymond A. Kreig[1] and Richard D. Reger[2]

ABSTRACT

The Trans-Alaska Pipeline System (TAPS) crosses 798 mi of diverse Alaskan terrain, including three major mountain ranges, 13 physiographic units, and 590 mi of permafrost. During preconstruction geotechnical evaluation of the TAPS route, primary reliance was placed on air-photo interpretation (supplemented by field checking) to map 55 individual landforms and four landform-surface phases within the 2-mi-wide inner corridor.

Detailed subsurface information on soils, bedrock, ground water, permafrost, and other environmental factors was obtained for 129 individual and composite landforms from 3,500 soil borings that produced over 33,700 test samples. This massive amount of information was stored in computer-data banks, and critical properties such as texture, moisture content, thaw strain, and dry density were summarized for each landform. The lessons learned during the TAPS geotechnical investigations, especially concerning landform identification and properties, can be applied to other mapping projects in the Subarctic and Arctic.

INTRODUCTION

Preliminary geotechnical investigations and construction of the Trans-Alaska Pipeline System presented geologists and engineers with a unique opportunity to improve techniques of terrain analysis in the Arctic and Subarctic. The lack of available detailed geotechnical information for design of the 798-mi-long, 48-in.-diameter warm-oil pipeline across 590 mi of permafrost (fig. 1) necessitated the collection of a massive amount of surface and subsurface data from a wide variety of landforms. Computerized techniques were used to evaluate soil properties in each landform along this north-south transect through complex arctic and subarctic terrain.

The purposes of this report are a) to briefly summarize the geotechnical properties of representative landforms identified during these investigations, and b) to present and discuss outstanding aerial photographs that show representative and unique landforms and significant terrain relationships.

[1]R.A. Kreig and Associates, 1503 W. 33rd Ave., Anchorage, Alaska 99503.
[2]DGGS, P.O. Box 80007, College, Alaska 99708.

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METHOD OF INVESTIGATION

Before the final TAPS route could be selected and the pipeline designed, detailed geotechnical information had to be gathered on soils, bedrock, ground water, permafrost, and other environmental conditions along the entire proposed route. Early in the geotechnical analysis, it was realized that a conventional foundation investigation (based on closely spaced soil borings to determine the specific geotechnical properties needed for design) was not feasible in the complex soils along the route because of the high expense of field operations, difficult logistics, and sheer magnitude of the project. Consequently, an efficient, integrated program of field reconnaissance, soil testing, and air-photo interpretation was developed and combined with a computer-assisted data-index and storage system to evaluate terrain conditions over large areas where ground-truth

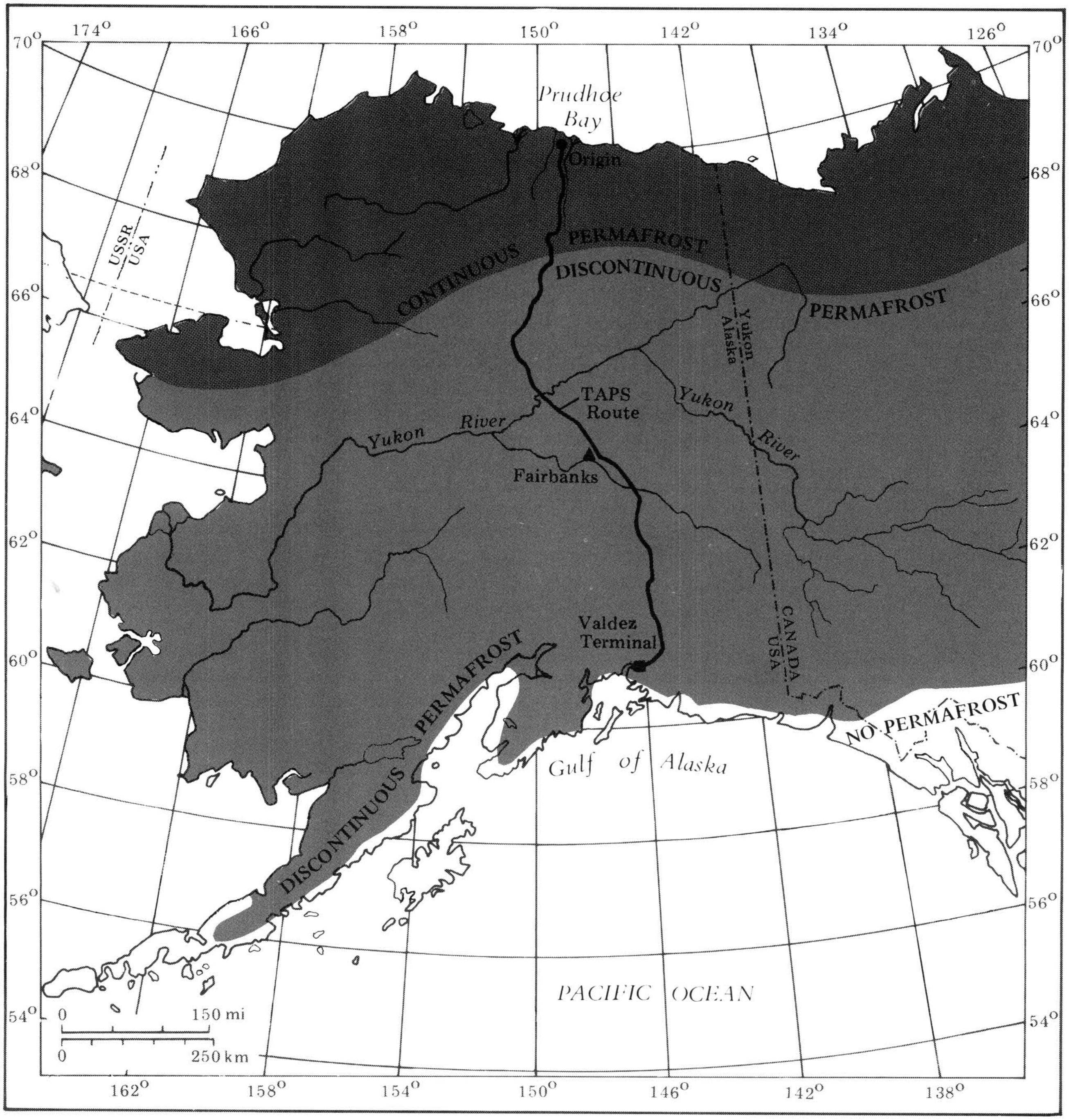

Figure 1. Map of Alaska showing route of the Trans-Alaska Pipeline System through the discontinuous and continuous permafrost zones.

information was meager. Heavy reliance was placed on the mapping of landforms on black-and-white, 1:24,000-scale aerial photographs by experienced photo-interpreters.

To provide detailed information on the distribution of permafrost, ground water, and bedrock, over 3,500 soil borings were eventually drilled along the proposed route, 2,100 on centerline. Several hundred frozen cores---obtained by the use of refrigerated drilling fluids (Hvorslev and Goode, 1966)---permitted laboratory testing and study of undisturbed soil samples, including ground ice. Soil-test data from over 33,700 samples documented variations of such soil properties as texture, moisture, density, specific gravity, and thaw settlement for each landform type. These characteristics were added to a computerized data bank of basic geotechnical information gathered during the field program, thereby permitting the first extensive correlation of landforms and soil characteristics in a complex terrain, much of which is perennially frozen (Kreig and Reger, 1976; Kreig, 1977).

During photointerpretation, special attention was given to delineating and collecting ground-truth information from landforms likely to contain permafrost. Permafrost mapping was most successful when based on converging evidence from several indicators, including vegetation, site slope and aspect, landform, soil type, and local drainage. It was less successful when sole reliance was placed on certain vegetation types (black spruce, sedge tussocks), or on terrain microfeatures (polygonal ground, solifluction features, thermokarstlike mounds) that may occur in nonpermafrost areas (Hopkins and others, 1955; Bird, 1967; Ferrians and others, 1969; Ferrians and Hobson, 1973). For example, stunted and scattered black spruce are usually an accurate indicator of near-surface permafrost in the Fairbanks area, but scrubby and sparse black spruce frequently occur on unfrozen ground in the Tonsina area. Solifluction lobes can be related to shallow bedrock rather than shallow permafrost, especially on moderate to steep slopes. Although polygonal ground, thaw ponds and lakes, pingos, beaded drainage, active rock glaciers, and well-preserved cryoplanation terraces are generally accurate indicators of permafrost, their absence does not necessarily imply unfrozen ground.

Permafrost distribution can be mapped accurately only with a thorough understanding of the natural environment of a particular site. Air-photo analysis, used in conjunction with ground-truth information, is the most efficient method of gathering data about terrain elements. In fact, we believe one cannot delineate the areal distribution of permafrost with reasonable accuracy without photointerpretation, even in areas where extensive ground-truth information is available.

ROUTE DESCRIPTION

PHYSIOGRAPHY AND GEOLOGY

The TAPS route traverses a terrain that includes three major mountain ranges and 13 physiographic units (fig. 2). From the Valdez Terminal at sea level in the Chugach Mountains, the pipeline extends up the intensely glaciated---and spectacularly scenic---Lowe River valley, bypasses Keystone Canyon, passes through Thompson Pass, winds down the Tsina River valley to the confluence of the Tiekel River, and then continues up the Tiekel River valley. Bedrock of the rugged Chugach Mountains in this section of the route is complexly folded and faulted Cretaceous graywacke, phyllite, and greenstone (Coulter and Coulter, 1961, 1962; Rose, 1965). Permafrost is absent at low elevations (Ferrians, 1965).

At the head of the Tiekel River, the pipeline crosses the inactive Border Ranges fault and enters a rugged terrane of late Paleozoic volcanic and volcaniclastic rocks that are regionally metamorphosed to greenschist and amphibolite facies and locally intruded by Mesozoic granitic plutons (Beikman, 1974; Robinson and Metz, 1979). The route then follows the drainage of the Tonsina River to Tonsina, across complex glaciofluvial and glaciolacustrine deposits that contain isolated masses of locally ice-rich permafrost. At Tonsina the pipeline leaves the Tonsina River valley and traverses the north flank of the Chugach Mountains to Willow Mountain, where it enters the Copper River Lowland, a broad basin floored by extensive and complexly interlayered glacial, glaciofluvial, glaciolacustrine, colluvial, eolian, and fluvial deposits (Nichols, 1956, 1960, 1961, 1963, 1966; Ferrians and Schmoll, 1957; Ferrians and others, 1958; Nichols and Yehle, 1961a,b, 1969; Ferrians, 1963a,b; Ferrians and Nichols, 1965). About 24 mi north of Willow Mountain, in the vicinity of the Tazlina River, the southern limit of discontinuous permafrost[3] is crossed; permafrost remains discontinuous through the Copper River Lowland, the Gulkana Upland, and the Alaska Range.

At Hogan Hill, about 65 mi north of Gulkana, the route enters the Gulkana Upland, an area of glacially modified bedrock hills and ridges separated by lowlands underlain by glacial and lacustrine deposits. The greenstone bedrock of Pennsylvanian to Triassic age is

[3]In this report, the term 'discontinuous permafrost' means that 50 to 90 percent of the land surface is underlain by perennially frozen ground. The terms 'sporadic permafrost' and 'continuous permafrost' mean that up to 50 percent and more than 90 percent of the terrain is underlain by perennially frozen ground, respectively.

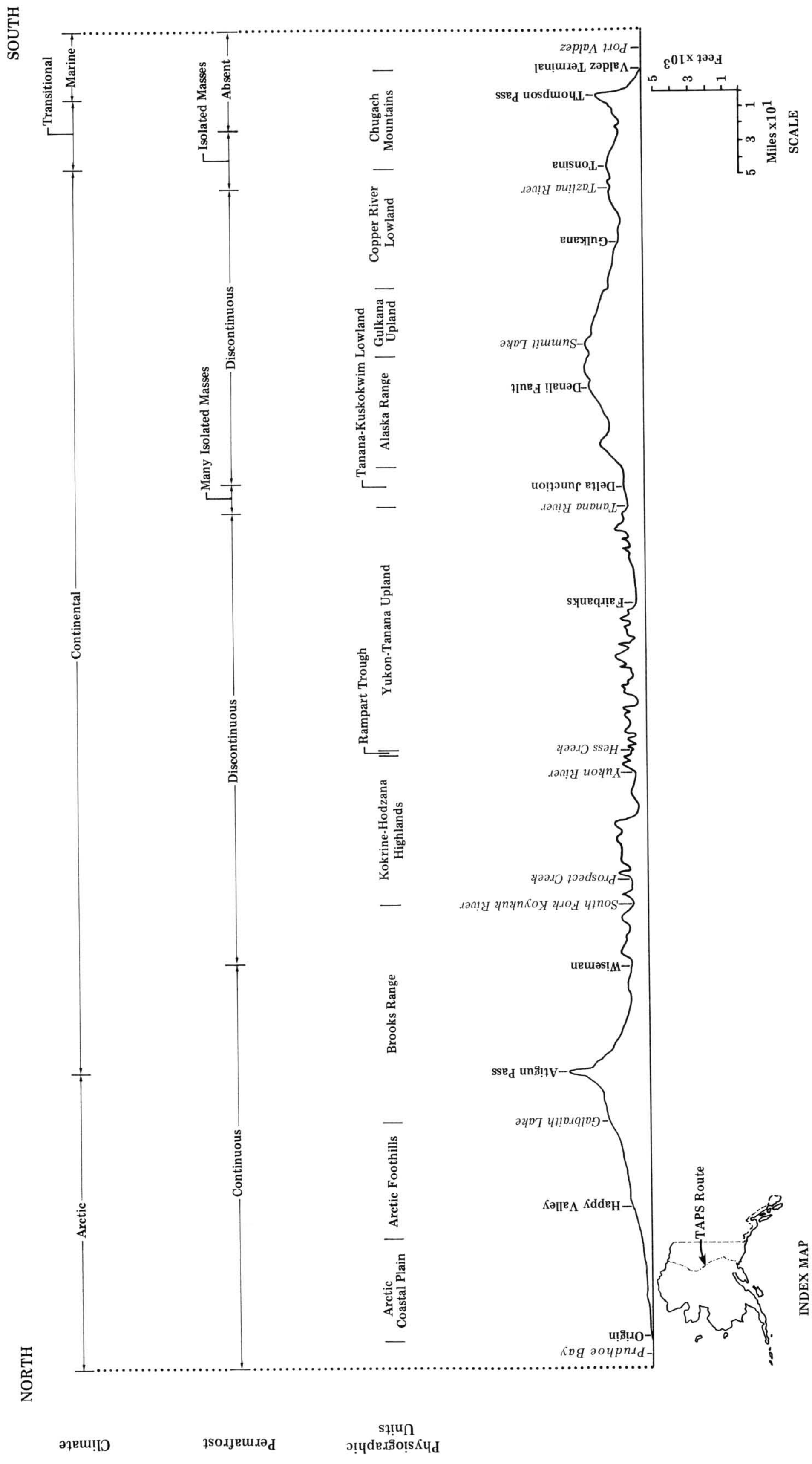

Figure 2. Summary of climate, permafrost, and physiography along the route of the Trans-Alaska Pipeline System (modified from Committee on Permafrost, 1975, fig. 3).

intruded by Mesozoic granitic stocks (Moffit, 1912, 1954; Stout, 1976).

The pipeline leaves the Gulkana Upland and enters the Alaska Range just north of Summit Lake. For the next 45 mi, the line closely parallels Phelan Creek and the upper Delta River, which cut through late Paleozoic marine sedimentary, volcaniclastic, and flow rocks and middle Tertiary coal-bearing continental clastic rocks as far north as the Denali fault (Bond, 1976; Stout, 1976). This major strike-slip fault and the associated McGinnis Glacier fault are both active and transect the TAPS route near the crest of the Alaska Range (Stout and others, 1973; Brogan and others, 1975; Packer and others, 1975). From the Denali fault north to the vicinity of Donnelly Dome, the Delta River flows through a U-shaped glacial valley cut across the structural trend of Precambrian to Paleozoic quartzite, schist, and amphibolite. About 24 mi south of Delta Junction, the pipeline alignment climbs out of the Delta River valley and curves around the west flank of Donnelly Dome, where it crosses an extension of the Donnelly Dome fault, an active normal fault (Péwé and Holmes, 1964; Hudson and Weber, 1977). From just north of Donnelly Dome to Delta Junction, the pipeline crosses discontinuously frozen late Pleistocene till and related outwash gravel. The boundary between the Alaska Range and the sediment-filled Tanana-Kuskokwim Lowland is about 12 mi south of Delta Junction.

From Delta Junction northward 9 mi to the Tanana River, the route crosses sporadically frozen glaciofluvial, fluvial, and eolian sediments of late Quaternary age. At the Tanana River, the route enters the southern Yukon-Tanana Upland and follows its southern margin, which roughly parallels the Tanana River, 90 mi northwest to the vicinity of Fairbanks. At the southern limit of the Yukon-Tanana Upland, permafrost becomes discontinuous and remains so northward into the southern Brooks Range. The southern Upland consists of rounded, loess-covered, stream-dissected hills and ridges of Precambrian to early Paleozoic crystalline quartzose and pelitic rocks of the greenschist and amphibolite facies that are locally intruded by small granitic plutons of Cretaceous and Tertiary age (Péwé and others, 1966; Foster and others, 1973; Bundtzen and Reger, 1977; Weber and others, 1978). North of Fairbanks, the route crosses this metamorphic terrane for about 30 mi to the vicinity of Globe Creek.

From Globe Creek north to the Yukon River, the route traverses northeast-trending belts of Paleozoic to Cretaceous volcanic and sedimentary rocks in fault contact with pods of ultramafic rocks (Beikman and Lathram, 1976). Eleven mi northwest of the Hess Creek crossing, the pipeline passes over the axis of the Rampart Trough, a very narrow and discontinuous belt of weakly consolidated volcaniclastic and coal-bearing Tertiary clastic sedimentary rocks that are tightly folded into mafic extrusive and intrusive rocks and associated clastic sedimentary rocks of Permian and Triassic age (Chapman and others, 1971). North of the Rampart Trough, the TAPS line enters the southern Kokrine-Hodzana Highlands and crosses frozen, loess-covered ridges of Permian to Triassic volcanic and sedimentary rocks north to the Yukon River (Chapman and others, 1971). The rest of the route through the Highlands to the South Fork Koyukuk River is over rounded, stream-dissected hills and ridges of late Paleozoic pelitic schist and phyllite, mafic volcanic and intrusive rocks, and pods of peridotite and dunite of Permian to Jurassic age; these rocks are intruded by Cretaceous granitic plutons (Patton and Miller, 1973). Lowlands contain fluvial and colluvial deposits of late Tertiary and Quaternary age. Evidence of Pleistocene glaciation from the Brooks Range occurs as far south as Prospect Creek.

The pipeline then enters the glaciated Brooks Range and ascends through the valleys of the Middle Fork Koyukuk River and the Dietrich River, climbs onto the Chandalar Shelf, and reaches its highest elevation (4,788 ft) at the Continental Divide in Atigun Pass. From there the system descends the Atigun River valley to the northern range front at Galbraith Lake. About 25 mi south of Wiseman, the pipeline corridor transects a narrow belt of Late Cretaceous continental sandstones and conglomerates containing shale, siltstone, and coal (Beikman and Lathram, 1976). From the northern limit of these rocks to Galbraith Lake, the route crosses east- and northeast-trending belts of middle to late Paleozoic marine sedimentary and volcanic rocks and low- to medium-grade schist, slate, and quartzite that are roughly equivalent in age (Reiser and others, 1979). North of Wiseman, the structural fabric is dominated by numerous low-angle faults resulting from northward thrusting in Late Cretaceous and early Tertiary time (Wahrhaftig, 1965; Churkin and others, 1979). Valleys contain a complex of glacial, glaciofluvial, lacustrine, alluvial, and colluvial deposits of early Pleistocene to Holocene age (Hamilton, 1978a-c, 1979a,b; Hamilton and Porter, 1975; Hamilton and Trexler, 1979). Wiseman marks the discontinuous-continuous permafrost boundary.

From Galbraith Lake north for 70 mi, the pipeline passes between low hills and over gentle piedmont slopes of the Arctic Foothills, closely following the Sagavanirktok River for 48 mi. Bedrock in the southern part of this section consists of Devonian to Cretaceous sedimentary rocks that are intensely folded and thrust faulted. In the northern part of this section, more gently folded marine and continental sedimentary rocks of Cretaceous and Tertiary age (Detterman and others, 1975) underlie Quaternary fluvial, glacial, eolian, and colluvial deposits containing continuous permafrost. The limit of Pleistocene glaciation lies about 50 mi north of the Brooks Range in the drainage of the Sagavanirktok River.

The northernmost segment of the TAPS route gradually descends from the Arctic Foothills---about 60 mi across the Arctic Coastal Plain---to the pipeline Origin, just south of Prudhoe Bay. The southern 47 mi of this section follows the Sagavanirktok River across a wedge of perennially frozen marine, fluvial, eolian, and lacustrine sediments that is underlain by nearly flat-lying Cretaceous and early Tertiary sedimentary rocks (Wahrhaftig, 1965; Detterman and others, 1975). Permafrost is continuous and shallow.

VEGETATION

The TAPS route crosses several major vegetation types (table 1). From the Valdez Terminal to the south side of Thompson Pass in the Chugach Mountains, the route passes through a coastal forest dominated by Sitka spruce and western and mountain hemlock with abundant black cottonwood on stream flood plains and low fluvial terraces. Beneath the upper canopy is a dense, shrubby understory, and profuse mosses cover the ground, logs, and lower tree limbs.

From the north side of Thompson Pass to the headwaters of the Dietrich River in the central Brooks Range, the pipeline traverses the interior boreal forest---a mosaic of white and black spruce, paper birch, aspen, balsam poplar, and tamarack formed largely in response to a complex fire history and the effects of permafrost. This extensive taiga includes widespread, open forests of low-growing spruce in the Copper River Lowland, in the Tanana River valley, in low areas of the Kokrine-Hodzana Highlands, and in numerous treeless bogs and fens on lower walls and floors of small stream valleys in the Yukon-Tanana Upland.

Alpine tundra, consisting of widespread barren soil and rock debris interspersed with low mats of herbaceous plants and shrubs, exists in Thompson Pass, in the uplands of the Kokrine-Hodzana Highlands, and across the crest of the Brooks Range from the headwaters of the Dietrich River to the headwaters of the Atigun River. A moist sedge-tussock tundra with scattered willows and dwarf birch overlies discontinuous and continuous permafrost from Paxson Lake to Isabelle Pass and from the headwaters of the Atigun River to the lower Sagavanirktok River. The route passes over wet tundra on the Arctic Coastal Plain along the lower course of the Sagavanirktok River to the Origin at Prudhoe Bay. This gently sloping section has widespread standing surface water and shallow continuous permafrost. Sedges and cottongrass mats, usually without tussocks, are widespread except in well-drained situations, where shrubs grow.

CLIMATE

The TAPS route passes through four climatic zones: maritime, transitional, continental, and arctic (Watson, 1959) (fig. 2).

A maritime climate dominated by oceanic influences affects the line from the Valdez Terminal to the north side of Thompson Pass. This area is characterized by cool, cloudy, moist summers and mild, cloudy, snowy winters. Annual and diurnal temperature variations are small. The mean annual temperature at Valdez is about 36°F; summer and winter extremes generally reach 64°F and -25°F, respectively. The freezing index, or average number of degree-days below 32°F each year, is 1,455 degree-days. Mean annual snowfall is heavy, about 245 in.; average annual precipitation is about 62 in.

From the north side of Thompson Pass to Willow Mountain just north of Tonsina, the climate is transitional between the maritime climate to the south and the continental climate to the north. Summers are warmer and less cloudy than in the vicinity of Valdez; winters are long, less cloudy, and colder. Diurnal and annual temperature fluctuations are more pronounced than in the maritime section. The mean annual temperature at Tonsina is 27°F; the coldest months, December and January, are as cold as -55° to -60°F and warmest summer days typically range from 65° to 69°F. The freezing index is 4,670 degree-days. Precipitation is less than south of Thompson Pass; at Tonsina, average annual snowfall is about 64 in. and average annual precipitation is about 13 in. Streams generally freeze in late October to late November; spring breakup, which is influenced by snowfall and rainfall, the presence of stream icings, and spring temperatures, usually occurs in April or early May.

A continental climate exists from Willow Mountain north to the Continental Divide at Atigun Pass in the central Brooks Range. Variations of daily and annual temperatures are the greatest in this 545-mi-long section of the route. For example, at Gulkana, in the southern part of this section, the mean annual temperature is 27°F, the maximum summer temperature is 91°F, and the winter minimum is -65°F. At Fairbanks, near the middle of the section, the mean annual temperature is 26°F, the highest summer temperatures are 93° to 96°F, and the lowest winter temperatures are below -60°F. At Bettles, 15 mi northwest of the alignment on the southern flank of the Brooks Range, the mean annual temperature is 21°F, summer highs reach 91° to 93°F, and winter minimums plummet to -65°F. Freezing indices range from 4,710 degree-days at Gulkana to about 6,600 degree-days at Bettles. Winter ice fog is common in low areas, especially near settlements, from late November through January, and steep temperature inversions develop during calm, clear weather. Winters are dry and the frequency of cloudy days is low relative to coastal areas. Average annual precipitation ranges from 11 in. at Gulkana to 14 in. at Bettles. Snowfall is quite variable, especially in mountainous areas, generally ranging from 46 in. at Gulkana to over 70 in. at Bettles. Streams usually freeze from late October through November. Stream breakup occurs from mid-April through

Table 1. *Relative abundance of woody plants of different vegetation types along the route of the Trans-Alaska Pipeline System (summarized from Viereck and Little, 1972).*

Symbols:
● common
○ occasional to rare

COMPOSITION	MAJOR VEGETATION TYPE														
		CLOSED SPRUCE-HARDWOOD FORESTS						TREELESS BOGS		SHRUB THICKETS			TUNDRA		
	COASTAL SPRUCE-HEMLOCK FOREST	WHITE SPRUCE TYPE	RECENT BURNS	QUAKING ASPEN TYPE	PAPER BIRCH TYPE	BALSAM POPLAR TYPE	OPEN, LOW-GROWING SPRUCE FOREST	COASTAL AREAS	INTERIOR AREAS	COASTAL ALDER TYPE	FLOOD-PLAIN TYPE	BIRCH-ALDER-WILLOW TYPE	MOIST TYPE	WET TYPE	ALPINE TYPE
TREES															
Alaska-cedar *(Chamaecyparis nootkatensis)*	●														
balsam poplar *(Populus balsamifera)*		●				●									
black cottonwood *(Populus trichocarpa)*	●					●									
black spruce *(Picea mariana)*				●	●		●								
mountain hemlock *(Tsuga mertensiana)*	●														
paper birch *(Betula papyrifera)*		●			●		●								
quaking aspen *(Populus tremuloides)*				●											
Sitka spruce *(Picea sitchensis)*	●														
tamarack *(Larix laricina)*							●								
western hemlock *(Tsuga meterophylla)*	●														
white spruce *(Picea glauca)*		●		●	●	●	●								
SHRUBS															
Alaska blueberry *(Vaccinium alaskaense)*	●									●					
Alaska bog willow *(Salix fuscescens)*									●			●	●	●	●
Alaska cassiope *(Cassiope mertensiana)*															●
Alaska sagebrush *(Artemisia alaskana)*				○											
Aleutian mountain-heath *(Phyllodoce aleutica)*													●		●
alpine-azalea *(Loiseleuria procumbens)*													●		●
alpine bearberry *(Arctostaphylos alpina)*												●	●		●
American green alder *(Alnus crispa)*			○			●			○		●		●	●	
American red current *(Ribes triste)*		●	○		●										
American red raspberry *(Rubus idaeus var. strigosus)*				○	○						●				
arctic willow *(Salix arctica)*													●		●
Barclay willow *(Salix barclayi)*	●		●		●			●	●	●	●	●	●		
Barratt willow *(Salix barrattiana)*													●		
barren-ground willow *(Salix brachcarpa ssp. niphoclada)*											●				
bearberry *(Arctostaphylos uva-ursi)*		○	○	●											
Beauverd spirea *(Spiraea beauverdiana)*			○						○			●	●		
Bebb willow *(Salix bebbiana)*		●	●	●	●		●				●				
bog blueberry *(Vaccinium uliginosum)*		●	○	○			●	●	●			●	●	●	●
bog cranberry *(Vaccinium oxycoccos)*							○	●	●				●	●	
bog-rosemary *(Andromeda polifolia)*								●	●					●	
buffaloberry *(Shepherdia canadensis)*		●	○	●		○					●				
bush cinquefoil *(Potentilla fruticosa)*		○	○			○	○		○			●			
Chamisso willow *(Salix chamissonis)*													●		●
common juniper *(Juniperus communis)*				○				●							
crowberry *(Empetrum nigrum)*		●	○	○	○		●	●	○			●			●
devilsclub *(Oplopanax horridus)*	●				○					●					
diamondleaf willow *(Salix planifolia ssp. pulchra)*							●		●		●	●	●	●	●
diapensia *(Diapensia lapponica)*															●
dwarf arctic birch *(Betula nana)*							○		●			●	●	●	●
drawf blueberry *(Vaccinium caespitosum)*	●	○	●	○	●		○			●					●
early blueberry *(Vaccinium ovalifolium)*	●									●					
entire-leaf mountain-avens *(Dryas integrifolia)*													●		●
feltleaf willow *(Salix alaxensis)*		●				●					●				
four-angled cassiope *(Cassiope tetragonal)*													●		●
fringed sagebrush *(Artemisia frigida)*				○											
grayleaf willow *(Salix glauca)*		○					●		○		●		●		
Greene mountain-ash *(Sorbus scopulina)*					○										
halberd willow *(Salix hastata)*		○									●				
high blueberry willow *(Salix novae-angliae)*		○				○					●				
high bushcranberry *(Viburnum edule)*	●	●		○	●	●					●				
Kamchatka rhododendron *(Rhododendron camtschaticum)*													●		●
Labrador-tea *(Ledum groenlandicum)*			●	○	●		●	●	●						
Lapland rosebay *(Rhododendron lapponicum)*													●		●
least willow *(Salix rotundifolia)*													●		●
leatherleaf *(Chamaedaphne calyculata)*									●						
leutkea *(Leutkea pectinata)*										●					●
littletree willow *(Salix arbusculoides)*		●	●			●	●				●				
low blueberry willow *(Salix myrtillifolia)*							●		●						
mountain-cranberry *(Vaccinium vitis-idaea)*		●	●	●	●		●	●	●			●	●	●	●
narrow-leaf Labrador-tea *(Ledum decumbens)*		●	●		●		○		●			●	●	●	●
netleaf willow *(Salix reticulata)*									○			●	●	●	●
northern black currant *(Ribes hudsonianum)*					○										
ovalleaf willow *(Salix ovalifolia)*													●	●	●
Pacific red elder *(Sambucus callicarpa)*	●				○					●					
Pacific willow *(Salix lasiandra)*											●				
park willow *(Salix monticola)*		○									●				
polar willow *(Salix polaris)*													●		●
prickly rose *(Rosa acicularis)*		●	●	●	●	●	●				●				
red-fruit bearberry *(Arctostaphylos rubra)*		●	○	○			●		○						
red-osier dogwood *(Cornus stolonifera)*											●				
resin birch *(Betula glandulosa)*		○		○			○		●			●	●	●	●
Richardson willow *(Salix lanata ssp. richardsonii)*		○									●	●	●	●	
rusty mensiesia *(Menziesia ferruginea)*	●	○			○		○	●		●					
salmonberry *(Rubus spectabilis)*	●									●					
sandbar willow *(Salix interior)*											●				
Scouler willow *(Salix scouleriana)*	●	○	●	●	●	○	●			●					
Setchell willow *(Salix setchelliana)*											●				
silverberry *(Eleagnus commutata)*						○					●				
Sitka alder *(Alnus sinuata)*	●		○			●			○	●	●	●			
Sitka willow *(Salix sitchensis)*	●									●	●				
skeletonleaf willow *(Salix phlebophylla)*															●
starry cassiope *(Cassiope stelleriana)*															●
stink currant *(Ribes bracteosum)*	●									●					
sweetgale *(Myrica gale)*									●		●				
tall blueberry willow *(Salix novae-angliae)*		○									●				
thinleaf alder *(Alnus tenuifolia)*			○			●			○		●				
trailing black currant *(Ribes laxiflorum)*	●									●					
undergreen willow *(Salix commutata)*								●			●	●	●		
white mountain-avens *(Dryas octopetala)*													●		●

May, and is earlier farther south.

The arctic climate of the North Slope is cold and maritime, with extreme summer temperatures moderated by the nearby Arctic Ocean (Walker and Webber, 1979). Summer fog is common. Maximum summer temperatures reach 71° to 74°F and minimum winter temperatures drop below -50°F. Mean annual temperatures are in the 9° to 21°F range (Johnson and Hartman, 1969). Freezing indices range from about 7,500 to over 8,500 degree-days. Winter winds sweep unhindered across the landscape (Sloan and others, 1979), preventing formation of the temperature inversions typical of the Interior. Average annual precipitation is low (4 to 8 in.), and average annual snowfall ranges from 20 to about 50 in. Fall freezeup generally occurs between late September and early October and spring breakup lasts from late May through early June (Harden and others, 1977).

LANDFORM CLASSIFICATION SYSTEM

In this report, a landform is defined as an element of the landscape that has a definite composition and range of physical and visual attributes---topographic form, drainage pattern, and gully morphology, for example---that occur wherever the landform exists (Belcher, 1946, 1948). Although the term 'form' implies shape only, for geotechnical purposes the composition must also be a major consideration in subdividing the landscape. Thus, in this report the term 'landform' is used to describe not only the surface topography, but also the deposits comprising the feature (Howard and Spock, 1940).

The landform classification developed during the TAPS geotechnical investigation groups 55 individual landforms on the basis of genesis, with the rationale that similar geologic processes result in landforms with similar properties that present similar engineering problems (Kreig and Reger, 1976, p. 57-61). Each landform is identified by letter symbols, the first of which is capitalized and indicates the basic genesis of the deposit, for example, C for colluvial deposits, F for fluvial deposits (table 2). Subsequent lowercase letters differentiate specific landforms in each genetic group, such as Fp for flood-plain alluvium and Ffg for coarse-grained alluvial-fan deposits. Compound symbols were developed to label composite landforms that cannot be readily mapped separately (an outstanding example is the complex glaciolacustrine deposits, G+L, in the Copper River Lowland), to demonstrate an uncertainty of landform identification (G or F), and to indicate

Table 2. *Landforms along the route of the Trans-Alaska Pipeline System.*

Symbol	Landform	Symbol	Landform
Bx	Bedrock	Fpa-c	Abandoned flood-plain cover alluvium
Bx-u	Unweathered, well-consolidated bedrock	Fpb	Braided flood-plain alluvium
Bx-w	Weathered or weakly consolidated bedrock	Fpb-c	Braided flood-plain cover alluvium
C	Colluvial deposit	Fpb-r	Braided flood-plain riverbed alluvium
Ca	Avalanche deposit	Fpc	Creek or small watercourse alluvium
Cg	Rock glacier	Fpm	Meander flood-plain alluvium
Cl	Slide deposit	Fpm-c	Meander flood-plain cover alluvium
Cm	Mudflow deposit	Fpm-r	Meander flood-plain riverbed alluvium
Cs	Solifluction deposit	Fpt	Old terrace alluvium
Css	Silty solifluction deposit	Fs	Retransported deposit
Ct	Talus	Fss	Retransported silt
Ctc	Talus-cone deposit	G	Glacial deposit
Ctp	Protalus rampart	Gt	Till
E	Eolian deposit	Gg	Glacier
El	Loess	GF	Glaciofluvial deposit
Ell	Lowland loess	GFo	Outwash
Elr	Frozen complex upland silt[a]	GFk	Kames and eskers
Elu	Upland loess	H	Man-made deposit
Elx	Frozen upland loess[b]	Hf	Fill and embankment deposits
Es	Sand-dune deposit	Ht	Tailings
F	Fluvial deposit	L	Lacustrine deposit
Fd	Delta deposit	Lt	Thaw-lake deposit
Ff	Alluvial-fan deposit	M	Marine deposit
Ffg	Coarse-grained alluvial-fan deposit	Mc	Coastal and coastal-plain deposit
Fp	Flood-plain alluvium	Mcb	Beach deposit
Fp-c	Flood-plain cover alluvium	Mct	Tidal-flat deposit
Fp-r	Flood-plain riverbed alluvium	O	Organic deposit
Fpa	Abandoned flood-plain alluvium	Ox	Organic basin filling[a]

[a]In Arctic Foothills only.
[b]In northern Yukon-Tanana Upland and southern Kokrine-Hodzana Highlands.

burial of one landform by another (G/F). Of the 129 individual and composite landforms mapped along the pipeline centerline during our geotechnical investigations, only 18 units represent more than 1 percent of the total area in the plane from the ground surface to a depth of 50 ft (table 3).

In addition to these landform subdivisions, some consideration was given to ground-surface conditions that have geotechnical significance but do not affect soils at depth. For example, in contrast to flood plains, stream terraces are not flooded and commonly have distinctive vegetation and surface-drainage characteristics that do not affect terrace alluvium. Because these surface differences do not reflect different soils, they are identified as distinctive surface phases by symbols enclosed in parentheses following the landform symbol (Kreig and Reger, 1976, p. 61) (table 4).

SUMMARY OF LANDFORM SOIL PROPERTIES

GENERAL STATEMENT

Although specific data on engineering properties, texture, and composition of Alaskan surficial deposits have been published (Péwé, 1955, 1958a, 1968, 1975a; Davidson and others, 1959; Williams and others, 1959; Rieger and others, 1962, 1963; Péwé and Holmes, 1964; Schoephorster, 1968, 1973; Péwé and others, 1969; Hinton, 1971; Schoephorster and Hinton, 1973; Furbush and Schoephorster, 1977; Hamilton and Trexler, 1979),[4] no systematic soil evaluation on the scale of the TAPS geotechnical effort has been attempted.

During the TAPS studies, two computer-based data banks were established to store all geotechnical information from field and laboratory investigations and to correlate ground-truth information with landforms in order to study soil-property variations. The Lab Data Bank (LDB) contains unweighted laboratory soil tests such as gradation and hydrometer analyses, modified Unified Soil Classification, organic content, specific gravity, dry density, plasticity characteristics, and moisture content. The Soil Data Bank (SDB) contains most of the soil-test information in the LDB, but these data are corrected to compensate for nonrandom soil sampling due to varying methods and spacing. The SDB also contains estimated properties for poorly sampled intervals in borings and values for properties not directly sampled (saturation, excess ice content, and thaw settlement) (Kreig and Reger, 1976).

To compare soil conditions in various physiographic and climatic conditions, the TAPS route was subdivided into segments (table 5), and the texture, percent frozen, ground-ice content, and median-thaw strain of landforms for which there is sufficient subsurface information were summarized for both the LDB and SDB (table 6). In general, a more accurate portrayal of the soil properties in each landform is obtained from weighted SDB data rather than unweighted LDB data. The magnitude of the difference between SDB and LDB data is a rough indication of sampling difficulties or bias for each landform.

TEXTURE

Double textural-triangle plots define the gravel, sand, silt, and clay content of 15 landforms for which the most complete unweighted LDB data are available (app. A). The sample population (N) differs between top and bottom triangles for a given landform in a given segment because not all samples were measured by both sieve and hydrometer analyses; typically, lower triangles have fewer data because fewer hydrometer analyses were completed on coarse-grained deposits. For this study, the division between silt and clay is 0.002 mm (U.S. Department of Agriculture and the Massachusetts Institute of Technology soil classifications).

MOISTURE CONTENT

Appendix B illustrates the variation of moisture content in 26 landforms in seven physiographic subdivisions. In general, samples of organic-rich, fine-grained soils such as lowland loess (Ell) and cover deposits (Fpb-c or Fpa-c) consistently had higher moisture contents than coarse-grained soils such as alluvium (Fp-r or Ffg).

THAW STRAIN

Because thawing of ice-rich frozen ground can have serious consequences, thaw strain (defined as the decrease in volume a frozen soil sample undergoes when thawed) is an important consideration in the design of engineering structures in subarctic and arctic regions. For the TAPS project, thaw strain was either computed from estimates of soil-index properties in the weighted frozen boring data of the SDB or was based on the results of laboratory tests (app. C). Samples of fine-grained, organic-rich frozen soils with high ice content, especially if the ice was in the form of clear lenses or massive bodies, were invariably subject to greater thaw strain than samples of coarse soil with less ice.

DRY DENSITY

Density-distribution curves were prepared from weighted SDB information for seven physiographic

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[4]Excellent sources of specific geotechnical data are the Engineering Geology and Soils Report, Engineering Geology and Foundation Report, Engineering Geology and Hydrology Report, and Materials Site Report series prepared by the Engineering Geology and Materials section of the Alaska Department of Transportation and Public Facilities. These references are too numerous to cite.

Table 3. *Frequency of individual and composite landforms along the Trans-Alaska Pipeline System centerline based on occurrence between ground surface and depth of 50 ft.* Landform symbols such as Cg are not listed and do not occur on centerline but are found within the 2-mi-wide inner pipeline corridor (Kreig and Reger, 1976).

Landform	Area (%)	Cumulative area (%)	Landform	Area (%)	Cumulative area (%)
Bx	13.63	13.63	GF or G + L	0.13	96.95
Gt	10.61	24.24	Ffg + Cs	0.12	97.07
G + L	10.32	34.56	Elr + Gt	0.12	97.19
Fp-r	8.86	43.42	Fp-c + C	0.12	97.31
Fpb-r	7.49	50.91	C or F	0.11	97.42
Bx-w	4.75	55.66	Ell	0.11	97.53
Bx-u	3.84	59.50	GF + Ffg	0.11	97.64
Ffg	3.24	62.74	Ff + Fp	0.11	97.75
C	3.23	65.97	Fp-b	0.10	97.85
Fss[a]	2.95	68.92	Fs[b] + Es	0.10	97.95
GFo	2.62	71.54	Ell + Lt	0.10	98.05
G + GF	2.39	73.93	Fp-r?	0.09	98.14
GF	2.27	76.20	Ell + Fs	0.09	98.23
Elx	1.73	77.93	G + F	0.08	98.31
Fs[b]	1.67	79.60	Ffg? + G	0.08	98.39
L	1.52	81.12	Fpt?	0.07	98.46
Mc	1.25	82.37	GF or Ffg	0.07	98.53
GF?	1.19	83.56	Fp-c?	0.07	98.60
Gt?	0.93	84.49	Elx + Cs	0.07	98.67
GF or L	0.91	85.40	L + F	0.07	98.74
Fpm-r	0.87	86.27	Elx?	0.06	98.80
Es	0.71	86.98	Elx or Css	0.06	98.86
Elr	0.67	87.65	Fs?[b]	0.06	98.92
GF + L	0.67	88.32	Fpm-c	0.06	98.98
Fp + GF?	0.65	88.97	Fpm-r	0.06	99.04
Fp-c	0.62	89.59	Ffg + Fp-r	0.06	99.10
C or F?	0.53	90.12	Fp	0.05	99.15
C + Cs	0.45	90.57	O	0.05	99.20
Bx-w?	0.40	90.97	G	0.05	99.25
F	0.40	91.37	Gt + Ff	0.05	99.30
Fpb-c	0.37	91.74	Cl	0.05	99.35
Fp-c + Fs	0.37	92.11	C or Bx-w	0.04	99.39
Ht	0.36	92.47	C or Bx	0.04	99.43
Fs[b] + Fss[a]	0.34	92.81	GF? + L	0.04	99.47
Fpa-c	0.34	93.15	C + G	0.04	99.51
Bx?	0.33	93.48	Cs	0.04	99.55
Fpt	0.29	93.77	El? + C	0.03	99.58
Fp	0.28	94.05	GF or L	0.03	99.61
Bx-u?	0.26	94.31	GF? or L?	0.03	99.64
F?	0.26	94.57	Fp-c + Es?	0.03	99.67
GFk	0.23	94.80	Fp-r + G	0.03	99.70
GF or F	0.22	95.02	C + Elx	0.03	99.73
Elu	0.22	95.24	Fp-c	0.02	99.75
Elx + Css	0.21	95.45	Fs + Ffg	0.02	99.77
G or GF	0.19	95.64	Lt	0.02	99.79
F + L?	0.18	95.82	Fp-c + Fs	0.02	99.81
Ell + Fp-c	0.16	95.98	L? or Fs[b]	0.02	99.83
L?	0.16	96.14	Ffg + C	0.02	99.85
G or F	0.14	96.28	Ff	0.02	99.87
C? or F	0.14	96.42	Elu + C	0.02	99.89
Mc?	0.14	96.56	Fs + O	0.02	99.91
Ff	0.13	96.69	El	0.02	99.93
El + Fp-c	0.13	96.82	El?	0.02	99.95

[a]Includes retransported silt from solifluction (Css).
[b]Includes retransported deposits from solifluction (Cs).

Table 3. *(Cont.). Frequency of individual and composite landforms along the Trans-Alaska Pipeline System centerline based on occurrence between ground surface and depth of 50 ft.* Landform symbols such as Cg are not listed and do not occur on centerline but are found within the 2-mi-wide inner pipeline corridor (Kreig and Reger, 1976).

Landform	Area (%)	Cumulative area (%)	Landform	Area (%)	Cumulative area (%)
Csf	0.01	99.96	C or Fpt	0.01	100.06
Ca + Fp-c	0.01	99.97	Fp or Gt	0.01	100.06
(G + L)?	0.01	99.98	Hf	0.01	100.07
C + F	0.01	99.99	C?	0.01	100.07
F or L	0.01	100.00	Ct + Ca	0.01	100.07
Es + Fp-c	0.01	100.01	Fpa-c + Fs	0.01	100.07
Fs? + Fp-c	0.01	100.02	Cs?	0.01	100.08
Fp-c + Fss	0.01	100.03	Gt or Bx	0.01	100.08
GF? or L	0.01	100.04	Fs[b] or El	0.01	100.08
Ff + Csf?	0.01	100.04	Fs[b] + El	0.01	100.08
Ct	0.01	100.05	Cs + Lt	0.01	100.08
Fss?[a]	0.01	100.05			

Table 4. *Landform surface phases that identify distinctive topographic conditions along the route of the Trans-Alaska Pipeline System.*

Symbol	Phase	Definition
(ft)	Young fluvial terrace or dissected remnant of alluvial fan	Former flood plain or alluvial-fan surface that is no longer actively flooded. Terrace deposit in this phase is not significantly weathered in contrast to older terrace deposit of landform Fpt.
(fk)	Permafrost-modified flood plain	Hummocky flood-plain surface, possibly modified by the formation or thawing of permafrost.
(gm)	Moraine	Irregular topography of discontinuous ridges, knolls, and hummocks surrounding closed depressions on till sheets.
(gd)	Drumlin	Low, linear ridge separated by shallow, linear valleys formed in unconsolidated deposits by the flow of glacial ice.

subdivisions for which a significant amount of data was available (app. D). Typically, samples of coarse sediments---alluvium (Fp-r) or till (Gt)---had higher dry densities than samples of organic-rich material such as peat (O) or cover deposits (Fpa-c).

PHOTOINTERPRETATION OF LANDFORMS

GENERAL STATEMENT

Although most general texts on aerial-photograph interpretation (Smith, 1943; Leuder, 1959; Miller, 1961; Scovel and others, 1965; Avery, 1968; and Way, 1973) illustrate a few typical arctic and subarctic landforms, the origin of these features is often misunderstood or not mentioned and the complex terrain invariably contains elements that are not discussed.

Individuals learning to interpret Alaskan terrain conditions with aerial photographs depend on several sources, including a scarce two-volume manual by Frost (1950), a report by Hopkins and others (1955), the collection by Ray (1960), a generally unavailable report by Hussey and Anderson (1963), and several short articles (for example, Belcher, 1943, 1948; Hussey, 1962; Pomeroy, 1964). A collection of aerial photographs and ground stereoscopic pairs by Zall (1974) includes examples of terrain features in the southern Yukon-Tanana Upland near Fairbanks. Terrain analogs in Canada, where a great deal of work has been done, provide useful comparisons (Arctic Construction and Frost Effects Laboratory, 1962; Mollard, 1975). Several references provide information on the photointerpreta-

Table 5. *Relation of the Trans-Alaska Pipeline System route segments and physiographic units.*

TAPS route segment	Segment limits	Physiographic units (from Wahrhaftig, 1965)
A	Valdez to Tonsina	Chugach Mountains
B	Tonsina to Willow Lake	Southern Copper River Lowland
C	Willow Lake to Hogan Hill	Central and northern Copper River Lowland
D	Hogan Hill to Big Delta	Gulkana Upland, Alaska Range
E	Big Delta to Yukon River	Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, southern Kokrine-Hodzana Highlands
F	Yukon River to Prospect Creek	Central and northern Kokrine-Hodzana Highlands
G	Prospect Creek to Bettles River	Ambler-Chandalar Ridge and Lowland, southern Brooks Range
H	Bettles River to Galbraith Lake	Central and northern Brooks Range
I	Galbraith Lake to Sagwon	Arctic Foothills
J	Sagwon to Prudhoe Bay	Arctic Coastal Plain

tion of vegetation in Alaska (Stoeckler, 1949, 1952; Lutz and Caporaso, 1958; Haack, 1962; Johnson and Vogel, 1966; Hegg, 1967). A particularly important aspect of terrain analysis in the Arctic and Subarctic has been delineation of permafrost by photointerpretation (Frost, 1950, 1951; Frost and Mintzer, 1950; Sager, 1951; Fletcher, 1964; Frost and others, 1966; Mollard and Pihlainen, 1966; Crampton and Rutter, 1973; Ferrians and Hobson, 1973). Most examples in these references were verified by fieldwork, but few references discuss the composition of a wide variety of landforms, information that is vital to any extensive geotechnical terrain analysis. A notable exception is Mollard's (1975) excellent collection of over 500 stereopairs.

The following 30 plates of aerial photographs were selected to illustrate the broad diversity of landforms crossed by the TAPS route (fig. 3).[5] The source and date of the photographs are given in parentheses after the plate title. In selecting these photographs, emphasis was placed on areas of permafrost terrain with considerable ground-truth information or pertinent references. Nearly all examples are in the TAPS corridor; however, some examples of important terrain features from other parts of Alaska that are also present along the pipeline route are included. Insets accompany several plates; directions and scales of these insets are identical to the accompanying plate unless otherwise indicated. Each plate is also accompanied by a discussion, usually including subsurface data from soil borings. The range of soil types in each landform can be estimated from the borings within each unit. Many references cited in the discussions describe field sites or data collected within, or directly pertaining to, the area or features illustrated. Reference citations are not comprehensive for general subjects. Only references published before 1980 are cited.

[5]The index at the end of this section provides quick reference to various plates for specific landforms.

KEY TO SUBSURFACE DATA ON PLATES

Soil-boring locations are indicated by various dot symbols that also illustrate the distribution of frozen ground encountered by each boring:

○ Unfrozen soils for entire depth
● Generally frozen soils for entire depth
◒ Unfrozen soils overlying frozen soils
◓ Frozen soils overlying unfrozen soils
◑ Both frozen and unfrozen soils in layers.

Although the active layer of annual freezing and thawing is not separated from permafrost in frozen borings, dates when drilling began and when the active layer was penetrated are provided in tables listing subsurface information. The lack of temperature-sensing devices made detection of permafrost difficult in borings into bedrock and dry dune sand. Therefore, symbols indicating thermal state in these units are

Table 6. *Summary of soil properties of selected landforms along the route of the Trans-Alaska Pipeline System. Values give percentage of landform in each soil-property category, except median thaw strain, which is expressed in average percentage thaw strain. The percentage of soils in a given landform containing more than 50 percent ground ice is obtained by adding Massive Ice and Soil + Ice columns. The limits of each route segment are defined in table 5. Lab Data Bank (LDB) is unweighted test information; Soil Data Bank (SDB) is weighted and estimated information.*

Modified Unified Soil Classification[a]

LAND-FORM	SEG-MENT	DATA BANK	Pt	OH	OL	MH	ML	MH-CH	ML-CL	CH	CL	SM-ML ML-SM	SC-CL CL-SC	SM	SC SM-SC	SP-SM SW-SM SP-SC SW-SC	SW SP	GM-ML ML-GM	GC-CL CL-GL	GM	GC GM-GC	GP-GC GW-GC GP-GM GW-GM	GW GP	FROZEN	MASSIVE ICE[b]	SOIL + ICE[c]	MEDIAN THAW STRAIN	NUMBER OF SAMPLES	FOOTAGE DRILLED
C	E	LDB		.3	2.3	.3	26.9		.7		1.3	11.8	.3	29.2	2.7	7.7		2.9		15.4	.3	3.6	.3	71	----	----	----	305	----
		SDB			2.8	.3	19.8		.9		.9	9.8		32.7	4.1	2.0	.7	5.7		10.4		3.7	5.7	61	.5	3.5	7	----	2007
	F	LDB	2.2		1.8	.9	10.8		1.3	.4	1.8	5.8		32.4	1.8	4.0	.4	3.6		21.2	4.5	5.8	1.3	91	----	----	----	223	----
		SDB	.1		.6	.4	13.9		1.2		3.6	7.8		27.2	.4	3.9	2.8	4.0		22.5	3.9	5.6	1.9	84	.2	2.6	4	----	2010
Ell	E	LDB	30.0		20.0		40.0					5.0								5.0				100	----	----	----	20	----
		SDB			48.0		48.0					4.0												95			24	----	38
Ell+ Lt	J	LDB			53.8		15.4					7.7		23.1										100	----	----	----	13	----
		SDB			31.3		42.5					5.0		2.2		.6							.6	87	17.8	35.8	46	----	90
Elu	E	LDB					100																	5	----	----	----	31	----
		SDB					100																					----	484
Elx	E	LDB	.4	.4	6.7	.8	89.7		.6			.6	.2	.6										99	----	----	----	509	----
		SDB		.8	4.9	.7	85.8		1.4			1.8												99	4.6	2.7	14	----	2158
Es	E	LDB					4.6					1.5		23.1		26.2	44.6							58	----	----	----	65	----
		SDB			.9		1.6					.4		22.8		27.4	46.9							45			6	----	579
Ffg	A	LDB					3.0							33.3		12.1				15.2		21.2	15.2		----	----	----	33	----
		SDB					.7					.7		34.6		4.7	.1			20.2		24.3	14.7					----	431
	D	LDB					1.4					1.4		18.9		18.9	1.4			8.7		37.8	11.5	8	----	----	----	69	----
		SDB					1.3					1.7		18.0		18.6	1.0			11.1		36.9	11.4	6			3	----	787
	G+H	LDB	.7			.7	6.3		.7			2.8		7.7	.7	2.1	2.8			8.4	.7	25.9	40.5	92	----	----	----	143	----
		SDB					2.0		.4			2.2		4.3		2.9	1.7			12.8	.8	29.8	43.0	85	.1	.2	2	----	1252
Fs	E	LDB	1.8	1.2	7.9	.6	61.1				1.2	17.1		6.7	1.2	1.2								95	----	----	----	164	----
		SDB	.1	.3	9.8		62.3		.7			16.5		5.9		.2	.2	1.1		.2		.2	.3	96	2.2	2.6	22	----	803
	F	LDB	5.0	1.3	5.0	6.3	71.0		1.3		1.3	1.3		7.5										95	----	----	----	80	----
		SDB	.3	.5	3.3	2.6	85.3				2.3	3.0		1.5				.4				.2		88	.6	7.3	12	----	500
	G+H	LDB	15.4	3.3	8.9	2.4	49.8		1.6			7.3		7.3				.8		2.4			.8	97	----	----	----	123	----
		SDB	4.1	2.4	17.9	1.7	54.3					5.5		3.6				1.2		1.0			.5	98	7.8	10.3	31	----	625
Fss	E	LDB	2.4	1.5	8.6	.1	85.0				.1	1.5		.8										95	----	----	----	792	----
		SDB	.3	1.0	7.5		85.7					2.2		.7			.3	.1		.1			.1	94	2.0	3.3	18	----	3702
Fp-c	E	LDB	1.4		2.8		69.2					9.8		5.6		7.0	2.8			1.4				78	----	----	----	71	----
		SDB			4.1		54.1					18.6		7.2		11.7	1.9					.2	2.2	62		1.1	17	----	318
	G+H	LDB	6.3		6.3		37.5				3.1	15.6		21.9		6.2							3.1	100	----	----	----	32	----
		SDB	1.7		7.2		39.4					11.7		27.8		2.2	6.4					2.2	1.4	91		3.3	18	----	182
Fpa-c	E	LDB		2.9	11.4		79.9		2.9					2.9										100	----	----	----	35	----
		SDB	7.1	1.9	14.6		62.7					5.5		3.0		4.7				.5				100		15.4	24	----	182
Fpb-c	I+J	LDB	5.0		10.0		65.0					10.0		5.0								5.0		80	----	----	----	20	----
		SDB			8.3		56.2		5.1			9.4		15.0		1.6						.4	1.6	93	2.4	1.2	22	----	127
Fp-r	D	LDB					1.7							13.8		41.4	10.3					13.8	19.0	11	----	----	----	58	----
		SDB			.3									11.1		47.7	5.3			9.5		2.9	23.2	8	----	----	3	----	628
	E	LDB					4.5				.6	.6		19.9	1.1	8.5	14.8			5.7		19.9	24.4	68	----	----	----	176	----
		SDB			.2		.7		.2		.1	.5		5.9	.2	6.3	12.5			14.3		21.3	37.8	53	----	.5	2	----	2591
	G+H	LDB					2.2					1.4		8.8		8.7	3.6			9.5	.7	24.1	41.0	70	----	----	----	137	----
		SDB			.1		.3					1.2		9.3		9.0	3.7			11.6	.3	29.2	35.3	51	----	----	2	----	1380
	I+J	LDB					1.3					1.4	.7	8.6		2.6	.7			6.0	.7	12.6	65.4	99	----	----	----	151	----
		SDB					.4							1.1			.7			.8		14.5	82.5	93		.4	1	----	671
Fpb-r	A	LDB												38.5		7.7				7.7		30.8	15.4	0	----	----	----	13	----
		SDB												24.1		22.5	6.7			2.3		21.5	22.9	0				----	170
	D	LDB	3.3											10.0		20.0	13.3			3.3		20.0	30.1	0	----	----	----	30	----
		SDB												7.2		23.3	12.6			1.3		18.3	37.3	2				----	383
	G+H	LDB												8.6	5.2					13.8		37.9	34.5	75	----	----	----	58	----
		SDB					.1							4.2	2.9	3.4				10.5	.1	36.5	42.3	55			1	----	696
	I+J	LDB					1.2				.4	.4		.8	.4		.8			4.3	1.6	9.0	81.1		----	----	----	254	----
		SDB					.3							.8			.3			4.7	.9	9.1	83.9			.2	1	----	2038
Fpt	F	LDB					5.3					10.5		42.0		26.3	10.6					5.3		81	----	----	----	19	----
		SDB			.9		2.1					7.9		49.3		21.6	13.0					4.3	.9	63			5	----	291
G+L	B	LDB			.4		29.1	.4		9.4	16.9	10.2	.4	21.3	1.2	2.8	.8			6.3		.8		59	----	----	----	254	----
		SDB			.9		18.1	.3		4.8	8.6	21.0		24.8	.6	3.0	2.8	.6		9.3		2.9	2.3	56		1.2	6	----	2472
	C	LDB	.4	.2	.3	.7	12.1	3.0	21.0	3.7	38.8	6.0	2.9	6.2	.9	.6	.7	.1	.3	.7	.4	.2	.8	87	----	----	----	1200	----
		SDB	.1		.5	.5	13.5	2.9	19.7	2.4	30.2	8.4	1.6	11.1	.8	.8	1.0	.3		1.3	.4	.7	3.4	77	.4	5.0	6	----	6407
Gt	A	LDB					18.8		2.1			10.4		43.6		6.3	2.1			16.7				7	----	----	----	48	----
		SDB					15.3					13.6		39.5	.6	5.0	2.5			20.2		3.2	.1	0				----	472
	D	LDB	1.9		2.6		8.7		2.3		1.0	11.0	1.0	33.7	1.6	6.7		.9	.3	19.0	.6	8.4	.3	57	----	----	----	311	----
		SDB			.3		4.4		1.7		.6	13.5	.9	32.7	1.6	7.7	1.5	.7	.4	21.0	.4	9.9	2.6	46	.1	.8	3	----	3668
	G+H	LDB	1.6		.8	1.6	13.0		1.6		3.3	11.4		14.7	3.2	4.0	1.6	1.6		11.4	4.1	17.1	9.0	91	----	----	----	123	----
		SDB	.2		.4	1.1	3.8		.2		.2	10.5		17.2	4.5	6.7	1.7	.5		17.9	4.7	16.1	11.2	82	3.1	3.7	3	----	666
	I[d]	LDB	3.4	.7	1.4				.7		2.1	2.8		12.9	6.2	1.4			2.1	32.0	17.8	9.6	6.9	100	----	----	----	146	----
		SDB	.1		.2		.5				.7	4.7		13.9	4.0	.6	.1		1.5	35.2	21.4	10.6	5.6	99	.9	4.3	3	----	1018
GF or L·	G	LDB					30.0					1.7		41.6		5.0	16.7			3.3		1.7		52	----	----	----	60	----
		SDB					27.4					5.7		45.4		4.2	12.6			3.3		1.4		43			9	----	578
GFo	D	LDB					3.3					1.7		15.0		8.3	1.7			8.3		31.7	30.0	6	----	----	----	60	----
		SDB					1.1					2.8		12.0		8.2	4.3			3.8		29.1	38.7	4			1	----	856
Ht	E	LDB			4.5		18.2					9.1		18.2		22.8				18.2		4.5	4.5	43	----	----	----	22	----
		SDB					6.8					7.5		18.0		22.2				8.1		10.8	26.6	41			5	----	295
L	G	LDB					81.7		3.8		1.9	2.0		7.7		1.9						1.0		63	----	----	----	104	----
		SDB					88.2				.5	.7		7.5		2.9								52	.2	----	10	----	1200
	H	LDB				17.7	50.2	5.9		2.9	2.9	5.8		2.9		8.8	2.9							97	----	----	----	34	----
		SDB			1.3	10.5	37.9		9.8	.7	9.6	12.8		13.8						.1				100	3.5	13.1	10	----	669
Mc	J	LDB			9.4		3.1					21.9		18.8		3.1	3.1					9.4	31.2	89	----	----	----	32	----
		SDB			.2		1.2					1.5		4.0		3.1	4.1			11.3		21.7	52.9	79		3.3	2	----	1137

[a]To better define borderline soil classes, the Unified Soil Classification was modified by 1) adding classes for coarse-grained soils having 45 to 55 percent fine fraction (passing the No. 200 sieve), 2) extending the dual-symbol borderline area through the entire range of liquid limits, and 3) deleting the dual symbols CL-OH, ML-MH, CH-OH, and CL-OL (Kreig and Reger, 1976, fig. 8).

[b]Percentage of total soil footage drilled through massive ice.

[c]Percentage of total soil footage drilled through soils containing between 50 and 99 percent ground ice.

[d]Sample data from till of Itkillik Glaciation (Hamilton and Porter, 1975).

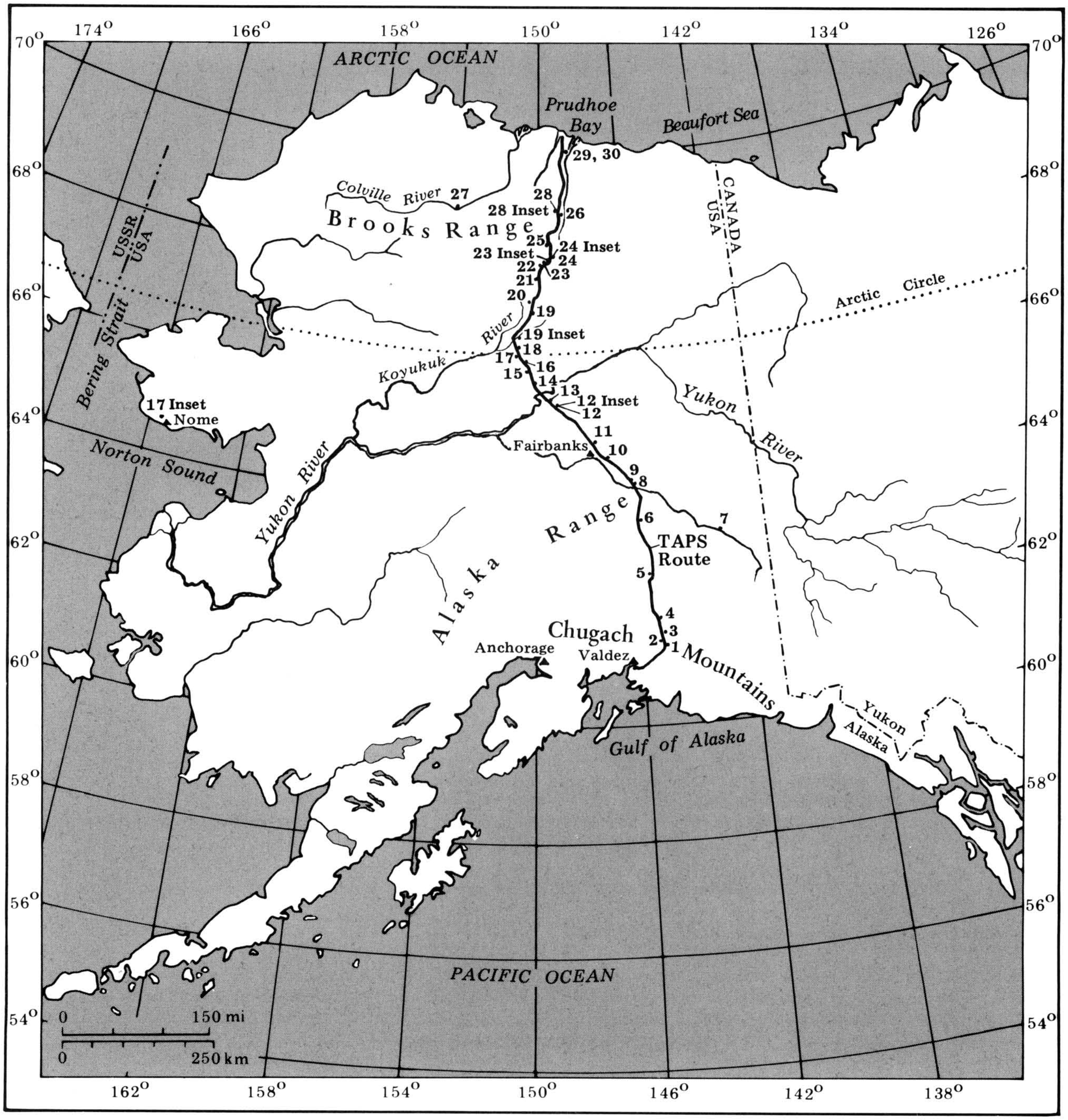


Figure 3. Location of plates and insets relative to the route of the Trans-Alaska Pipeline System.

tentative. Lowercase letters next to borings are keyed to detailed subsurface data (logs) that are presented in abbreviated form (table 7) in tables accompanying appropriate discussions. To avoid confusion, the letters 'l' and 'o' are not used. Large numbers on photographs designate specific locations and features. Small numbers next to small dots indicate depth to permafrost (pl. 7), thickness of silty cover deposits over granular riverbed deposits (pl. 13), or thickness of colluvium over bedrock (pl. 17).

Table 7. *Explanation of abbreviations, terms, and format used in logs of soil borings along the route of the Trans-Alaska Pipeline System.*

Org - organic or organic material
Cl - clay or clayey
Si - silt or silty
Sa - sand or sandy
Gr - gravel or gravelly
Cob - cobbles
Bol - boulders
Massive Ice - large ice wedge or lens
Ice - ground ice of undefined form (lake ice is identified separately)
Ice + - more than 50 percent nonmassive ground ice
Basalt - basaltic volcanic bedrock
Schist - schistose metamorphic bedrock
Phyllite - phyllitic metamorphic bedrock
Granite - granitic igneous bedrock
Wea - weathered
High - highly
Rock Frag - angular rock fragments
Fract - fractured
Interbed - interbedded
w/ - with
tr - trace (4 - 12 percent)
s - some (12 - 30 percent)
and - with major component (more than 30 percent)
occ - occasional (drilling encountered two cobbles or boulders within interval of more than 15 ft)
sc - scattered (drilling encountered two cobbles or boulders within interval of 10 to 15 ft)
num - numerous (drilling encountered two cobbles or boulders within interval of 2 ft)
to - grading downward to
WT@ - water table encountered at (depth follows)
? - questionable occurrence or precise information lacking
Fr - frozen

Example:

d) 0-3 ft Org; 3-25 ft SiGr w/s Sa, occ Cob; 25-30 ft Wea Schist. Fr 0-20 ft.
WT@4 ft. [7-21-73] (24-32).— Source and reference number (unless otherwise indicated, all borings are by Alyeska Pipeline Service Company)

—Date soil boring commenced (month-day-year)

—Location of boring on appropriate aerial photograph

The following soil conditions were encountered: from the ground surface to a depth of 3 ft, organic material; from 3 to 25 ft, more than 50 percent silty gravel with 12 to 30 percent sand and occasional cobbles; and from 25 to 30 ft, weathered, schistose metamorphic bedrock. The ground was frozen from the surface to a depth of 20 ft and unfrozen between depths of 20 and 30 ft. The water table was encountered at a depth of 4 ft.

INDEX OF SELECTED LANDFORMS ON PLATES

Landform	Route segment[a]	Air-photo example[b]
C	E	11, 12, 13
	F	14, 15, 16
Ell	E	(6), 8
Ell + Es	J	30
Ell + Lt	J	28
Elu	E	10, 11
Elx	E	12, 13
Es	E	9
Ffg	A	none
	D	6
	G+H	21, 23, 24
Fs	E	9
	F	14, 15, 16, 18
	G+H	19, 21
Fss	E	10, 11
Fp-c	E	8, 13
	G+H	19, 20
Fpa-c	E	13, (18)
Fpb-c	I+J	29

Landform	Route segment[a]	Air-photo example[b]
Fp-r	D	(3)
	E	8, 13
	G+H	19, 20, 22, 25
	I+J	28
Fpb-r	A	none
	D	6
	G+H	21, 24
	I+J	29, 30
Fpt	F	14
G+L	B	1, 2, 3
	C	4
Gt	A	none
	D	5, 6
	G+H	19, 20, 21, 22, 24
	I[c]	none
	I[d]	28
GF or L	G	19
GFo	D	none
Ht	E	11
L	G	20
	H	25
Mc	J	29, 30

[a] Table 5 defines route segments.

[b] Plate numbers in parentheses indicate landform in different segment.

[c] Young (late Pleistocene) till (Itkillik Glaciation of Hamilton and Porter, 1975).

[d] Upper 20 ft is mid-Pleistocene(?) till (Sagavanirktok Glaciation of Detterman and others, 1958; Sagavanirktok River Glaciation of Hamilton, 1978b,c).

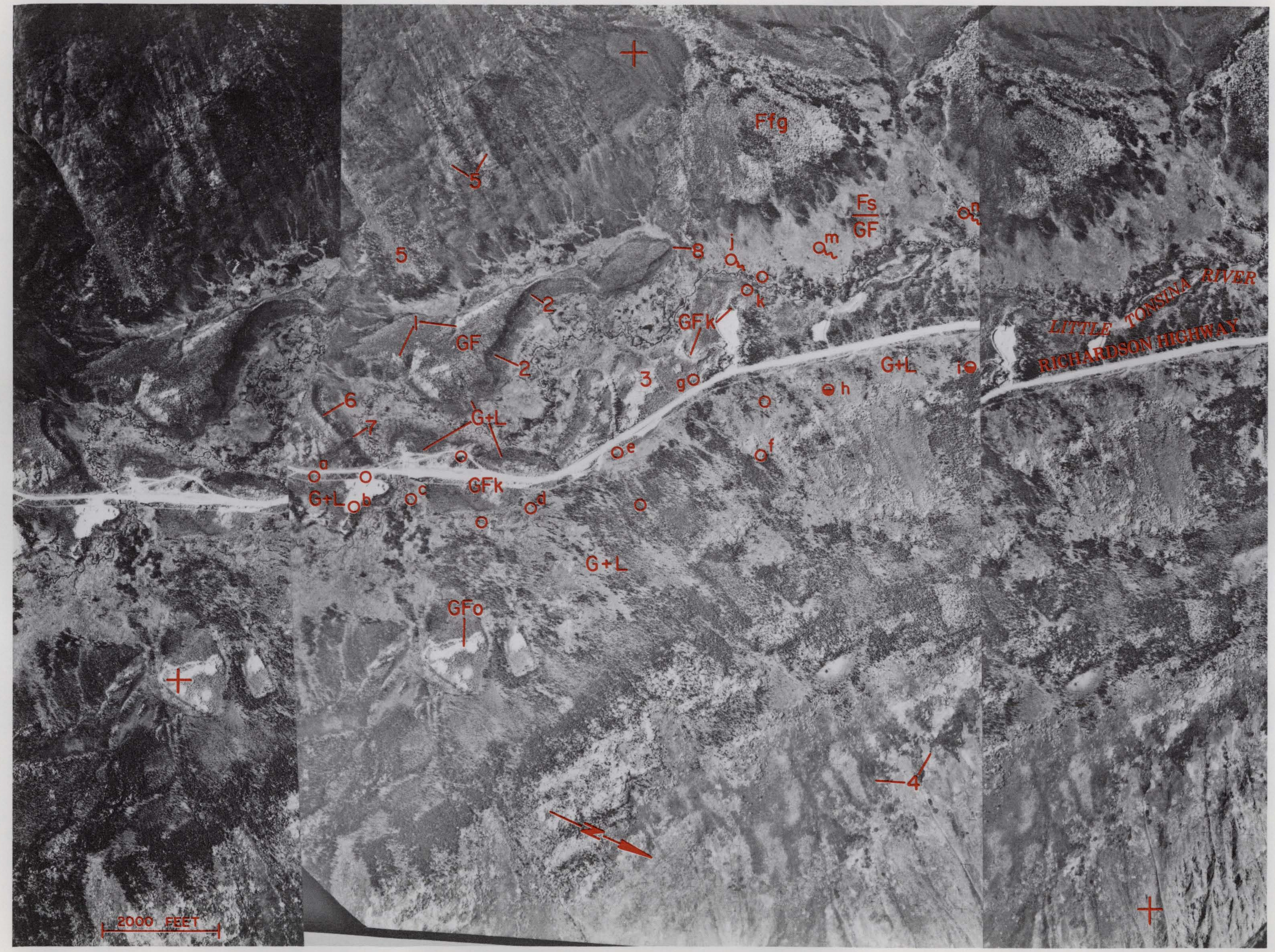

LITTLE TONSINA RIVER
RICHARDSON HIGHWAY
Ffg
Fs
GF
GF
GFk
GFk
GFo
G+L
G+L
G+L
G+L
2000 FEET

Plate 1. Alluvial fans and glacial deposits, Little Tonsina River valley, Valdez Quadrangle
(Alyeska Pipeline Service Company photos 16-25/27, September 2, 1969).

Soil borings in this area encountered lacustrine clay and silt and glaciofluvial gravel and cobbles (Coulter and Coulter, 1962) (table 8). Stratigraphic relationships are generally too complex for direct correlation of soil types between borings, but the area can be divided into landforms. Steep upper slopes and short, steep, V-shaped gullies (1) indicate granular glaciofluvial material [GF] covered with scattered spruce. Other glaciofluvial landforms include eskers and kames [GFk] and a high-level outwash terrace [GFo]. Concave lower slopes (2) indicate the presence of predominantly fine-grained, complexly interbedded glacial and lacustrine deposits [G+L] that underlie most of the valley floor. Coarse-grained alluvial fans [Ffg] are recharge areas for artesian ground water (♀) encountered in borings j, m, and n (table 8). Relatively impervious retransported silt and sandy silt apparently act as an aquiclude over fluvial or glaciofluvial material at depth [Fs/GF].

Broad-leafed vegetation such as quaking aspen (3) is bright toned because the photography was taken after the foliage had turned yellow. Dark, circular thickets of alder (4) grow on lower mountain slopes. Linear avalanche tracks (5) through the spruce forest are vegetated by aspen and willows.

Dynamic instability of underlying, water-saturated glaciolacustrine deposits produced ground cracking (6) in surface glaciofluvial sand and gravel during the Great Alaska Earthquake of 1964 (Ferrians, 1966). Simultaneously, along the base of the slope between localities 7 and 8, ground shaking and lateral movement produced ground cracks through which liquefied silty sand was ejected. Pressure ridges subparallel to the scarp were raised as high as 6 ft by the transmission of horizontal forces through 2 ft of frozen surface peat and sand overlying water-saturated silty sand.

There is probably more permafrost in this valley than is evident from the preponderance of unfrozen borings, most of which were drilled in poorly drained areas of scrubby or sparse forest vegetation that apparently do not correlate with perennially frozen ground at the southern limit of permafrost (see discussion for pl. 2) (Kreig, 1977).

Table 8. *Logs of soil borings on plate 1 (see table 7 for explanation of abbreviations and terms).*

a) 0-3 ft Sa Si & Org; 3-10 ft Si Sa; 10-30 ft interbed Si Sa and Sa Gr. WT @ 28 ft. [3-4-70]. (P.S. 12A-3).
b) 0-50 ft Sa Gr w/occ Cob & Bol. [3-4-70]. (P.S. 12A-2).
c) 0-8 ft Sa w/s Si; 8-20 ft Gr Sa w/tr Si; 20-42 ft Cl Si w/tr Sa & Gr. [2-11-70]. (13-62).
d) 0-8 ft Sa Si; 8-10 ft Org; 10-32 ft Cl Si. WT @ 25 ft. [2-11-70]. (11-102).
e) 0-37 ft Si Sa w/tr Gr; 37-72 ft Si w/s Cl; 72-100 ft Sa w/tr Si. WT @ 16 ft. [2-9-70]. (14-8).
f) 0-5 ft Si; 5-28 ft Sa w/s Gr, tr Si; 28-37 ft Si w/s Sa & Gr. WT @ 5 ft. [2-12-70]. (11-104).
g) 0-4 ft Si w/tr Sa & Gr; 4-50 ft Sa Si w/Gr. [11-16-70]. (94-5).
h) 0-3 ft Org Si; 3-8 ft Sa Gr w/s Si; 8-39 ft Si; 39-50 ft Sa. Fr 24-50 ft. [5-12-71]. (52-1).
i) 0-5 ft Org & Si Sa; 5-9 ft Sa; 9-19 ft Si Sa w/s Gr; 19-20 ft *Massive Ice*; 20-50 ft Sa Gr w/s Si & Cob. Fr 19-50 ft. WT @ 5 ft. [5-12-71]. (53-1).
j) 0-4 ft Sa Si; 4-6 ft Sa Gr w/s Si; 6-13 ft Sa w/s Si; 13-34 ft Sa Gr w/s Si; 34-49 ft Sa Si w/tr Gr. WT initially @ 4 ft, flowing artesian. [11-19-72]. (95-4).
k) 0-60 ft interbed Gr & Sa w/s Gr & Cob; 60-71 ft Sa Si. WT @ 47 ft. [12-21-74]. (209-12).
m) 0-4 ft Org; 4-27 ft Si w/tr to s Sa; 27-34 ft Sa Gr w/s Si; 34-39 ft Sa; 39-51 ft Si w/s Sa. WT initially @ 27 ft, flowing artesian. [11-20-72]. (90-17).
n) 0-14 ft Si w/s Sa & Org; 14-16 ft Sa; 16-32 ft Si w/s Sa & Org; 32-46 ft Sa w/s Gr & Si; 46-50 ft Si w/s Sa. WT initially @ 14 ft, flowing artesian. [11-23-72]. (94-6).

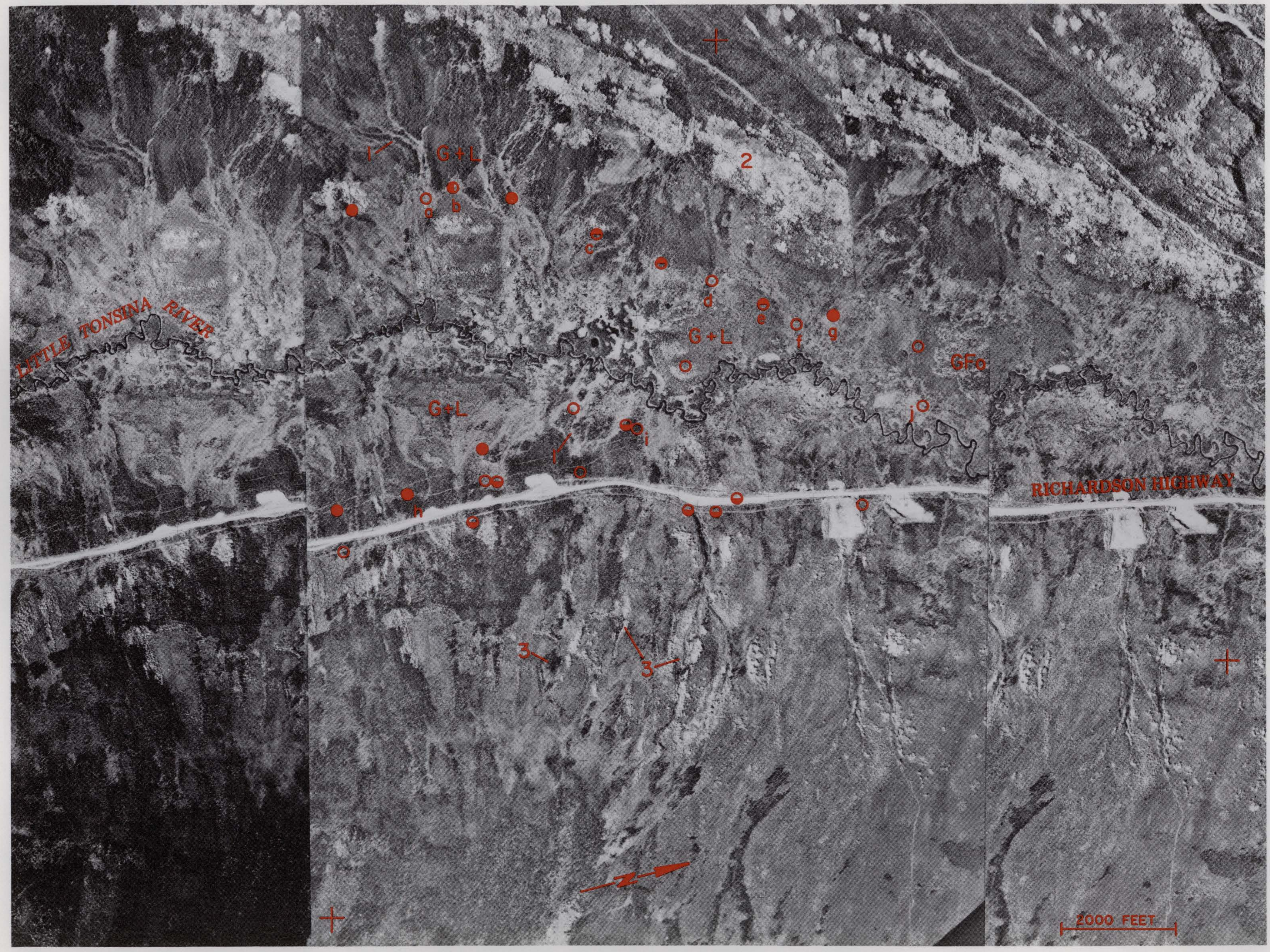

LITTLE TONSINA RIVER
RICHARDSON HIGHWAY
G+L
G+L
G+L
GFo
2
1
1
3
3
a
b
c
d
e
f
g
h
i
j
N
2000 FEET

Plate 2. Microtopography and permafrost distribution, Little Tonsina River valley, Valdez Quadrangle
(Alyeska Pipeline Service Company photos 16-12/14, September 2, 1969).

This stereotriplet illustrates relationships between permafrost, microtopography, and vegetation near the southern limit of permafrost. The glacially scoured valley of the Little Tonsina River is floored with lacustrine silt and clay interbedded with tills [G+L] (Nichols and Yehle, 1969) derived from Cretaceous phyllitic graywackes and associated weakly metamorphosed rocks of the Chugach Mountains (Coulter and Coulter, 1962; Ferrians, 1971a) (table 9). In this area, permafrost is particularly sensitive to minor site differences because its temperature is close to 32^{O}F, which presents special problems in terrain analysis (Kreig, 1977). Surface water or significant movement of ground water at depth generally precludes permafrost formation. Drainage differences are controlled by microtopography that is usually not visible on aerial photographs because of forest cover. Willows (1), which are light toned in drainage ways, and dark-toned, stunted black spruce are characteristic of fine-textured soils and shallow ground water in lowland areas. On slightly better drained low hummocks, permafrost accumulates under spruce trees up to 35 ft tall if the site does not receive ground water from higher slopes (fig. 4). A dry active layer combined with forest shading apparently provides enough insulation to maintain permafrost; this condition contrasts with interior Alaska, where stunted spruce and poor drainage conditions are associated with shallow permafrost.

Boring b (table 9) is located in a 55-yr-old burn now covered with secondary white and black spruce. The unfrozen zone in the boring may represent the period of thaw initiated by destruction of the insulating *Sphagnum* moss mat during the fire. Aspen (2), which has light-toned fall foliage, grows on well-drained sites. Stream gullies (3) are modified by thermokarst effects that indicate the presence of perennially frozen, fine-grained, ice-rich soils; these particular features now appear to be stabilized. Outwash deposits [GFo] are unfrozen sandy gravel with occasional cobbles and boulders. Holocene alluvium is thin or absent in this valley (boring j, table 9) because the Little Tonsina River is underfit.

Table 9. *Logs of soil borings on plate 2 (see table 7 for explanation of abbreviations and terms).*

a) 0-3 ft Org & Si Sa; 3-18 ft Si w/s Sa & Gr; 18-42 ft Sa w/s Si & Gr; 42-49 ft Sa Si to Cl Si. WT @ surface. [1-19-75]. (211-5).
b) 0-1.5 ft Org; 1.5-26 ft interbed Si w/s Sa & Cl and Si Sa w/s Gr; 26-40 ft Gr Sa w/s Si & Cob; 40-51 ft Cl Si w/s Sa. Fr. 0-10 ft & 40-51 ft. [1-17-75].(211-4).
c) 0-3 ft Org & Si; 3-6.5 ft Sa w/s Gr; 6.5-30 ft Sa Si w/tr Gr, Cl & Cob; 30-42 ft Cl w/s Sa; 42-50 ft Sa Gr w/s Si. Fr. 0-10 ft & 35-43 ft. WT @ 11 ft. [1-3-75] (211-2).
d) 0-4 ft Org; 4-21 ft Sa w/tr Si; 21-30 ft Sa Si; 30-50 ft Sa. WT @ 5 ft. [1-29-75]. (211-10).
e) 0-6 ft Si w/s Sa; 6-51 ft Sa w/tr Si, Gr & Cob. Fr 0-13 ft. [1-28-75]. (211-9).
f) 0-31 ft Si w/s Sa, Gr & Cob. [2-3-70]. (11-100).
g) 0-3 ft Org; 3-36 ft interbed Sa w/s Si & Si Sa. Fr 0-36 ft. [2-3-75]. (211-14).
h) 0-11 ft Si Sa w/s Gr; 11-50 ft Si w/tr Cl. Fr 3-50 ft. [10-1-70]. (13-122A).
i) 0-16 ft Si w/s Sa; 16-28 ft Cl Si w/s Sa; 28-51 ft Sa Gr. [9-15-71]. (51-28).
j) 0-8 ft Si w/s Cl, tr Gr; 8-25 ft Si Sa w/Cob. WT @ 9 ft. [2-4-70]. (12-84).

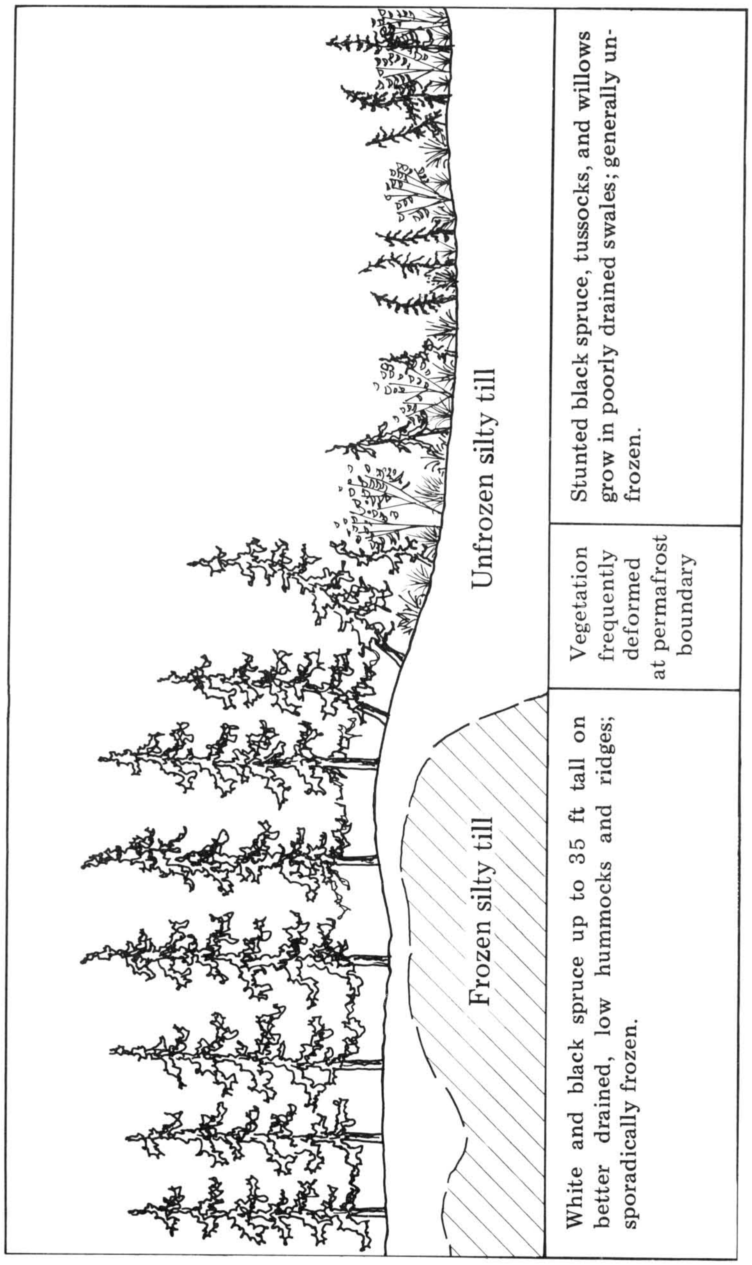


Figure 4. Relation of vegetation to near-surface permafrost and drainage conditions near the southern limit of permafrost in the Little Tonsina River valley, Valdez Quadrangle.

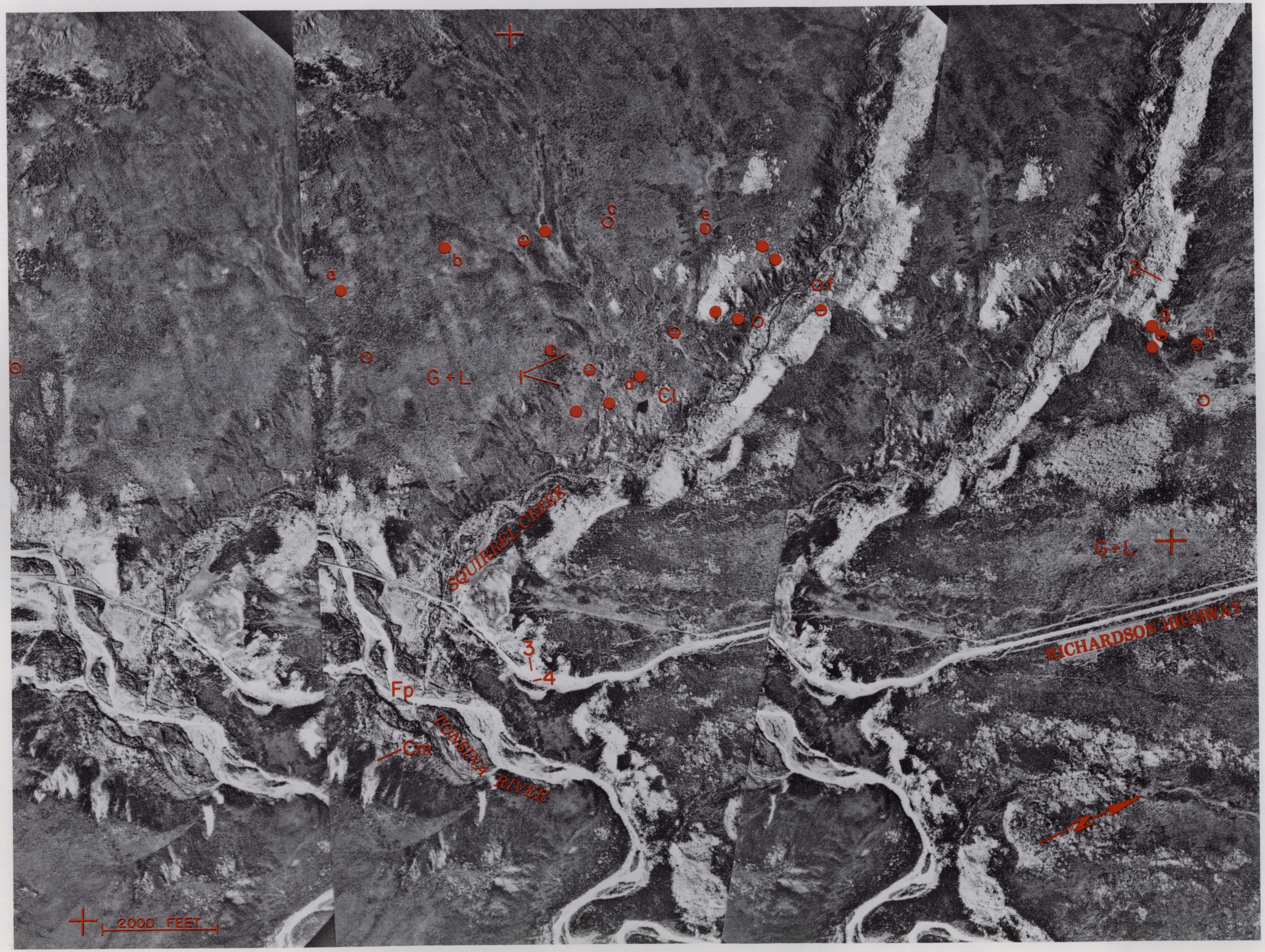

RICHARDSON HIGHWAY
SQUIRREL CREEK
TONSINA RIVER
G+L
G+L
Fp
Cm
Cl
2
3
4
a
b
c
d
e
f
g
h
2000 FEET

Plate 3. Slope instability in glacial and lacustrine deposits, Tonsina area, Valdez Quadrangle
(Alyeska Pipeline Service Company photos 16-6/8, September 2, 1969).

About 9,400 yr ago (Ferrians, 1963a, p. C121), soon after deglaciation of the margins of the Copper River Lowland and drainage of the proglacial lake that formerly occupied the central part of the basin, streams flowing across the basin cut rapidly into the newly exposed, thawed floor and formed the deeply incised canyons and valleys that are typical of the Lowland. Large slope failures such as the Squirrel Creek failure [Cl] occurred late in the downcutting phase, before the glaciolacustrine sediments [G+L] became perennially frozen, as they are today. The antiquity of the Squirrel Creek failure, is indicated by a) modification of the headwall through rill development and growth of an extensive colluvial apron, b) the frozen state of the failure (table 10), and c) the development of thermokarst ponds and gullies on the body of the failure. The unusual occurrence of active solifluction and associated mudflows within a dense forest of black spruce (1) is caused by soaking of headwall soils by suprapermafrost water from the upland surface. Fresh ground cracks at the toe of the fresher headwall scarp (2) are probably related to the failure of dynamically unstable, thawed glaciofluvial sediments during the Great Alaska Earthquake of 1964.

Differences in slope angle, degree of dissection, and vegetation indicate slopes of different relative ages. Youngest slopes, many of which are being actively undercut, are steepest, are unvegetated or bear discontinuous vegetation, and are subject to rapid surface raveling, common mudflow activity, or small-scale slumping; rills are incipient and shallow. Valley walls of intermediate age bear well-developed rill systems and extensive colluvial aprons; they support a deciduous cover of aspen and willows, and surface raveling is limited to discontinuous patches. Only remnants of the oldest valley walls remain, and basal colluvial aprons dominate the slopes, which are less steep than younger walls; oldest walls are generally covered with dense black spruce, willows, and moss, which promote the development and preservation of permafrost, especially on northern aspects.

About 200 ft of a) interbedded, discontinuously frozen, varved lacustrine sand, silt, and clay, b) sandy glaciofluvial gravel, and c) dense silty clay with gravel (till) is exposed on the 34^{o} backslope of the Tonsina Hill roadcut (3). Thawing of ice-rich, low-density, fine-grained terrace deposits beneath the buttress below the Richardson Highway has produced arcuate cracks >8 ft deep in the buttress (4). Actively ablating, locally ice-rich lacustrine deposits commonly produce mudflows [Cm]. Coarse-grained alluvium [Fp] beneath the flood plain of the Tonsina River is unfrozen.

Table 10. *Logs of soil borings on plate 3 (see table 7 for explanation of abbreviations and terms).*

a) 0-20 ft Sa Gr w/s Si & Cob; 20-35 ft Si Sa w/s Gr & Cob; 35-52 ft Gr Sa, Cob & Bol. Fr 0-52 ft. [4-9-70]. (13-98).
b) 0-31 ft Si w/s Sa, Gr & Cob; 31-47 ft Basalt. Fr 0-31 ft. [5-29-71]. (54-6).
c) 0-5 ft Sa Si w/tr Gr; 15-23 ft Cl; 23-43 ft Si Sa. WT @ 4 ft. [5-31-71]. (54-7).
d) 0-2 ft Org; 2-33 ft Si Cl w/s Sa; 33-82 ft Cl Si. Fr 0-82 ft. [1-4-70]. (13-39).
e) 0-2 ft Org; 2-14 ft Si Sa w/s Gr; 14-52 ft Sa Si w/tr Gr. Fr 0-7 ft & 13-52 ft. WT @ 7 ft. [4-8-70]. (13-96).
f) 0-33 ft Sa Gr w/Cob & Bol. WT @ 18 ft. [4-10-70]. (12-135).
g) 0-5 ft Si Cl; 5-28 ft Si Gr w/s Sa; 28-33 ft Si Cl w/s Sa; 33-37 ft *Massive Ice* + Si Cl; 37-50 ft Si Cl w/s Sa, tr Gr. Fr 6-50 ft. [9-27-71]. (51-30).
h) 0-8 ft Si w/tr Sa; 8-10 ft Cob & Bol; 10-32 ft Si w/tr Sa; 32-50 ft Cl Si. Fr 0-8 ft. [5-16-71]. (53-3).

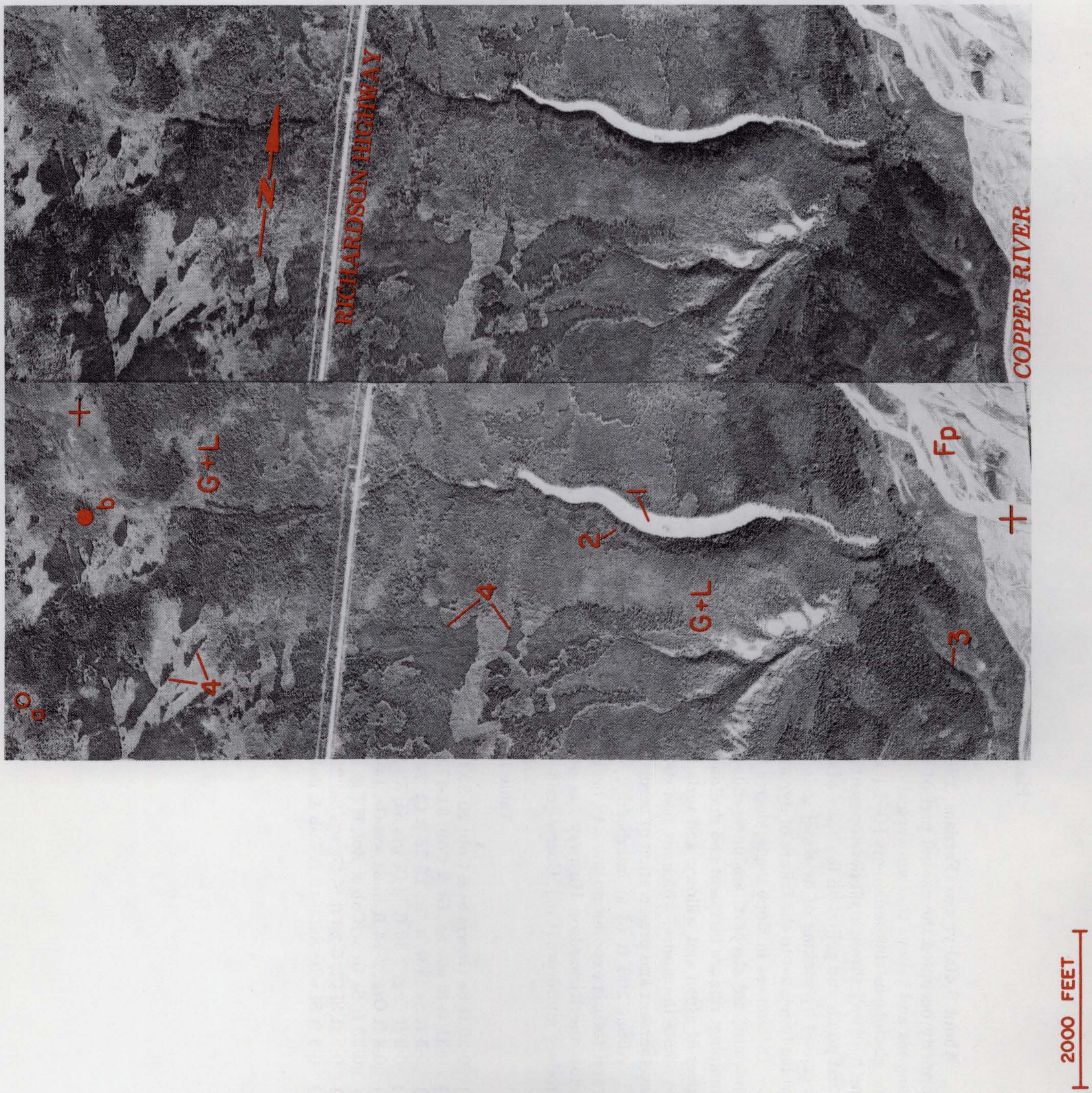

RICHARDSON HIGHWAY
COPPER RIVER
N
G+L
G+L
Fp
a
b
1
2
3
4
4
2000 FEET

Plate 4. Gully morphology in frozen sediments, Copper Center area, Valdez Quadrangle
(Alyeska Pipeline Service Company photos 11-86/87, August 14, 1969).

Although analysis of gully form is widely used to identify soil textures on aerial photographs (Belcher, 1946; Leuder, 1959, p. 49-75; Way, 1973, p. 13) (figs. 5a-c), the causes of gully asymmetry in a permafrost environment are complex and not well understood (Kennedy and Melton, 1972; Washburn, 1973, p. 212-214; French, 1976, p. 178-183; Kennedy, 1976). Different orientations and styles of asymmetry are apparently produced for various reasons in different areas. The large, simple gully illustrated in this stereopair is eroded in frozen, fine-grained glacial and lacustrine soils [G+L], including varved blocky clay, silty till, silty clay with some very fine sand, and occasional layers of gravel, cobbles, and boulders (Nichols and Yehle, 1969) (table 11). Its asymmetrical cross profile (fig. 5d) is typical of east-west drainages in the southern Copper River Lowland, where south-facing slopes receive considerably more direct solar radiation than opposite gully walls. South-facing slopes (1) are typically very steep, dry, generally unvegetated or colonized by scattered xerophytic grasses and *Artemesia*, and deeply thawed. In contrast, north-facing slopes (2) are convex, moist, vegetated by black spruce, willows, and an insulating ground cover of *Sphagnum* moss, and underlain by shallow permafrost. Perhaps the intermittent stream draining down this gully is forced against the base of the steep, south-facing wall by colluvium moving over shallow permafrost and down the convex north-facing slope.

The fresh scarp of an unfrozen terrace (3) has the planar morphology indicative of coarse clastic materials. Upland vegetation of stunted black spruce, *Sphagnum* moss, and sedge tussocks is characterized by numerous forest-fire scars (4) that should not be confused with vegetation changes due to differences in depth to permafrost or in soil texture.

Table 11. *Logs of soil borings on plate 4 (see table 7 for explanation of abbreviations and terms).*

a) 0-14 ft Sa Si w/s Cl & Gr; 14-25 ft Si Sa w/s Gr. WT @ 18 ft. [12-6-67]. (11-67).
b) 0-15 ft Si Cl w/tr Sa & Gr; 15-31 ft Sa Si w/tr Gr. Fr 0-31 ft. [12-5-69]. (13-26).

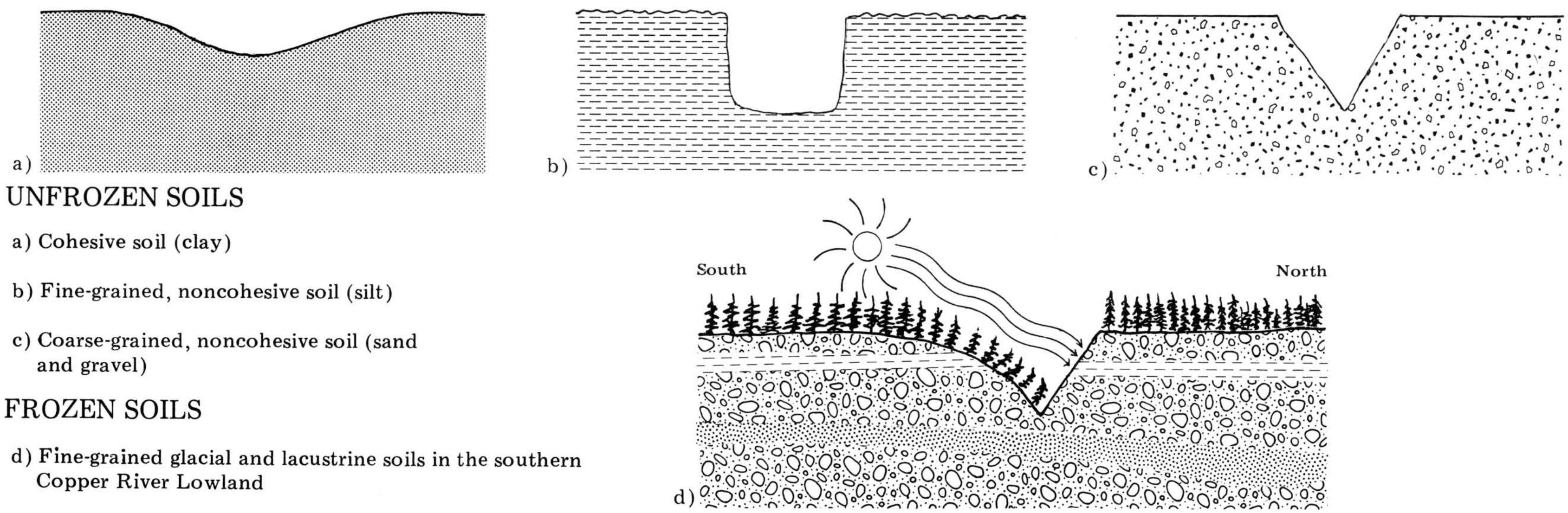


Figure 5. Comparison of cross-sectional forms of gullies cut in various soils.

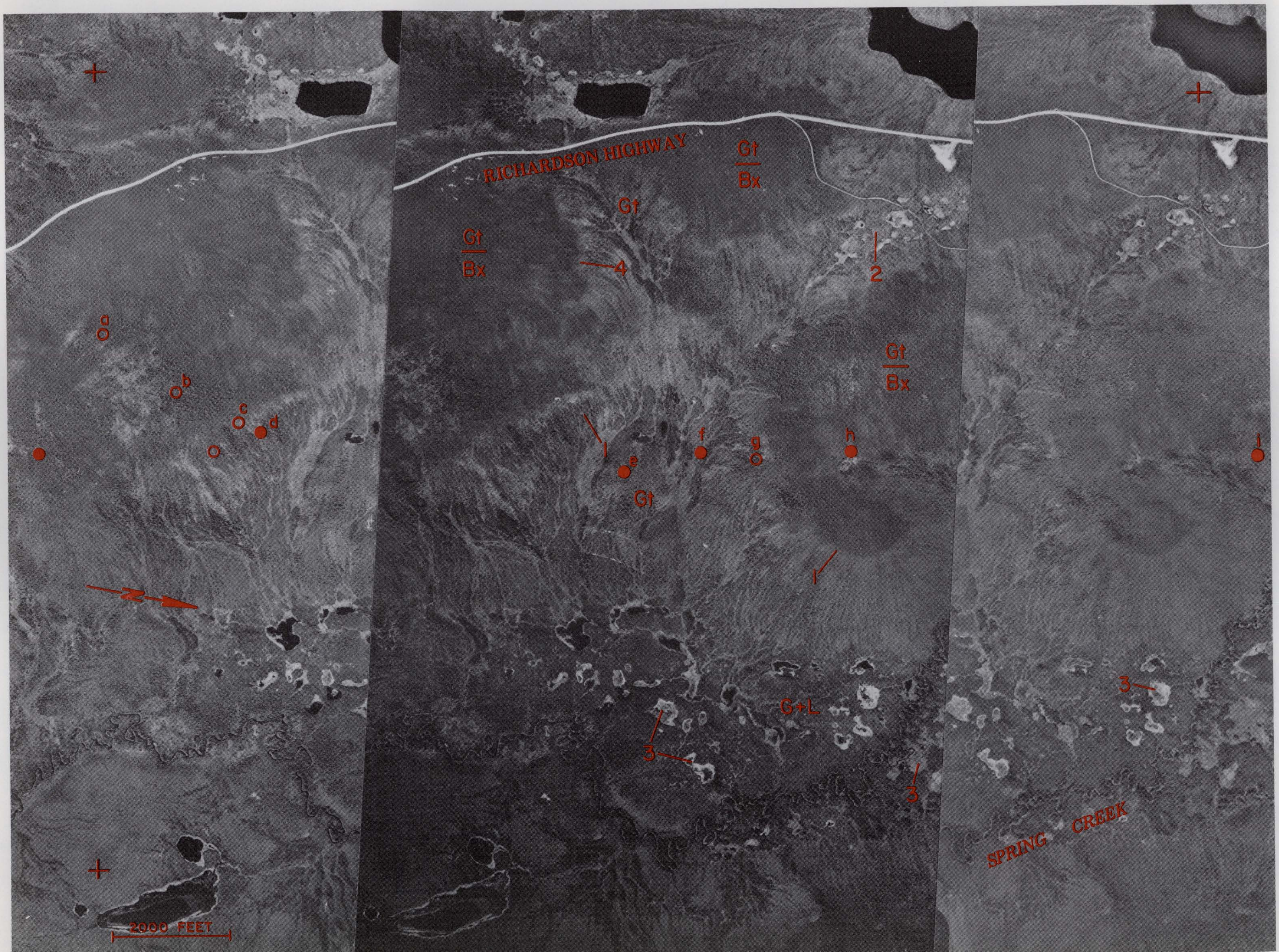

RICHARDSON HIGHWAY
SPRING CREEK
Gt/Bx
Gt
G+L
2000 FEET
N
a
b
c
d
e
f
g
h
i
1
2
3
4

Plate 5. Organic terrain and till over bedrock, Hogan Hill area, Gulkana Quadrangle
(Alyeska Pipeline Service Company photos 11-47/49, September 14, 1969).

Organic terrain is broadly classified as bogs and fens (Zoltai and Pettapiece, 1973; Moore and Bellamy, 1974; Mollard, 1975). Bogs are ombrotrophic, that is, they receive little mineral-rich ground water, because they stand above surrounding wetlands or occur on convex summit slopes and in saddles. They are nourished primarily by rainfall and are very acidic, with pH values as low as 3.1. Vegetation is primarily mosses (chiefly *Sphagnum*), shrubs, black spruce, and heath. *Sphagnum* peat provides excellent insulation and favors the development and preservation of permafrost in bogs (Brown, 1966; Brown and Williams, 1972). During winter the coefficient of thermal conductivity of frozen saturated peat is essentially that of ice, 1.50 to 2.05 cal/m/hr/^{o}C, and during summer the coefficient of thermal conductivity of saturated peat is essentially that of water, 0.47 to 0.58 cal/m/hr/^{o}C (Muller, 1945, p. 55). Thus, in wet *Sphagnum* bogs, heat flow out of the ground during winter is 2.5 to 4.5 times greater than heat flow into the ground during summer. Fens are generally wetter than bogs because they are usually located in topographic depressions, concave landforms, and lower watersheds. They are minerotrophic, that is, they are fed by alkaline or neutral ground water flowing from mineral soils on nearby slopes, and are weakly acidic to neutral, with pH values as high as 7.0. The dominant vegetation is sedges, grasses, and willows.

Peat plateaus are flat-topped to slightly domed organic landforms developed by the coalescence of adjacent palsas as surface peat accumulates and ice-rich permafrost develops in underlying mineral soil (Brown, 1970; French, 1976). They are composed of frozen peat and stand 3 to 12 ft above surrounding wet fens. Two types of peat plateaus are illustrated in this stereotriplet. Elongate peat plateaus form dark-toned ridges (1) aligned downslope between drainages. Intervening fen peat is light toned. The saddle contains a second type: interconnected peat plateaus (2) that are separated by small, peat-filled thermokarst basins (3) known as alases, a Yakutian (Siberian) term (Czudek and Demek, 1970, p. 111). The dense concentration of thaw lakes and alases to the east on the valley floor is typical of ice-rich, fine-grained glaciolacustrine deposits [G+L] in the Copper River Lowland (Wallace, 1948). The development of bogs, thaw depressions, and thaw lakes is reviewed in Drury (1956) and Black (1969).

Thin sandy till over Mesozoic granitic bedrock [Gt/Bx] (Ferrians, 1971b) may be recognized by darker photo tones on broadly convex hills. The inflection point of the slopes (4) generally corresponds to the lower limit of shallow bedrock and indicates a change in slope processes---from stripping upslope to colluvial and fluvial deposition downslope. Thick till [Gt] lies in valley bottoms and depressions where limited surface drainage favors the formation of organic deposits (table 12).

Table 12. *Logs of soil borings on plate 5 (see table 7 for explanation of abbreviations and terms).*

a) 0-12 ft Si Sa w/s Gr & Cob; 12-19 ft High Wea Graywacke. WT @ 5 ft. [3-2-72]. (73-4).
b) 0-7 ft Gr w/s Sa, Si & Cob; 7-15 ft Wea Graywacke. WT @ 11 ft. [3-4-72]. (74-4).
c) 0-9 ft Sa w/s Si & Gr; 9-17 ft High Wea Gneiss. WT @ 7 ft. [3-6-72]. (74-5).
d) 0-2 ft Org; 2-14 ft Sa Si w/s Gr; 14-24 ft High Wea Schist. Fr 2-24 ft. WT @ 8 ft. [9-11-74]. (206-9).
e) 0-2 ft Org & Si; 2-4 ft Si w/tr Sa & Gr; 4-14 ft Sa w/s Si, Gr & Cob; 14-24 ft Bol w/Sa; 24-41 ft Sa w/s Si. Fr 0-41 ft. [9-9-74]. (204-11).
f) 0-6 ft Cl Si w/s Sa; 6-36 ft Si Sa w/s Gr. Fr 0-36 ft. [3-7-70]. (11-120).
g) 0-31 ft Sa Si w/s Gr; 31-39 ft Bedrock. WT @ 28 ft. [6-7-71]. (54-9).
h) 0-7 ft Gr Sa w/s Si; Bedrock @ 7 ft. Fr 0-7 ft. [3-8-70]. (12-110).
i) 0-10 ft Si w/s Sa, Gr & Cob; 10-15 ft Graywacke. Fr 3-11 ft. [9-2-74]. (205-8).

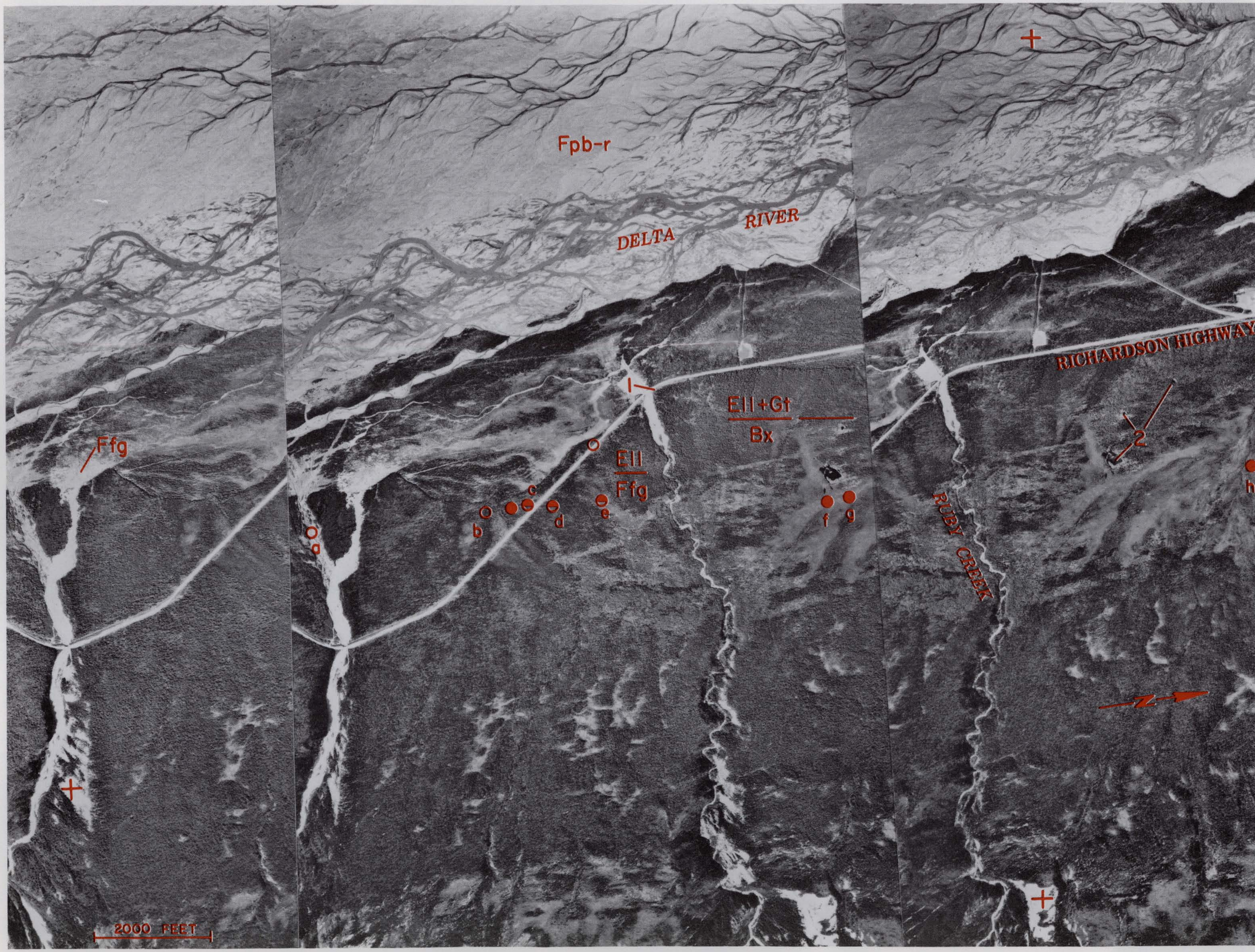

Fpb-r
DELTA RIVER
RICHARDSON HIGHWAY
RUBY CREEK
Ell+Gt
Bx
Ell
Ffg
Ffg
1
2
a
b
c
d
e
f
g
h
N
2000 FEET

Plate 6. Loess deposition and permafrost, Delta River valley, Mt. Hayes Quadrangle
(Alyeska Pipeline Service Company photos 10-205/207, August 15, 1969).

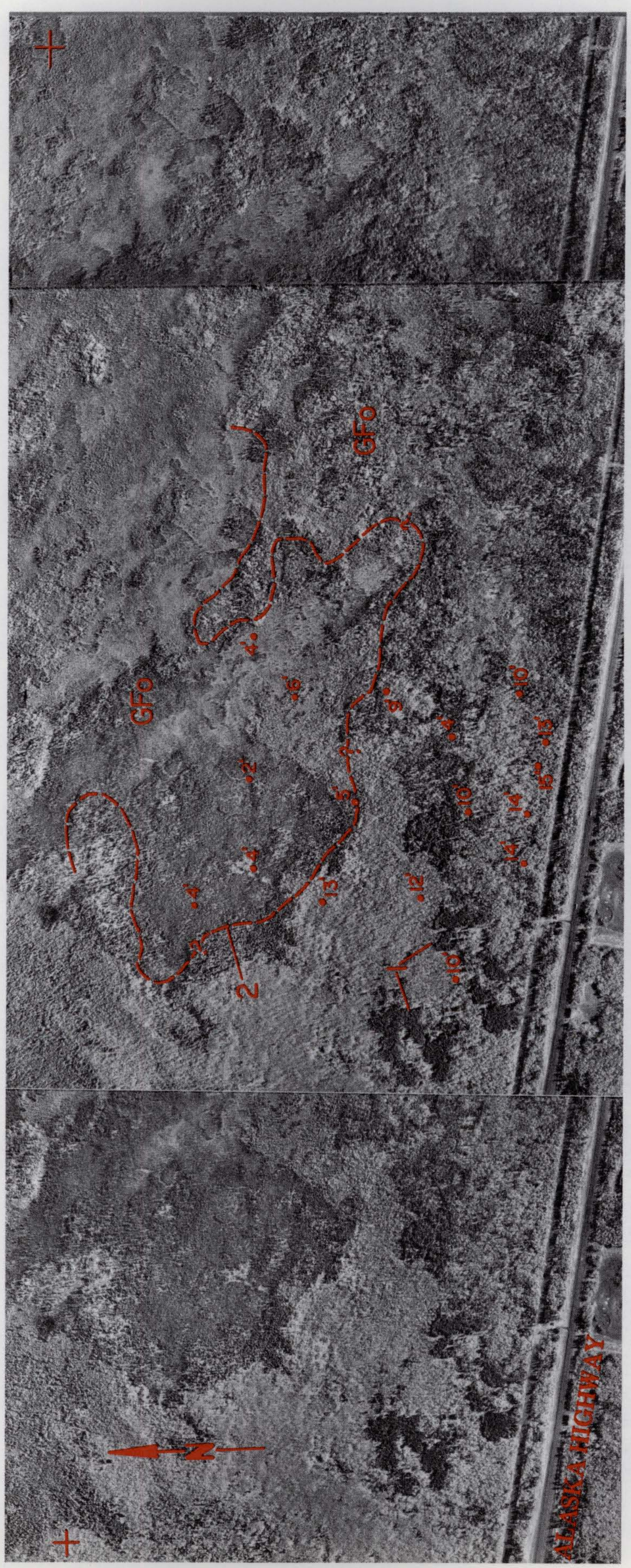
Three types of loess are recognized in interior Alaska. Lowland loess [Ell] is typically deposited on frozen, poorly drained terrain. Vegetation buried by wind-blown silt is preserved when ice-rich permafrost aggrades into the accumulating sediment, making these deposits organic rich. Unfrozen upland loess is thawed after deposition or deposited on unfrozen upland sites. This silt is typically massive and buff colored because much of the incorporated organic matter is oxidized when the loess is unfrozen; it frequently has well-developed vertical jointing and weathering profiles (Péwé, 1955). Along the TAPS route, perennially frozen, organic-rich upland loess occurs from just north of the Yukon River crossing southward to within 5 mi of Livengood (see discussion for pl. 12).

The periodically replenished source area for wind-borne sand and silt in the Delta River valley is the frequently inundated part of the braided Delta River flood plain (Péwé, 1951, 1955). Factors influencing magnitude and duration of short-term, summer-stage fluctuations of the debris-laden Delta River are complex, but include melt rate of glacial ice and snow patches, rainfall intensity and areal variation, degree of soil saturation, amount of water lost to alluvial fill, and air temperatures at high elevations (Dingman and others, 1971). Loess derived from the unvegetated braided flood plain [Fpb-r] of the Delta River blankets surrounding surfaces, where thicknesses of silt and sandy silt range up to 55 ft (Péwé and Holmes, 1964). Deposition of windborne silt on well-drained eolian sand or alluvium increases the soil moisture available for the growth of insulating plants such as *Sphagnum* moss and tussock-forming sedges, which in turn promotes the aggradation and preservation of permafrost.

Thick loess accumulation is prevented on active surfaces of coarse-grained fans [Ffg] by the shifting of streams. These fans are generally unfrozen because of insufficiently thick insulating ground cover and the movement of shallow ground water. When the Delta River shifted laterally, the toe of the Ruby Creek fan was eroded and the fan dissected, allowing 5 to 15 ft of loess to accumulate on the fan surface [Ell/Ffg] (Reger and others, 1964). Permafrost subsequently developed in the organic-rich loess, causing road maintenance problems near boreholes c and d (table 13) (Péwé, 1965a). A 6,000-yr radiocarbon date from the base of the 17-ft-thick loess blanket overlying granular alluvial fan deposits at an archeological site (1) indicates the local average rate of lowland loess accumulation has been 3.4 in./century (Péwé, 1968). The light-toned area in the vicinity of boreholes f and g (table 13) is characteristic of poorly drained lowland loess surfaces that have been vegetated by tussocks and *Sphagnum* moss and underlain by continuous permafrost. The bedrock hill is covered by lowland loess and till [(Ell+Gt)/Bx]; thaw ponds (2) have developed in ice-rich surficial silts.

Table 13. *Logs of soil borings on plate 6 (see table 7 for explanation of abbreviations and terms).*

a) 0-21 ft Gr Sa w/s Cob; 21-29 ft Si w/s Sa, tr Org; 29-40 ft Sa w/s Gr, Si & Cob. [8-2-71]. (52-29).
b) 0-6 ft Sa Si w/tr Org; 6-30 ft Sa w/s Si & Gr; 30-50 ft Sa w/tr Si. WT @ 18 ft. [7-30-71]. (52-27).
c) 0-4 ft Si w/s Sa & Org; 4-9 ft Sa Gr & Cob; 9-16 ft Si w/s Sa; 16-31 ft Sa w/s Gr & Cob; 31-40 ft Sa; 40-50 ft Gr w/s Sa & Cob. Fr 2-16 ft. [9-21-74]. (206-15).
d) 0-9 ft Org Si; 9-33 ft Sa Gr; 33-42 ft Sa w/s Si, tr Gr; 42-52 ft Sa Gr & Cob. Fr 3-13 ft. [9-24-73]. (63-44).
e) 0-5 ft Org Si; 5-27 ft Gr Sa w/s Si & Cob; 27-50 ft Sa w/s Gr & Si. Fr 2-27 ft. WT @ 49 ft. [7-28-71]. (52-26).
f) 0-7 ft Org Si; 7-17 ft Sa w/s Gr & Si; 17-23 ft Si Sa; 23-34 ft Si Gr w/s Sa & Cob. Fr 0-34 ft. [8-14-70]. (7-97).
g) 0-2 ft Org Si; 2-6 ft Si; 6-12 ft Sa w/s Si; 12-19 ft Si Gr w/s Sa; 19-30 ft Si Sa; 30-33 ft Si Gr w/s Sa. Fr 0-33 ft. [8-14-70]. (7-96).
h) 0-4 ft Si w/s Org; 4-6 ft Sa Gr w/s Si; 6-10 ft Si; 10-16 ft Si Sa; 16-23 ft Gr Sa w/s Si. Fr 0-23 ft. [8-15-70]. (7-99).

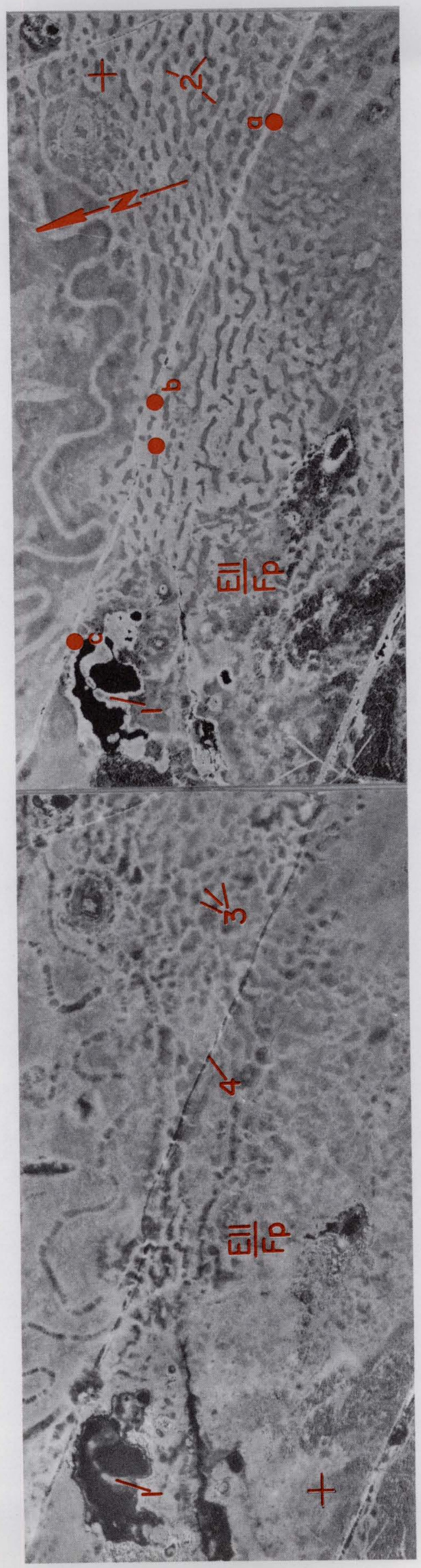


Note: Small numbers next to borings located by small dots indicate depths in feet to permafrost. Borings all drilled between 9-7-74 and 9-27-74.

1000 FEET

Plate 7. Permafrost and vegetation relationships, Tok area, Tanacross Quadrangle
(U.S. Forest Service photos ETS-19-88/90, August 13, 1968).

This typical mosaic of vegetation reflects a history of forest fires and permafrost aggradation in outwash alluvium [GFo] (Foster, 1970; Carter and Galloway, 1978). Soils throughout this area consist of a surficial cover of silt and sand up to 5 ft thick over sandy gravel with occasional cobbles. Soil borings indicate that depth to permafrost varies from 2 to 15 ft. Sharp vegetation boundaries (1) between old, unburned stands of white spruce (dark tone) and a secondary succession of birch and aspen in a former burn (light tone) are not related to underlying permafrost. A more gradational boundary (2) indicates a transition between stunted black spruce and muskeg where permafrost is 2 to 6 ft deep. Apparently, only permafrost more shallow than 6 ft affects vegetation on this landform and soil type. Ground water was not encountered in the borings, which were all less than 50 ft deep.



A. Aerial photograph of a portion of Shaw Creek Flats taken June 8, 1972.

B. Aerial photograph of the same area of Shaw Creek Flats taken May 27, 1970.

1000 FEET

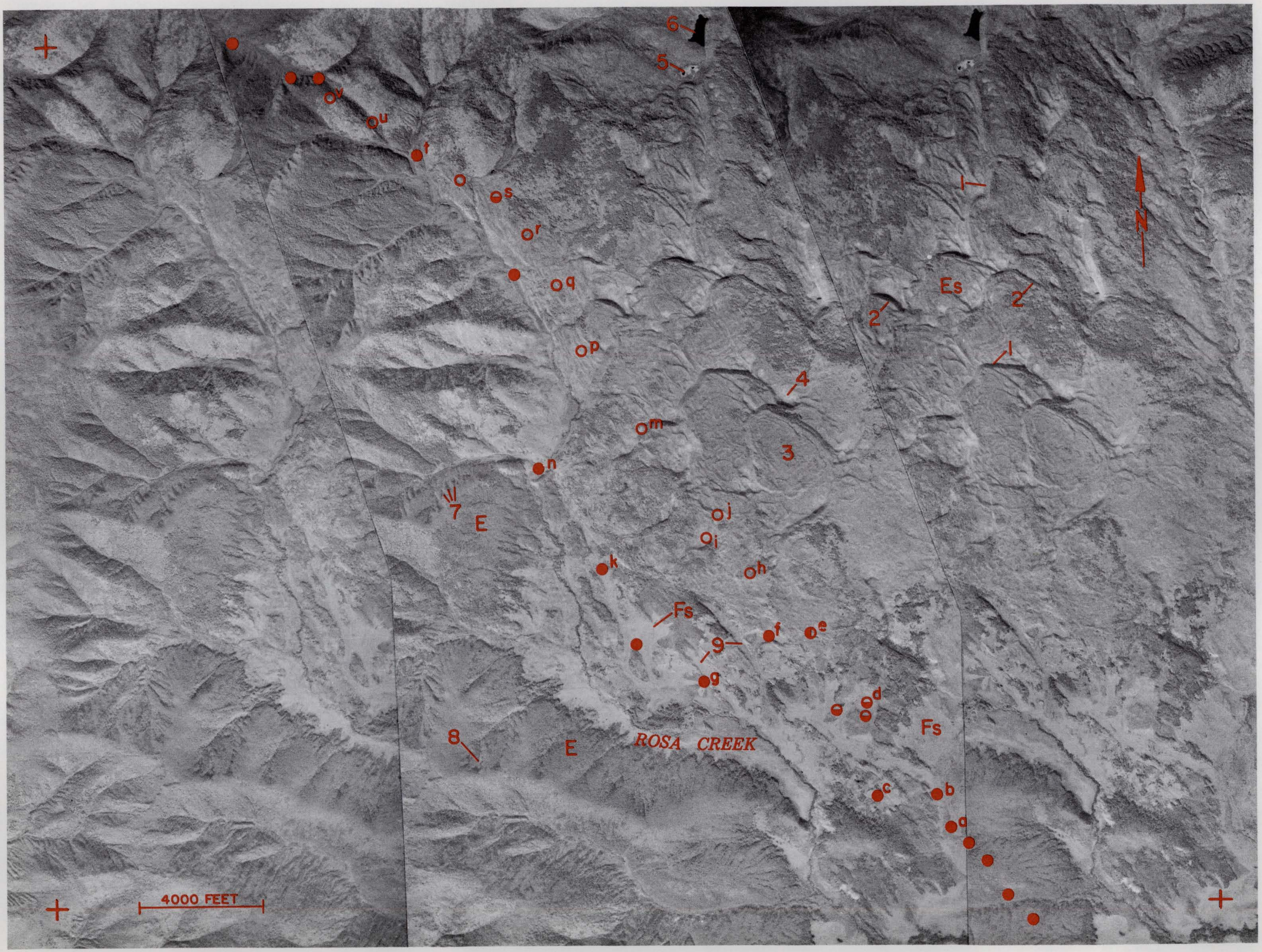
Plate 8. Variable appearance of identical terrain, Shaw Creek Flats, Big Delta Quadrangle
(U.S. Forest Service photo ETS-63-17, June 8, 1972; Alyeska Pipeline Service Company photo 4-14, May 27, 1970).

Examination of aerial photographs of the same landform during different seasons or years can frequently provide more terrain information than that provided by a single photograph. These two photographs, taken 2 yr apart, show markedly different surface patterns at the same locality. Shaw Creek Flats is a continuously frozen terrace of the Tanana River. The surface is underlain by 3 to 5 ft of lowland loess (organic silt) blanketing 3 to 9 ft of silty sand over gravelly river alluvium [Ell/Fp] (table 14). Comparison of locality 1 reveals that the surface-water level was relatively high in early June 1972 and low in late May 1970. During the winter of 1971-72, a total of 49 in. of snow---well above the normal 40 in.---fell at Delta Junction, 18 mi to the southeast. During the winter prior to photo B (1969-70), 21 in. of snow---half the normal amount---fell at Delta Junction. Dark, wormlike features (2) in photo B are 1- to 2-ft-high palsas of peat covered with bog plants like *Sphagnum* moss and heather. These features are much less visible on photo A, where the water level is higher. Light-toned areas surrounding palsas are wet fens that support sedges and grasses. Photo A exhibits the reticulate pattern of low-center ice-wedge polygons (3) that cut across or surround palsas. Palsa ridges may have initially developed on the margins of low-center polygons that were subsequently raised above the level of the surrounding wet fens (Zoltai and Pettapiece, 1973, p. 29).

The route of the buried Haines-Fairbanks petroleum-products line is delineated by a shallow, water-filled trough (4) that was formed by preferential thawing of ice-rich, organic silt in response to disturbances of surface vegetation.

Table 14. *Logs of soil borings on plate 8 (see table 7 for explanation of abbreviations and terms).*

a) 0-3 ft Org Si; 3-6 ft Sa w/s Si; 6-10 ft Sa Gr w/Cob. Fr 0-10 ft. [5-20-70]. (7-14).
b) 0-4 ft Org Si; 4-8 ft Si Sa; 8-10 ft Sa Gr. Fr 0-10 ft. [5-21-70]. (7-15).
c) 0-5 ft Org Si; 5-14 ft Si w/tr Sa & Org; 14-31 ft Gr w/s Sa, Si & Cob. Fr 0-31 ft. [5-22-70]. (9-15).



N
ROSA CREEK
4000 FEET
Es
Fs
E

Plate 9. Sand dunes, Rosa Creek area, Big Delta Quadrangle
(U.S. Geological Survey photos M843-183/185, August 20, 1949).

Sand that forms this stabilized dune field was derived from the extensive, braided, and formerly unvegetated flood plain to the south. Sand [Es] was driven against and over ridges of Precambrian or Paleozoic gneiss and amphibolite-facies rocks (Weber, 1971; Weber and others, 1978) by south winds during the Delta Glaciation (Péwé, 1965b, p. 47). The remarkable steepness of slip faces (1) and sharpness of dune crests (2) indicate reactivation of the field, perhaps in response to destruction of the forest cover by wild fires or perhaps by climatic change. Sand waves form a typical parabolic dune complex that develops when a moderate to large supply of sand is moved against a sloping obstruction by generally unidirectional winds (Hack, 1941). Superimposed on larger dunes are smaller, secondary dune forms such as rosette dunes (3), which are an example of surface modification by variable-direction winds. Dry depressions (4) indicate the dune area is generally dry frozen or unfrozen and permeable. However, some depressions (5) are floored with several feet of frozen silt and organic material (boring i, table 15). The pond (6) was dammed against a bedrock spur by an advancing sand wave with a 200-ft-high slip face. Although loess is slowly being deposited in this area, borings in the dune field did not encounter surface silt, probably because of recent surface deflation (table 15).

Retransported deposits [Fs] in this stereotriplet are more sandy than normal because they are derived from dune sand; nevertheless, they contain considerable silt and organic material and are ice rich (borings a and b, table 15). A mixture of loess and sand [E] covering surrounding hills and ridges exhibits characteristic pinnate gully patterns (7). Floors of north-facing gullies (8) are vegetated with stunted spruce and *Sphagnum* moss, indicating shallow permafrost; perennially frozen ground is deeper beneath crests of intervening ridges covered with birch and aspen.

Deeply weathered schist (boring v, table 15), phyllite, and coarse-grained acidic intrusive rocks are common in the Yukon-Tanana Upland despite the prevailing cold climate (Blackwell, 1965). Where perennially frozen, weathered bedrock typically contains considerable ice. Parallel photogeologic lineaments (9) may indicate hairpin sand dunes or recent faulting. Schoephorster (1973) described pedologic soil conditions in the southern part of this stereotriplet.

Table 15. *Logs of soil borings on plate 9 (see table 7 for explanation of abbreviations and terms).*

a) 0-12 ft Org; 12-19 ft Org Si w/s Sa; 19-40 ft Sa w/s Si. Fr 0-40 ft. [8-11-71]. (53-44).
b) 0-3 ft Org; 3-11 ft Si w/tr Sa; 11-51 ft Sa w/s Si. Fr 0-51 ft. [6-12-70]. (7-35).
c) 0-51 ft Sa w/tr Si. Fr 0-51 ft. [6-4-70]. (9-24).
d) 0-9 ft Si w/tr Sa; 9-51 ft Sa w/tr Si. Fr 14-51 ft. WT @ 4 ft. [6-12-70]. (7-34).
e) 0-72 ft Sa w/tr Si. Fr 20-44 ft. [6-11-70]. (9-27).
f) 0-3 ft Org Si; 3-15 ft Sa w/s Si, tr Org; 15-51 ft Sa w/tr Si. Fr 0-51 ft. [6-9-70]. (9-26).
g) 0-8 ft Sa w/s Si; 8-24 ft Sa; 24-39 ft Sa Si; 39-43 ft Si; 43-50 ft Sa. Fr 0-50 ft. [6-3-70]. (8-21).
h) 0-50 ft Sa. [9-21-74]. (204-18).
i) 0-7 ft Sa w/s Si & Org; 7-51 ft Sa. WT @ 45 ft. Fr 0-7 ft. [6-13-70]. (9-29).
j) 0-50 ft Sa. [6-12-70]. (9-28).
k) 0-5 ft Si w/tr Org; 5-8 ft Sa w/tr Si & Org; 8-25 ft Sa Si; 25-50 ft Si w/tr Sa. Fr 0-50 ft. [6-9-70]. (7-33).
m) 0-50 ft Sa. [6-13-70]. (9-30).
n) 0-3 ft Org w/s Si; 3-30 ft Si Sa; 30-32 ft Wea Bedrock. Fr 2-32 ft. WT @ 5 ft. [6-10-70]. (8-23).
p) 0-50 ft Sa. [6-11-70]. (8-24).
q) 0-50 ft Sa. [4-20-72]. (73-19).
r) 0-50 ft Sa. [4-17-72]. (74-14).
s) 0-29 ft Sa w/tr Si; 29-50 ft Sa w/s Si. Fr 29-50 ft. [4-17-72]. (73-18).
t) 0-2 ft Org Si; 2-12 ft Sa w/s Si, tr Org; 12-24 ft Si Sa w/Gr layers. Fr 0-24 ft. [6-13-70]. (8-26).
u) 0-22 ft Sa Gr w/s Si; 22-50 ft Si Sa. [9-22-74]. (204-19).
v) 0-28 ft High Wea Schist; 28-60 ft Wea Schist. [6-14-70]. (8-27).


JOHNSON ROAD
LITTLE SALCHA RIVER
2000 FEET
Fss
Elu
Bx
Elu
Fss
Fss

Plate 10. Upland loess and retransported silt, Little Salcha River area, Big Delta Quadrangle

(Alyeska Pipeline Service Company photos 5-20/22, May 27, 1970)

The loess cover over the weathered, mylonitic mica schist, quartzite, and augen gneiss of Precambrian or Paleozoic age (Weber, 1971; Weber and others, 1978) that comprise these typical ridges of the southern Yukon-Tanana Upland ranges in thickness from less than 3 ft along ridge crests [Elu/Bx] to as much as 173 ft [Elu] on side slopes (table 16). Light-toned aspen and birch with interspersed dark-toned white spruce (1) grow on thawed convex upper slopes and ridge tops. Aspen (2) has a characteristic patchy appearance on aerial photographs because of the uniform heights of circular clumps formed by cloning (Stoeckler, 1952; Hegg, 1967). Birch trees (3) have irregular crowns. Sharp vegetation boundaries (4) between mixed deciduous and coniferous upland trees and dark-toned, stunted black spruce, tamarack, tussocks, and *Sphagnum* moss (5) growing on frozen lower slopes are fairly accurate indicators of upper permafrost limits in this area. Permafrost usually wedges out within 50 to 75 ft upslope from this obvious demarcation, which is higher on north-facing slopes than on sunnier south-facing slopes because of differences in incident solar radiation (Péwé, 1958b). Stunted black-spruce trees at locality 6 probably indicate a small, isolated mass of shallow permafrost.

Thick deposits of frozen, retransported organic silt [Fss] in valley bottoms contain massive, relict ground ice (fig. 6). Large, buried ice wedges survived general lowering of the permafrost table during periods of regional warming 27,000 to 35,000 yr ago and 3,500 to 8,000 yr ago (Sellman, 1967; Péwé, 1975a). Mackay (1971) discussed the forms and origins of different types of massive ground ice. Thermokarst features indicate the presence of ice-rich permafrost beneath lower slopes and valley bottoms. Dark-toned thaw ponds (7) have formed in bulldozed trails that are vegetated by light-toned grasses and sedges. Alases (8) at the base of the ridge are watered by springs. The width of strips of tall, riparian spruce (9) indicates the approximate size of thaw bulbs formed by small streams flowing through frozen terrain. Light-toned willows (10) in low-gradient drainages indicate the general extent of seasonal aufeis (stream icings) (11). Relatively tall aspen and spruce grow in well-drained near-surface soils on an open-system pingo (12) (Holmes and others, 1966, 1968).

Table 16. *Logs of soil borings on plate 10 (see table 7 for explanation of abbreviations and terms).*

a) 0-14 ft Si w/tr Sa; 14-29 ft Si Sa w/tr Gr (Wea Schist); 29-35 ft Wea Schist. Fr 0-35 ft. [6-22-70]. (7-40).
b) 0-52 ft Si w/tr to s Sa (10-15 ft sc. Rock Frag). Fr 15-44 ft. WT @ 43 ft. [6-24-70]. (7-42).
c) 0-32 ft Si w/s to tr Sa. WT @ 29 ft. [7-14-70]. (7-61).
d) 0-51 ft Si w/s Sa. Fr 4-51 ft. [7-14-70]. (7-62).
e) 0-3 ft Si; 3-5 ft Si w/s Gr & Rock Frag; 5-20 ft Wea Schist. [7-29-74]. (200-90).
f) 0-24 ft Wea Schist. [8-15-70]. (24-35).
g) 0-40 ft Si; 40-46 ft Si w/Rock Frag; 46-64 ft High Wea Bedrock. [6-20-70]. (P.S. 8-9).
h) 0-65 ft Si w/tr Sa; 65-104 ft Wea Bedrock. [5-31-70]. (P.S. 8-3).
i) 0-173 ft Si; 173-195 ft Wea Bedrock. [5-23-70]. (P.S. 8-1).
j) 0-100 ft Si. Fr 30-68 ft. [6-12-70]. (P.S. 8-5).
k) 0-52 ft Si w/tr Sa & Org. Fr 7-52 ft. [7-11-70]. (9-45).
m) 0-9 ft Org Si; 9-52 ft Si w/tr Sa & Org. Fr 0-52 ft. [7-13-70]. (9-46).
n) 0-5 ft Si w/s Gr; 5-20 ft Wea Phyllite & Schist. Fr 4-20 ft. [7-14-70]. (9-47).

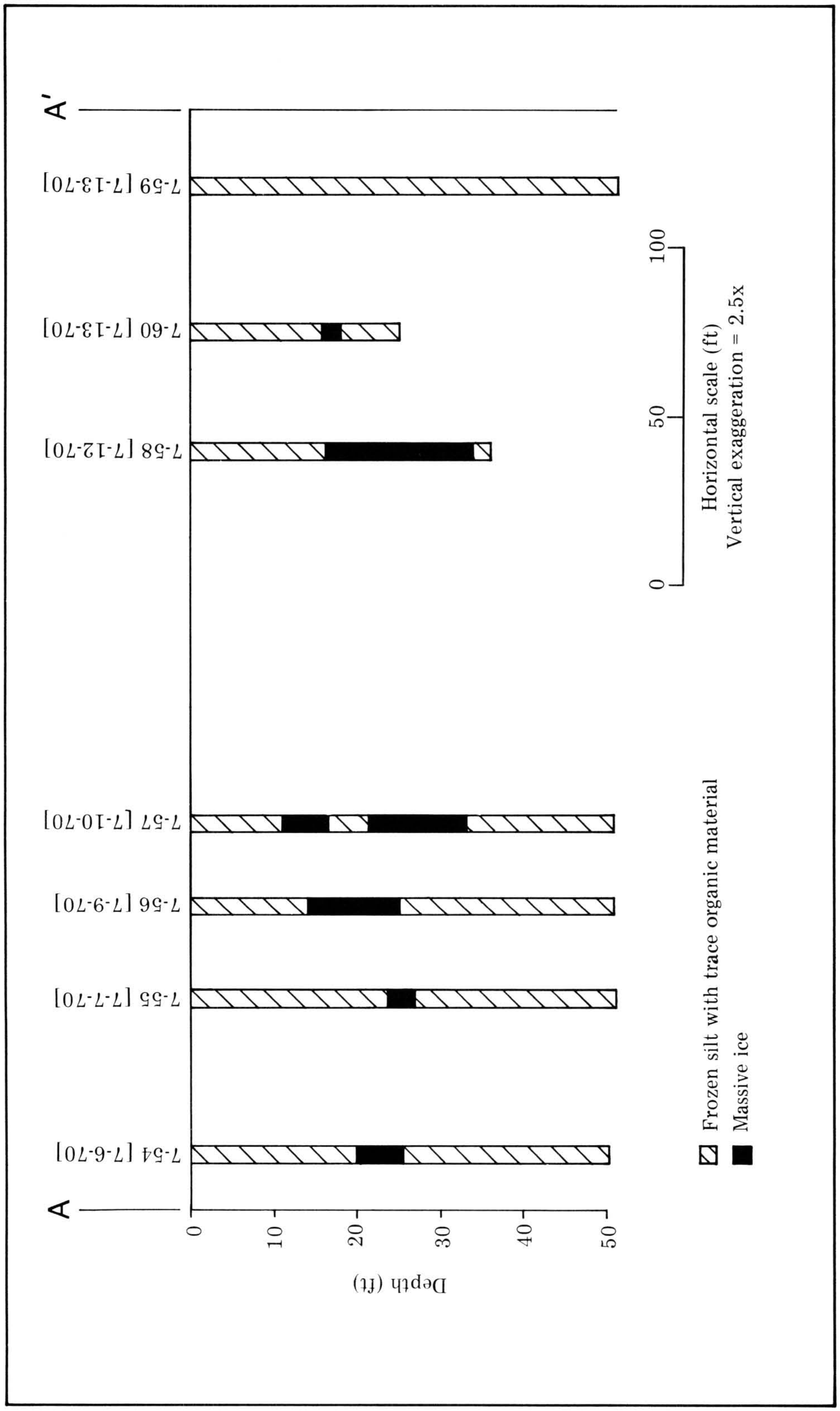
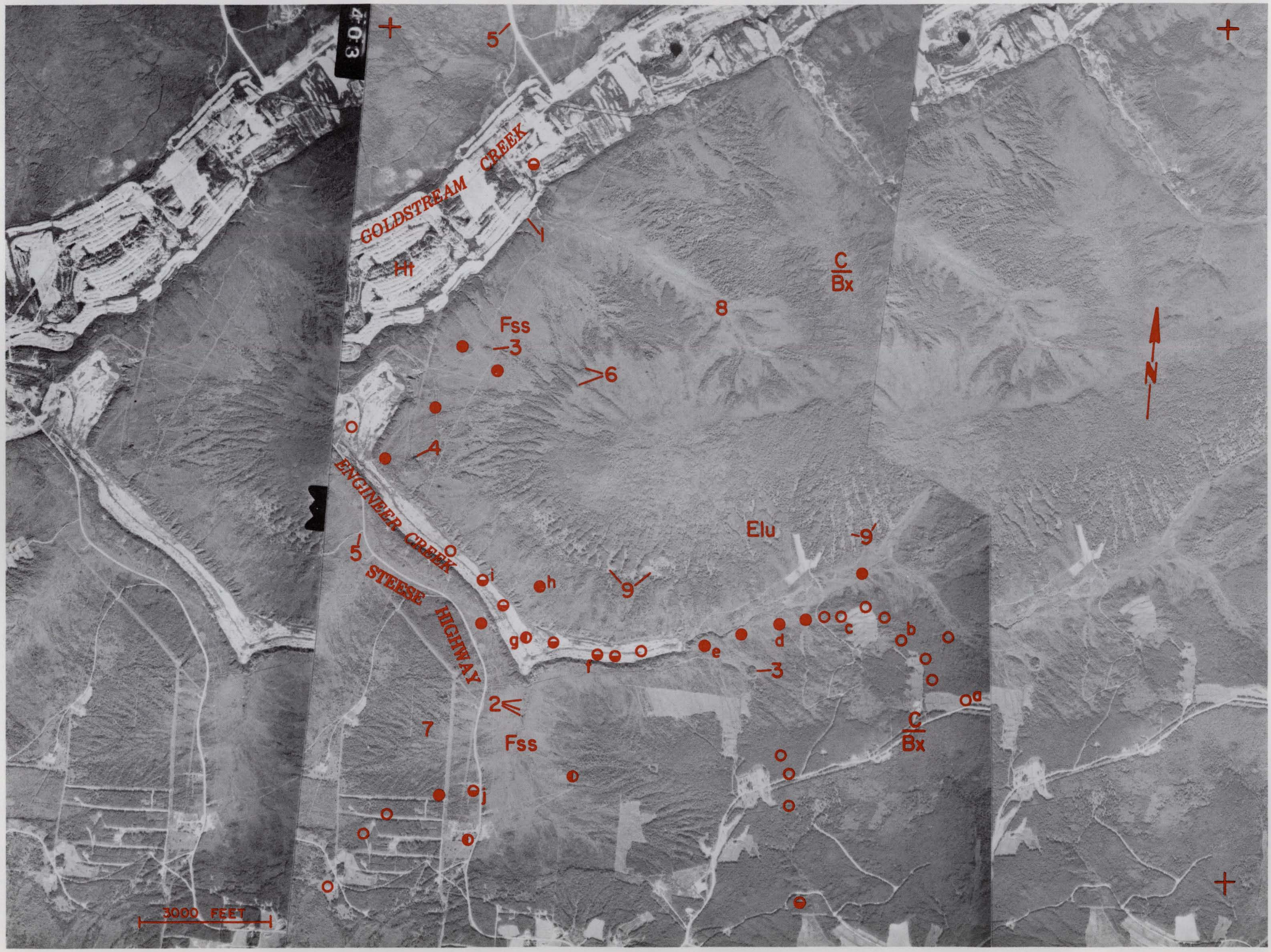


Figure 6. Distribution of massive ice in soil borings in perennially frozen retransported organic silt along line A-A′ (pl. 10).



GOLDSTREAM CREEK
ENGINEER CREEK
STEESE HIGHWAY
N
Ht
Fss
Elu
C
Bx
3000 FEET
403

Plate 11. Retransported silt, tailings, and vegetation, Fox area, Fairbanks Quadrangle
(U.S. Geological Survey photos GS-VBME-2-182/184, August 11, 1966).

Thick deposits of ice-rich, retransported silt [Fss], termed 'muck' by the early miners because of its fetid smell, form a unique landform in interior Alaska. This landform is usually crossed by transportation and utility routes or used for development sites because it occurs in the bottoms and lower walls of upland valleys and, except for the flood plains of major streams, generally has the most gentle slopes and least relief in any area. Its inherent engineering problems and land-use constraints create impacts on development that far outweigh the actual percentage of the landscape it covers. Retransported silt eroded from loess [Elu] on upper slopes and ridge crests have filled valleys of the southern Yukon-Tanana Upland to depths of over 200 ft. Much of the retransportation process involved slope and rill wash, although the presence of locally folded layers indicates that some soil flow occurs (Tuck, 1940; Péwé, 1965c, 1975b; Matthews, 1970, 1974); the landform also contains primary airfall silt (lowland loess). Valley-bottom silts were laid down over late Tertiary or early Quaternary stream gravels that locally contain placer gold during late Quaternary time, when loess deposition was rapid. Between 1963 and 1966, a 360-ft-long adit (1) was dug by the U.S. Army Cold Regions Research and Engineering Laboratory in perennially frozen silt, exposing complex stratigraphic relationships, numerous foliated ice wedges, massive ice lenses, and buried plant and animal remains (Sellman, 1967, 1972; Swinzow, 1970). Radiocarbon dates indicate that 40 to 50 ft of retransported silt was deposited during the past 33,000 yr.

Tailings [Ht] were deposited by dredges extracting placer gold from stream gravels after silt overburden was hydraulically removed (Beistline, 1966). Discontinuous permafrost, which is locally ice-rich, has developed in the tailings during the past 25 yr (borings g and i, table 17). Water-filled and thaw-modified prospect and production shafts (2) delineate buried pay streaks followed by early drift miners working frozen gravels beneath the thick cover of perennially frozen silt. Open-system pingos (3) form when ground water from thawed upslope areas flows downslope, below the permafrost table. These landforms appear initially as surface mounds that eventually reach a maximum size, break open at the summit, and collapse. The ice lens melts to form rimmed, circular thermokarst ponds (4). Well-formed open-system pingos in Alaska's interior apparently require more than 10 yr to develop and may persist for several centuries, depending especially on the fire history of the site (Holmes and others, 1968). Seasonal icings are produced by springs (5) (Péwé, 1958a; Péwé and Bell, 1975c).

Upland loess [Elu] has been nearly stripped from ridges of Precambrian or Paleozoic greenschist and Mesozoic or Tertiary granite or intermediate intrusive rocks (Weber, 1971), leaving bedrock covered with thin colluvium and residual soils [C/Bx]. Ellipsoidal and triangular "flatironlike" ridges pointing upslope (6) are composed of *in-situ* loess and retransported silt. These ridges are generally shallowly frozen except where well-developed aspen and birch grow on their upper margins. Pedologic soil units have been mapped in this area by Rieger and others (1963).

The sharp vegetation boundary between stunted black-spruce forest on retransported silt and the woodland of large aspen, birch, and white spruce on unfrozen loess is very useful for roughly separating perennially frozen and nonpermafrost terrain in interior Alaska (pl. 10). Nevertheless, large white spruce and birch trees also grow on lower slopes, where ice-rich permafrost is only 4 to 8 ft deep. If the vegetation boundary is diffuse, as at locality 7, test-hole drilling is required to conclusively delineate the upper limit of perennially frozen ground. Dingman and Koutz (1974) used the amount of solar radiation received at the ground surface to predict the location of permafrost and nonpermafrost terrain in the Glenn Creek experimental watershed (8). When they contoured the terrain of this drainage basin with isopleths of potential insolation based on values calculated from slope and aspect data for points on a grid over the watershed, they found that permafrost boundaries are almost always between isopleths representing 52 and 56 percent of the potential insolation at the earth's equator, or about 265 cal/cm^2/day at the ground surface. The striking asymmetry of vegetation on north- and south-facing slopes is related to these insolation differences.

Unique open woodlands (9), or 'parks,' that probably result from repeated wildfires (Lutz, 1956; Viereck, 1973) contain a light-toned ground cover of *Cladonia* lichens, grass, scattered shrubs dominated by prickly rose, and scattered birch, aspen, and willow clumps. Typically, a shrubby growth dominated by willows develops after a burn in this area, although postburn succession is a function of topography, climate, previous vegetation, severity of burning, and available seed sources at the time of the fire (Slaughter and others, 1971; Viereck and Little, 1972; Foote, 1979).

Table 17. *Logs of soil borings on plate 11 (see table 7 for explanation of abbreviations and terms).*

a) 0-3 ft Org Si; 3-6 ft Wea Schist; 6-15 ft Schist. [9-14-70]. (24-65).
b) 0-3 ft Si & Si Gr w/s Sa & Rock Frag; 3-10 ft Sa Gr w/tr Si (High Wea Schist); 10-15 ft Wea Schist. [9-15-70]. (24-69).
c) 0-9 ft Si; 9-15 ft Si Gr w/s Sa & Rock Frag; 15-30 ft Wea Schist; 30-35 ft Schist. [9-17-70]. (24-73).
d) 0-15 ft Si w/s Org; 15-17 ft Sa; 17-33 ft Si w/tr Org; 33-36 ft *Massive Ice*; 36-43 ft Si w/tr Org; 43-54 ft Gr Si w/s Sa & Rock Frag; 54-60 ft Wea Schist. Fr 2-58 ft. WT @ 1 ft. [9-19-70]. (24-76).
e) 0-50 ft Si w/tr Sa & Org. Fr 1-50 ft. [9-25-70]. (24-81).
f) 0-14 ft Gr w/s Sa & Cob (Tailings); 14-27 ft Sa w/s Si & Gr; 27-46 ft Si w/s Sa, tr Gr; 46-50 ft High Wea Gneiss (?). Fr 40-50 ft. WT @ 14 ft. [8-4-74]. (200-102).
g) 0-19 ft Cob & Bol w/tr Sa & Si (Tailings); 19-38 ft Si Gr w/s Sa & Cob; 38-49 ft Si Sa; 49-58 ft Sa Gr w/s Si & Rock Frag. Fr 10-43 ft & 50-58 ft. WT @ 16 ft. [11-2-72]. (90-14).
h) 0-54 ft Si; 54-100 ft Gr; 100-109 ft Bedrock. Fr 2-109 ft. WT? [Drilling date unknown]. (Péwé, 1958a, well log 65).
i) 0-14 ft Gr w/s Sa (Tailings); 14-21 ft Si Sa w/tr Gr; 21-34 ft Si; 34-36 ft High Wea Schist. Fr 9-36 ft. [8-7-74]. (200-112).
j) 0-105 ft Si; 105-123 ft Wea Schist; 123-230 ft Schist. Fr 25-105 ft. WT @ 154 ft. [Drilling date unknown]. (Péwé and Bell, 1975a, 1975b, borehole 120).

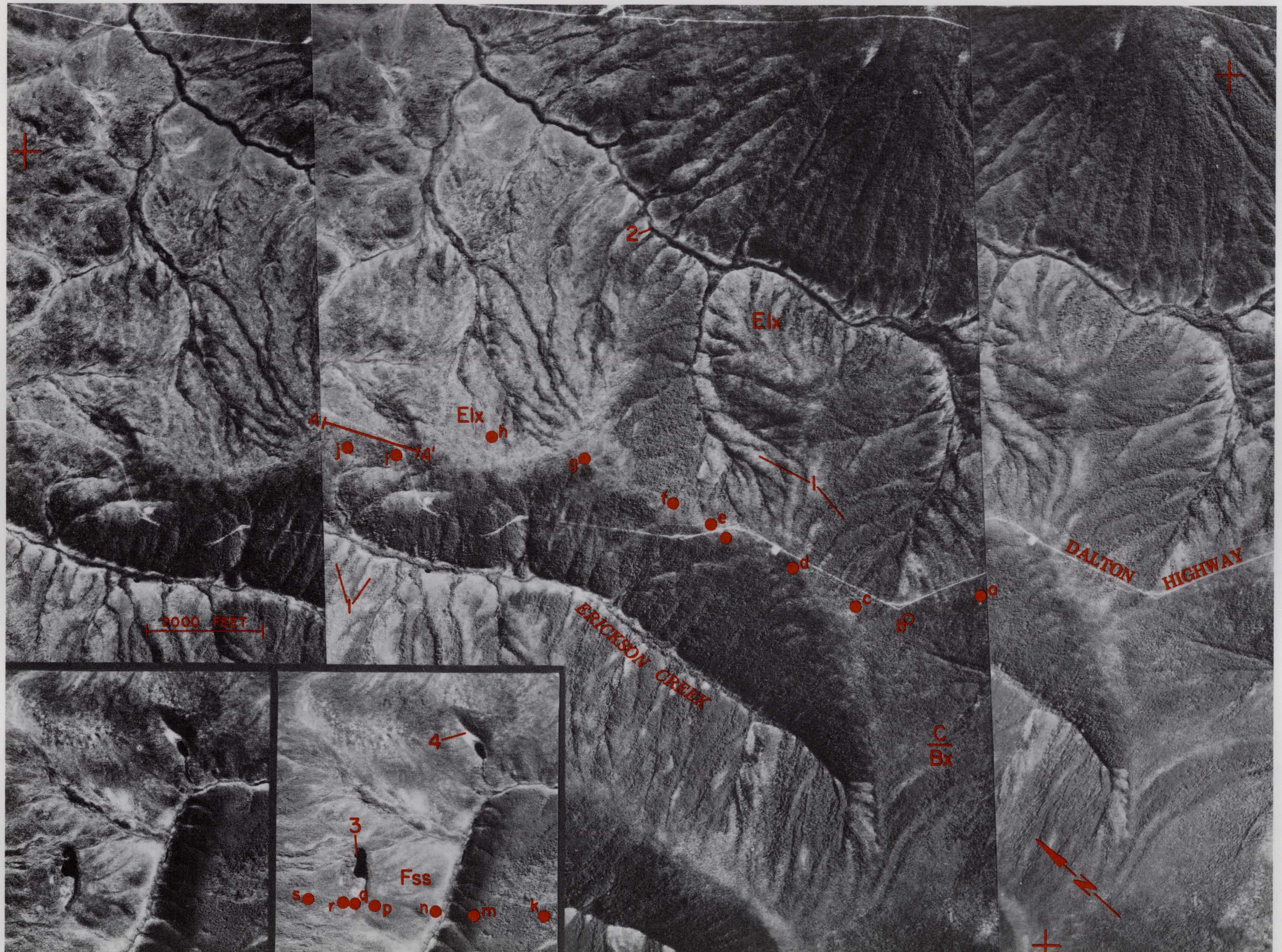

DALTON HIGHWAY
ERICKSON CREEK
Elx
Elx
C
Bx
Fss
2000 FEET
A
A'
1
2
3
4
N

Plate 12. Massive ice in frozen silt, Erickson Creek area, Livengood Quadrangle (Alyeska Pipeline Service Company photos 7-16/18, August 10, 1969). **Inset — Thermokarst depressions in frozen retransported silt, Erickson Creek drainage, Livengood Quadrangle** (Alyeska Pipeline Service Company photos 7-14/15, August 10, 1969).

Thickness and thermal state of loess deposits along the TAPS route through the Yukon-Tanana Upland vary with distance to silt source and climate, respectively. Thick, unfrozen loess derived from the braided flood plain of the Tanana River blankets bedrock ridges in the southern Yukon-Tanana Upland from near Delta Junction to Fox (pls. 10 and 11). From Fox to about 5 mi north of Livengood, loess is thin or absent. Between 5 mi north of Livengood and just north of the Yukon River, most hills and ridges are covered with moderately thick, perennially frozen loess [Elx] derived from braided reaches of the Yukon River (Williams, 1962). This frozen organic silt contains massive ice as thick as 55 ft (fig. 7) and is compositionally similar to retransported silt farther south; however, its location on ridge crests (boring d, table 18) precludes the possibility of reworking and indicates an eolian origin. On this plate, frozen loess has the dendritic-pinnate drainage pattern characteristic of loess elsewhere. The presence of convex interfluves (1) between gullies in the loess distinguishes it from shallow bedrock [C/Bx], a sequence of early to middle Paleozoic chert, argillite, slate, quartzite, siltstone, and limestone (Chapman and others, 1971). In frozen upland loess, gullies have convex walls and narrow floors in contrast to gullies with broad floors in unfrozen upland loess (fig. 8). Large trees, mostly black spruce, follow drainage lines where the permafrost table is locally deeper (2).

Lotspeich (1971) and Smith and Berg (1973) described the performance of roadcuts through ice-rich upland loess 7 mi northwest of this area during construction of the Dalton Highway. Vertical cuts that were properly cleared of standing trees prior to excavation stabilized more rapidly and required less maintenance because more of the organic mat along the top of the cut remained intact as the mat slumped down, to cover and insulate the ablating cut face. Where trees were not removed, they were undermined and toppled, ripping the organic mat and aggravating recession of the thawing face. Organic silt released from thawing walls accumulated against their bases, also providing further insulation and promoting early stabilization. Cuts made at the normal 1:1 slope were less successful.

Depths of two large thermokarst depressions (3, 4) located 2.7 mi northwest of borehole j (table 18) in thick frozen retransported silt [Fss] dramatically demonstrate the volume of massive ice in this landform. Boring q (table 18) in the floor of one depression (3) encountered no massive ice, unlike borings p and r in frozen silt on either side of the pit. The depression at locality 3 appears younger because its walls are steeper than the pit at locality 4.

Table 18. *Logs of soil borings on plate 12 (see table 7 for explanation of abbreviations and terms).*

a) 0-5 ft Si w/s *Massive Ice*; 5-6 ft Gr w/Rock Frag. Fr 0-6 ft. [7-22-70]. (16-83).
b) 0-4 ft Si w/s Sa & Gr; 4-8 ft Wea Shale. [6-23-70]. (16-64).
c) 0-6 ft Si w/s Org; 6-15 ft *Massive Ice*; 15-25 ft High Wea Bedrock. Fr 0-25 ft. [7-24-70]. (16-84).
d) 0-5 ft Si w/tr Org; 5-10 ft *Massive Ice*; 10-36 ft Si w/s Org; 36-41 ft Si w/s Gr & Rock Frag; 41-43 ft Wea Phyllite. Fr 0-43 ft. [7-26-70]. (16-85).
e) 0-42 ft Si w/tr Org; 42-50 ft Si w/s Gr. Fr 0-48 ft. [7-4-70]. (16-66).
f) 0-6 ft Si w/s Org; 6-19 ft *Massive Ice*; 19-42 ft Si w/tr Org; 42-46 ft Wea Phyllite. Fr 0-46 ft. [7-27-70]. (16-86).
g) 0-29 ft Si w/s Org; 29-36 ft High Wea Phyllite. Fr 0-36 ft. [7-28-70]. (16-87).
h) 0-26 ft Si w/tr Org; 26-33 ft *Ice* + Silt; 33-52 ft Si w/s Org. Fr 0-52 ft. [7-29-70]. (16-88).
i) 0-14 ft Si w/tr Org; 14-22 ft *Massive Ice*; 22-36 ft Si w/tr Org; 36-37 ft *Massive Ice*; 37-50 ft Si w/tr Org. Fr 0-50 ft. [7-30-70]. (16-89).
j) 0-46 ft Si. Fr 0-46 ft. [7-31-70]. (16-90).
k) 0-30 ft Si; 30-35 ft *Massive Ice*; 35-51 ft Si. Fr 0-51 ft. [8-20-70]. (18-68).
m) 0-4 ft Si; 4-27 ft *Massive Ice*; 27-52 ft Si w/s Org. Fr 0-52 ft. [8-17-70]. (18-66).
n) 0-48 ft Si w/s Org. Fr 0-48 ft. [8-15-70]. (18-65).
p) 0-22 ft Si to Org Si; 22-47 ft *Massive Ice*; 47-56 ft Si. Fr 0-56 ft. [8-13-70]. (18-64).
q) 0-20 ft Si w/s Org; 20-30 ft Org Si; 30-52 ft Si w/s Org. Fr 0-52 ft. [8-12-70]. (18-63).
r) 0-6 ft Si w/tr Org; 6-17 ft *Massive Ice*; 17-27 ft Si w/s Org to Si Sa w/s Org; 27-41 ft *Massive Ice*. Fr 0-41 ft. [8-11-70]. (18-62).
s) 0-5 ft Si w/s Org; 5-18 ft *Massive Ice*; 18-32 ft Si; 32-50 ft *Massive Ice*. Fr 0-50 ft. [8-2-70]. (18-61).

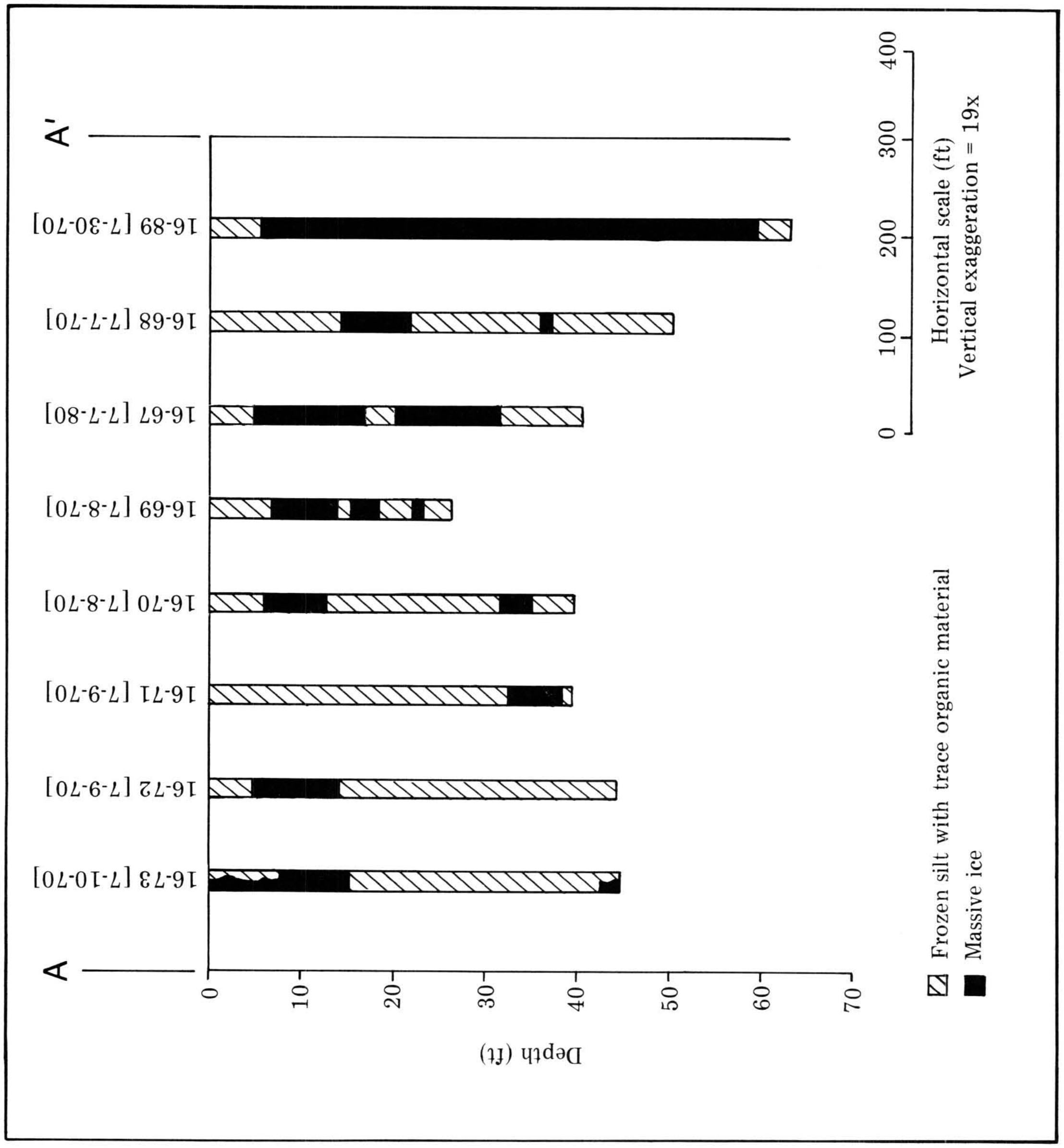


Figure 7. Distribution of massive ice in soil borings along line A-A′ (pl. 12).

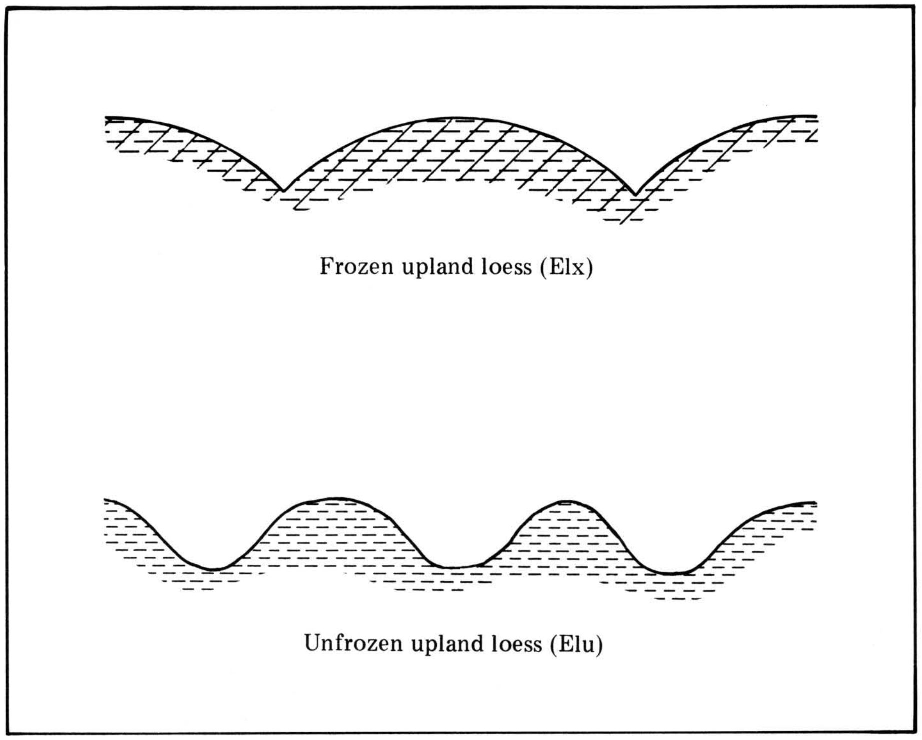


Figure 8. Comparison of cross-sectional forms of gullies cut in frozen and unfrozen upland loess.

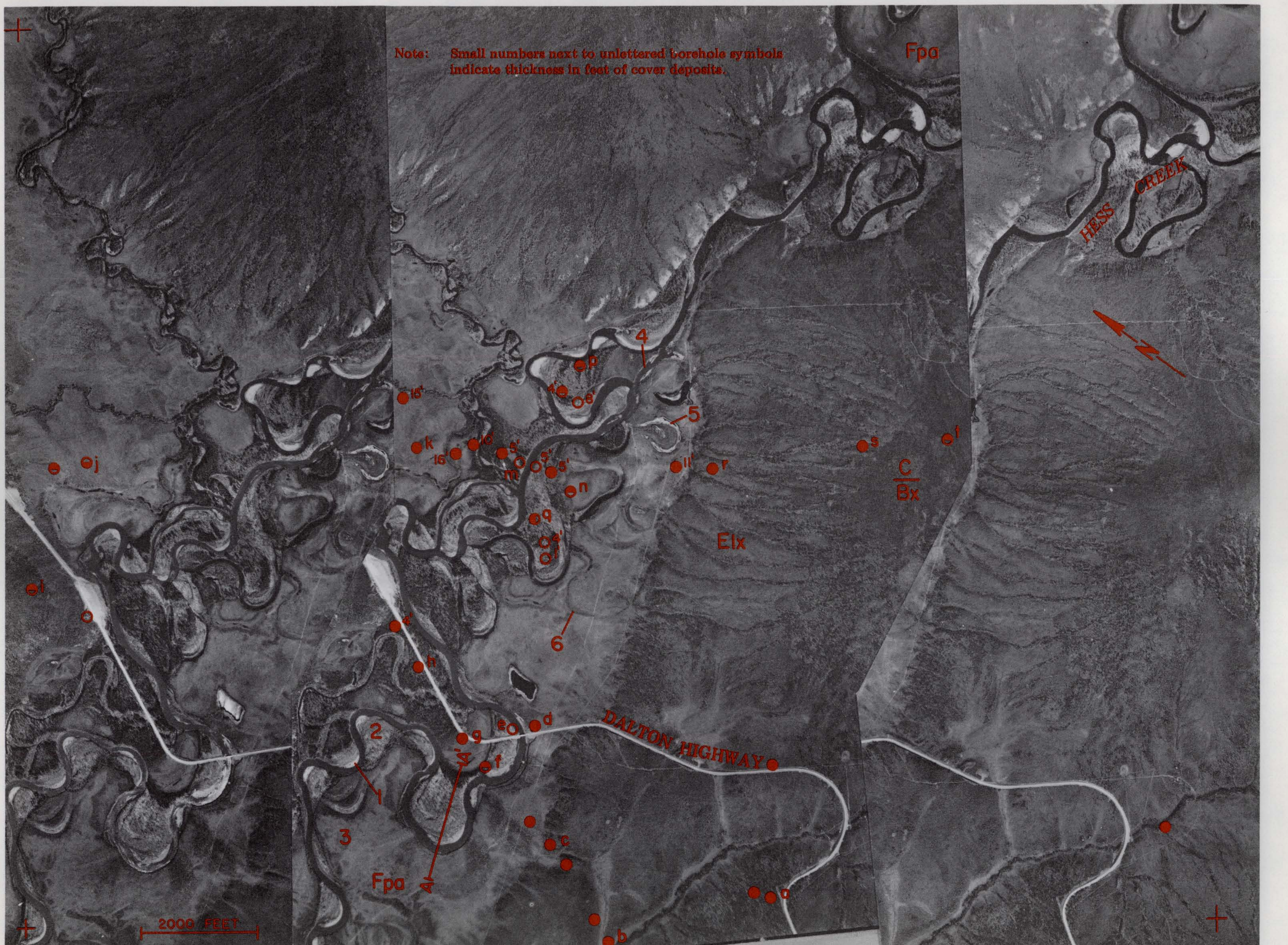

Note: Small numbers next to unlettered borehole symbols indicate thickness in feet of cover deposits.
Fpa
HESS CREEK
N
C/Bx
Elx
DALTON HIGHWAY
2000 FEET

Plate 13. Vegetation and permafrost relationships, Hess Creek valley, Livengood Quadrangle (Alyeska Pipeline Service Company photos 8-18/20, May 20, 1970).

The vegetation succession that develops as permafrost aggrades into recent point-bar deposits is a very useful key for predicting permafrost beneath flood plains in subarctic areas (Viereck, 1970a,b; Gill, 1972, 1973). A typical succession exists along line A-A′. Fresh silt and sand surfaces on the inside of meanders are quickly colonized by scattered willows, alders, and small balsam poplars (fig. 9). Because of their rapid growth, willows dominate initially but are overtopped by balsam poplar in about 10 to 15 yr. Permafrost is generally absent beneath willows and poplars, although deep relict permafrost is preserved where rapid meandering fails to thaw all previously frozen ground.[6] White spruce, which has shade-tolerant seedlings, becomes established in balsam poplar stands about 50 yr after the initial growth of vegetation on bare flood-plain surfaces, and within 75 to 100 yr overtops and gradually replaces the poplar. As the white-spruce stand matures and poplars die out, an insulating mat of moss develops on the forest floor, especially if the river shifts enough to reduce flood frequency and deposition of sediments, particularly calcareous sediments (Zoltai and Pettapiece, 1973, p. 13). The moss layer favors the development of permafrost perhaps 200 to 300 yr after formation of the flood-plain surface, and as permafrost aggrades into shallow soils, white spruce is gradually replaced by black spruce. Eventually permafrost incorporates all mineral soil and restricts annual thaw and plant roots to the surface organic layer. Bog vegetation of black spruce, *Sphagnum* moss, and heath plants is the final stage of the succession on the abandoned flood plain [Fpa]. Tonal differences on the flood plain primarily reflect ground cover. Brightest tones (1) are bare sand and gravel bars; light tones (2) indicate scattered leaf litter and ferns growing on silty forest floors; dull tones (3) are thick moss and tussocks in frozen bogs.

Hess Creek is actively meandering; cutoffs (4) are less than 18 yr old. Old oxbows gradually fill with organic material (5) and eventually blend with surrounding surfaces (6). Sediments beneath the flood plain of Hess Creek consist of 4 to 10 ft of organic silt and silty sand that represent vertical accretion (cover) deposits over sand; some gravel and sandy gravel represent lateral accretion (riverbed) deposits (table 19). Although borings in the Hess Creek flood plain did not reach the bottom of permafrost, deeper holes in flood-plain alluvium elsewhere demonstrate that permafrost generally thickens with increasing age (Williams, 1970; Crampton, 1979).

Table 19. *Logs of soil borings on plate 13 (see table 7 for explanation of abbreviations and terms).*

a) 0-8 ft Si; 8-40 ft *Massive Ice.* Fr 0-40 ft. [6-29-70]. (18-40).
b) 0-19 ft Si; 19-52 ft Org Si. Fr 0-52 ft. [7-30-70]. (20-24).
c) 0-32 ft Org Si; 32-52 ft *Massive Ice.* Fr 0-52 ft. [8-2-70]. (20-27).
d) 0-9 ft Sa Si; 9-18 ft Si Sa; 18-26 ft Sa Gr w/Si. Fr 0-26 ft. [8-14-69]. (6-23).
e) 0-7 ft Sa; 7-46 ft Sa Gr. WT @ 1 ft. [8-15-69]. (6-24).
f) 0-10 ft Si Sa; 10-30 ft Sa w/s Gr. Fr 2-10 ft. WT @ 8 ft. [7-18-70]. (17-77).
g) 0-4 ft Si w/tr Sa; 4-10 ft Gr Sa. Fr 0-7 ft. WT @ 2 ft. [7-7-70]. (17-67).
h) 0-5 ft Si & Si Sa; 5-20 ft Gr Sa. Fr 0-19 ft. WT @ 8 ft. [7-8-70]. (17-69).
i) 0-7 ft Gr Sa w/Si; 7-14 ft High Wea Argillite; 14-46 ft Wea Argillite. Fr 0-11 ft. [7-15-70]. (17-75).
j) 0-27 ft Gr w/s Sa. Fr 15-27 ft. [9-22-70]. (20-60).
k) 0-9 ft Org Si w/tr Sa; 9-28 ft Gr w/s Sa. Fr 0-28 ft. [9-23-70]. (20-61).
m) 0-4 ft Si w/tr Org; 4-12 ft Sa w/s Gr; 12-20 ft Gr Sa; 20-35 ft Sa w/s Si & Gr; 35-73 ft Sa w/tr Si & Gr; 73-75 ft High Wea Schist. WT @ 10 ft. [12-6-74]. (208-6).
n) 0-9 ft Sa Si; 9-25 ft Sa w/tr Gr. Fr 0-16 ft. [9-1-70]. (20-46).
p) 0-6 ft Si w/tr Org & Sa; 6-30 ft Sa Gr. Fr 0-7 ft. WT @ 21 ft. [12-6-74]. (209-9).
q) 0-7 ft Si; 7-16 ft Si Sa w/s Gr; 16-27 ft Sa Gr w/s Si. Fr 0-7 ft & 16-27 ft. [12-2-74]. (209-6).
r) 0-6 ft Si w/s Gr & Sa; 6-12 ft Gr w/s Sa, Si & Rock Frag; 12-20 ft Wea Bedrock. Fr 0-20 ft. [9-8-70]. (20-51).
s) 0-9 ft Si w/s Sa & Org; 9-19 ft Si Cl w/s Sa, tr Gr. Fr 0-17 ft. [9-7-70]. (20-50).
t) 0-10 ft Si w/s Gr, Sa & Rock Frag; 10-26 ft Sa w/s Si, Gr & Rock Frag. Fr 0-16 ft. [9-5-70]. (20-49).

[6] According to Hal Livingston (written commun., July 6, 1981), soil drilling programs in small upland drainages near Fairbanks and in the channels of Chatanika, Chena, and Tanana Rivers demonstrated that meander migration is commonly rapid enough to leave permafrost at depths of 5 to 15 ft beneath stream channels. Drilling in fine gravel beneath the main channel of the Noatak River, where the annual migration rate is 5 to 10 ft, encountered permafrost as shallow as 3 ft.

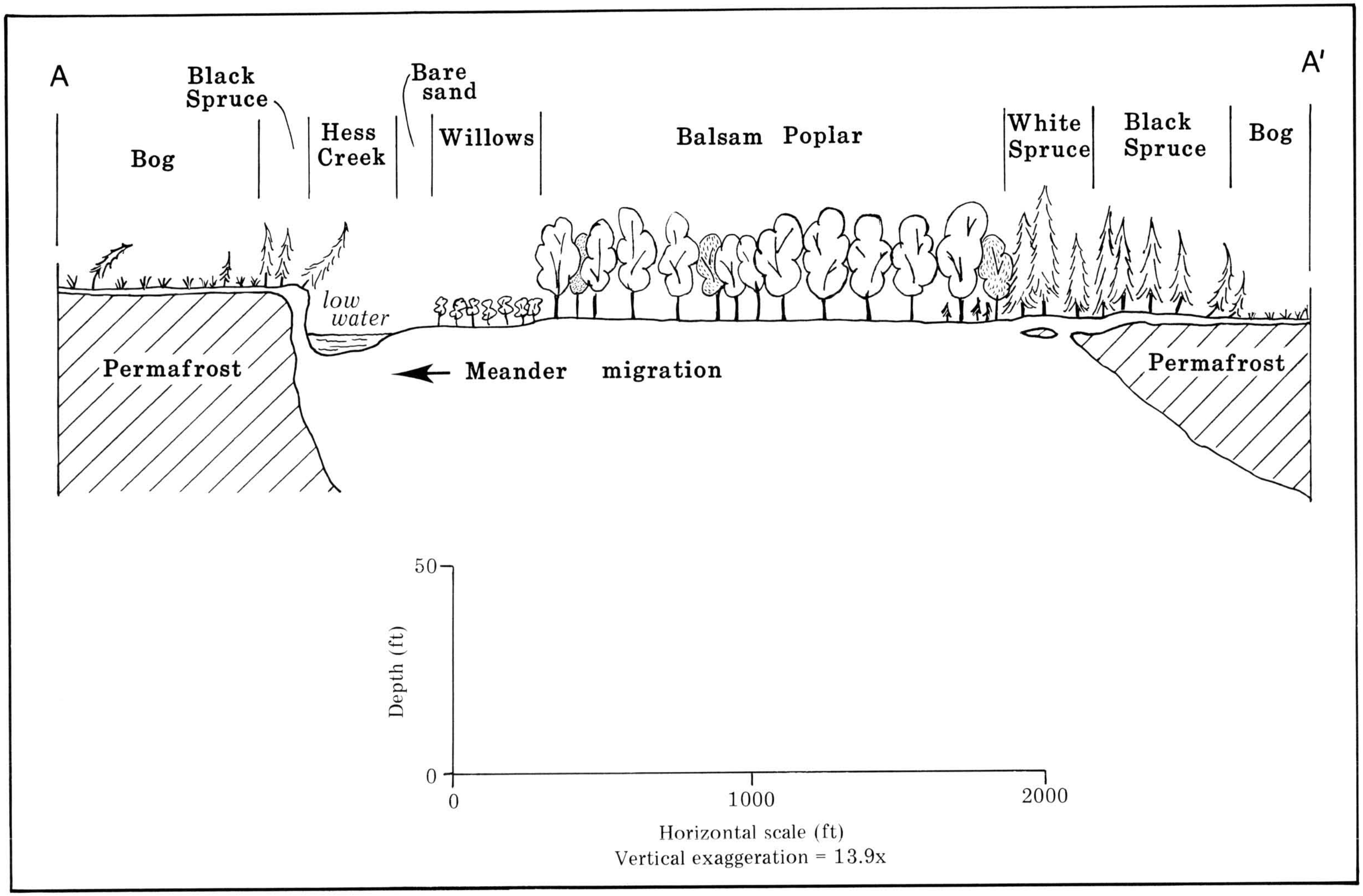


Figure 9. Cross section A-A′ (pl. 13) across Hess Creek, Livengood Quadrangle, showing relation between direction of meander migration, vegetation, and inferred permafrost conditions.

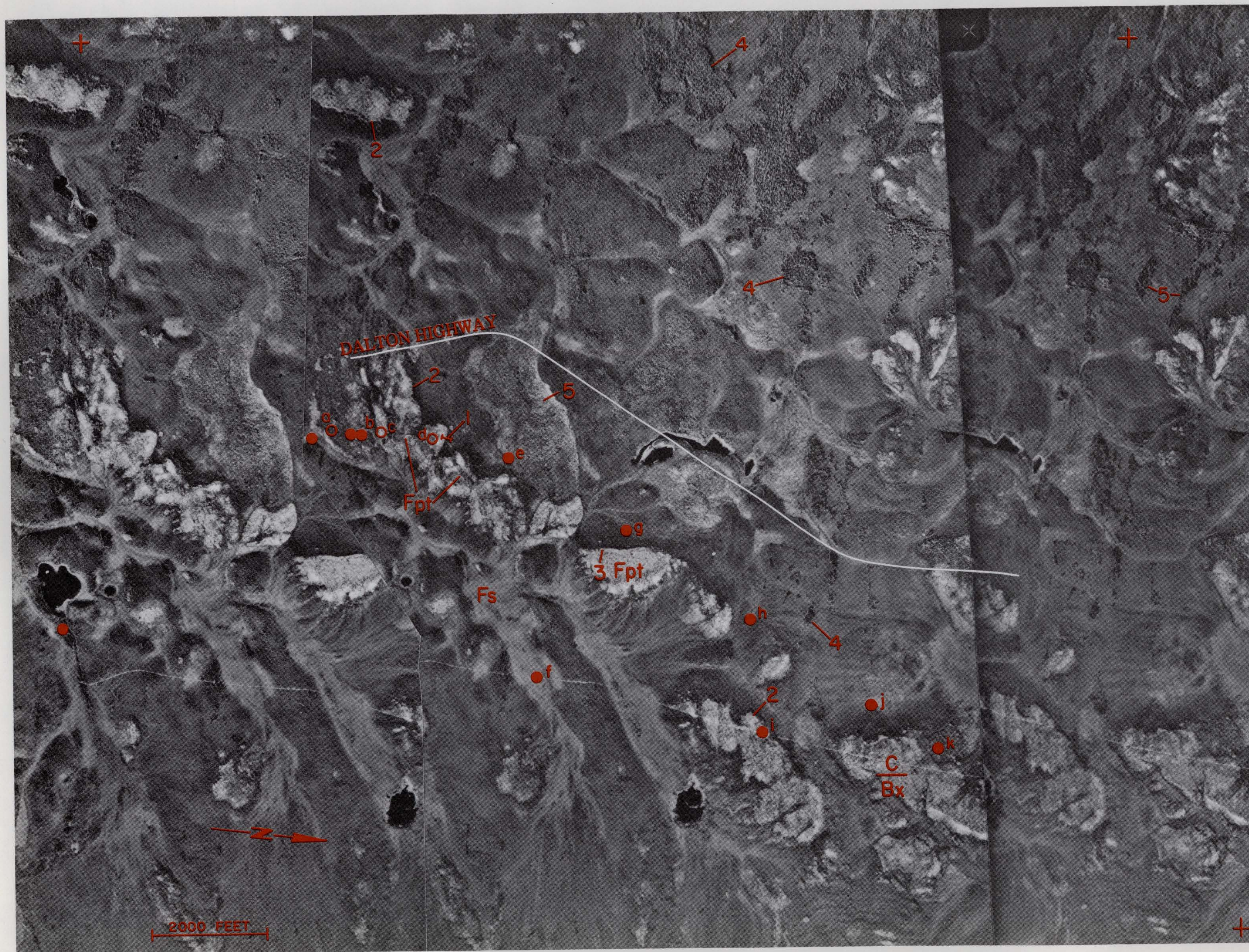

DALTON HIGHWAY
2000 FEET
N
Fs
Fpt
3 Fpt
C
Bx

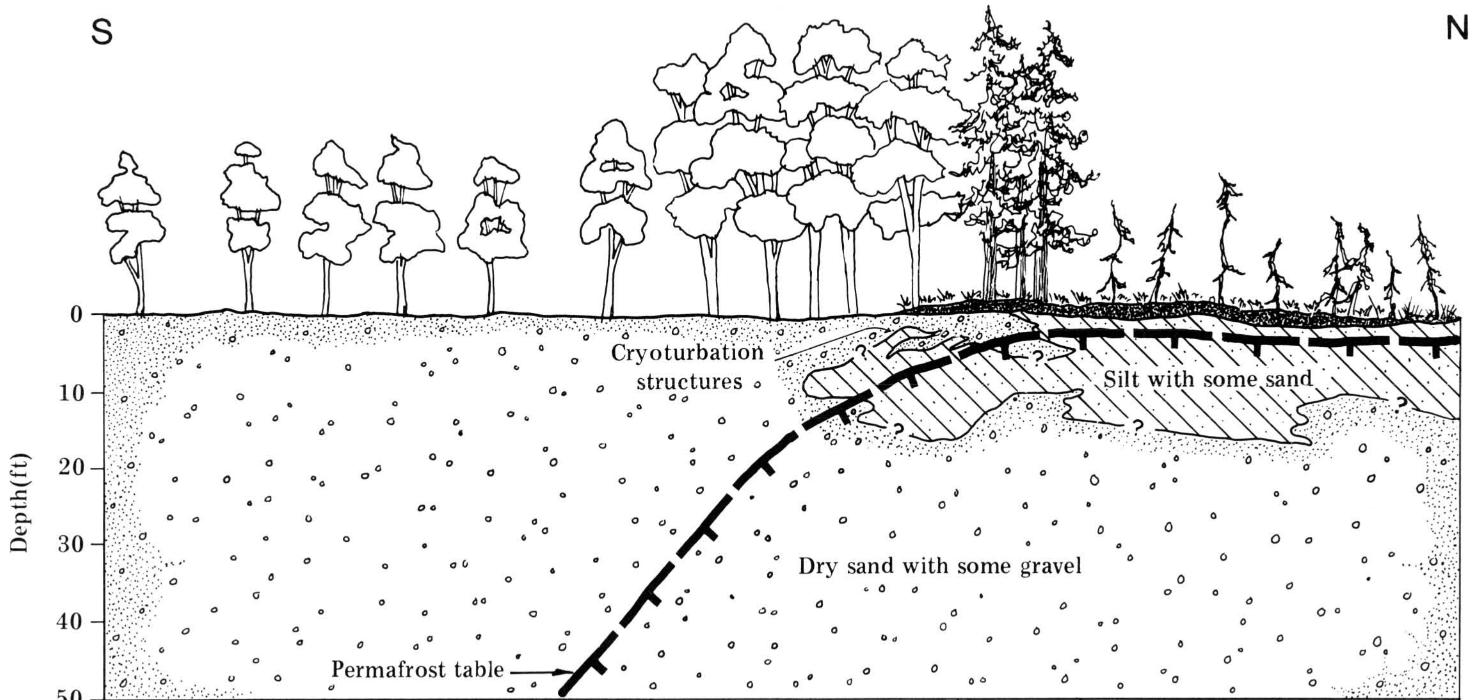
Plate 14. Sharp vegetation boundaries on high terrace deposits, Ray River valley, Bettles Quadrangle
(Alyeska Pipeline Service Company photos 7-110/112, August 11, 1969).

Radical vegetation and soil-type changes at the edge of perenially frozen ground may occur within extremely short distances (<2 yd) in interior Alaska. (Krause and others, 1959). Associations of large trees, especially aspen, typically grow where near-surface permafrost does not exist and obviously stunted vegetation grows over shallow permafrost. However, on high-level, ancient terrace deposits [Fpt] in the drainage of Ray River, trees that grow along permafrost boundaries (1) are taller and thicker than trees growing on either side (2) (fig. 10), which suggests that more favorable growing conditions exist at the edge of permafrost. Aspen and spruce growing on dry, unfrozen sand and gravel receive less moisture than those growing at the edge of permafrost, where trees are able to use moisture perched on shallow frozen ground. The permafrost boundary at locality 3 apparently is not controlled by slope or aspect (differences in solar radiation incident to the ground surface), two of several factors that usually govern permafrost distribution (Brown, 1969) (pls. 10 and 11). Sharp spruce boundaries (4) are fire scars.

Light-toned ground cover must be used with care in interpreting terrain conditions. On well-drained, high-level terrace sand and gravel [Fpt] and on relatively dry sand and rock fragments over basalt [C/Bx] (table 20), the dominant ground cover is the reindeer lichen, *Cladonia*. However, light tones in poorly drained bogs indicate either the presence of *Cladonia* on the upper, relatively dry surfaces of tussocks or accumulations of *Sphagnum* moss thick enough to stand a foot or more above the surface water. A distinction between these two *Cladonia* habitats can usually be made on the basis of topographic setting. Lichens growing in bogs also frequently have a mottled or scaly pattern (5). Tussocks without lichens have a medium-gray tone and indicate shallow permafrost in retransported deposits [Fs].

Table 20. *Logs of soil borings on plate 14 (see table 7 for explanation of abbreviations and terms).*

a) 0-22 ft Si Sa; 22-32 ft Basalt. [9-12-71]. (60-5).
b) 0-10 ft Si Sa w/s Gr to Sa Gr; 10-21 ft Cl Si w/tr Sa & Gr; 21-25 ft Gr w/s Sa & Cob; 25-32 ft Wea Basalt. Fr 0-32 ft. [6-2-75]. (210-85).
c) 0-10 ft Sa; 10-41 ft Sa w/s Gr, tr Si; 41-51 ft Si Cl. [9-11-71]. (60-4).
d) 0-20 ft Sa w/tr Gr; 20-32 ft Sa w/s Gr; 32-44 ft Cl; 44-50 ft Cl Sa. [7-18-74]. (201-2).
e) 0-3 ft Si; 3-6 ft Si + *Ice*; 6-22 ft Gr Sa w/tr Si; 22-31 ft Wea Basalt; 31-39 ft Basalt. Fr 0-39 ft. [3-22-72]. (76-5).
f) 0-2 ft Org; 2-9 ft Org Si w/Sa; 9-20 ft Si. Fr 0-20 ft. [3-30-69]. (4-36).
g) 0-15 ft Si w/tr Sa; 15-50 ft Sa w/tr Si. Fr 0-50 ft. [3-31-72]. (78-5).
h) 0-32 ft Si w/s Sa; 32-50 ft Sa w/s Si. Fr 0-50 ft. [3-29-72]. (79-6).
i) 0-3 ft Sa w/Si; 3-9 ft Sa Gr; 9-17 ft Si Sa; 17-24 ft Sa w/Gr; 24-32 ft Sa w/Si. Fr 0-32 ft. [3-30-69]. (4-37).
j) 0-4 ft Sa Si; 4-46 ft Sa w/s Si; 46-49 ft Org; 49-50 ft Si Sa. Fr 0-50 ft. [9-15-71]. (60-6).
k) 0-3 ft Si Sa; 3-9 ft Sa w/s Gr & Si; 9-19 ft Basalt. Fr 0-19 ft. [3-24-72]. (83-5).



Trees	Scattered 25-ft aspen	Vigorous, dense 35-40-ft aspen		Tall, thick spruce	Stunted and deformed 12-15-ft black spruce	
Ground cover	Absent or thin (less than 2-in.-thick lichen (*Cladonia*)			6 in. *Sphagnum* moss and tussocks over 8 in. black peat		
Permafrost depth	10-14 ft +			3-6 ft	1.5 ft	
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 10. Vegetation and soil conditions across the permafrost boundary in high-level terrace deposits in the Ray River drainage, Bettles Quadrangle, (locality 2, pl. 14).

N
h
i
g
f
e
d
c
b
a
C/Bx
Bx + C/Bx
DALTON HIGHWAY
Fs
5
4
3
2
WEST FORK DALL RIVER
2000 FEET

Plate 15. Cryoplanation landforms, West Fork Dall River, Bettles Quadrangle
(Alyeska Pipeline Service Company photos 7-136/138, August 11, 1969).

The smoothly rounded landscape of the Kokrine-Hodzana Highlands has typical landforms produced by frost weathering and mass movement under periglacial conditions (Peltier, 1950). This region has probably remained essentially unglaciated throughout Quaternary time (Coulter and others, 1965) and periglacial processes have undoubtedly been active for much of that time. Rounded uplands are composed of highly weathered schist of Paleozoic and Precambrian age (Patton and Miller, 1973) overlain by a thin mantle of silty colluvium and residual material [C/Bx]. Between borings f and h (table 21), the pipeline trench encountered 2 to 6 ft of silty colluvium over highly weathered schist; both contain up to 10 percent ice. Below 7 to 11 ft, ice content in the schist is less than 5 percent. Poorly sorted deposits [Fs] retransported by slopewash, solifluction, and frost creep mantle lower slopes and choke valley bottoms. Two types of soil striping illustrated are sorted stripes (1) formed by frost sorting of mixed coarse- and fine-grained deposits on slopes, and nonsorted stripes (2), which trace drainage lines but probably were not formed by mass movement.

The morainelike mounds (3) that stand up to 70 ft above the center of the basin are composed of silt and angular gravel retransported from surrounding slopes. The origin of these mounds is uncertain. The lack of supporting evidence for glaciation in the area argues against a glacial origin, but the irregular topography may be the result of degradation of ice-rich permafrost in retransported deposits. Although numerous irregular thaw ponds (4) indicate a thermokarst origin, the present distribution of diamicton in the basin precludes this genesis. According to a thermokarst model, the maximum elevation of existing hills in the center of the basin would represent the lowest surface of colluvium and slopewash deposits shed from the basin walls before thaw and subsidence began; this requirement exists because colluvial aprons typically have concave surfaces (Peltier, 1950). Therefore, similar hills should occur on lower slopes around the basin margin, at least to the elevation of the tops of the highest hills in the center of the basin. Instead, the diamicton level is lower near the basin margin, and the irregular topography appears to be buried by debris at the base of the surrounding slopes, raising the questions of how and when the missing fill was removed. Although the surface morphology is similar to extensive thermokarst topography developed in ice-rich lacustrine deposits (pls. 5 and 25), the apparent lack of lacustrine deposits in the basin precludes a lake genesis. The complex of hummocky terrain is probably the result of the aggradation of ice-rich permafrost. Ground water moving under hydrostatic pressure through colluvium on the surrounding slopes toward the basin center probably formed a complex of open-system pingos on the floor of the basin (Holmes and others, 1966, 1968). The presence of several circular springs (5) at the base of long colluvial slopes supports this concept. Hummocky topography also results from the development of ice-rich pingos or palsas (Lundqvist, 1969) through a water injection mechanism under closed-system rather than open-system conditions (Czudek and Demek, 1970; Mackay, 1971; Soloviev, 1973) (see discussion for pl. 19).

Stunted black spruce trees cover most of the area. Poorly drained concave slopes and valley bottoms have a ground cover of *Sphagnum* moss and tussocks; convex highlands [Bx + C/Bx] are better drained and have a discontinuous ground cover of lichens and xerophytic alpine plants.

Table 21. *Logs of soil borings on plate 15 (see table 7 for explanation of abbreviations and terms).*

a) 0-4 ft Org; 4-20 ft Wea Schist. Fr 0-20 ft. [7-21-74]. (201-4).
b) 0-7 ft Sa Si w/s Gr; 7-16 ft Gr Sa w/s Si; 16-29 ft Wea Schist. Fr 0-29 ft. [3-31-72]. (80-8).
c) 0-2 ft Org Si; 2-19 ft Sa w/s Si & Gr; 19-49 ft Sa Gr w/s Si; 49-54 ft High Wea Schist (?). Fr 0-54 ft. [8-18-73]. (65-9).
d) 0-6 ft Sa Si; 6-16 ft Schist. Fr 2-16 ft. [9-19-71]. (59-8).
e) 0-2 ft Si Org; 2-15 ft Gr Sa w/tr Si; 15-33 ft Sa Si w/s Gr; 33-50 ft Gr w/s Sa. Fr 0-50 ft. [4-6-72]. (81-6).
f) 0-7 ft Si w/s Sa, Gr & Rock Frag; 7-50 ft High Wea Phyllite. [7-19-74]. (202-3).
g) 0-0.5 ft Org; 0.5-30 ft High Wea Schist. [9-19-71]. (60-8).
h) 0-4 ft Org & Si w/s Gr; 4-15 ft High Wea Phyllite. Fr 2-15 ft . [7-20-74]. (202-4).

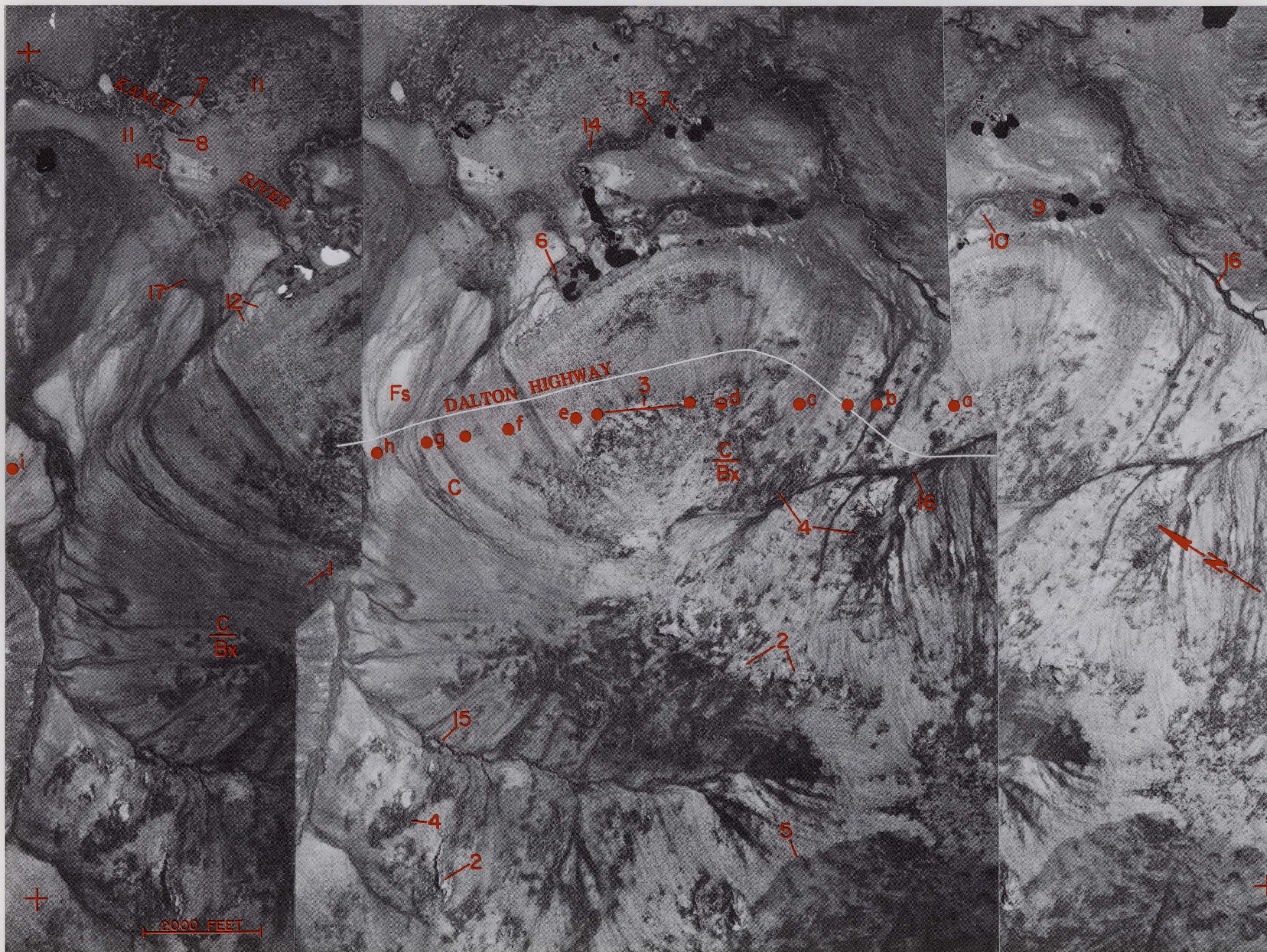

KANUTI
RIVER
DALTON HIGHWAY
Fs
C
C/Bx
C/Bx
2000 FEET
N

Plate 16. Cryoplanation and thermokarst landforms, Little Kanuti Flats, Bettles Quadrangle
(Alyeska Pipeline Service Company photos 10-4/6, August 14, 1969).

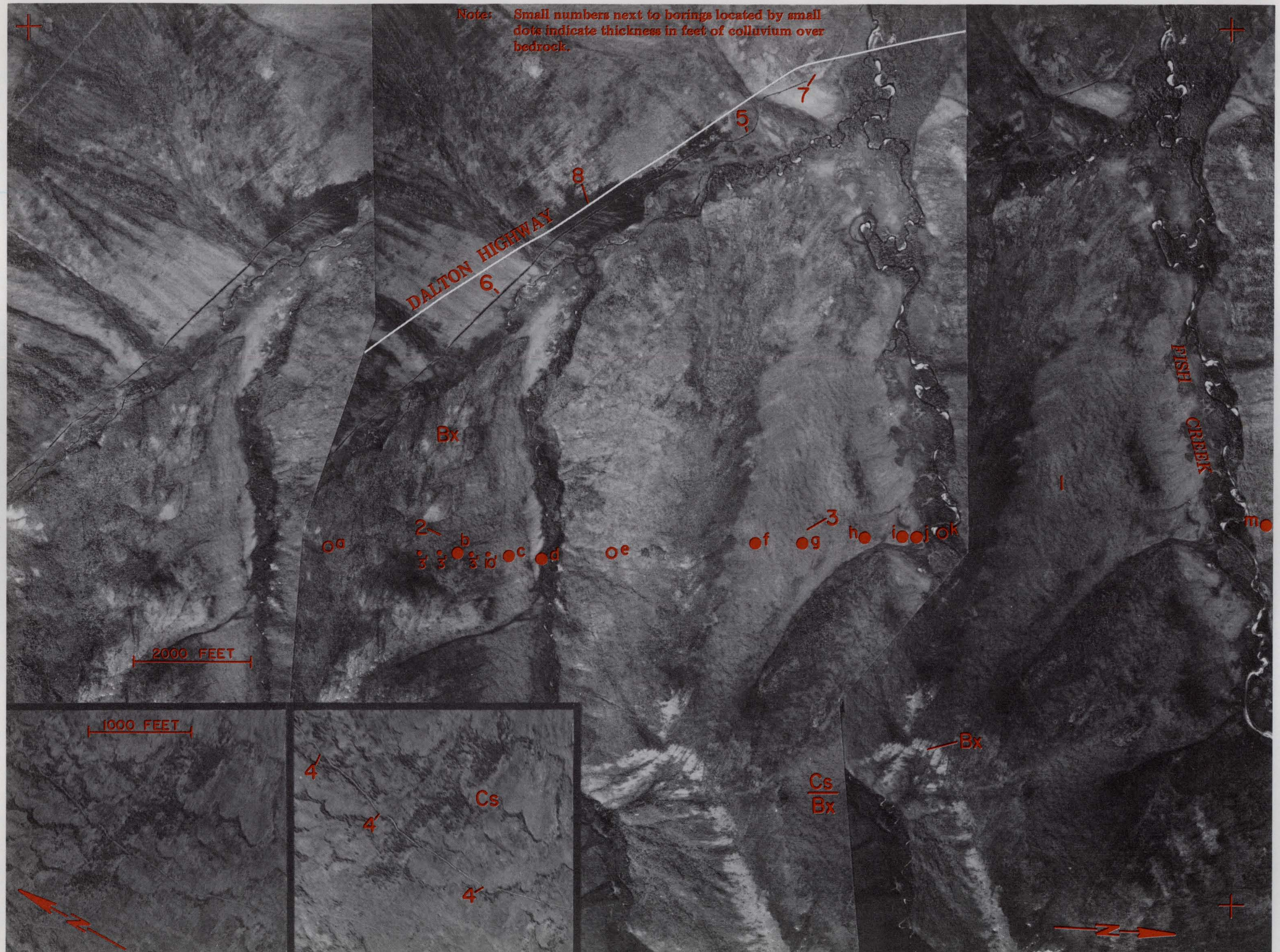
In the central Kokrine-Hodzana Highlands, colluvial deposits, which are thin [C/Bx] on rounded hills and thick [C] in lowlands (table 22), cover a bedrock terrane of Mesozoic granitic, mafic, and ultramafic rocks (Patton and Miller, 1973). On upper slopes where bedrock is shallow, turf-banked lobes (1) have formed by soil flow and frost creep (solifluction of Andersson, 1906, and Benedict, 1970, or gelifluction of Washburn, 1973) (see discussion for pl. 17). Differential weathering has produced bedrock tors (2) that are relatively dry and have resisted frost wedging and mass wasting (cryoplanation), whereas less resistant surrounding bedrock was selectively removed, forming smooth, rounded, moist surfaces. On concave lower slopes, sorted circles and stripes formed by frost sorting and mass movement in the surface layer of thick diamictic colluvium (Washburn, 1956, 1973); seven borings along line 3 penetrated more than 35 ft of ice-rich colluvium (silty sand with gravel and cobbles) without reaching bedrock, suggesting that the bedrock surface dips steeply toward the lowland beneath the colluvial apron. Light upland tones are generally reindeer lichen (*Cladonia*). Birch (4) is the dominant treeline species on well-drained sites in this area. A sharp vegetation boundary (5) marks the limit of a recent tundra fire.

The Little Kanuti Flats has been extensively modified by the cyclic growth and decay of permafrost. Thaw basins (alases) exhibit a continuum of forms suggestive of a sequence of progressive surface changes produced by the aggradation of permafrost into thawed soils (see discussion for plate 19). A typical young thaw basin (6) has a clearly defined and rectangular outline with moderately to steeply sloping walls, a dark-toned, flat floor vegetated by sedges growing in shallow water or on moist ground, and large thaw ponds with rounded and occasionally scalloped outlines. Although they retain a clear rectangular outline, older thaw basins (7) are differentiated by the mottled medium tones of their fen vegetation, occasional marginal thermokarst gullies (8), the generally smaller sizes and irregular outlines of ponds, and a slightly irregular floor produced by uneven uplift as ice-rich permafrost initially develops. This stage in the evolution of the thaw basins is known by the Yakutian (Siberian) term "khonu" (Czudek and Demek, 1970, p. 114). Still older thaw basins (9) have diffuse margins with numerous high-center polygons; sometimes they are dissected by a well-integrated, incised drainage system, and occasionally they contain a closed-system pingo (10) (Muller, 1963; Mackay, 1972). The oldest surfaces on the lowland exhibit the obvious cellular patterns of mature, low-center, ice-wedge polygons (11) and numerous thermokarst features, including high-center polygons (12), beaded drainage (13), and angular drainage (14).

A large fan is composed of ice-rich sandy silt [Fs] (boring h, table 22) stripped from upland slopes by slopewash, gully erosion, and piping (Smith, 1968). Small tributaries (15) have dissected valley fills. Dark bands of dense willow shrubs (16) on small flood plains and low terraces frequently indicate locations of winter icings. Bright tones on the lowland indicate the presence of *Cladonia* on well-drained tussocks or thick accumulations of *Sphagnum* moss in moist sites. String fens (17) have developed in gently sloping, wet situations.

Table 22. *Logs of soil borings on plate 16 (see table 7 for explanation of abbreviations and terms).*

a) 0-5 ft Sa w/s Si; 5-7 ft Gr w/s Sa; 7-17 ft High Wea Granite. Fr 0-17 ft. [9-23-71]. (58-7).
b) 0-2 ft Org w/s Si; 2-16 ft Cob & Gr w/s Si & Sa; 16-25 ft Wea Granite. Fr 0-25 ft. [6-4-75]. (210-86).
c) 0-8 ft Si Sa w/s Gr; 8-24 ft High Wea Granite. Fr 0-24 ft. [4-5-72]. (82-10).
d) 0-18 ft Cob & Bol; 18-34 ft Wea Granite & Schist. Fr 13-34 ft. [9-25-71]. (59-11).
e) 0-28 ft Cob, Bol & Gr w/s Sa & Si; 28-45 ft Wea Basalt. Fr 0-45 ft. [4-12-72]. (79-11).
f) 0-49 ft Gr w/s Si & Cob, tr Sa. Fr 0-49 ft. [9-26-71]. (56-9).
g) 0-5 ft Org w/s *Ice*; 5-13 ft Si Sa w/s Gr; 13-15 ft Si; 15-50 ft Gr w/s Sa & Si. Fr 0-50 ft. [4-18-72]. (80-11).
h) 0-6 ft Si w/s Org; 6-14 ft Interbed Si & Sa; 14-60 ft Sa Gr w/s Si. Fr 0-60 ft. [9-23-71]. (55-8).
i) 0-2 ft Org; 2-21 ft Sa Si; 21-50 ft Gr w/s Sa, tr Si. Fr 0-50 ft. [4-6-72]. (83-10).



Note: Small numbers next to borings located by small dots indicate thickness in feet of colluvium over bedrock.
DALTON HIGHWAY
FISH CREEK
Bx
Cs
Cs/Bx
2000 FEET
1000 FEET
N

Plate 17. Solifluction features, Fish Creek area, Bettles Quadrangle (Alyeska Pipeline Service Company photos 10-15/17, August 14, 1969). **Inset — Active solifluction slope, Rock Creek drainage 8.5 mi northwest of Nome, Nome Quadrangle** (Donald J. Belcher and Associates photos B-4/5, date unknown).

Phyllite and metagraywacke of probable late Paleozoic age (Patton and Miller, 1973) crop out along ridge crests and underlie upper slopes where dark lineaments indicate shallow jointed or faulted bedrock [Bx]. On generally thawed middle and upper south-facing slopes or frozen middle and upper north-facing slopes, colluvium [Cs/Bx] is generally 3 to 6 ft thick (table 23). The colluvial mixture of organic material, some loess, and the products of bedrock weathering is deformed into distinctive turf-banked lobes (1) by a combination of soil flow and frost creep (solifluction or gelifluction) on slopes of moderately thick snow accumulation, where a) soil moisture is unevenly distributed but locally develops excess porewater pressure and b) there is a downslope decrease in the velocity of the moving soil (Benedict, 1970, 1976; Washburn, 1973; McRoberts and Morgenstern, 1974). Solifluction slopes in the Fish Creek area are vegetated by scattered 4-ft-high alders and birch and have a 4- to 6-in.-thick organic surface mat of Labrador tea, blueberry, sedges, and *Sphagnum* moss. Surface measurements on turf-banked lobes during the summer of 1974 at location 2 indicated an annual displacement of 1 to 2 cm, but a longer measuring period is required to substantiate lobe activity. Long-term quantitative monitoring of solifluction slopes in Europe, Canada, and Colorado demonstrate surface movements ranging from 0.2 to 12 cm/yr; most studies cite displacements less than 4 cm/yr (table 24). Radiocarbon dates from buried organic layers in a lobe at location 3 indicate a downslope advance of about 2 m during the past 2,000 to 2,700 yr (fig. 11). The timing of this movement is not known, but most of it probably occurred during one or more short time intervals---perhaps close to 2,000 yr ago---and the lobes may have been stable since. The maximum thickness of colluvium on lower slopes and valley bottoms ranges from 15 to 26 ft (borings d and h-j, table 23).

Solifluction has affected some engineering structures (Sigafoos and Hopkins, 1952; Jahn, 1978, fig. 6). The inset illustrates an active solifluction slope where the downslope advance of turf-banked lobes [Cs] has closed an abandoned drainage ditch (4). The ditch had not been maintained for at least 20 yr when the photographs were taken. Where engineering structures or their foundations are solidly placed in shallow bedrock, solifluction movement in the colluvial layer should cause no structural damage if routine monitoring and maintenance procedures are followed.

In early 1969 a winter road (5) was constructed to haul supplies to the Arctic Slope. The roadway was prepared simply by smoothing minor surface irregularities and compacting a hard snow surface with bulldozers and graders. These improper construction techniques destroyed the insulating surface organic mat and partially degraded the permafrost by the end of the first summer following construction, producing a rapidly deteriorating, impacted roadway such as the dark section (6) across ice-rich, fine-grained organic deposits. Light-toned, ice-poor sections (7) across coarse-grained soils or bedrock were not subject to such deleterious effects when the permafrost thawed. The dark area (8) is a recent fire scar.

Table 23. *Logs of soil borings on plate 17 (see table 7 for explanation of abbreviations and terms).*

a) 0-6 ft Sa Gr w/s Si & Rock Frag; 6-13 ft Fract Schist. [9-28-71]. (55-12).
b) 0-2 ft Org & Si; 2-5 ft Sa Gr w/Si; 5-11 ft Wea Schist; 11-18 ft Schist. Fr 0-18 ft. [9-30-71]. (60-13).
c) 0-4 ft Org Si w/s Gr & Sa; 4-16 ft Gr w/s Sa, Si & Rock Frag; 16-26 ft Schist. Fr 0-26 ft. [4-13-72]. (80-13).
d) 0-5 ft Si Org; 5-9 ft Sa w/s Si & Gr; 9-22 ft Gr w/s Sa & Cob; 22-34 ft Sa Si; 34-44 ft High Wea Schist. Fr 0-44 ft. [10-2-71]. (59-13).
e) 0-4 ft Sa Si w/s Gr; 4-5 ft Wea Schist. [9-29-71]. (44-1).
f) 0-7 ft Gr w/s Si & Sa; 7-24 ft Wea Schist. Fr 0-24 ft. [4-11-72]. (76-12).
g) 0-6 ft Sa Si w/Gr; 6-20 ft Schist. Fr 0-20 ft. [9-29-71]. (55-13).
h) 0-5 ft Gr Sa w/s Si; 5-20 ft Wea Schist. Fr 0-20 ft. [4-12-72]. (82-14).
i) 0-10 ft Si Sa; 10-16 ft Gr Sa; 16-28 ft Sa w/s Gr & Si; 28-43 ft Gr w/s Sa. Fr 0-43 ft. [8-15-73]. (63-35).
j) 0-6 ft Si Sa w/tr Org; 6-20 ft Si Sa w/s Gr, Cob & Bol. Fr 0-20 ft. [7-23-74]. (203-6).
k) 0-7 ft Interbed Si & Sa; 7-14 ft Sa Gr; 14-18 ft Si Sa; 18-23 ft Wea Schist; 23-32 ft Schist. WT @ 7 ft. [10-21-70]. (41-7).
m) 0-21 ft Sa Gr w/s Si & Cob; 21-33 ft Wea Schist. Fr 0-33 ft. [10-2-71]. (56-11).

Table 24. *Rates of downslope movement by combined solifluction and frost creep.*

Location	Gradient (o)	Average rate (cm/yr)	Reference
Colorado			
Front Range	6-14	0.2 - 2.2	Benedict (1970)
Greenland			
Mesters Vig	10-14	0.9 - 3.7	Washburn (1967)
Lapland			
Kärkevagge	15 (mean)	2.0 (mean to 25-cm depth)	Rapp (1960)
Norra Storfjall area	5	0.9 - 3.8	Rudberg (1964)
Tarna area	5	0.9 - 1.8	Rudberg (1962)
Norway			
Okstindan	5-17	1.0 - 6.0	Harris (1972)
Spitsbergen			
Barentsoya	11	1.5 - 3.0	Budel (1961), *in* Washburn (1973)
North side, Hornsund	3-4	1.0 - 3.0	Jahn (1960)
" "	7-15	5.0 - 12.0	" "
Yukon Territory			
Ruby Range	14-22	0.6 - 3.5	Price (1973, 1974)

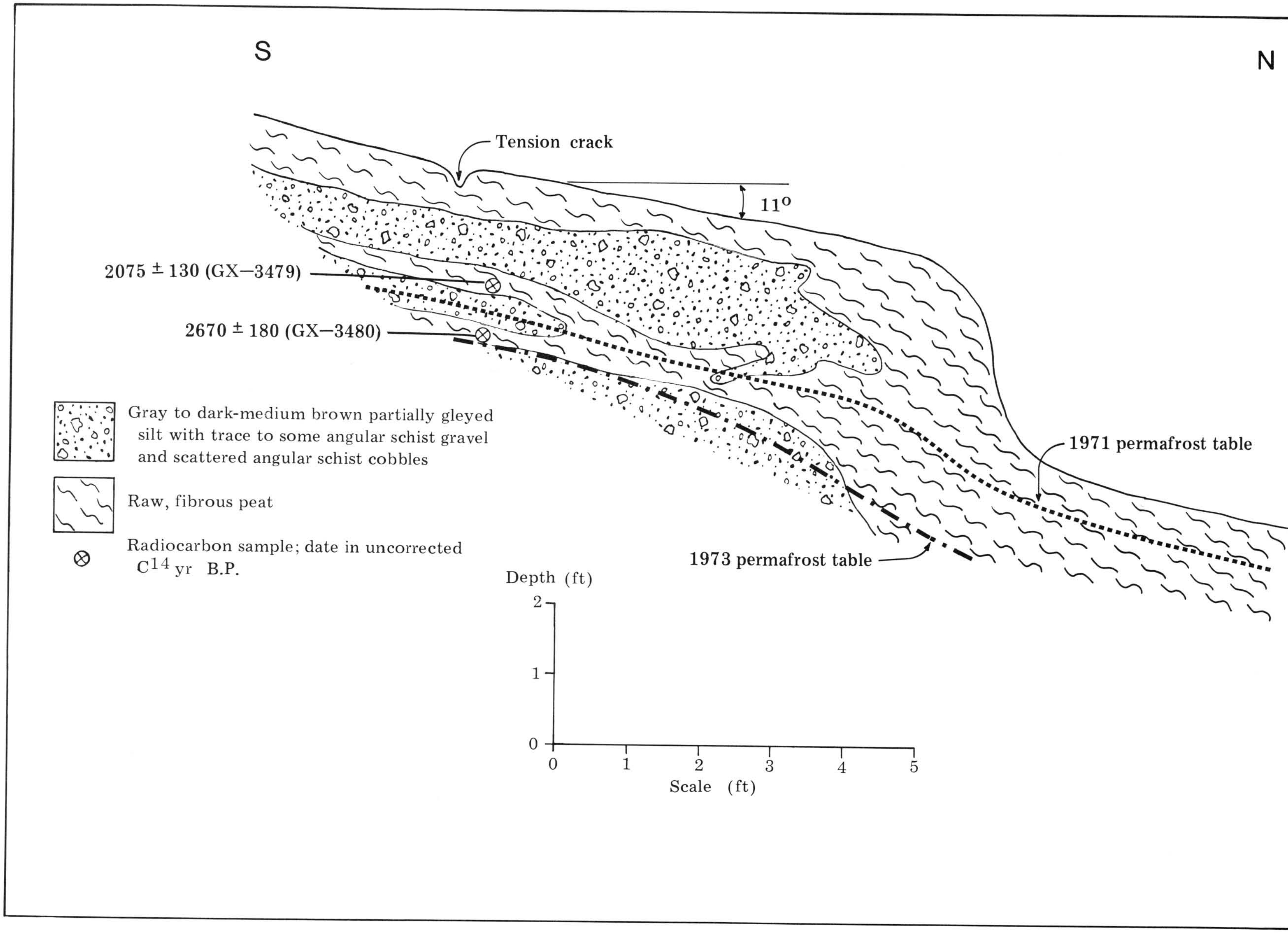
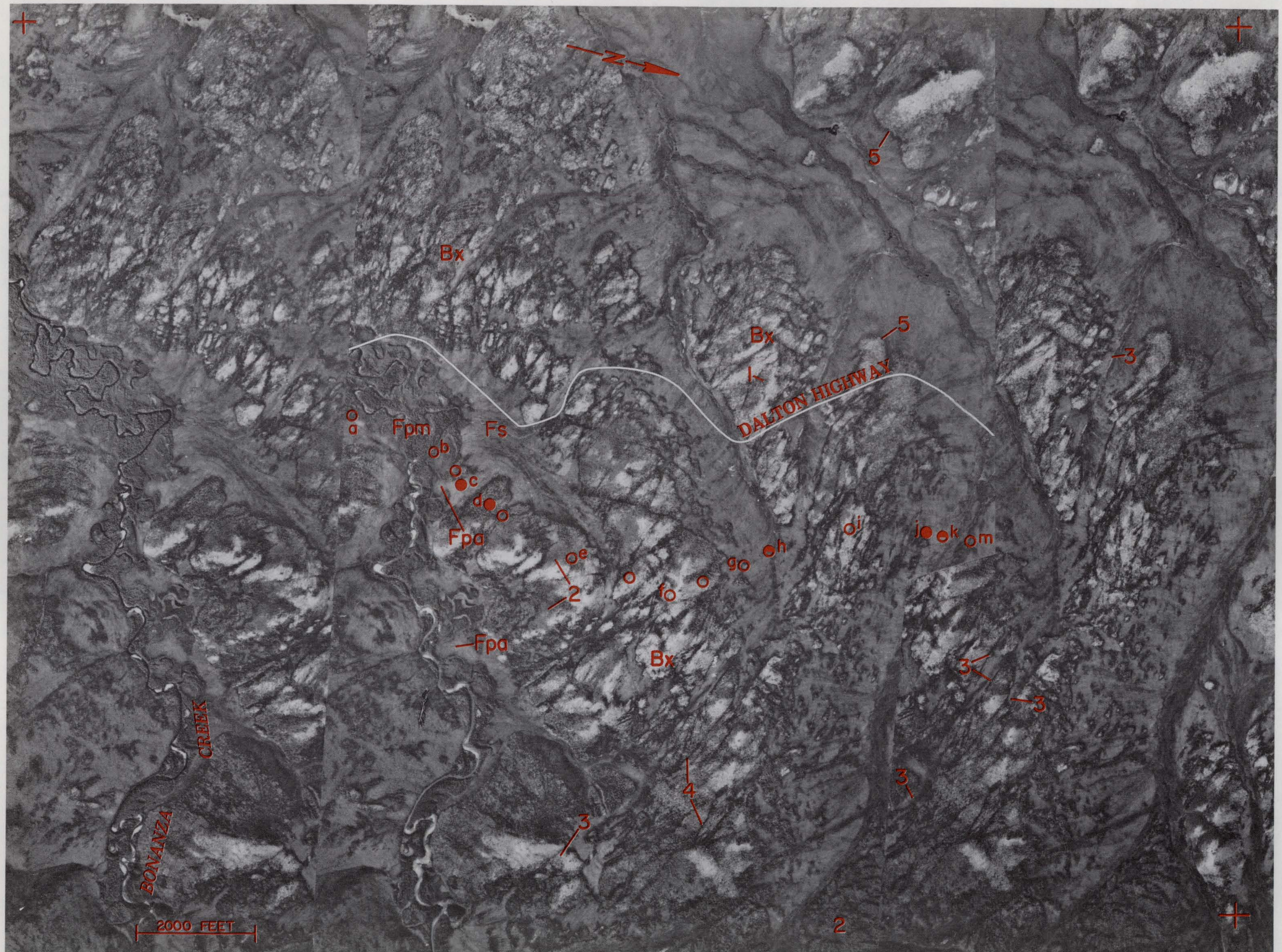


Figure 11. Longitudinal section through turf-banked lobe in silty colluvium, south slope of Fish Creek valley, Bettles Quadrangle (locality 3, pl. 17).



N
5
Bx
Bx
5
DALTON HIGHWAY
1
3
a
Fpm
Fs
b
c
d
Fpa
j
k
m
i
e
h
g
f
2
2
Fpa
Bx
3
3
3
CREEK
BONANZA
4
3
3
2000 FEET
2

Plate 18. Granitic terrane, Bonanza Creek area, Bettles Quadrangle
(Alyeska Pipeline Service Company photos 10-29/31, August 14, 1969).

This quartz monzonite stock of Cretaceous age [Bx] (Patton and Miller, 1973) exhibits the characteristic outcrop forms and fracture patterns of granitic terrane in a subarctic environment. Light tones identify a ground cover of reindeer lichen (*Cladonia*) growing on a thin surficial layer of dry, sandy, decomposed and disintegrated rock (grüs) (table 25). These sandy soils support a scattered growth of spruce (1) and deciduous birch and aspen (2). An extensive, complex fault or shear zone (3) is indicated by aligned linear stream segments, topographic troughs, and fracture traces. Ground-water seepage along joints and faults in bedrock promotes growth of tall spruce (4).

Dense vegetation at boundaries between frozen and unfrozen soils (5) suggests local conditions are especially conducive to tree growth (see discussion for pl. 14). A fan of frozen, retransported silt and sand [Fs] vegetated by stunted spruce and tussocks has partially buried the flood plain of Bonanza Creek. Along Bonanza Creek, a relatively tall riparian forest of balsam poplar and spruce shows the lateral limits of the thaw bulb in gravelly alluvium [Fpm]; it does not grow on adjacent, generally frozen and tussock-covered abandoned-flood-plain deposits [Fpa] (table 25).

Table 25. *Logs of soil borings on plate 18 (see table 7 for explanation of abbreviations and terms).*

a) 0-4 ft Si Sa; 4-49 ft Interbed Sa Gr & Gr Sa. WT @ 10 ft. [11-13-70]. (42-12).
b) 0-3 ft Si w/s Org; 3-35 ft Gr Sa. WT @ 2 ft. [11-11-70]. (41-25).
c) 0-5 ft Org Si w/s Sa; 5-8 ft Si Sa w/s Org; 8-10 ft *Massive Ice*; 10-43 ft Interbed Gr Sa & Sa Gr; 43-55 ft Wea Granite. Fr 0-55 ft. [4-16-72]. (80-14).
d) 0-3 ft Sa w/s Si & Gr; 3-8 ft Wea Granite; 8-18 ft Slightly Wea Granite. Fr (?) 0-18 ft. [4-15-72]. (79-12).
e) 0-15 ft Wea Granite. [11-14-70]. (41-27).
f) 0-15 ft Wea Granite. [11-14-70]. (41-28).
g) 0-2 ft Si w/s Sa & Org; 2-14 ft Wea Granite. [11-16-70]. (41-30).
h) 0-2 ft Org; 2-7 ft Sa; 7-30 ft High Wea Granite. Fr 0-7 ft. [11-16-70]. (43-25).
i) 0-15 ft Wea Granite. [11-18-70]. (43-26).
j) 0-6 ft Sa w/s Si & Gr; 6-14 ft Wea Granite. Fr 0-14 ft. [11-19-70]. (43-27).
k) 0-8 ft Org Si; 8-14 ft Si Gr w/s Sa & Bol; 14-49 ft Wea Granite. Fr 0-16 ft. WT @ 2 ft. [11-22-70]. (43-28).
m) 0-4 ft Org Sa Si; 4-6 ft Gr Sa; 6-26 ft High Wea Granite. WT @ 2 ft. [11-25-70]. (43-29).

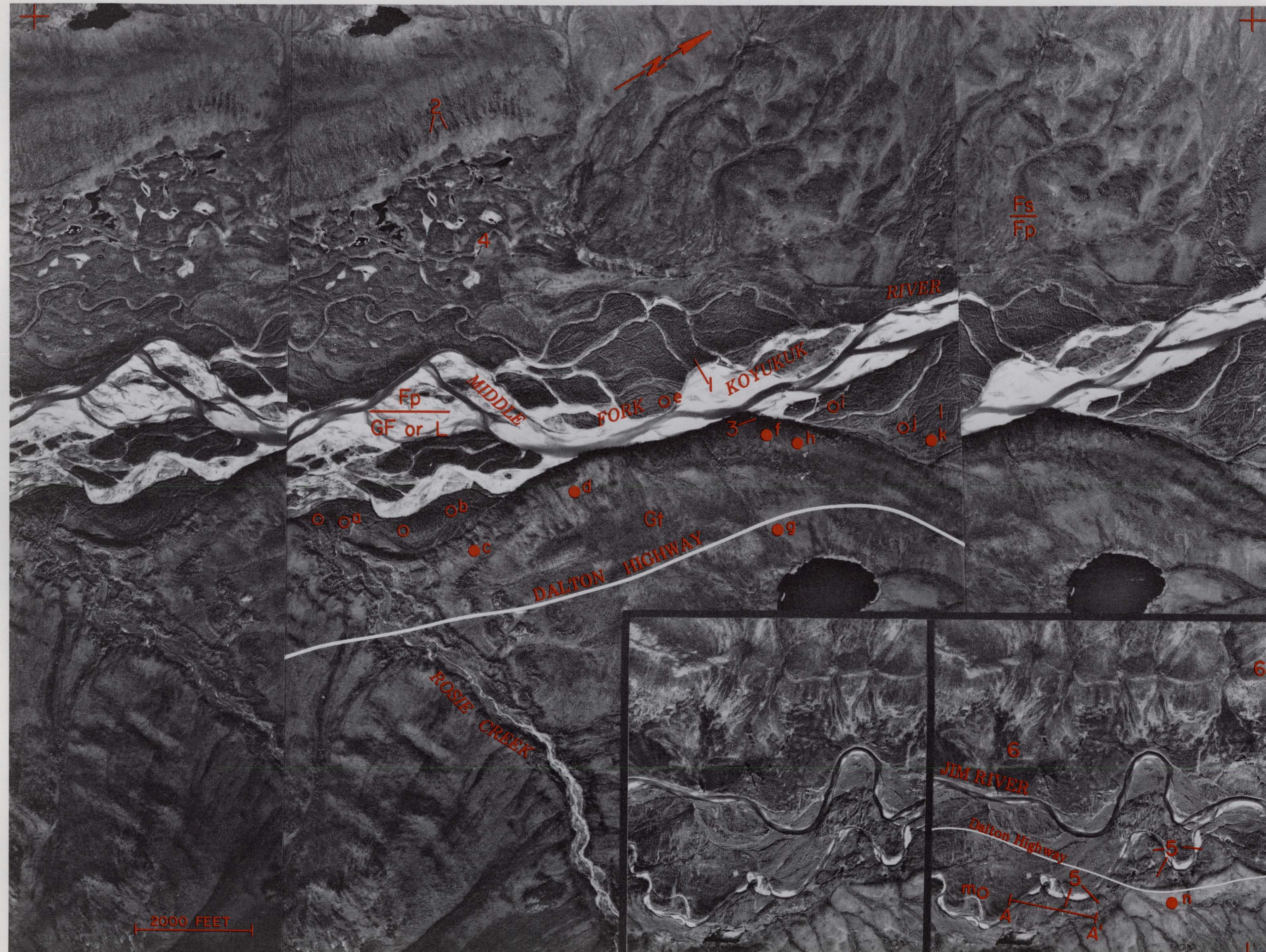

N
2
4
Fs
Fp
RIVER
KOYUKUK
FORK
MIDDLE
Fp
GF or L
3
Gt
DALTON HIGHWAY
ROSIE CREEK
JIM RIVER
Dalton Highway
6
5
A
A'
2000 FEET

Plate 19. Landforms produced by ground-ice growth, Coldfoot area, Wiseman Quadrangle (Alyeska Pipeline Service Company photos 8-95/97, August 13, 1969).
Inset — Permafrost-modified flood plain of Jim Creek near junction with Douglas Creek, Bettles Quadrangle (Alyeska Pipeline Service Company photos 8-69/70, August 13, 1969).

In the southern Brooks Range, permafrost is generally absent beneath flood plains that are either unvegetated or vegetated by light-toned balsam poplar (borings e and i, table 26). Flood plains vegetated by white spruce (1) are underlain by sporadic permafrost. Aspen and birch (2) grow on dissected, well-drained slopes with deep permafrost. In this reach of the Middle Fork Koyukuk River, a 10-ft-thick layer of Holocene alluvium covers glaciofluvial or lacustrine sandy silt and silty sand [Fp/(GF or L)] (table 26). Coalescing fans of fine-grained, retransported deposits have locally buried flood-plain alluvium [Fs/Fp] and are frozen. Mudflows (not visible) (3) occur on steep slopes of clayey Itkillik I till [Gt] (Hamilton and Porter, 1975, fig. 2; Hamilton, 1979d) that overlies schistose sandstone, phyllite, and slate of Devonian(?) to Permian(?) age (Brosgé and Reiser, 1971).

The relatively old flood-plain surface (4) has unusual, irregular hummocks and ridges that are composed of fluvial sand and gravel and have a maximum relief of 10 to 15 ft. Interspersed between the hummocks and ridges are numerous, irregular flood-plain lakes and ponds that 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 inset illustrates similar prominent ridges and mounds (5) formed on the flood plain of Jim River 30 mi to the south. Borings along cross-section A-A′ encountered ground water below permafrost that is 5 to 50 ft thick (fig. 12). Ice-rich alluvium in test hole 215-131, located at the top of the highest ridge, contained a cumulative thickness of 17 ft of ground ice in the form of lenses and layers, an amount equal to the height of the ridge above the surrounding flood plain. Subparallel ground cracks trending along the ridge crest probably have origins similar to radial cracks in summits of growing pingos. However, no tilted trees grow on the ridges and mounds, which indicates that disturbance of the ground surface predates the trees.

The lack of summit accordance indicates the hummocks and ridges are not terrace remnants, even though they are composed of coarse alluvium. Variation in height and the irregular form of ridges and mounds may be explained by differential settlement as ice-rich permafrost thaws, but the irregular form of the intervening lakes and ponds is analogous to the outline of ponds developed by aggrading, ice-rich permafrost and is different from the typical rounded or scalloped forms of thaw lakes (pl. 16). These hummocky flood-plain surfaces are probably the result of the aggradation of ice-rich permafrost. 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. A similar injection origin for massive tabular ice and pingos in arctic Canada was described by Mackay (1971). An analogous topography, called 'khonu' by the Yakutians, develops in thaw basins being refrozen in Siberia (see discussion for pl. 16) (Czudek and Demek, 1970). There is no evidence that ice wedges have grown in the alluvium in this khonu area near Coldfoot.

A forest fire has blackened terrace surfaces in the inset (6).

Table 26. *Logs of soil borings on plate 19 (see table 7 for explanation of abbreviations and terms).*

a) 0-3 ft Si w/s Org; 3-6 ft Si Sa; 6-50 ft Gr. WT @ 4 ft. [8-8-74]. (201-38).
b) 0-2 ft Si Sa w/s Org; 2-46 ft Sa Gr; 46-50 ft Si Sa w/s Gr. WT @ 12 ft. [8-6-74]. (202-24).
c) 0-7 ft Sa Gr w/s Si; 7-12 ft Sa Gr; 12-19 ft Sa Si w/s Gr; 19-45 ft Gr Sa w/tr Si; 45-50 ft Si. Fr 0-50 ft. [8-12-73]. (61-33).
d) 0-50 ft Interbed Si Gr w/s Sa & Sa Si w/s Gr. Fr 0-50 ft. [8-11-73]. (61-32).
e) 0-5 ft Sa & Gr; 5-11 ft Sa Gr; 11-22 ft Sa Si w/s Gr; 22-40 ft Sa Gr. WT @ 7 ft. [10-22-71]. (60-20).
f) 0-4 ft Si w/s Sa, Org & *Ice*; 4-51 ft Si w/s Sa & Gr. Fr 0-51 ft. [8-9-73]. (65-4).
g) 0-22 ft Si w/tr Sa; 22-36 ft Schist. Fr 0-36 ft. [7-21-70]. (30-1).
h) 0-2 ft Org w/s Sa; 2-5 ft Gr w/s Sa & Si, 5-16 ft Schist. Fr 0-16 ft. [8-13-73]. (61-34).
i) 0-4 ft Si Sa; 4-24 ft Gr Sa w/tr Si; 24-39 ft Si Sa; 39-50 ft Sa w/s Si. WT @ 4 ft. [8-8-73]. (62-40).
j) 0-2 ft Org Si; 2-38 ft Sa Gr w/s Cob; 38-50 ft Si Sa. WT @ 3 ft. [8-8-74]. (201-37).
k) 0-5 ft Si w/s Sa; 5-13 ft Sa w/tr Si & Gr; 13-17 ft Sa Gr; 17-34 ft Si w/s Sa; 34-49 ft Sa Gr w/s Si. Fr 0-49 ft. [5-23-72]. (77-29).
m) 0-2 ft Org; 2-27 ft Sa Gr w/Cob; 27-50 ft Sa w/s Gr & Cob. WT @ 15 ft. [7-27-74]. (203-12).
n) 0-5 ft Org; 5-13 ft Org Si; 13-23 ft Si; 23-28 ft Sa Gr w/s Si; 28-50 ft Cl Si. Fr 0-50 ft. [3-12-72]. (84-5).

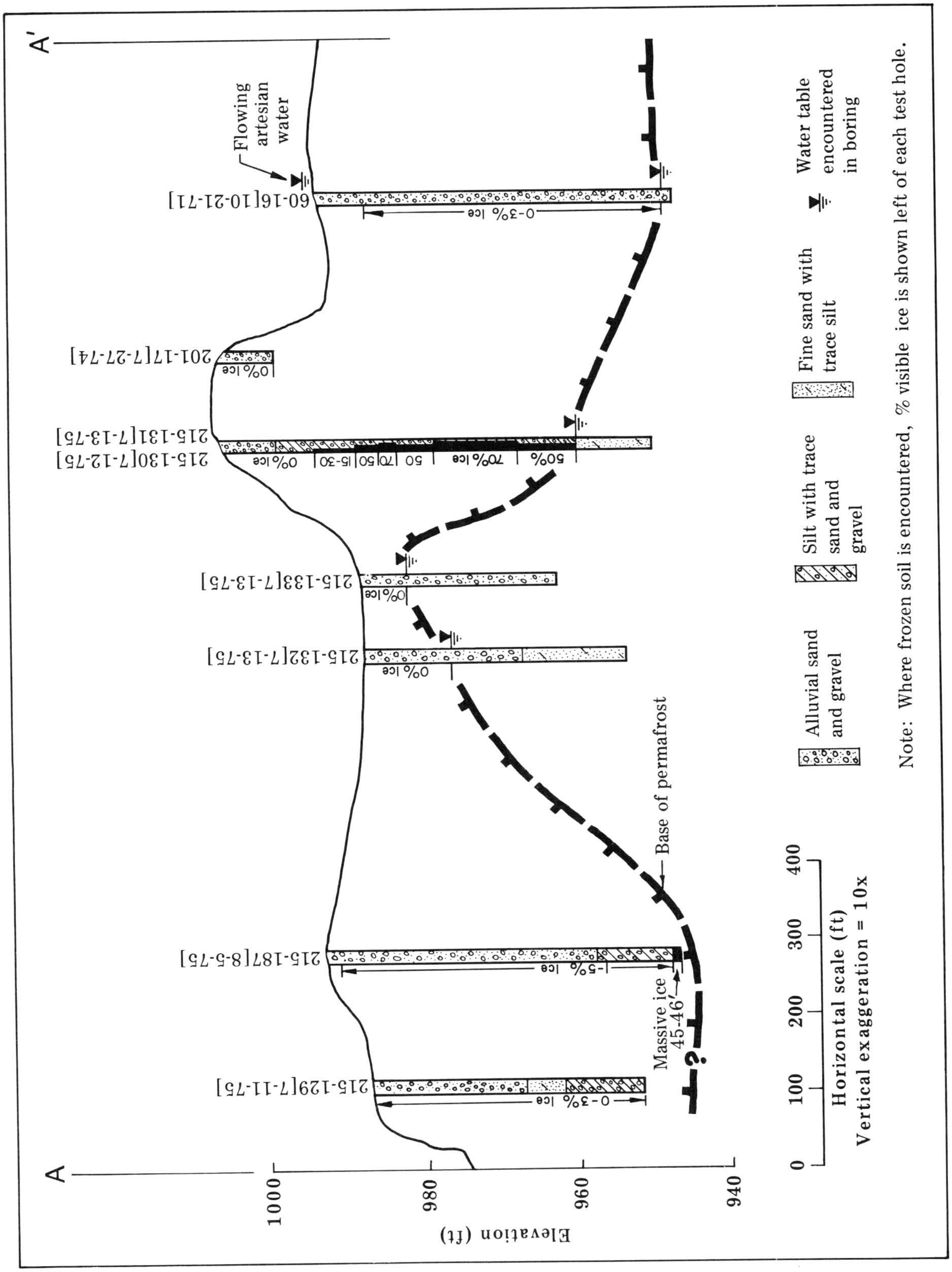
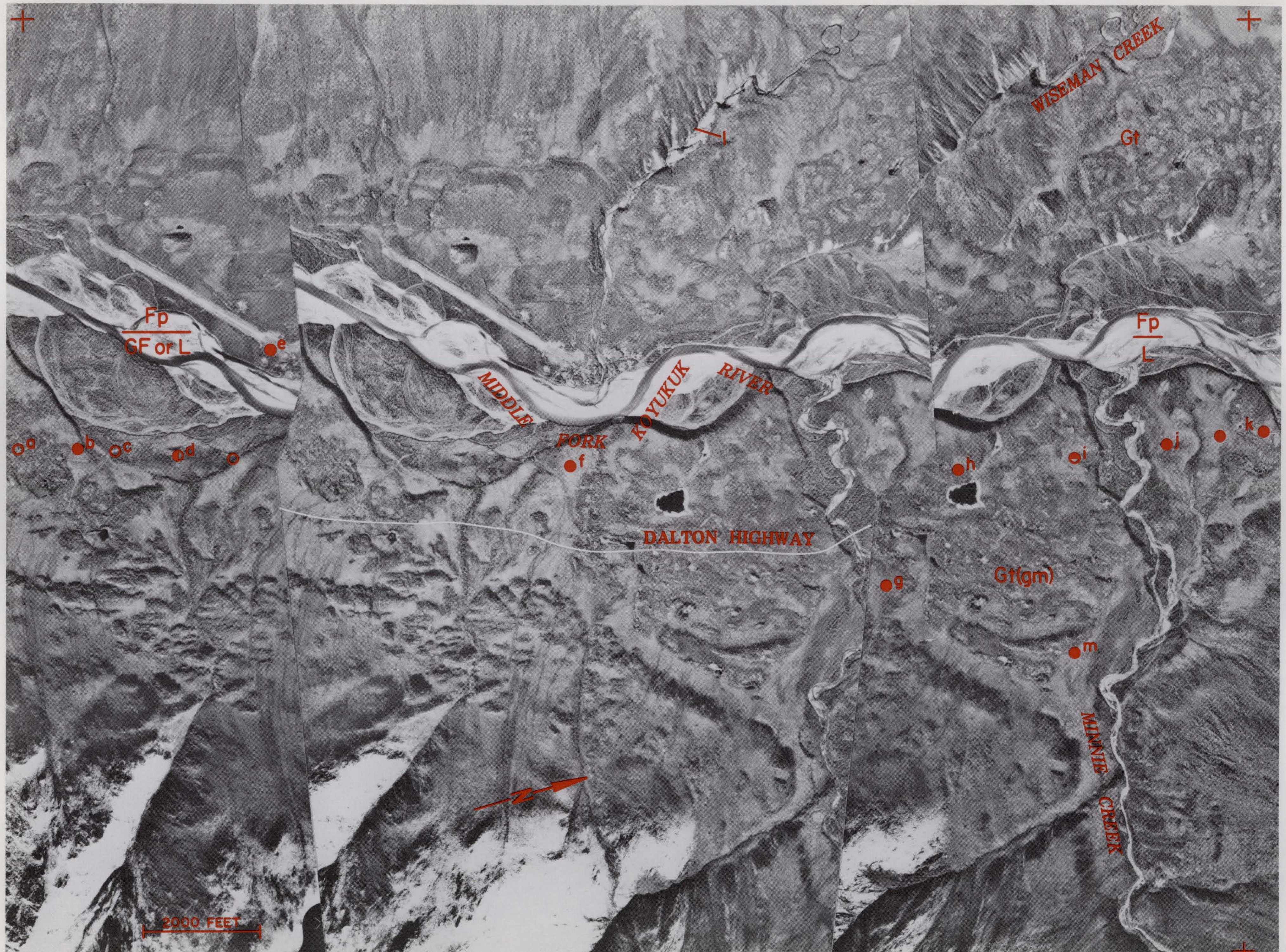


Figure 12. Cross section A-A′ (pl. 19) through typical perennially frozen hummock on flood plain of Jim River, Bettles Quadrangle.



WISEMAN CREEK
Gt
Fp
L
Fp
GF or L
MIDDLE FORK KOYUKUK RIVER
DALTON HIGHWAY
Gt(gm)
MINNIE CREEK
N
2000 FEET
a
b
c
d
e
f
g
h
i
j
k
l
m

Plate 20. Lacustrine deposits behind moraine, Wiseman area, Wiseman Quadrangle
(Alyeska Pipeline Service Company photos 8-108/110, August 13, 1969).

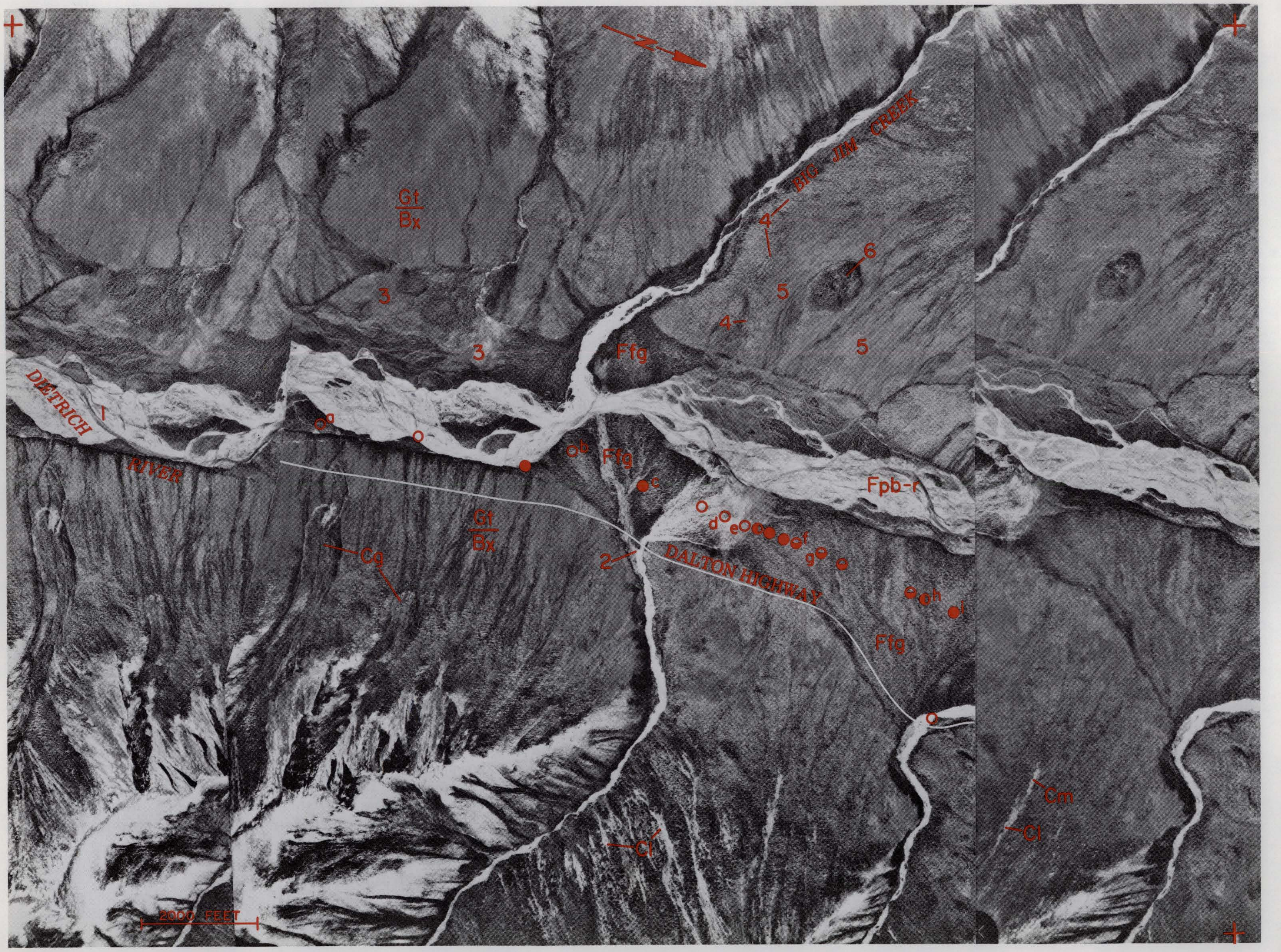
This area is typical of the central and southern Brooks Range (also see pls. 19 and 21). Glacially scoured valleys walled by 6,000-ft-high ridges of Paleozoic limestone, shale, sandstone, phyllite, and schist contain glaciofluvial deposits, alluvium, and till. Flood-plain deposits are frequently underlain by glaciofluvial or lacustrine silt and sand [Fp/(GF or L)]. Alluvial fans built by tributary streams and colluvial aprons commonly extend from lower valley walls. This terrain is generally frozen except for the active flood plain and riparian zones of balsam poplar and white spruce.

Lacustrine deposits underlying 12 to 15 ft of Holocene alluvium of the Middle Fork Koyukuk River [Fp/L) (borings c, d, and j, table 27) were laid down in a lake behind an end moraine [Gt(gm)] of late Itkillik age (Hamilton, 1979d) that formerly blocked the postglacial drainage. Lacustrine deposits are rarely exposed and contain varying amounts of massive ice.

The lower course of Wiseman Creek formerly flowed through a valley that was subsequently filled with drift [Gt] by the late Itkillik glacier that diverted the creek along the ice margin, where it cut a sideglacial canyon (1) into quartz-mica schist.

Table 27. *Logs of soil borings on plate 20 (see table 7 for explanation of abbreviations and terms).*

a) 0-51 ft Interbed Sa Gr w/tr Si & Gr Sa w/tr Si. [5-9-72]. (86-29).
b) 0-3 ft Si w/tr Gr; 3-50 ft Sa Gr w/tr Si. Fr 0-50 ft. [5-13-72]. (84-32).
c) 0-8 ft Sa; 8-12 ft Gr Sa w/tr Si & Cob; 12-51 ft Sa. WT @ 13 ft. [8-7-74]. (203-22).
d) 0-12 ft Sa Gr w/tr Si; 12-33 ft Si; 33-51 ft Gr Sa. Fr 34-38 ft. WT @ 38 ft. [11-2-71]. (58-23).
e) 0-30 ft Sa Gr w/Cob. Fr 0-30 ft. [3-23-69]. (3-1).
f) 0-6 ft Si w/s Sa; 6-37 ft Gr w/s Sa; 37-52 ft Sa Si w/s Gr. Fr 0-52 ft. [5-10-72]. (84-31).
g) 0-30 ft Gr w/Si & Cob. Fr 0-30 ft. [3-25-69]. (3-3).
h) 0-7 ft Si w/s Sa; 7-27 ft *Massive Ice*; 27-40 ft Sa Gr; 40-48 ft Sa w/s Gr. Fr 0-48 ft. [11-5-71]. (57-15).
i) 0-47 ft Sa w/s Gr, tr Si to Sa Gr w/tr Si; 47-50 ft Si w/s Sa, tr Gr. Fr 0-16 ft. [5-12-72]. (78-22).
j) 0-2 ft Si w/tr Sa; 2-20 ft Sa Gr; 20-52 ft Si Sa; 52-61 ft Si; 61-85 ft Sa w/tr Si. Fr 0-85 ft. [5-9-72]. (78-21).
k) 0-4 ft Si Sa; 4-14 ft Gr w/s Sa & Cob; 14-37 ft Si; 37-39 ft *Massive Ice*; 39-59 ft Si. Fr 0-59 ft. [5-12-72]. (87-20).
m) 0-2 ft Org; 2-4 ft Org Si; 4-17 ft Si Sa w/Cob; 17-30 ft Si Gr w/Cob. Fr 0-30 ft. [3-24-69]. (3-2).



N
BIG JIM CREEK
DIETRICH RIVER
DALTON HIGHWAY
Gt/Bx
Gt/Bx
Ffg
Ffg
Ffg
Fpb-r
Cg
Cl
Cl
Cm
1
2
3
3
4
4
5
5
6
a
b
c
d
e
f
g
h
i
2000 FEET

Plate 21. Alluvial fans, braided flood plain, and slope deposits, Dietrich River valley, Chandalar Quadrangle
(Alyeska Pipeline Service Company photos 8-142/144, August 13, 1969).

The upper Koyukuk-Dietrich River system has a steeper gradient and is more extensively braided than the middle reach (pls. 19 and 20). The unvegetated and braided flood-plain surface (1) is the site of seasonal icing sheets that are as thick as 16 ft (Sloan and others, 1976). Tributaries have built large, coarse-grained alluvial fans [Ffg] over the margins of the flood plain and over glacial deposits. These alluvial fans are now discontinuously frozen (table 28). A channel diversion (2) during recent flooding has directed bright-toned sands and gravels onto a new part of the fan. On alluvial fans such as these, the size of sediment clasts decreases and the degree of sorting increases as the slope decreases downfan (McPherson and Hirst, 1972). Fine sediment is commonly carried off the fan during floods; at the distal limits of these fans (3), fine material is deposited over alluvium of the Dietrich River. Borings b, d, and f (table 28) penetrated fan material and encountered fine-grained lacustrine and glacial deposits at depth.

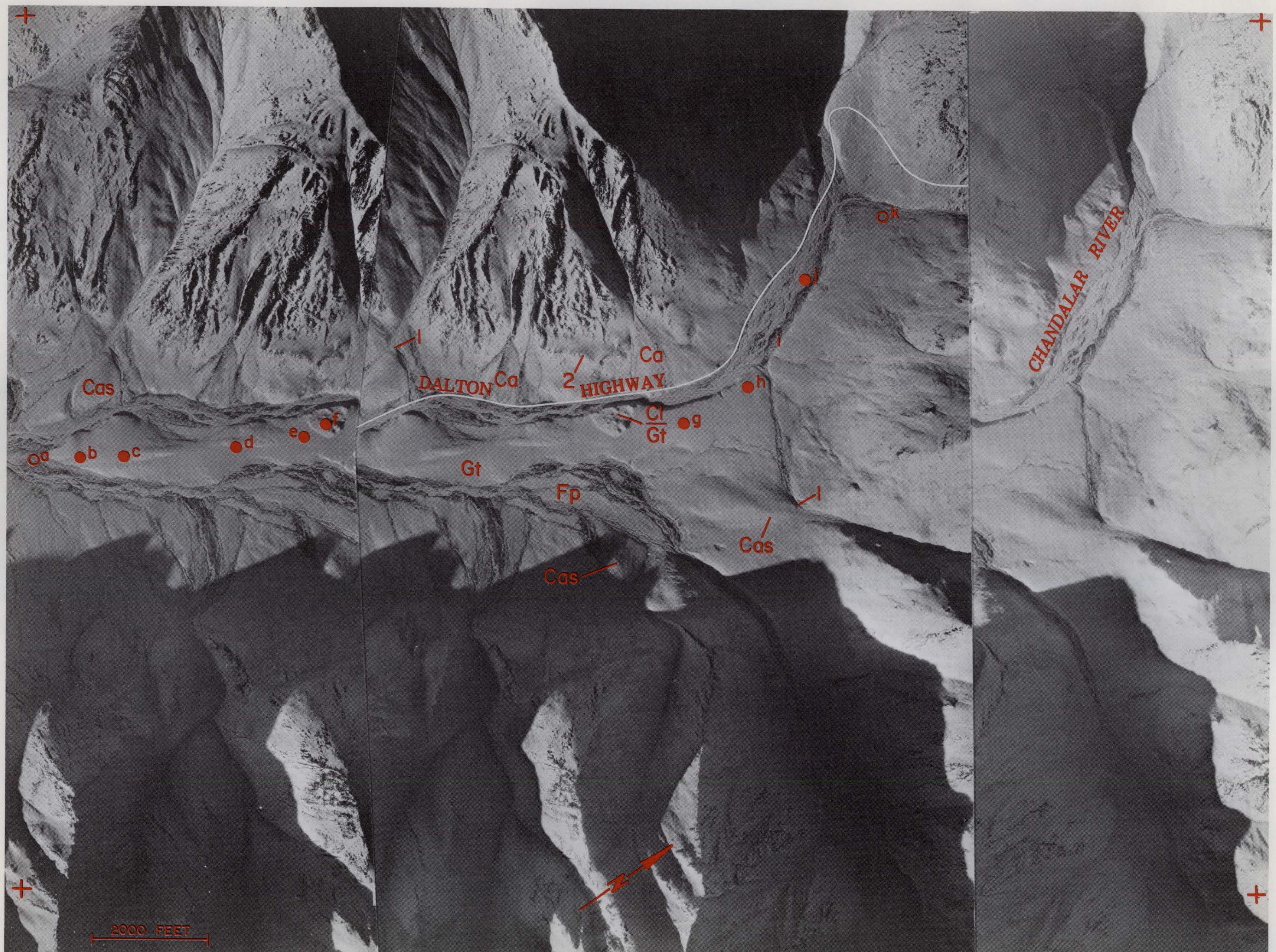
Frozen till blankets valley slopes of Late Devonian slate, phyllite, siltstone, sandstone, and limestone [Gt/Bx] (Brosgé and Reiser, 1964). Although surface polygons and thermokarst features are not visible, polygonal ice-wedge networks are probably present throughout the upper part of the till. A fire scar on comparable terrain 70 mi to the west in the John River valley is associated with thermally degraded permafrost, as demonstrated by an extensive polygonal surface pattern caused by thawing ice wedges (similar to situation in pl. 26). No polygonal ground or other evidence of ground ice is visible on adjoining unburned surfaces.

Numerous mass-movement features are visible on steep slopes, including rock glaciers [Cg], debris slides [Cl], and mudflows [Cm]. Tongue-shaped rock glaciers are composed of angular rock fragments and silt. Once talus accumulating at the base of steep slopes of valleys and cirques reaches a critical thickness, temperatures at depth remain below freezing throughout the year, providing the annual temperatures are sufficiently cold. On the Arctic Slope, for example, permafrost will form in 5 to 10 ft of fill material. The thickness needed to form permafrost increases farther south; in the Fairbanks area 30 to 50 ft of fill is required. Water derived primarily from precipitation, but also including ground water and overland flow, enters the cold talus and freezes in interstitial openings; movement of the ice-cemented rubble mass occurs by viscous flow of the interstitial ice if the rate of talus accumulation is sufficient (Wahrhaftig and Cox, 1959). However, these rock glaciers are no longer active, as indicated by the dense vegetation cover (including trees), the irregular upper surface with longitudinal gullies, the rounded margins, and dissected termini. Debris slides [Cl] are released on steep slopes by saturation of a thin layer of organic material, till, and colluvium over bedrock during intense summer storms (Rapp, 1960); they change downslope to mudflows [Cm] bounded by natural levees.

Sorted stripes (4) occur on poorly sorted deposits such as till. Lack of similar patterns in adjoining dull-gray areas (5) suggests the presence of a surface layer of silt that was removed by both piping (Smith, 1968) and gully erosion from colluvium and till on higher slopes; this material was subsequently transported downslope by active-layer interflow or overland flow. Drainage channels extending downslope from the lower margins of the conspicuous hill (6) and summit depressions---one with a spring that drains through the breach to the southwest---demonstrate that the hill is an open-system pingo formed in till of late Itkillik age (Hamilton, 1978a, 1979a). This example in a continuous permafrost zone (Ferrians, 1965) is exceptional because most open-system pingos occur in discontinuous permafrost and in areas unglaciated in Wisconsin time (Péwé, 1975a, fig. 31). The site of this pingo was glaciated by an ice advance that culminated 12,500 to 13,000 yr ago; the locality may have been free of ice by 10,500 yr ago (Hamilton, 1979b,d; Hamilton and Porter, 1975).

Table 28. *Logs of soil borings on plate 21 (see table 7 for explanation of abbreviations and terms).*

a) 0-2 ft Si Sa w/tr Org; 2-9 ft Sa Gr; 9-46 ft Interbed Gr Sa & Sa Gr; 46-51 ft Wea Phyllite. WT @ 9 ft. [4-23-72]. (78-13).
b) 0-9 ft Sa Si w/tr Gr; 9-37 ft Sa Gr w/tr Si; 37-48 ft Sa Si w/tr Gr. WT @ 19 ft. [4-23-72]. (87-11).
c) 0-7 ft Gr Sa w/s Si; 7-20 ft Gr w/s Sa & Cob; 20-24 ft Si w/s Sa; 24-48 ft Sa Gr w/Cob. Fr 0-48 ft. [11-28-71]. (56-27).
d) 0-10 ft Gr Sa w/s Si; 10-20 ft Sa Si; 20-50 ft Gr Sa w/s Si. WT @ 25 ft. [7-31-73]. (62-35).
e) 0-7 ft Org Si; 7-50 ft Si Sa. WT @ 7 ft. [8-27-74]. (201-64).
f) 0-17 ft Gr w/s Sa; 17-37 ft Gr Sa w/tr Si; 37-47 ft Sa w/tr to s Si & Gr; 47-52 ft Sa Si. Fr 11-52 ft. [4-23-72]. (86-19).
g) 0-8 ft Sa Gr w/s Si; 8-20 ft Cob w/s Sa, Si & Gr. Fr 8-20 ft. WT @ 6 ft. [8-22-74]. (203-46).
h) 0-50 ft Sa Gr w/tr Si. Fr 7-16 ft. WT @ 5 ft. [8-27-74]. (201-63).
i) 0-5 ft Sa Gr w/s Si; 5-42 ft Gr w/s Sa & Cob. Fr 0-42 ft. [11-13-71]. (56-25).



CHANDALAR RIVER
DALTON HIGHWAY
Cas
Ca
Ca
2
Cl
Gt
Gt
Fp
Cas
Cas
l
l
a
b
c
d
e
f
g
h
i
j
k
2000 FEET

Plate 22. Slushflow features, Chandalar Shelf, Philip Smith Mountains Quadrangle
(Alyeska Pipeline Service Company photos 22-4/6, October 17, 1969).

Terrain microrelief features and detail are obscured by seasonal snow cover on this stereotriplet, but major landforms can be identified. Steep cones [Ca] are composed of talus, mudflow deposits, and snow-avalanche debris and can be distinguished from gently sloping, coarse-grained alluvial fans with braided stream channels (pl. 21). Flows of water-saturated snow, called slushflows (Washburn, 1973), are common in stream courses in this subarctic alpine terrain. Slushflows are a type of wet-snow avalanche that occurs primarily in arctic and subarctic mountainous regions with rapid spring melting of the seasonal snow cover (Washburn and Goldthwait, 1958; Nobles, 1966); they are also reported---albeit on a smaller scale and less frequently---in mid-latitude alpine areas (Luckman, 1978; Butler, 1979). Slushflows are very powerful geomorphic agents (Rapp, 1960, 1966; Jahn, 1967; Alaska Department of Highways, 1971) and their engineering ramifications should not be overlooked (Reger, 1979). Colluvial fans [Cas] at the mouths of slushflow chutes have a characteristic proximal hump that frequently diverts drainage (1). Slushflow deposits are unsorted and till-like, consisting of large blocks and small rock fragments (boring k, table 29), fine-grained material, and occasional shredded plant remains.

The arcuate ridge (2) may be a protalus rampart (Bryan, 1934) that accumulated when angular fragments of frost-wedged bedrock rolled and tumbled across a former perennial snow bank to form a ridge or it may be part of the 12-ft-thick landslide lobe that overlies till [Cl/Gt] (boring f, table 29) on the valley floor across the Chandalar River. The conspicuous mounds of angular blocks on the landslide deposit are similar to 'protalus mounds' formed by deposition of rock debris on snow (Yeend, 1972). Because of these unique mounds, Hamilton (1979c, p. 42; oral commun., August 17, 1977) postulated that the landslide may have been deposited on a stagnant, ablating glacier; similar conditions produced an analogous topography in Pasayten River valley, Washington (Waitt, 1979).

Till [Gt] of Itkillik age (Hamilton, 1978b, 1979b) is derived from Devonian conglomerate, siltstone, and shale (Brosgé and others, 1979). At this 3,500-ft altitude and northern latitude, flood-plain deposits [Fp] are discontinuously frozen and vegetated by scattered willow shrubs (dark tones).

Table 29. *Logs of soil borings on plate 22 (see table 7 for explanation of abbreviations and terms).*

a) 0-10 ft Sa Gr w/Cob & Bol; 10-26 ft Sa Gr w/s Si; 26-36 ft Wea Phyllite. Fr 18-24 ft. WT @ 3 ft. [8-27-74]. (203-50).
b) 0-10 ft Gr w/s Sa, tr Si; 10-28 ft Gr Sa w/s Si; 28-39 ft Wea Graywacke. Fr 0-39 ft. [4-17-72]. (77-14).
c) 0-23 ft Gr Sa w/s Si. Fr 0-23 ft. [8-18-70]. (31-5).
d) 0-16 ft Sa Gr w/s Si; 16-30 ft Graywacke. Fr 0-30 ft. [11-17-71]. (60-29).
e) 0-3 ft Si Sa w/s Org & Cl; 3-14 ft Gr w/s Sa; 14-25 ft Wea Graywacke. Fr 0-25 ft. [4-17-72]. (77-13).
f) 0-12 ft Angular Bol w/Gr; 12-29 ft Gr w/s Sa; 29-40 ft Graywacke. Fr 0-40 ft. [4-15-72]. (77-12).
g) 0-50 ft Gr w/s Sa & Cob. Fr 4-50 ft. WT @ 4 ft. [7-25-73]. (63-25).
h) 0-51 ft Gr w/s Sa & Si. Fr 0-51 ft. [4-11-72]. (77-11).
i) 0-6 ft Gr w/s Sa & Cob; 6-12 ft Sa Gr w/s Si & Cob; 12-25 ft Mudstone. Fr 0-25 ft. [11-14-71]. (60-28).
j) 0-37 ft Gr w/s Sa & Cob; 37-47 ft Slate. Fr 0-47 ft. [4-8-72]. (77-10).
k) 0-3 ft Sa Gr w/Cob; 3-25 ft Bol & Cob. WT @ 19 ft. [8-23-70]. (31-7).

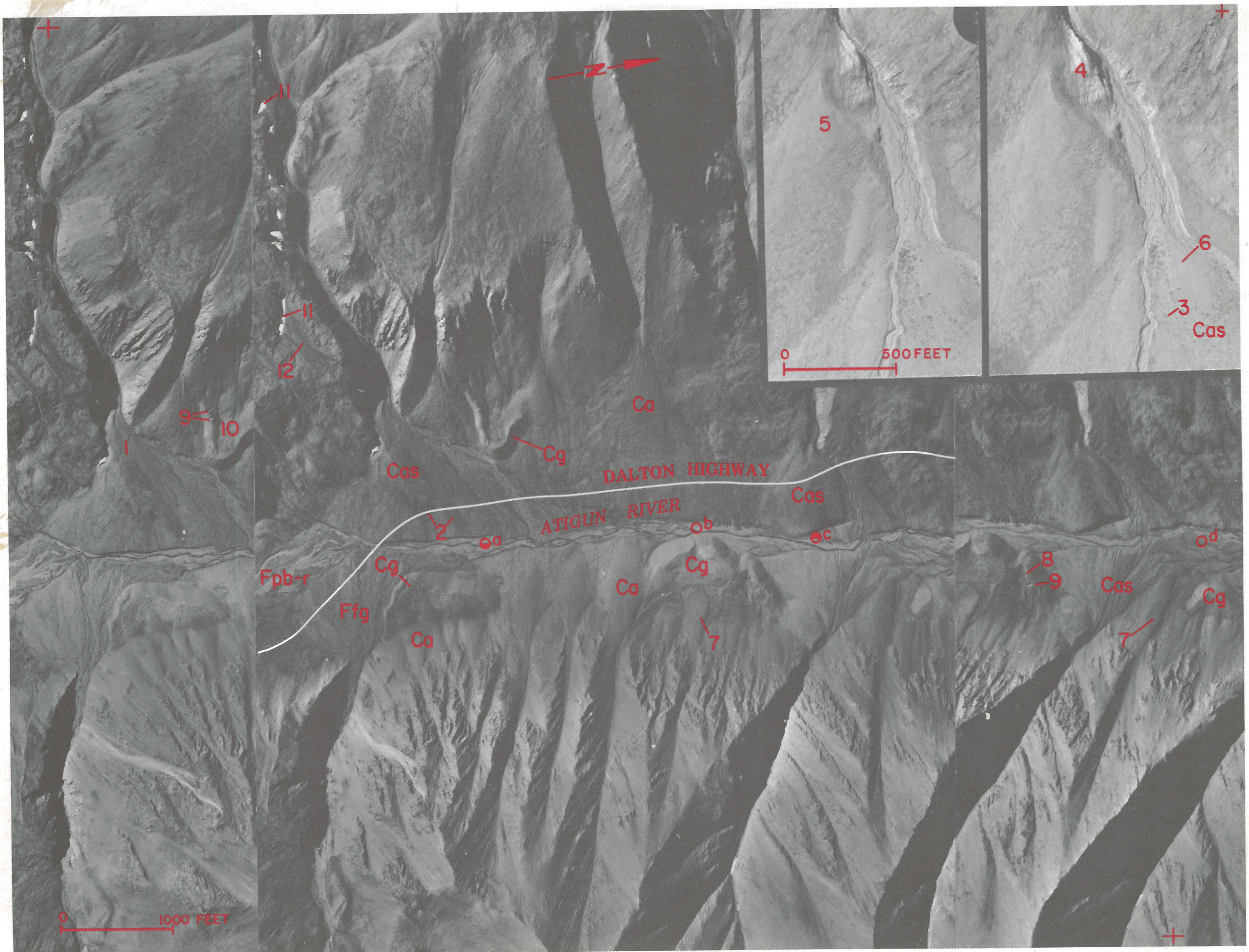

N
DALTON HIGHWAY
ATIGUN RIVER
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Plate 23. **Slushflow, talus, and nivation features, upper Atigun River valley, Philip Smith Mountains Quadrangle** (Alyeska Pipeline Service Company photos 9-2/4 Chandalar Pass, August 10, 1970). **Inset — Slushflow features, west wall of upper Atigun River valley, Philip Smith Mountains Quadrangle** (Alyeska Pipeline Service Company photos 5-14/15 Chandalar Pass, August 10, 1970).

This large-scale photography illustrates alpine fans and cones built by various combinations of fluvial and colluvial processes. On steep slopes in this area just north of the Continental Divide in the central Brooks Range, winter snow cover is thin and redistribution of surface debris by snow avalanching has major geomorphic implications. Snow avalanches moving downslope on the ground surface have stripped material wedged by frost action from the Devonian conglomerate, shale, and siltstone (Brosgé and others, 1979) and carried debris into tributary valleys or to the bases of faceted spurs. During the period of rapid snowmelt from mid-May to mid-June, slushflows scouring the floors of tributary valleys flush out this debris and build distinctive fans [Cas] at the mouths of tributary valleys. Proximal humps (1), steeper slopes, numerous surface boulders, and the lack of an extensive surface network of braided stream channels clearly distinguish fans built mainly by slushflows from coarse-grained fans [Ffg] built primarily by fluvial deposition. However, scattered boulders on the surface of the alluvial fan [Ffg] indicate that slushflows periodically sweep across it, depositing a relatively small volume of debris compared to the alpine stream, which normally builds the fan. Garlands and tongues of dark-toned, lichen-covered debris (2) on the colluvial fan demonstrate that former slushflows were larger than their modern counterparts or mark the limits of infrequent, large-magnitude events. The inset illustrates numerous boulders (3) on a colluvial fan and on a bedrock surface (4) that was scoured by former slushflows. Incision of the bedrock canyon at the head of the old colluvial fan (5) rendered the upper fan surface inactive; this surface is now well vegetated by tundra---in contrast to the lower, light-toned, unvegetated, active-fan surface (6).

Steep talus cones [Ca] are built of debris deposited by rock falls and snow avalanches (Potter, 1969; Gardner, 1970; Gray, 1972, 1973; Church and others, 1979). Two cones (7) exhibit the asymmetric form of roadbank boulder tongues formed through uneven erosion of the cone surface by scouring snow avalanches (Rapp, 1959, 1960; Luckman, 1972, 1977, 1978). Talus cones provide debris to ice-cemented, lobate rock glaciers [Cg] (Ellis and Calkin, 1979), that advance slowly by viscous flow of interstitial ice (table 30). Excavation through the terminus of a nearby active, ice-cemented rock glacier exposed contorted bands of clear, dirty, and white bubbly ice occupying 60 to 70 percent by volume of the body of the rock glacier; individual clasts were isolated in the ice. Surface pits (8), high lateral ridges---some with transverse cracks (9)---and low centers (10) indicate partial melting of interstitial ice; steep, angular margins suggest weak forward movement or recent stabilization.

Slope hollows (11) have been modified by nivation (differential erosion of soil and rock related to melting snowbanks and caused by frost action, overland and rill flow, chemical attack, and solifluction) (Thorn, 1975, 1976). Soils downslope from melting snowbanks (12) are frequently soaked with water from daily snowmelt and a thawing active layer which enhances frost action and solifluction (Ballantyne, 1978; Thorn, 1979).

Soil borings (table 31) demonstrate that flood-plain alluvium [Fpb-r] is discontinuously frozen.

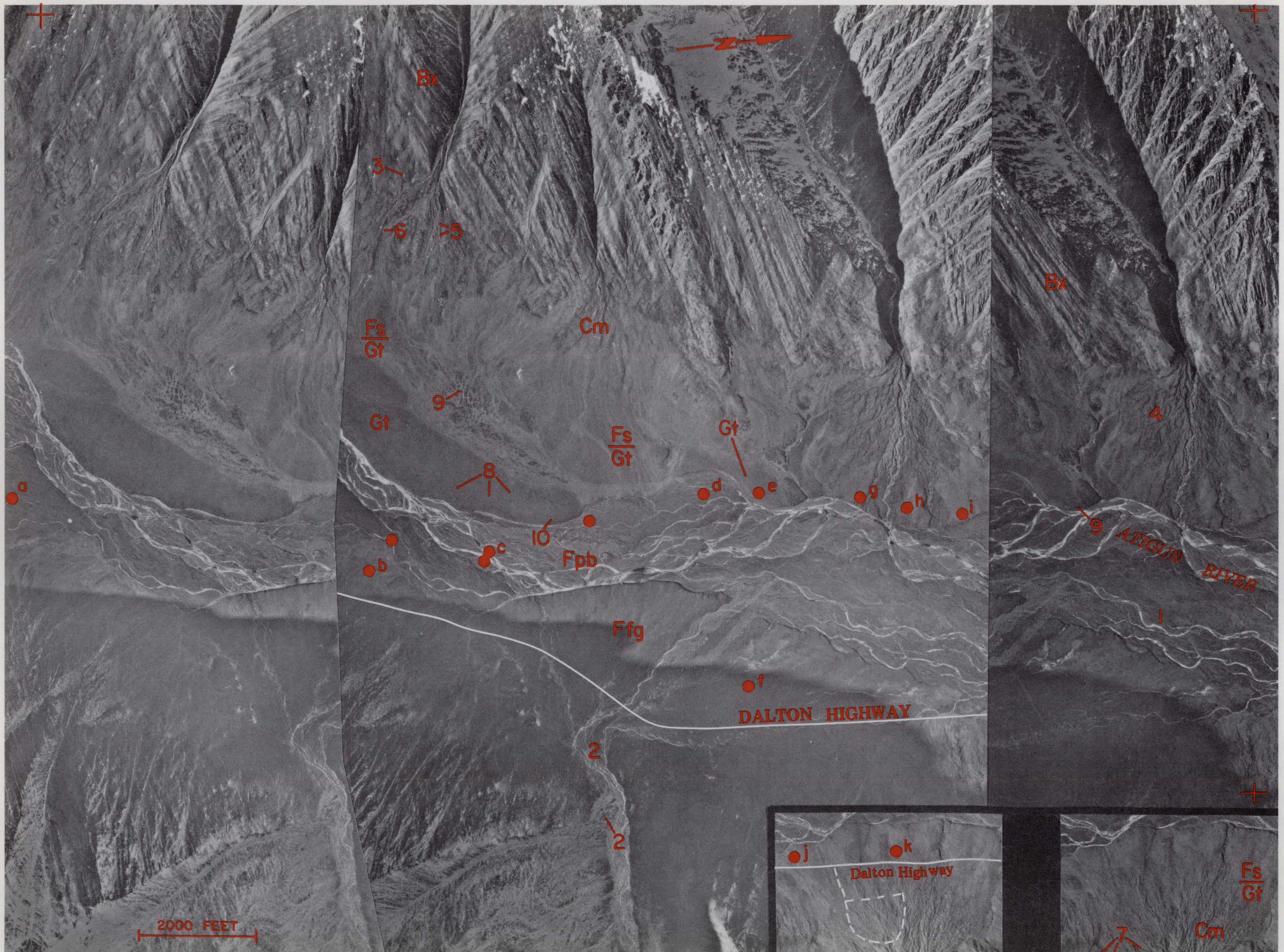
Table 30. *Average downvalley velocity of representative rock glaciers.*

Location	Period of observation	Upper surface (m/yr)	Terminus (m/yr)	Reference
Austria				
Otztaler Alpen	1938-1955	1.5	3.0-4.0	Pillewitzer (1957), *in* Wahrhaftig and Cox (1959)
Upper Engadine, Switzerland				
Val Sassa	1918-1942	1.37	0.4	Chaix (1923, 1943), *in* Wahrhaftig and Cox (1959)
Val dell' Acqua	1918-1942	1.60	0.48	Chaix (1923, 1943), *in* Wahrhaftig and Cox (1959)
Absaroka Mountains, Wyoming				
Galena Creek rock glacier	1963-1967	0.01-0.83	- - -	Potter (1972)
Front Range, Colorado				
Arapaho rock glacier	1961-1967	0.01-0.83	0.04-0.12[a]	White (1971)
Taylor rock glacier	1961-1966	0.03-0.12	- - -	" "
Fair rock glacier	1961-1966	0.04-0.15	- - -	" "
Green Lake No. 5 rock glacier	1964-1972	- - -	0.003-0.024[b]	White (1976)
Canadian Rocky Mountains, Lake Louise area				
Northeastern rock glacier	1902-1974	- - -	?	Osborn (1975)
	1947-1974	- - -	0.3	" "
Middle rock glacier	1902-1974	- - -	0.8	" "
	1947-1974	- - -	0.4	" "
Southwestern rock glacier	1902-1974	- - -	0.7-0.8	" "
	1947-1974	- - -	0.6	" "
St. Elias Range, Yukon Territory, Canada				
Sheep Mountain rock glacier	1966-1971	0.35	- - -	Hughes and others (1972, p. 17); Johnson (1973)
Alaska Range, Alaska				
Clear Creek rock glacier	1949-1957	0.73	0.47	Wahrhaftig and Cox (1959)

[a]1961-1968
[b]Measured at two-thirds of height above base on front and sides.

Table 31. *Logs of soil borings on plate 23 (see table 7 for explanation of abbreviations and terms).*

a) 0-12 ft Gr w/tr Sa, Si & Cob; 12-34 ft Sa Gr w/s Si & Cob; 34-45 ft Wea Mudstone. Fr 12-45 ft. [4-28-72]. (76-14).
b) 0-4 ft Gr w/s Sa; 4-9 ft Sa Si; 9-30 ft Argillite. WT @ surface. [7-24-73]. (63-24).
c) 0-12 ft Sa Gr w/s Si; 12-30 ft Sa w/s Si & Gr; 30-40 ft Argillite. Fr 0-25 ft. [4-26-72]. (79-13).
d) 0-2 ft Sa Gr w/s Si & Bol; 2-7 ft interbed Si Sa & Sa w/s Gr; 7-14 ft Sa Gr; 14-23 ft Sa Gr w/s Si. WT @ 8 ft. [8-29-70]. (30-21).



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Fs/Gt
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Fpb
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e
g
h
i
4
9
ATIGUN RIVER
1
Ffg
f
DALTON HIGHWAY
2
2
j
k
Dalton Highway
Fs/Gt
7
Cm
2000 FEET

Plate 24. Alpine fans and cones, upper Atigun River valley, Philip Smith Mountains Quadrangle (Alyeska Pipeline Service Company photos 22-23/25, October 17, 1969). **Inset — Alpine fan built primarily by mudflows, upper Atigun River valley, Philip Smith Mountains Quadrangle** (Alyeska Pipeline Service Company photos 22-24/25, October 17, 1969).

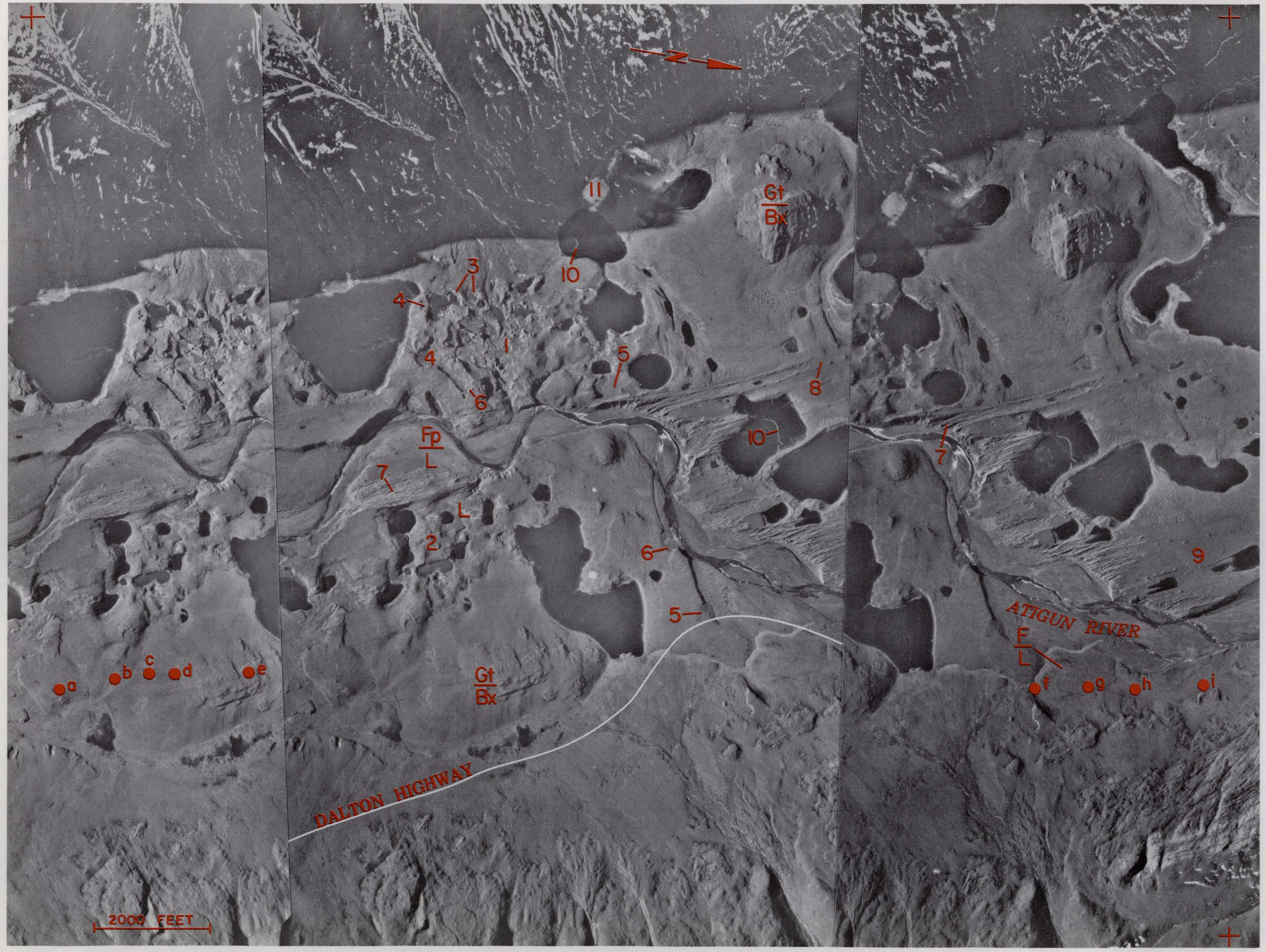
Bedrock [Bx] in this part of the north-central Brooks Range consists of a sequence of intensely folded and faulted Devonian conglomerate, sandstone, siltstone, and shale (Brosgé and others, 1979). The valley fill of Late Itkillik till [Gt] (Hamilton, 1978b, 1979b), postglacial alluvium [Fpb], and alpine-fan deposits is continuously frozen, except for discontinuously frozen alluvium beneath the unvegetated flood plain where seasonal icings develop (table 32). Cover deposits of sandy silt are thin or absent over most of the braided flood plain, even where vegetated by dark-toned willow shrubs (1).

Alpine fans in this area exhibit evidence of formation or modification by more than one process. A large alluvial fan [Ffg] is built of coarse detritus transported by torrential floods during short periods of heavy rainfall or during extended periods of rainfall in tributary valleys walled by bedrock; between floods, stream flow across the fans is generally low and channels are stable. One result of periodic flooding on the fan is the formation of braided ephemeral or intermittent distributary channels that have irregular depths, truncate and undercut each other, are floored and walled by very coarse alluvium (Stewart and LaMarche, 1967), including boulder bars (Cooley and others, 1977), and are bounded by bouldery berms or natural levees of cobbles and boulders without sand or silt matrices (Stewart and LaMarche, 1967; Mears, 1979). Mudflow diamicton forms relatively steep, rough-surfaced cones (2) at the head of the alluvial fan and in the valley from which the fan is derived. Other fans are built almost entirely of mudflow deposits derived from tributary valleys where the products of bedrock weathering become saturated and flow because of snowmelt; these weathered products are also mobilized during summer storms with daily precipitation rates of 1 to 4 in. (Rapp, 1960; Winder, 1965; Curry, 1966; Broscoe and Thompson, 1969). The locations of sudden debris flows in till or colluvium on lower valley walls (3) are difficult to predict, but they start in thawing ice-rich till or are released during summer storms (Rapp, 1960). Unsorted mudflow deposits [Cm] are readily recognized by their dark-toned network of overlapping debris tongues (4), many with obvious light-toned levees of cobbles and boulders (5) separated by U-shaped medial channels (Sharp, 1942). Crustose lichens growing on surface boulders of dark-toned levees (6) are several centuries old. Although levees are deposited with silt and sand matrices, these fine sediments commonly wash out after deposition, leaving only coarse clasts (Broscoe and Thompson, 1969).

Scattered surface blocks (7) on alpine fans and lower valley walls were either transported by mudflows (Blackwelder, 1928) or slushflows (Rapp, 1960), or individually fell, tumbled, and rolled to the base of steep bedrock slopes. Near the axis of the valley, erratic blocks (8) are scattered on the till surface. Fine material washed from deposits on upper fan surfaces and in tributary valleys was laid down as relatively thin fans and aprons [Fs/Gt] on the valley floor. The distal surfaces of many fans are underlain by 3 to 25 ft or more of fluvial and eolian sandy silt that is commonly rich in ice and organic material (borings j and k, table 32). High-center polygons (9) result from partial melting of polygonal ice wedges. The mechanism of formation of earth hummocks on till surfaces (10) is not certain, but they probably result from seasonal-frost action (Washburn, 1973).

Table 32. *Logs of soil borings on plate 24 (see table 7 for explanation of abbreviations and terms).*

a) 0-50 ft Gr w/s Sa. Fr 0-50 ft. [4-27-72]. (83-17).
b) 0-3 ft Sa Si w/s Org; 3-17 ft Interbed Sa Gr w/Cob & Sa Si w/s Org; 17-35 ft Gr w/s Sa & Cob. Fr 0-35 ft. [3-29-75]. (214-16).
c) 0-18 ft Sa Gr w/s Cob; 18-50 ft Gr w/s Sa, Si & Cob. Fr 0-50 ft. [5-6-72]. (76-15).
d) 0-2 ft Si Sa; 2-39 ft Sa Gr; 39-49 ft Sa Gr w/s Si. Fr 0-49 ft. [4-24-72]. (82-17).
e) 0-9 ft Sa Si w/s Gr; 9-15 ft Si Sa w/s Gr; 15-49 ft Gr w/s Sa & Cob. Fr 0-49 ft. [4-28-72]. (82-18).
f) 0-2 ft Gr Sa w/s Si; 2-35 ft Gr w/s Sa, Cob & Bol. Fr 0-35 ft. [3-19-75]. (214-8).
g) 0-5 ft Si w/s Sa; 5-13 ft Gr w/s Sa; 13-50 ft Sa Gr w/s Si. Fr 0-50 ft. [4-30-72]. (83-18).
h) 0-5 ft Sa w/tr Si; 5-50 ft Gr w/s Sa & Cob. Fr 0-50 ft. [7-23-73]. (64-18).
i) 0-22 ft Gr w/s Sa & Cob; 22-29 ft Si Gr w/s Sa; 29-50 ft Sa Gr. Fr 0-50 ft. [5-1-72]. (82-19).
j) 0-13 ft *Massive Ice* + Sa Si; 13-45 ft Gr w/s Sa, Si, Cob & Bol. Fr 0-45 ft. [3-25-75]. (214-13).
k) 0-7 ft Sa Gr w/tr Si & Org; 7-25 ft *Massive Ice* + Si w/s Sa & Gr; 25-44 ft Gr w/s Sa, Si, Cob & Bol. Fr 0-44 ft. [3-27-75]. (214-14).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ATIGUN RIVER
DALTON HIGHWAY
2000 FEET
Gt/Bx
Fp/L
F/L
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Plate 25. Slope instability in fine-grained, ice-rich sediments, Galbraith Lake area, Philip Smith Mountains Quadrangle
(Alyeska Pipeline Service Company photos 22-32/34, October 17, 1969).

Glacial and glaciofluvial sediments underlie lacustrine, fluvial, and eolian deposits beneath the floor of this broad glaciated valley just south of Galbraith Lake in the northern Brooks Range. Lacustrine silt and clay [L] (boring b, table 33) commonly have 25 to 95 percent visible ice; fluvial silt and sand over clayey lake deposits [F/L] typically contain up to 15 percent visible ice (borings a, f-i, table 33). Thermokarst badlands (French and Egginton, 1973) are actively developing in these ice-rich deposits (1) or have recently become quasi-stabilized (2). Active badlands are characterized by irregular topography, numerous irregular thermokarst lakes with receding shorelines (3), and bimodal failures (4).

Bimodal failures, also termed 'flowslides' (Zoltai and Pettapiece, 1973), 'ground-ice slumps' (Mackay, 1966, 1971), 'ground-ice mudslumps' (French and Egginton, 1973), and 'retrogressive thaw-flow slides' (Hughes, 1972), are characterized by two distinct modes of mass movement: a steep, rapidly receding ablation scarp and a low-angle, flowing tongue of soil slurry (McRoberts and Morgenstern, 1974). The retreat of the steep ablation face may be triggered by several mechanisms that expose ice-rich, fine-grained sediments, including undercutting by current or wave action, forest fires, and human disturbance. McRoberts and Morgenstern (1974) reported rates of scarp retreat between 1 and 20 cm/day at 13 sites in arctic Canada; Mackay (1966) recorded ablation-scarp recession rates of 1.5 to 4.6 m/yr on the Mackenzie Delta. A bimodal failure was monitored 5.5 mi northwest of this stereotriplet in clay-rich till of late Itkillik age (Hamilton, 1978b, 1979b). Ground ice in the form of clear seams and foliated wedges comprised 25 to 75 percent of the till. The average rate of scarp retreat was 7.5 cm/day in July 1974, and 20 cm/day the following month. Meltwater from the thawing ice-rich scarp saturates soils that accumulate at the toe of the ablating face. In fine-textured soils with low permeabilities, porewater pressures cannot dissipate and excess pressures develop, greatly reducing the shear strength of accumulating soils and producing the flowing slurry tongue, the surface of which generally slopes 2^{o} to 8^{o}. Stakes placed in the surface of the active tongue 5.5 mi northwest of this stereotriplet were displaced 6.7 to 9.8 cm/day during July and August, 1974. Where thin, ice-poor soils and organic mats overlie ice-rich sediments, the continuous flow of mud slurry prevents buildup of an insulating apron of colluvium over the ablating face. Blocks of surface soil and organic mat falling onto the slurry tongue are removed from the toe of the scarp (Lambert, 1972), promoting scarp retreat that can continue until the failure encounters either ice-poor soils, such as eolian and fluvial sands (5), or ice-poor surface deposits that are thick enough to insulate the ablating scarp (6).

Eolian features are conspicuous on this stereotriplet. Linear features along the margins of the Atigun River flood plain parallel the dominant wind direction down the valley. Yardangs (7) are linear, sharp-crested ridges cut by wind deflation of fluvial silty sand; they are separated by yardang troughs, which are linear grooves with U-shaped cross sections up to 15 ft deep and 70 ft across. Sand deflated from the yardang troughs is deposited downwind of the troughs as longitudinal dunes (8) and dark-toned sand blankets between 2 and 15 ft thick (9).

In this area the bedload of the Atigun River is sand. Sandy flood-plain deposits are 4 to 8 ft thick and overlie lacustrine clays and silts [Fp/L].

Frozen lake surfaces appear very dark; cracks in the lake ice are accentuated by small, curved to linear snow drifts (10). The remnant of a perennial icing sheet (11) covers the lower part of a till slope, indicating the presence of a spring. Ice-scoured hills of Mississippian-Pennsylvanian limestone (Brosgé and others, 1979) are thinly veneered by till [Gt/Bx] (borings c-e, table 33) near the base of steep mountain slopes.

Table 33. *Logs of soil borings on plate 25 (see table 7 for explanation of abbreviations and terms).*

a) 0-4 ft Si Sa w/tr Org; 4-11 ft *Ice* + Sa Si; 11-27 ft Si; 27-34 ft Sa Gr w/s Si & Cob; 34-46 ft Si Cl. Fr 0-46 ft. [10-6-70]. (31-29).
b) 0-2 ft *Ice* + Si w/s Org; 2-13 ft *Massive Ice*; 13-15 ft *Ice* + Si Cl; 15-51 ft Si Cl w/tr Sa. Fr 0-51 ft. [10-7-70]. (30-43).
c) 0-10 ft Sa Si w/s Org; 10-15 ft Si Sa; 15-23 ft Si w/s Cl; 23-38 ft Si Gr w/Sa; 38-45 ft Wea Limestone. Fr 2-45 ft. [10-8-70]. (32-7).
d) 0-2 ft Si w/s Sa & Org; 2-5 ft *Ice* + Sa Si; 5-6 ft Sa w/s Si; 6-12 ft *Ice* + Si Sa w/tr Gr; 12-13 ft Rock Frag; 13-20 ft Limestone. Fr 1-20. [10-8-70]. (31-30).
e) 0-1 ft Org; 1-3 ft Si Gr w/s Sa; 3-15 ft Limestone. Fr 3-15 ft. [10-8-70]. (31-31).
f) 0-1 ft Org; 1-15 ft *Ice* + Si w/tr Org; 15-42 ft Si Cl. Fr 0-42 ft. [10-11-70]. (31-32).
g) 0-1 ft Org Si; 1-14 ft Si; 14-23 ft Cl Si; 23-48 ft Gr w/s Si & Cob; 48-50 ft Si Sa; 50-56 ft Limestone. Fr 2-56 ft. [10-14-70]. (30-47).
h) 0-1 ft Org; 1-4 ft Si w/tr Org; 4-15 ft *Massive Ice*; 15-34 ft Si w/tr Cl. Fr 1-34 ft. [10-22-70]. (30-48).
i) 0-2 ft Org Si; 2-8 ft *Ice* + Si; 8-24 ft Si; 24-46 ft Cl Si; 46-49 ft *Ice* + Cl Si. Fr 2-49 ft. [10-25-70]. (30-49).

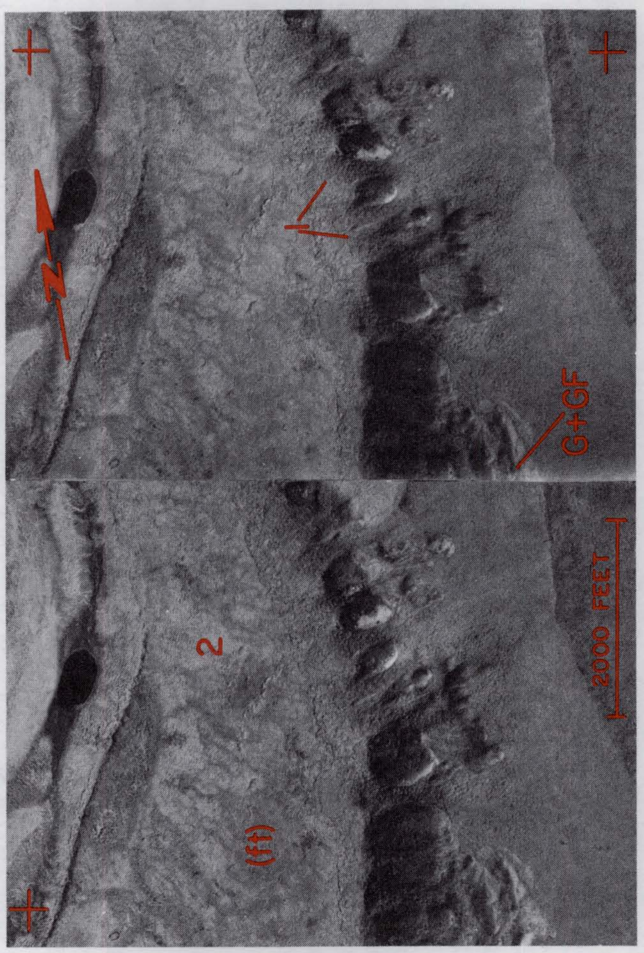

N
G+GF
(ft)
2
2000 FEET

Plate 26. Solifluction features and string fens, Sagavanirktok River valley, Philip Smith Mountains Quadrangle
(Alyeska Pipeline Service Company photos 570-5-16-009/010, July 27, 1973).

Rounded uplands of till and ice-contact gravels [G+GF] are perennially frozen and covered by sedge tussocks. Within the seasonally thawed surface layer, colluvium is flowing down a terrace scarp to form solifluction cones (1) that are spreading onto the low fluvial terrace (ft) of the Sagavanirktok River. The cones have a thick organic mat of *Sphagnum* moss, sedge tussocks, and willow shrubs that stand 1 to 2 ft high. The string fen (2), often known as strangmoor or string bog, is wet and occurs here on shallow permafrost. The term 'string bog' is technically incorrect because strings, which are low ridges of vegetation, including peat, do not form in acidic ombrotrophic bogs, but occur in minerotrophic fens with considerable surface water (pl. 5). String fens form on planar, very gently sloping to flat surfaces covered with slowly moving shallow water. Strings are oriented normal to the direction of water movement and each ridge functions as a low dike that separates grassy fens at slightly different elevations, much like a rice paddy. This stereopair demonstrates that string fens are not limited to the discontinuous permafrost or boreal forest zones as reported by Troll (1944, p. 639), Drury (1956, p. 62), and Schenk (1966, p. 157), but exist in favorable situations on the treeless and continuously frozen Arctic Slope. Hypotheses proposed for the origin of the weblike string pattern emphasize solifluction, downslope sliding and tilting of broken peat blocks, frost heaving and thrusting, thermokarst effects, flooding, plant-growth habits, or combinations thereof (Washburn, 1973). Drury (1956, p. 71) and Thom (1972) concluded that most string ridges probably develop on gently sloping surfaces when snow meltwater or heavy rainfall generate moving sheets of water, which pile up sinuous riffles and rows of plant debris and slush. The common occurrence of string fens on very gentle slopes or flat surfaces does not support a total mass-movement origin.

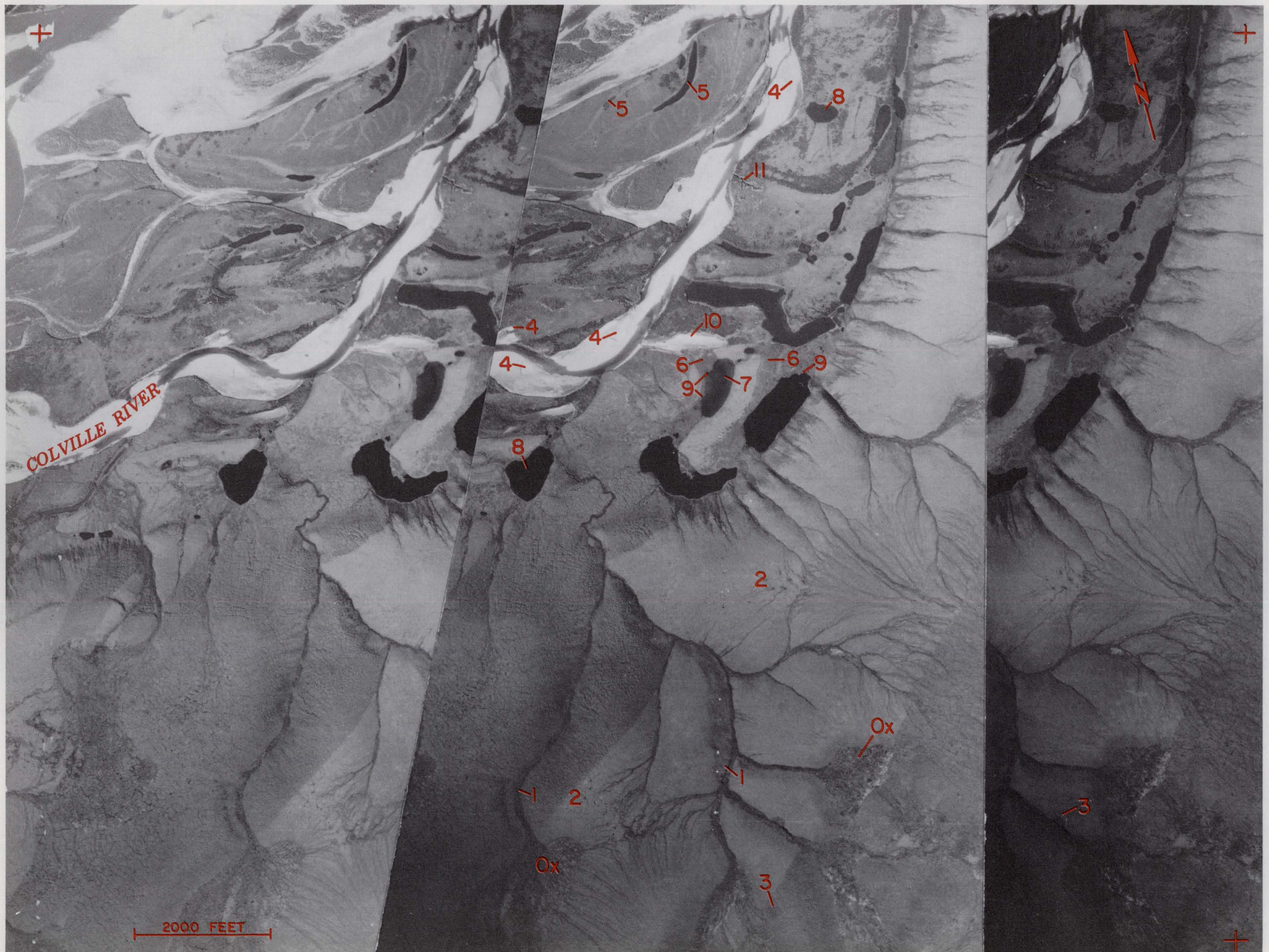
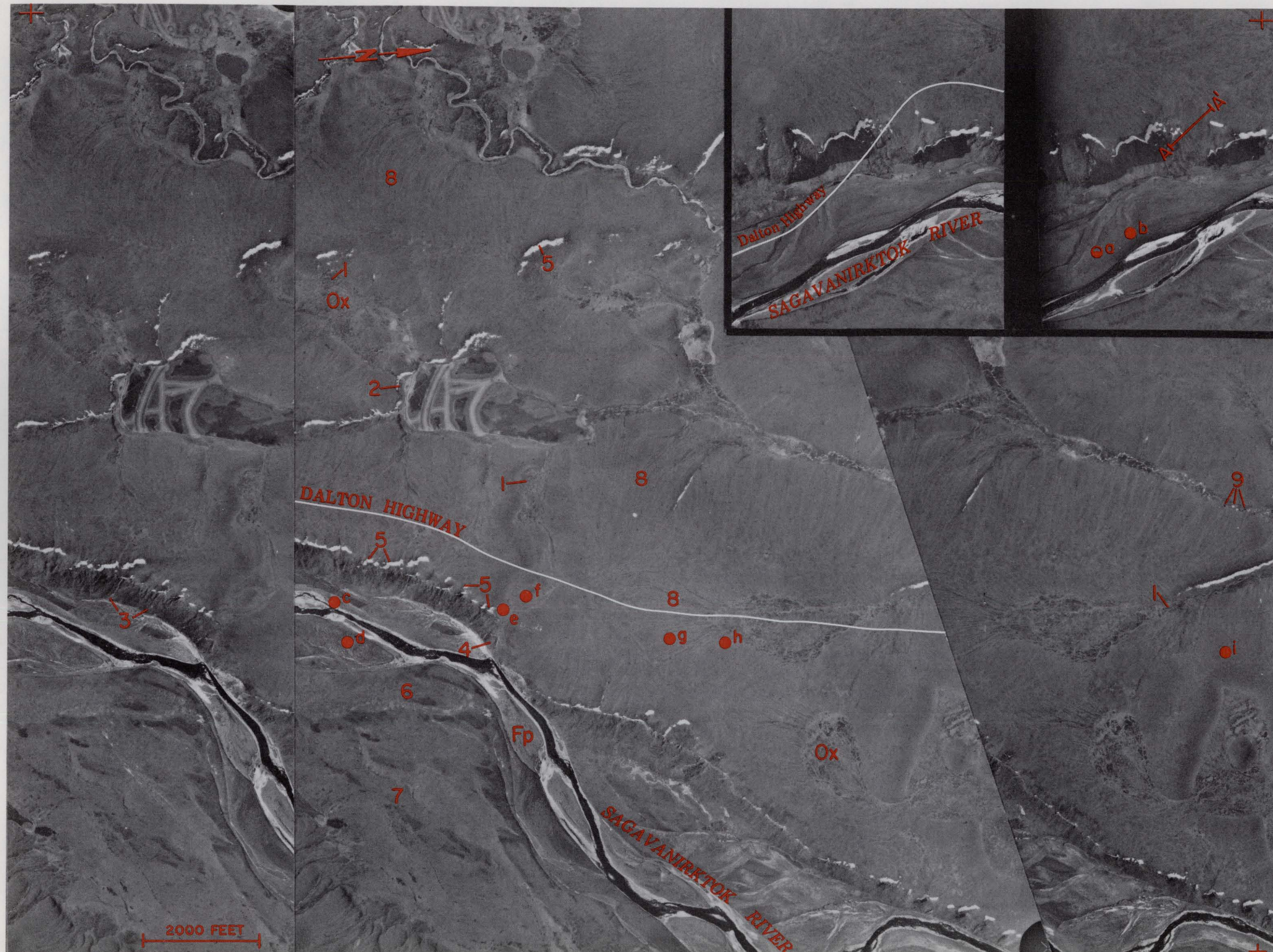

COLVILLE RIVER
2000 FEET
N
1
2
3
4
5
6
7
8
9
10
11
Ox

Plate 27. Tundra fire scars that reveal polygonal ice wedges, Puiklik Bluff area, Ikpikpuk River Quadrangle
(U.S. Geological Survey photos 6M5-46RS-236/238, July 26, 1946).

The absence of polygonal ground or thermokarst features is not proof that ground-ice masses are absent. Permafrost degradation following the fires that produced these dark-toned scars on tussock-covered tundra 48 mi southwest of Umiat revealed the presence of polygonal ice wedges that have no surface expression in adjacent unburned areas with the same soils. Before the tundra fires, polygonal ground was visible only on the surface of organic basin fillings [Ox]. When analyzing terrain for ground ice, one should assume that if ice-wedge polygons are present in the area, ground-ice wedges probably occur in all fine-grained, frozen landforms, except perhaps in well-drained, south-facing situations. However, surface polygons in granular soils may ensure only the former presence of polygonal ice wedges (Péwé and others, 1969).

Other evidence of ice-rich soils in this stereotriplet includes beaded drainage in small upland valleys (1), concentrations of thermokarst ponds in poorly drained divides (2), and scars of small bimodal failures (3). This terrain is underlain by thin, high-level fluvial gravel, sand, and silt of Quaternary age capping the gently folded lower sandstone, shale, and coal member of the Late Cretaceous Chandler Formation (Detterman and others, 1963, pl. 27).

Distinctive depressions (4) with steep upstream walls were scoured by spring floods of the Colville River (Arnborg and others, 1966, 1967) when discontinuous icing sheets filled much of the channel and covered low terrace surfaces. At that time stream-bed and terrace deposits were doubtlessly frozen. Lakes on the flood plain and low terraces display forms demonstrating changes in lake morphology through time. On young, low terraces, lakes (5) are linear to arcuate and follow inactive stream channels. On old, high terraces, former stream channels contain significant accumulations of ice-rich, perennially frozen sediments (6), and lake forms are less controlled by the form of the original channels; lakes cross former channel limits (7), have rounded outlines (8), and have scalloped shorelines (9) due to differential thawing of ice-rich sediments. The flood-plain lake at locality 10 recently drained when the laterally migrating stream channel intersected the west end of the lake. A thermokarst gully (11) demonstrates the ice-rich nature of near-surface flood-plain deposits.



N
8
5
Ox
2
1
8
DALTON HIGHWAY
5
5
c
e
f
8
g
h
d
4
3
6
Fp
Ox
7
SAGAVANIRKTOK RIVER
2000 FEET
Dalton Highway
SAGAVANIRKTOK RIVER
A
A'
a
b
9
1
i

Plate 28. Old till plain with massive ice, Happy Valley area, Sagavanirktok Quadrangle (Alyeska Pipeline Service Company photos 22-89/91, October 17, 1969).
Inset — Location of Happy Valley roadcut (line A-A′), west wall Sagavanirktok River valley, Sagavanirktok Quadrangle (Alyeska Pipeline Service Company photos 22-89/90, October 17, 1969).

This terrain is typical of the Arctic Foothills physiographic province. 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 (Ferrians, 1971c). Cryoplanation processes (Peltier, 1950) have greatly modified the original morainal topography, lowering and rounding topographic highs and filling low areas, and surface streams have become well integrated. Conspicuous flat-floored upland depressions that are partially filled with ice-rich peat [Ox], organic-rich slopewash deposits, and colluvium at least 5 ft thick (boring f, table 34) may be partially filled kettles or partially filled thaw ponds and basins developed through local, deep thawing of ice-rich sediments (Hopkins, 1949; Czudek and Demek, 1970). Very similar features occur in many areas beyond the known limits of glaciation. Most basin floors display the polygonal pattern of cellular ice-wedge networks. High-center polygons (1) indicate local degradation of permafrost. The terrace (2) marginal to the lake with the unique ice-fracture pattern was developed by thermal erosion of ice-rich soils during a period of lake expansion perhaps 3,500 to 4,000 yr ago (Carson and Hussey, 1962; Carson, 1968; Black, 1969; Tedrow, 1969).

Ice content of the till is partly related to its antiquity; old tills generally contain more massive ground ice than young tills because more time has been available for epigenetic ice growth. Till in the Happy Valley area was deposited during the Sagavanirktok Glaciation (Sagavanirktok River Glaciation of Hamilton, 1978b,c) of middle(?) Pleistocene age (Detterman and others, 1958). Test holes and observations of a large roadcut (table 34, fig. 13) indicate that the upper 25 to 40 ft of till is volumetrically composed of up to 75 percent massive ice. Till between large ice wedges in the fresh roadcut had uniformly disseminated visible ice in the form of lenses, pods, and coatings around clasts that constituted up to 50 percent by volume of the soil. Bimodal failures (Mackay, 1966; French and Egginton, 1973; McRoberts and Morgenstern, 1974) developed soon after construction of the roadcut where disseminated ice occurred in till in the southern half of the cut (fig. 13), but winter installation of an insulating gravel blanket stabilized this section (McPhail and others, 1975, 1976). 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 porewater pressures needed to generate mudflow tongues at the base of the ablating cut face. Late Itkillik moraines deposited east of Toolik Lake closer to the Brooks Range have a rounded topography similar to that illustrated in this stereotriplet; however, till of these younger moraines contains less wedge ice and has only a very thin cover of eolian silt.

Mudflows (3) and a slump failure (4) occur in the colluvial apron covering lower slopes of bedrock bluffs along the Sagavanirktok River. Concave nivation hollows (5) indent upper bluff slopes and surfaces leeward of rounded hill tops.

Coarse flood-plain alluvium [Fp] is discontinuously frozen adjacent to the active channel of the Sagavanirktok River where silty cover deposits are thin or absent and where the flood plain is either bare or vegetated with low willow shrubs and a ground cover of lichens and mosses (table 34). Alluvium beneath the remainder of the flood plain (6) is continuously frozen and, where the surficial silt layer is up to 5 ft thick, infrequent flooding permits development of an insulating mat of *Sphagnum* moss and sedge tussocks. String fens (7), which grow perpendicular to slowly moving sheets of water and remain continuously wet (Drury, 1956), have formed on the very gently sloping surface (table 34; pl. 26).

The horsetail drainage pattern (8), which is typically only moist---not wet---during late summer, is related to early summer runoff on moderate to gentle slopes and not to solifluction or slope instability as indicated by Miller (1961, p. 130). Beaded drainage (9) consists of a series of small pools, each formed by thawing of shallow ice wedges beneath the stream channel (Hopkins and others, 1955, p. 141).

Table 34. *Logs of soil borings on plate 28 (see table 7 for explanation of abbreviations and terms).*

a) 0-23 ft Gr w/s Sa, num Cob. Fr 8-23 ft. WT @ 4 ft. [10-25-70]. (35-11).
b) 0-3 ft Sa w/tr Si & Org Si; 3-48 ft Sa Gr w/tr Si; 48-51 ft Wea Mudstone. Fr 0-51 ft. [5-23-72]. (80-21).
c) 0-4 ft Si Sa w/s Org; 4-22 ft Gr w/s Si, Sa & Cob; 22-33 ft Wea Mudstone. Fr 0-33 ft. [6-15-73]. (62-17).
d) 0-14 ft Gr w/tr Sa, num Cob; 14-30 ft Wea Mudstone. Fr 4-30 ft. [6-17-72]. (79-23).
e) 0-4 ft Si w/tr Sa & Org; 4-30 ft Gr w/s Cl, Si, Sa & Cob; 30-46 ft Wea Sandstone. Fr 0-46 ft. [5-24-72]. (82-25).
f) 0-5 ft Org Si & Sa w/tr Si & Gr; 5-50 ft Si Gr w/s Sa, tr Cl & Cob. Fr 0-50 ft. [5-24-72]. (81-14).
g) 0-4 ft Org Si + *Massive Ice*; 4-20 ft *Massive Ice*; 20-33 ft *Massive Ice* + Sa Si w/tr Gr & Org; 33-45 ft Sa Gr w/s Si; 45-50 ft Sa Si w/tr Gr & Cob. Fr 0-50 ft. [9-22-70]. (32-3).
h) 0-9 ft Si w/tr Sa & Gr; 9-36 ft *Massive Ice*; 36-43 ft *Massive Ice* + Gr w/s Cl Si & Sa, 43-50 ft Gr w/s Cl, Si, Sa & Cob. Fr 0-50 ft. [5-26-72]. (83-24).
i) 0-4 ft Sa Si w/s Org; 4-13 ft *Massive Ice*. Fr 0-13 ft. [10-24-70]. (33-9).

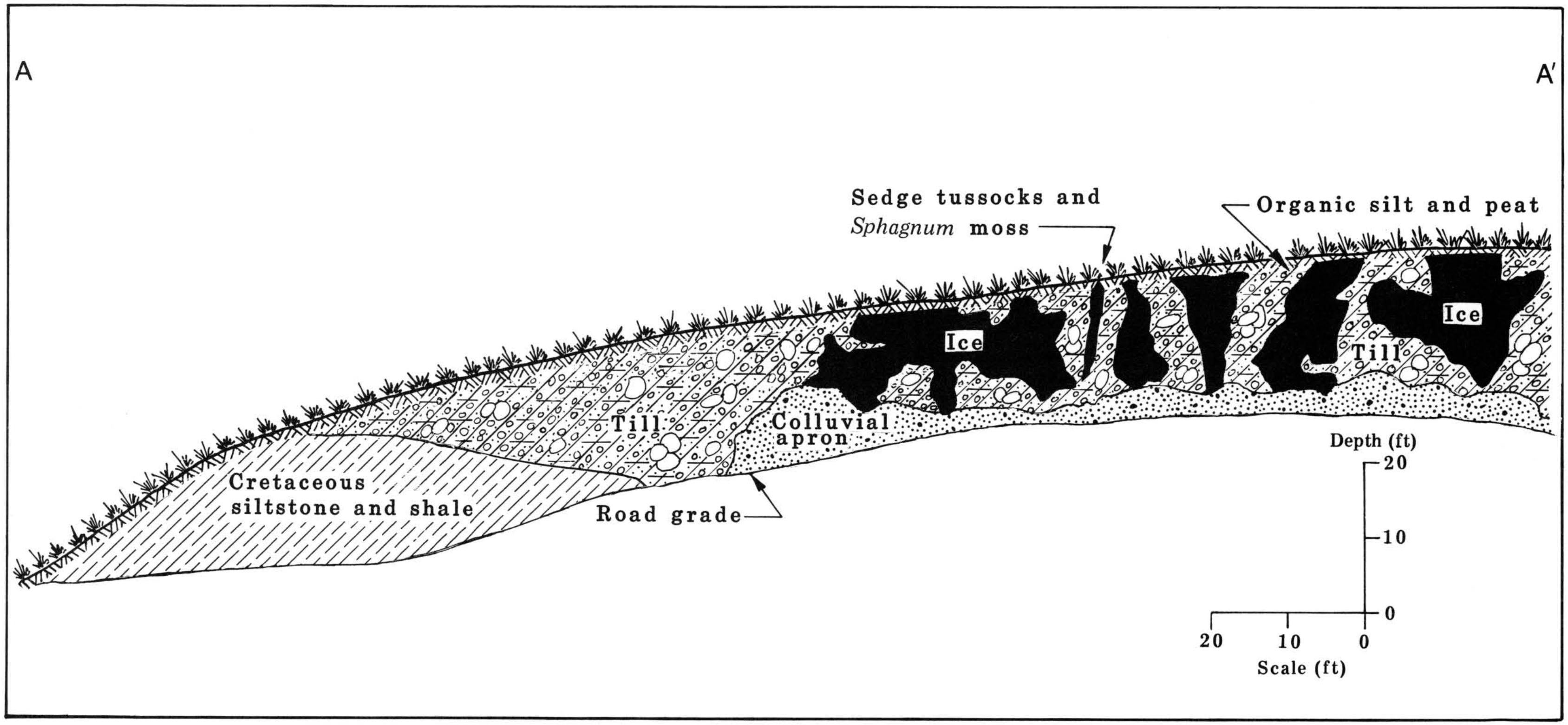
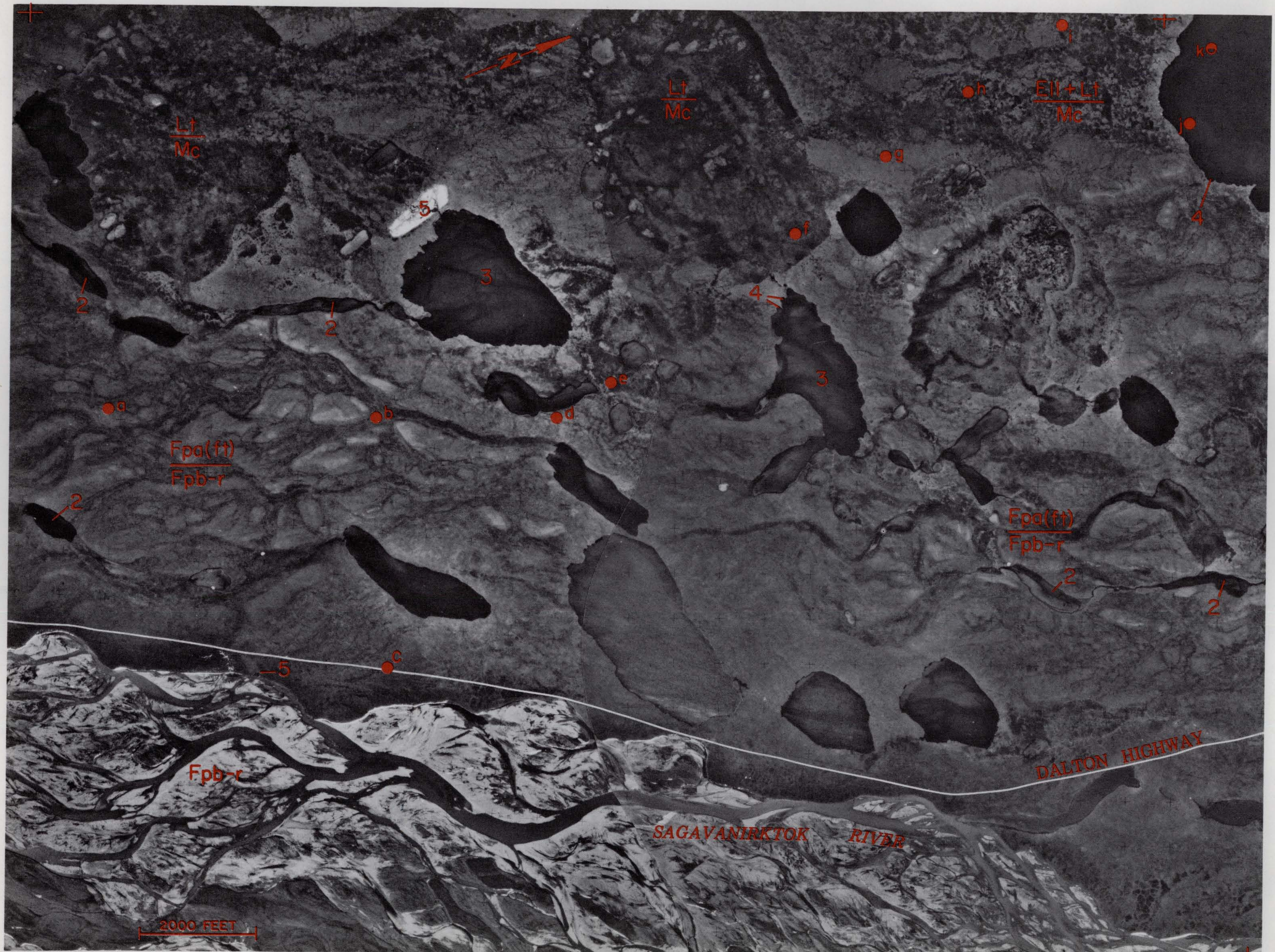


Figure 13. Geologic section A-A′ exposed in southwest wall of Happy Valley roadcut, Sagavanirktok Quadrangle (inset, pl. 28).



Lt/Mc
Lt/Mc
Ell + Lt/Mc
Fpa(ft)/Fpb-r
Fpa(ft)/Fpb-r
Fpb-r
DALTON HIGHWAY
SAGAVANIRKTOK RIVER
2000 FEET
a
b
c
d
e
f
g
h
i
j
k

Plate 29. Flood plain and low terraces of Sagavanirktok River, Beechey Point Quadrangle
(Alyeska Pipeline Service Company photos 15-58 and 15-60, August 31, 1969).

Unvegetated coarse alluvium [Fpb-r] of the braided Sagavanirktok River flood plain contains continuous permafrost, except for shallow thaw bulbs beneath active channels. During most of 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; however, channel changes occur once coarse bedload and bank deposits thaw and stream competence is sufficient to move coarse material (Scott, 1978). Perennially frozen, cohesive banks of the Sagavanirktok River are undercut and retreat primarily by thermoerosional niching that produces scalloped banks (1) and tilted soil blocks that retard lateral erosion.

Anastomosing channel patterns braid the surface of 3- to 8-ft-high terraces of the Sagavanirktok River. Some of these channels are floored with sandy gravel (boring b, table 35) and others are partially filled with up to 8 ft of frozen lowland loess and sandy silt (cover deposits) (boring c). Between channels, low terrace treads are capped by 1 to 8 ft of continuously frozen sandy silt that comprises abandoned-flood-plain sediments overlying sand and gravel [Fpa/Fpb-r(ft)].

Irregularly shaped thaw lakes are localized along former stream channels (2). These thermokarst lakes postdate the channels with which they are associated. Relatively deep, anastomosing former stream channels (3) are visible in sand and gravel beneath younger, shallow thaw lakes. Accelerated thawing of ice-rich bank deposits has produced scalloped lake banks (4) (Black, 1969). Dry sedges and grass in the recently drained lake basin (5) have especially bright gray tones.

Thaw-lake deposits [Lt], organic sediments, and lowland loess [Ell], which are generally 3 to 12 ft thick and ice rich, overlie coastal-plain sand and gravel [Lt/Mc and (Ell+Lt)/Mc].

Table 35. *Logs of soil borings on plate 29 (see table 7 for explanation of abbreviations and terms).*

a) 0-3 ft Si w/tr Sa & Org; 3-5 ft *Ice* + Si; 5-50 ft Gr w/tr Sa. Fr 0-50 ft. [6-21-72]. (81-23).
b) 0-45 ft Gr w/s Sa; 45-50 ft Sa w/tr Gr. Fr 0-50 ft. [6-25-72]. (81-24).
c) 0-8 ft Si + *Ice*; 8-14 ft Gr. Fr 0-14 ft. [4-25-69]. (2-97).
d) 0-7 ft Sa w/tr Gr & Org; 7-50 ft Gr w/s Sa & Cob. Fr 0-50 ft. [11-30-70]. (47-11).
e) 0-3 ft Org; 3-9 ft *Massive Ice* + Org Si; 9-20 ft Sa Gr. Fr 0-20 ft. [5-9-74]. (200-43).
f) 0-3 ft *Ice* + Org Si; 3-9 ft Sa Si w/s Gr; 9-11 ft Sa Gr. Fr 0-11 ft. [4-27-70]. (22-68).
g) 0-3 ft Org Si w/s Sa; 3-6 ft *Massive Ice*; 6-10 ft *Ice* + Sa Gr w/tr Si; 10-50 ft Sa Gr w/tr Si. Fr 0-50 ft. [4-27-70]. (22-67).
h) 0-3 ft Org Si w/s Sa; 3-8 ft *Ice* + Si; 8-12 ft Sa Si; 12-15 ft Sa w/s Si & Gr; 15-30 ft Sa Gr. Fr 0-30 ft. [4-26-70]. (22-66).
i) 0-3 ft Org Si w/s Sa; 3-11 ft Si Sa w/tr Gr; 11-30 ft Sa Gr. Fr 0-30 ft. [11-25-70]. (22-65).
j) 0-5 ft *Lake Ice*; 5-8 ft Si Gr w/s Sa; 8-16 ft Sa Gr w/s Si; 16-30 ft Sa Gr. Fr 0-30 ft. [4-25-70]. (22-64).
k) 0-4 ft *Lake Ice*; 4-30 ft Gr w/s Sa. Fr 0-10 ft. [4-24-70]. (22-63).

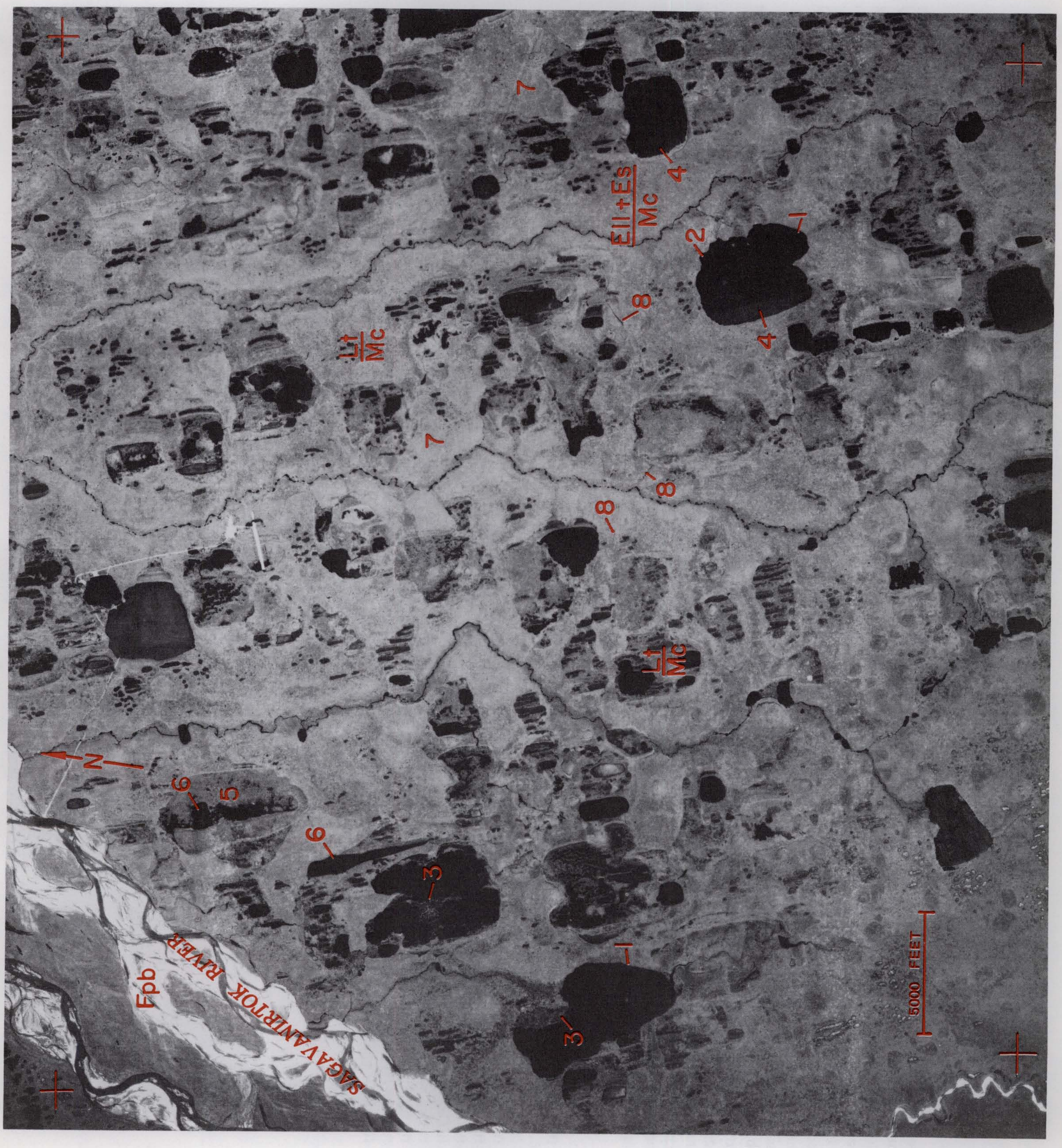

SAGAVANIRTOK RIVER
Fpb
5000 FEET
N
Lt/Mc
Lt/Mc
Ell+Es/Mc
1
1
2
3
3
4
4
5
6
6
7
7
8
8
8

Plate 30. Oriented thaw lakes, Prudhoe Bay area, Beechey Point Quadrangle
(NASA Ames photo 2491, Accession 2786, July 13, 1979).

Most of the Arctic Coastal Plain is poorly drained because of its gentle northward gradient and the presence of widespread, shallow permafrost; surface water stands and flows almost everywhere in late spring and summer. Britton (1973) reviewed terrain and environmental studies of this regional surface, which is underlain by a complex sequence of interfingering fluvial, eolian, and marine sediments that comprise the Gubik Formation of Pleistocene age (Black, 1964; Hopkins, 1967; U.S. Geological Survey, 1976; Carter and others, 1977; Williams and others, 1978). Permafrost is continuous and is from 670 to 2,150 ft thick (Péwé, 1975a, fig. 23).

The eastern Arctic Coastal Plain is transected by numerous north-flowing streams separated by interfluves with very little relief; larger flood plains of coarse sand and gravel [Fpb], such as the Sagavanirktok River flood plain, are typically braided and terminate northward in deltas. Interfluve surfaces are underlain by a 1- to 12-ft-thick blanket of lowland loess and eolian sand overlying complex coastal-plain sediments [(Ell+Es)/Mc]. On the basis of an extensive boring program in similar soils near Barrow, Brown (1967) estimates that 10 percent of the perennially frozen, near-surface soils is composed of ice wedges. However, according to Sellmann and Brown (1973), the greatest volume of ground ice, as much as 50 to 75 percent in the upper 6 ft, is in the form of small ice segregations.

The most widespread features on interfluves are thaw lakes, which are frequently elliptical and have axial ratios of 1.6 to 2.1 (Sellman and others, 1975). The striking aspect of these lakes is their remarkably consistent orientations; long axes are generally aligned north-northwest perpendicular to dominant July and August winds (Black and Barksdale, 1949; Carson and Hussey, 1962; Sellmann and others, 1975). Lake shores commonly have steep, linear to curvilinear banks up to 5 ft high (1). Deep indentations locally scallop these banks where soils are ice rich (2), and cuspate to irregular shores are produced in partially drained shallow basins that are infilled and shaped by the growth of ice-wedge polygons (3) (Mackay, 1956). Submerged shelves (4) develop on east and west sides of elongate lake basins, which have deeper central troughs. Partial drainage of these basins exposes these shelves (5), leaving irregular deeper zones filled with water (6).

Lacustrine deposits of organic-rich silt and sand grade downward into remnants of tundra peat that were let down essentially in place onto coastal-plain deposits [Lt/Mc] during formation of thaw lakes (Carson, 1968; Tedrow, 1969). Thaw bulbs exist beneath lakes that are deeper than about 6 ft and do not freeze to the bottom each year (Sellmann and others, 1975); the thickness of these thawed soils is affected by lake extent (especially where deeper than 6 ft), lake volume, and the long-term average annual water temperature. Geothermal investigations demonstrate that the thaw bulb beneath 6- to 10-ftdeep Imikpuk Lake near Barrow is as deep as 190 ft (Brewer, 1958).

A thermokarst origin for oriented lakes on the Arctic Coastal Plain is universally accepted, although specific mechanisms and controls of alignment remain controversial (Rosenfeld and Hussey, 1958; Carson and Hussey, 1959; Kaczorowski, 1977). Lake formation is initiated by disturbance of the tundra surface, which allows accelerated thawing of ice-rich soils by heat introduced by solar radiation. Banks are undercut by thermoerosional niching, collapse, and recede. Shapes of initial small lakes are much less uniform than large lakes and are determined by local conditions such as soil texture, ground-ice content, local topography, and surface cover; these factors influence thaw rates in frozen soils (Britton, 1967; Black, 1969). The most widely accepted hypothesis for controlling orientation of large lakes is predicated on the consistent alignment of long axes perpendicular to dominant surface winds during July and August, when melting rates are highest and wave action in lakes is most effective. Comparison of aerial photographs taken 20 yr apart of large, elongate, subparallel lakes demonstrates that erosion is fastest at the ends (Sellmann and others, 1975). Lake banks recede up to several feet during single storms (Livingston, 1954). Circulation studies indicate that this differential erosion is probably the product of two wind-generated, near-surface, littoral circulation cells in shallow lakes (Carson and Hussey, 1962).

Oriented thaw lakes are modern dynamic features that constantly migrate, coalesce, enlarge, drain, and reform. Most coastal-plain surfaces have been reworked by several thaw-lake cycles (Britton, 1967, p. 117-123). When disturbed, relatively old surfaces (7), unmodified for centuries by the thaw-lake cycle, are subject to the greatest settlement (thaw consolidation) because they are underlain by soils with high ice content (Hussey and Michelson, 1966). Tracks of vehicles that crossed the sensitive tundra during the summer are most obvious on older surfaces (8) (Ferrians and others, 1969, fig. 29; Hok, 1969; Haugen and Brown, 1971).

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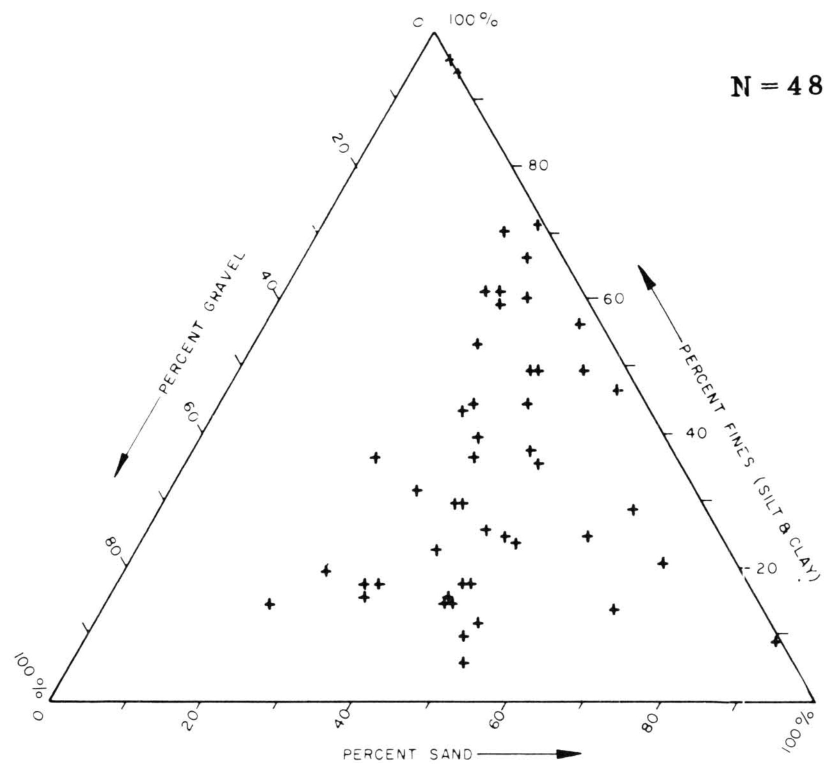
APPENDIX A

Textural triangle plots of landforms along the route of the Trans-Alaska Pipeline System (TAPS)



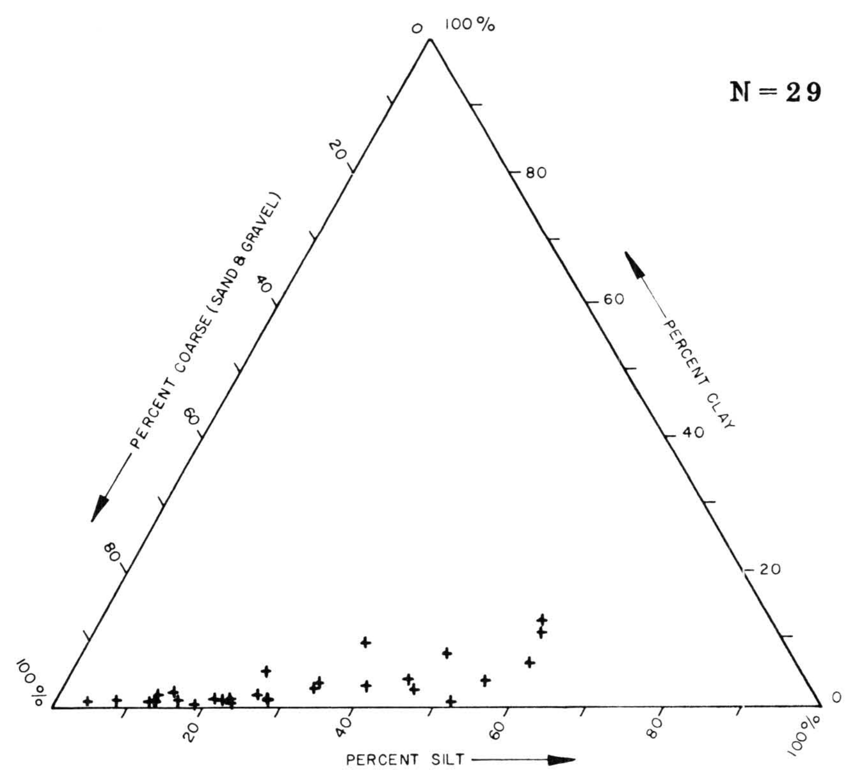
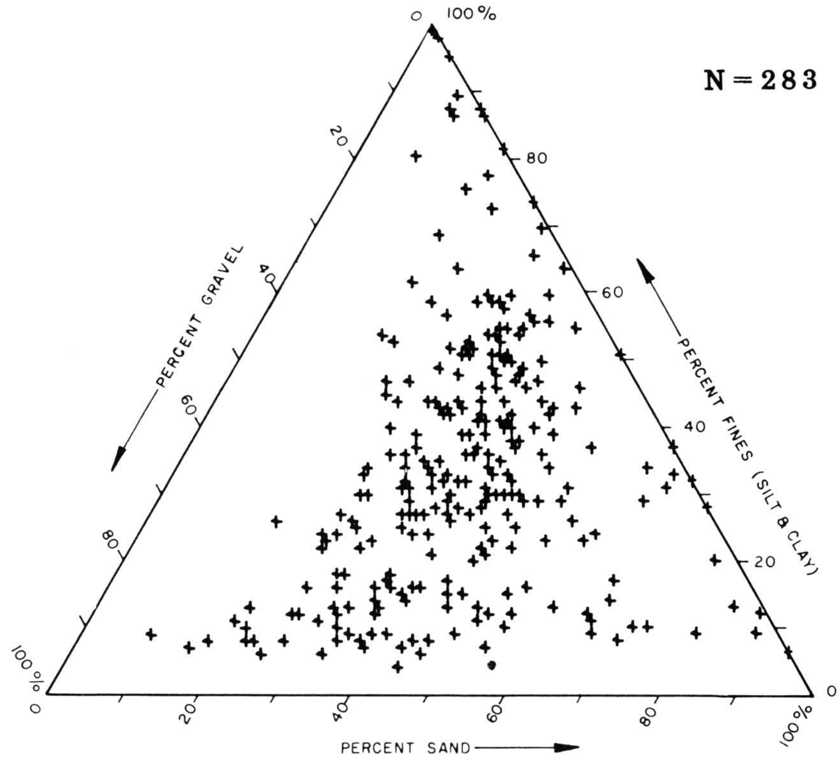


Figure 14. Textural triangle plots of till [Gt] along the TAPS route through the Chugach Mountains (route segment A, table 5).



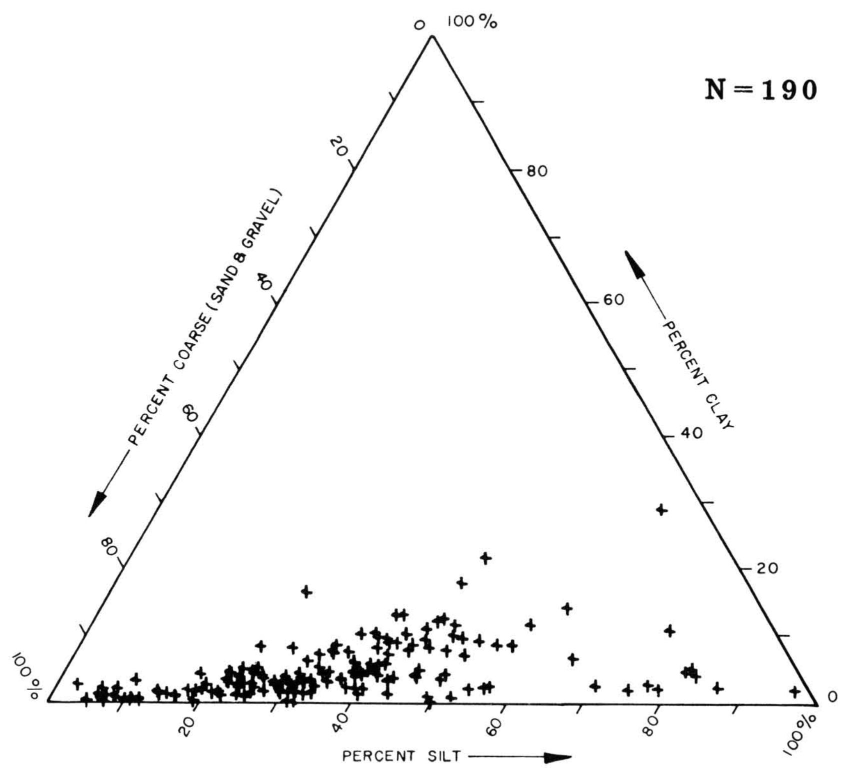
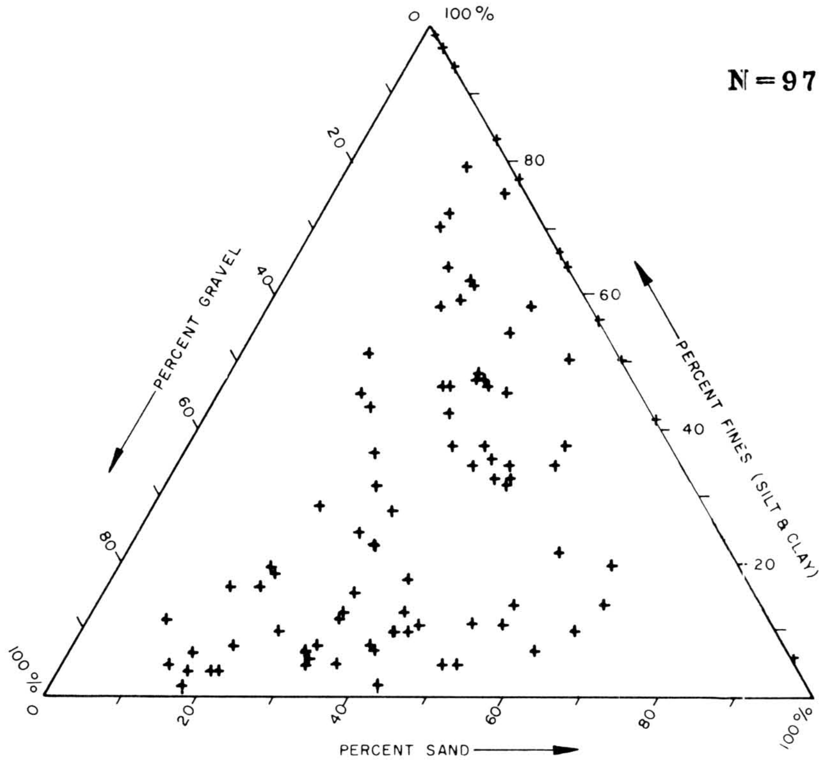


Figure 15. Textural triangle plots of till [Gt] along the TAPS route through the Gulkana Upland and Alaska Range (route segment D, table 5).



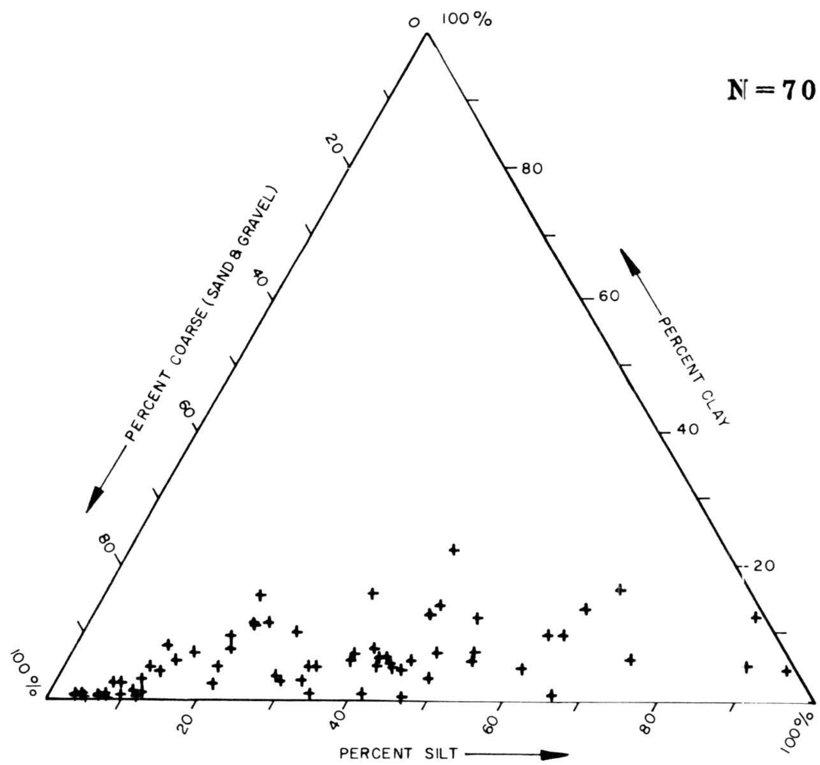
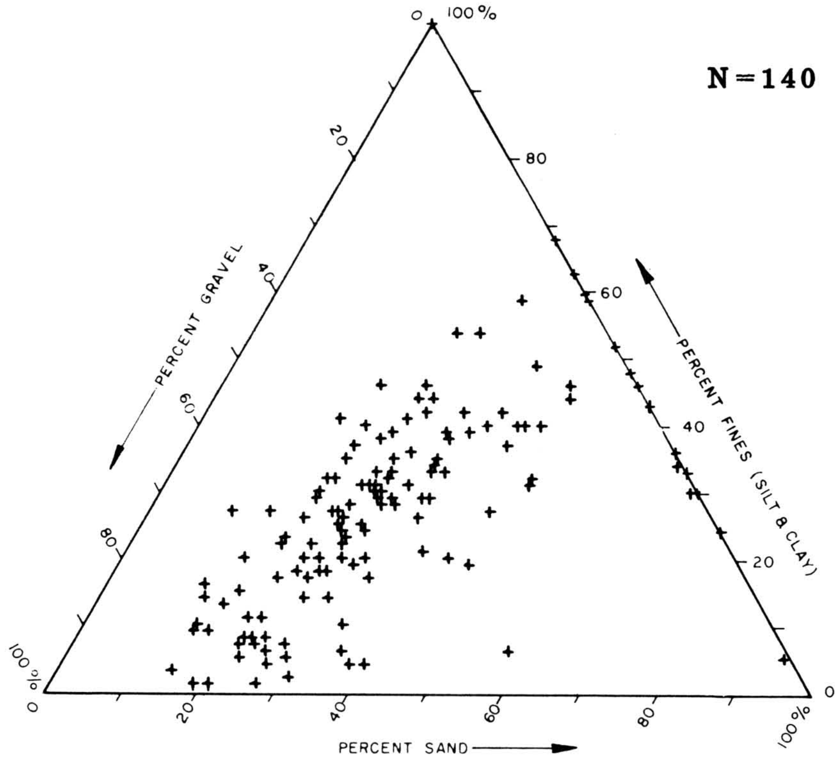


Figure 16. Textural triangle plots of till [Gt] along the TAPS route through the Ambler-Chandalar Ridge and Lowland physiographic unit and Brooks Range (route segments G and H, table 5).



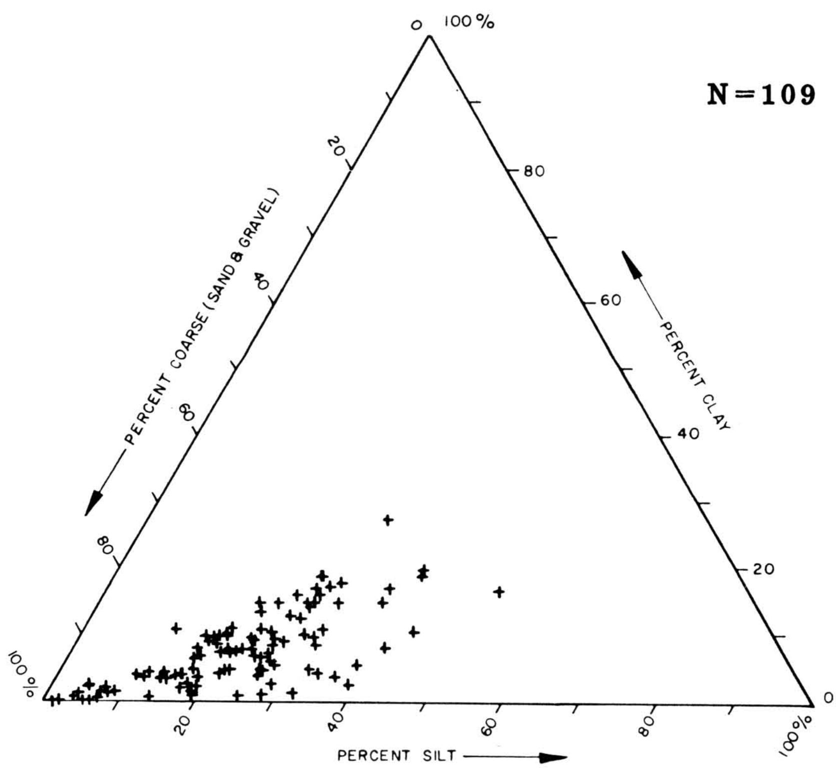
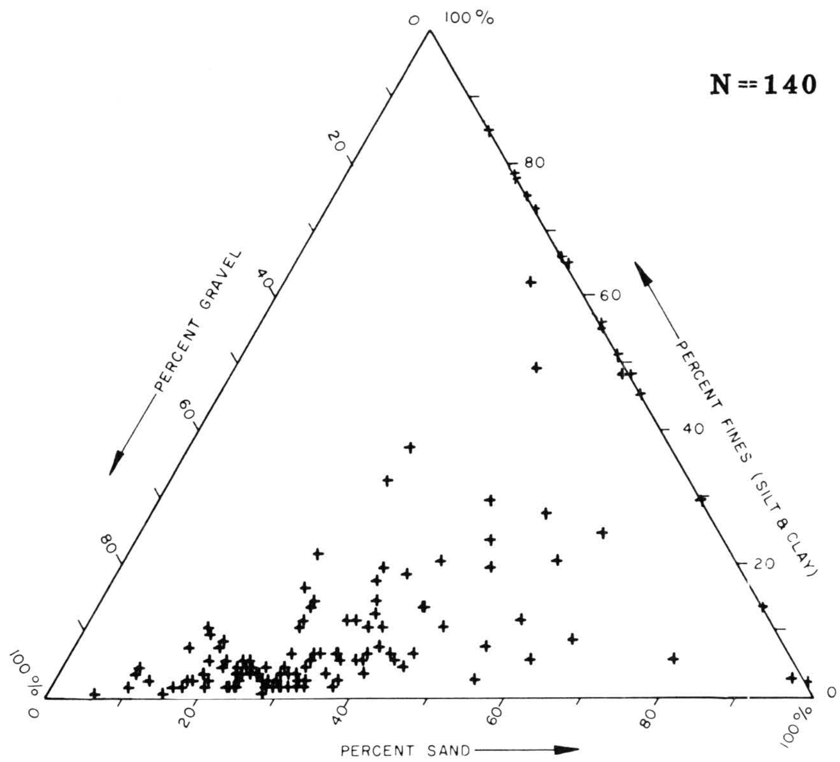


Figure 17. Textural triangle plots of till [Gt] along the TAPS route through the Arctic Foothills (route segment I, table 5).



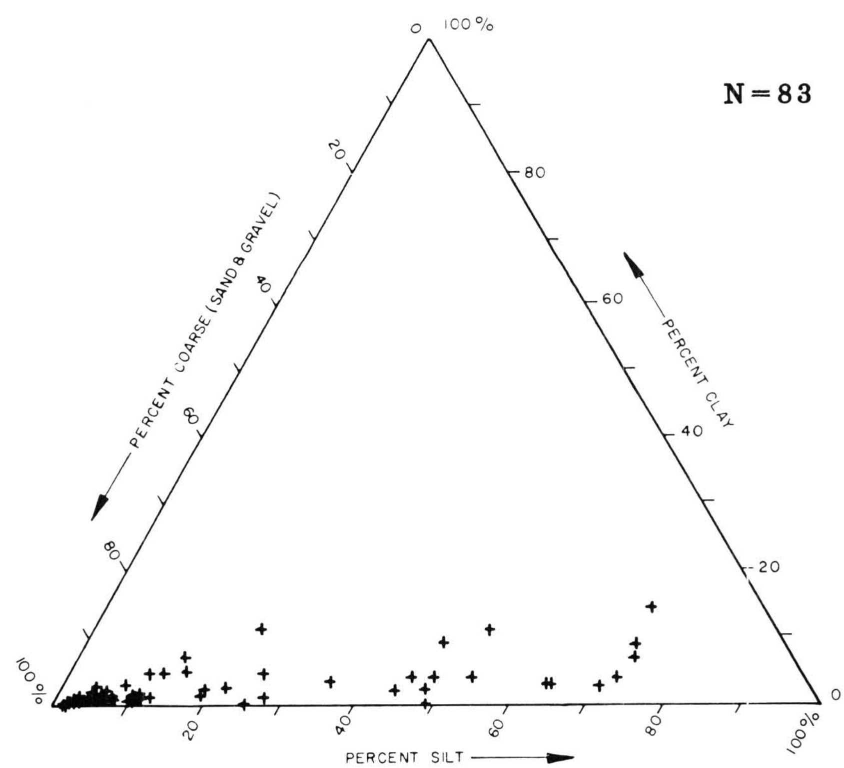


Figure 18. Textural triangle plots of coarse-grained alluvial-fan deposits [Ffg] along the TAPS route through the Ambler-Chandalar Ridge and Lowland physiographic unit and Brooks Range (route segments G and H, table 5).

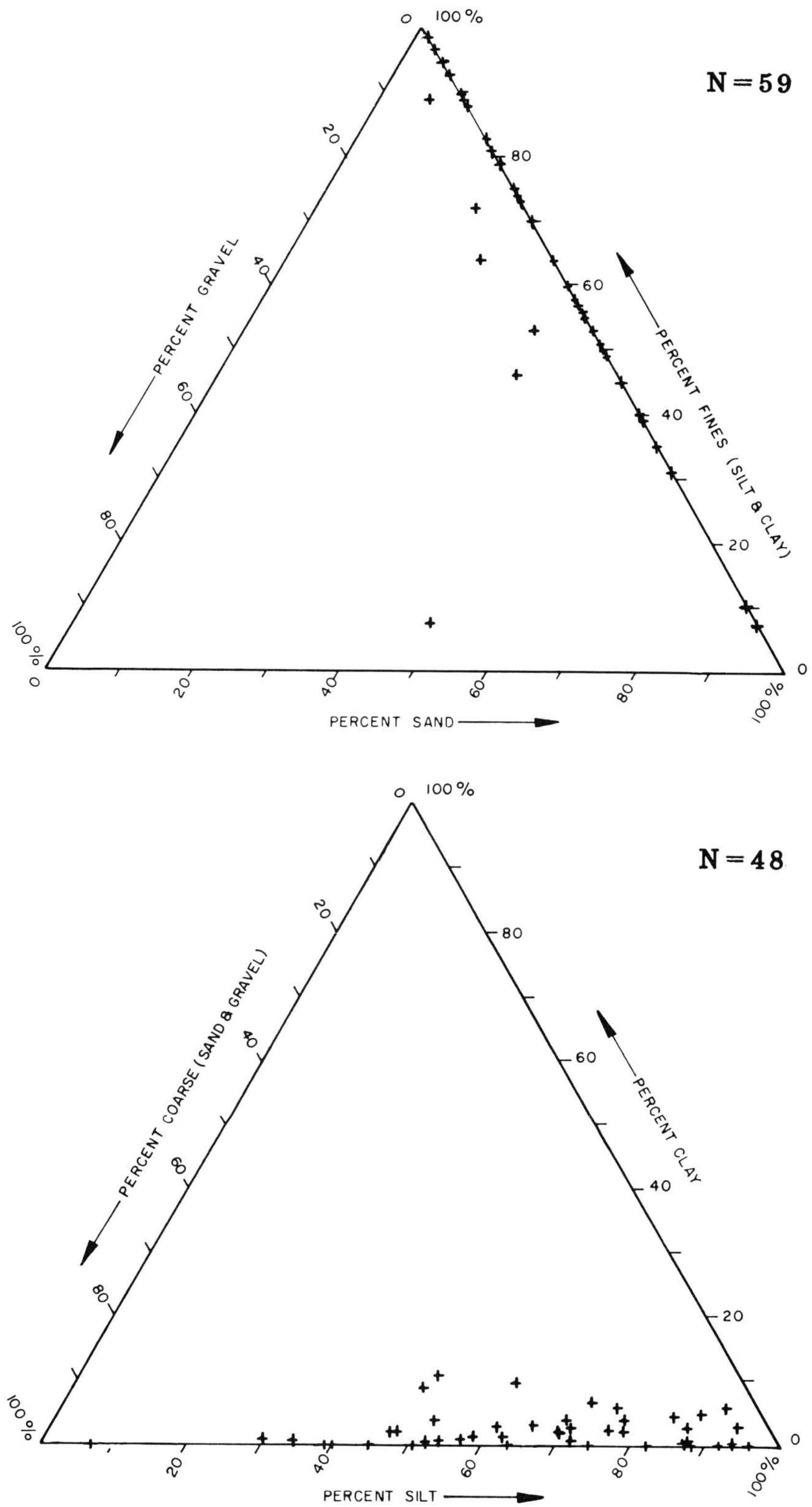


Figure 19. Textural triangle plots of overbank alluvium [Fp-c] along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5).

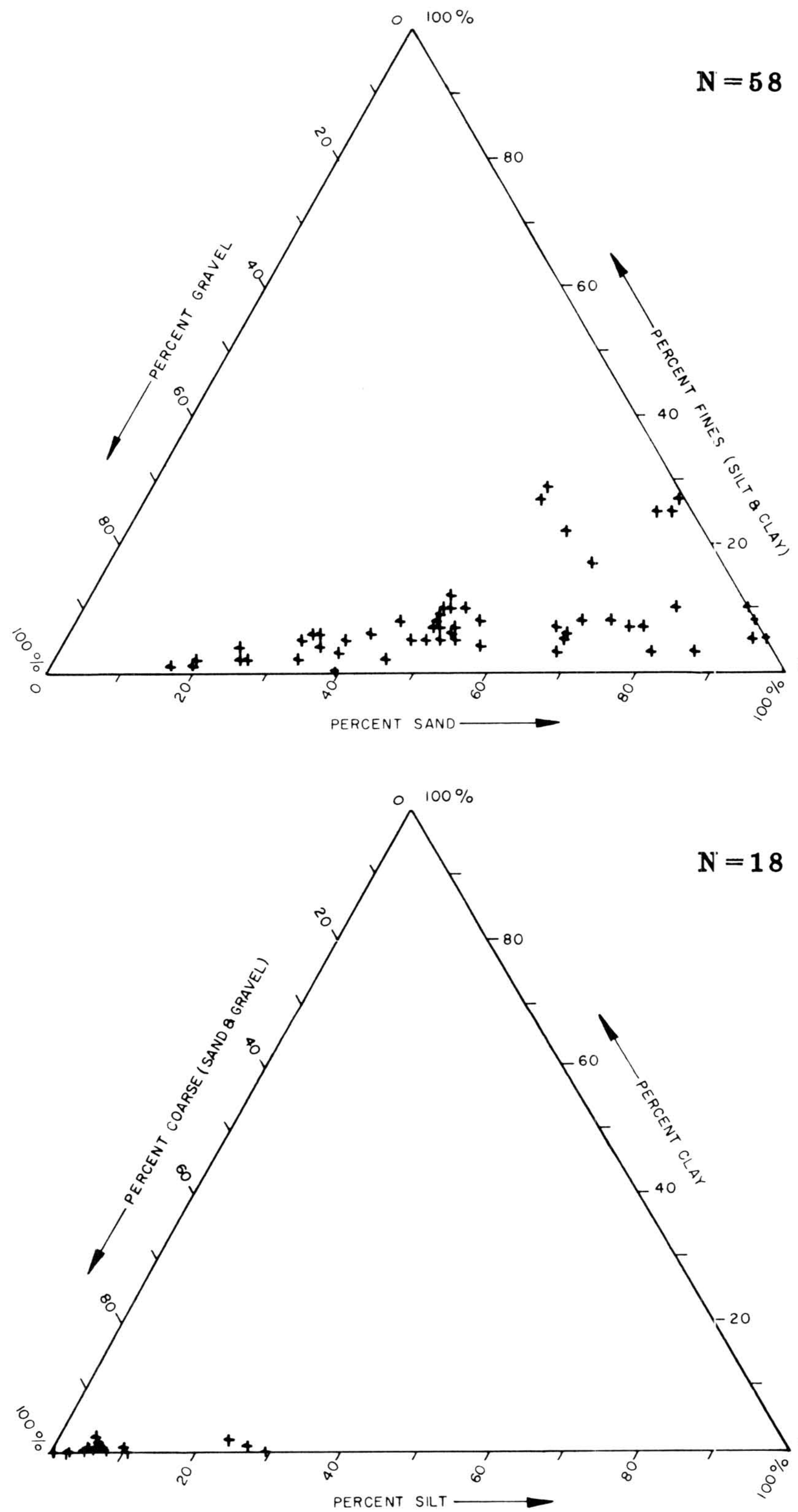
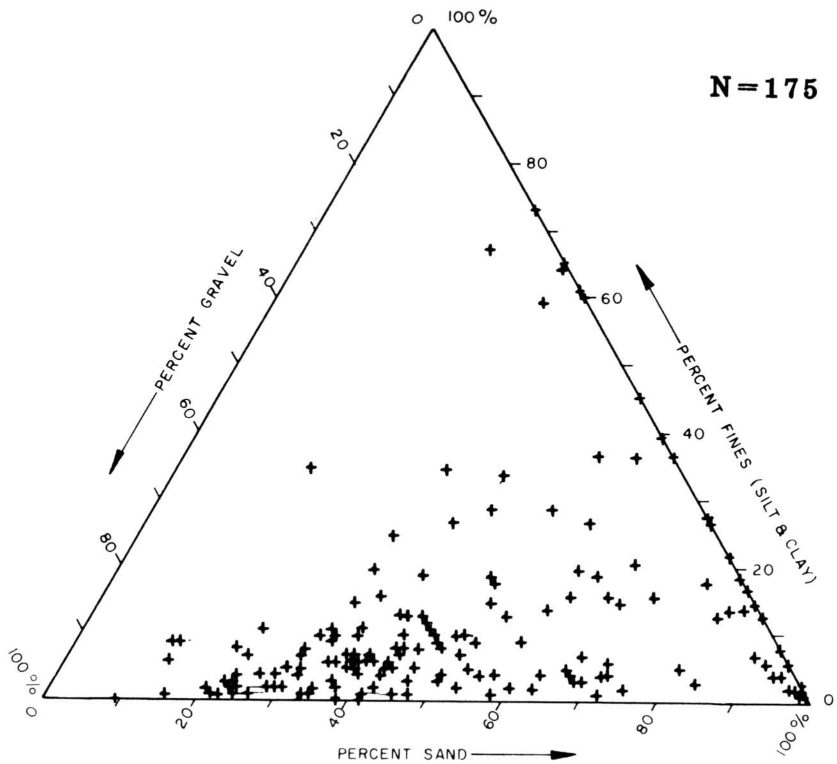


Figure 20. Textural triangle plots of riverbed alluvium [Fp-r] along the TAPS route through the Gulkana Upland and Alaska Range (route segment D, table 5).



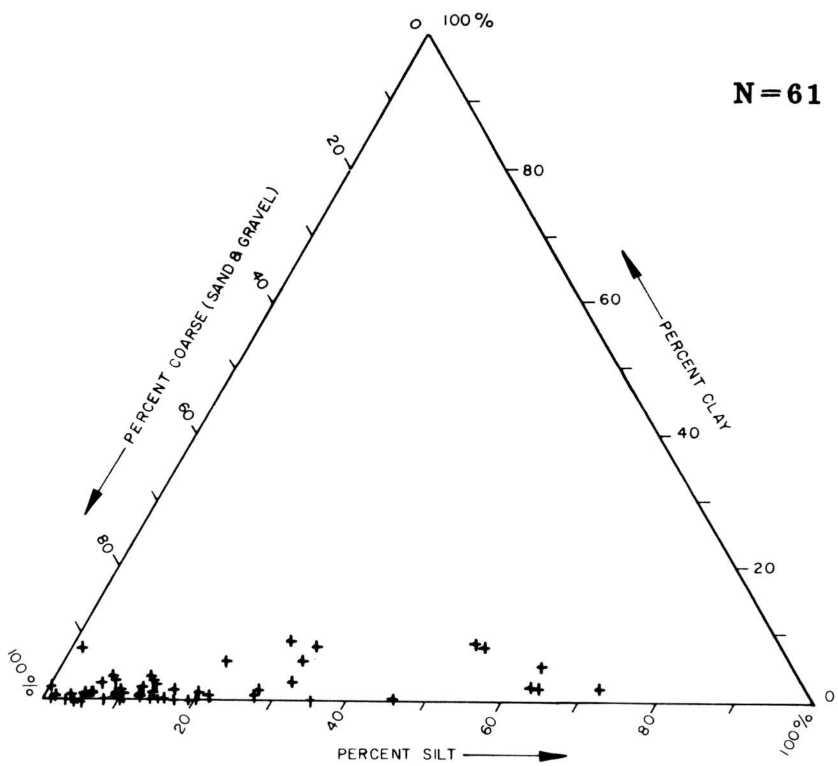


Figure 21. Textural triangle plots of riverbed alluvium [Fp-r] along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5).

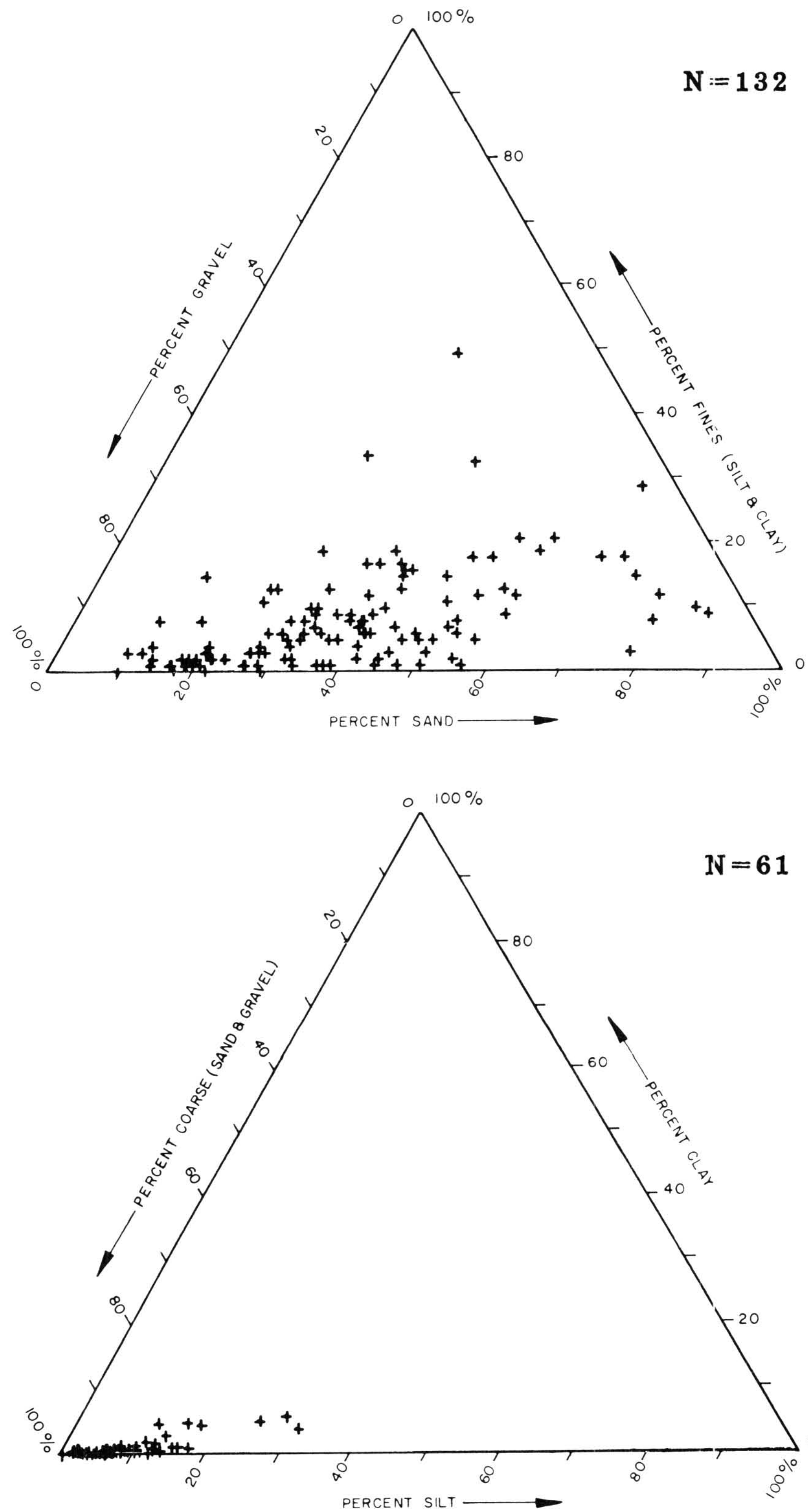
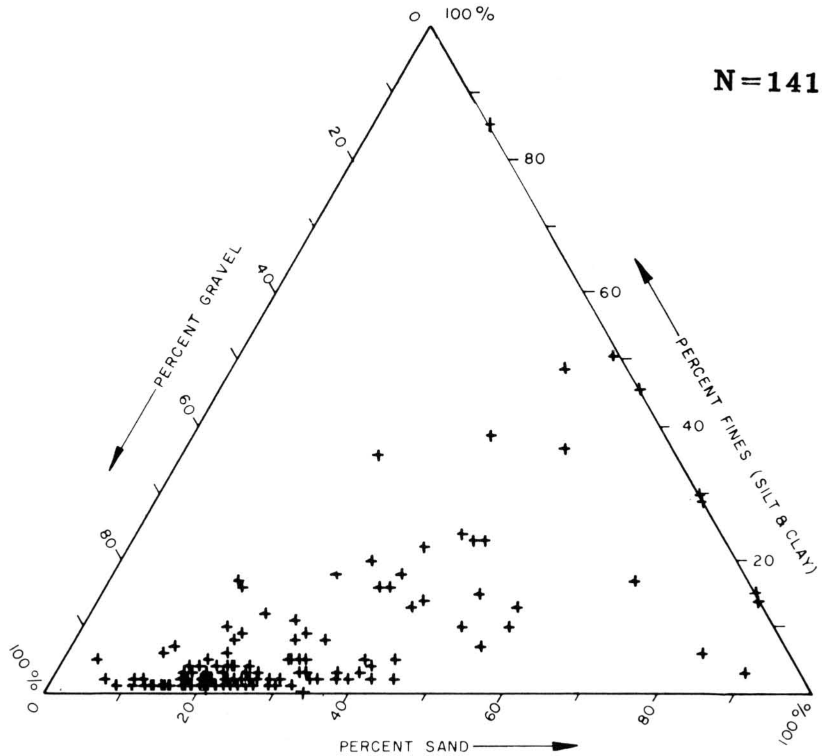


Figure 22. Textural triangle plots of riverbed alluvium [Fp-r] along the TAPS route through the Ambler-Chandalar Ridge and Lowland physiographic unit and Brooks Range (route segments G and H, table 5).



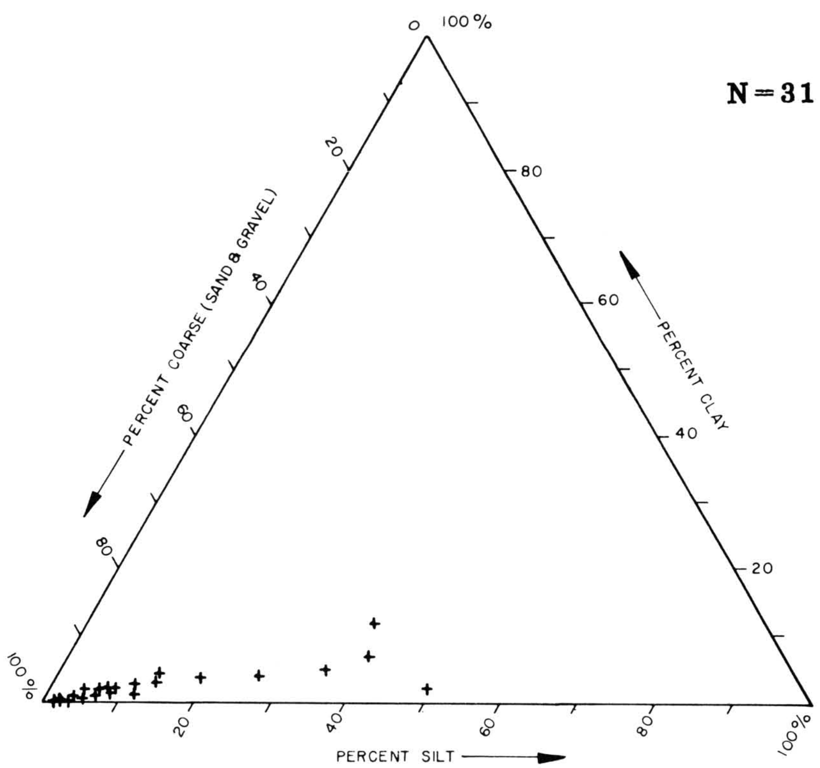


Figure 23. Textural triangle plots of riverbed alluvium [Fp-r] along the TAPS route through the Arctic Foothills and Arctic Coastal Plain (route segments I and J, table 5).

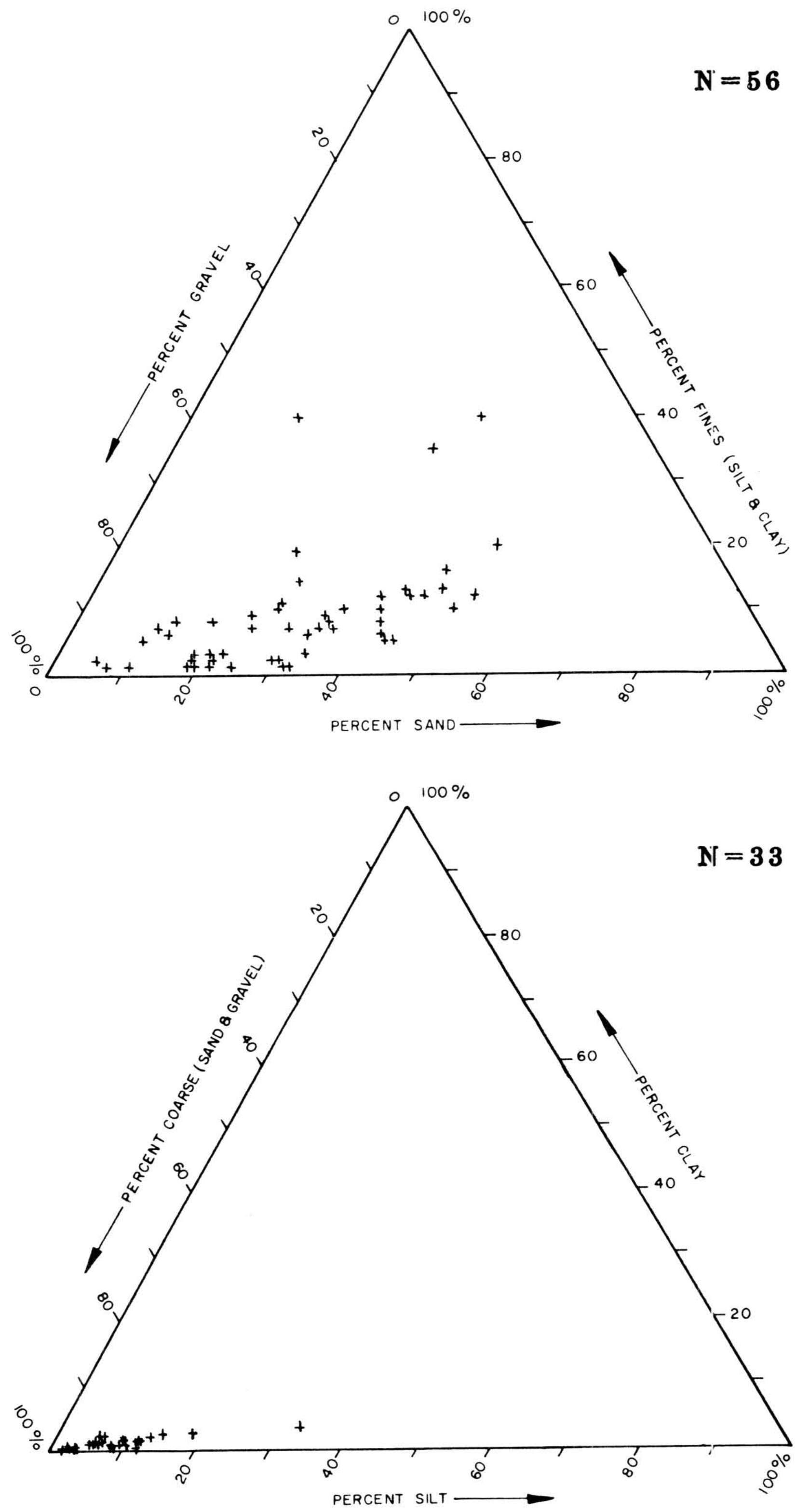


Figure 24. Textural triangle plots of braided flood-plain alluvium [Fpb-r] along the TAPS route through the Ambler-Chandalar Ridge and Lowland physiographic unit and Brooks Range (route segments G and H, table 5).

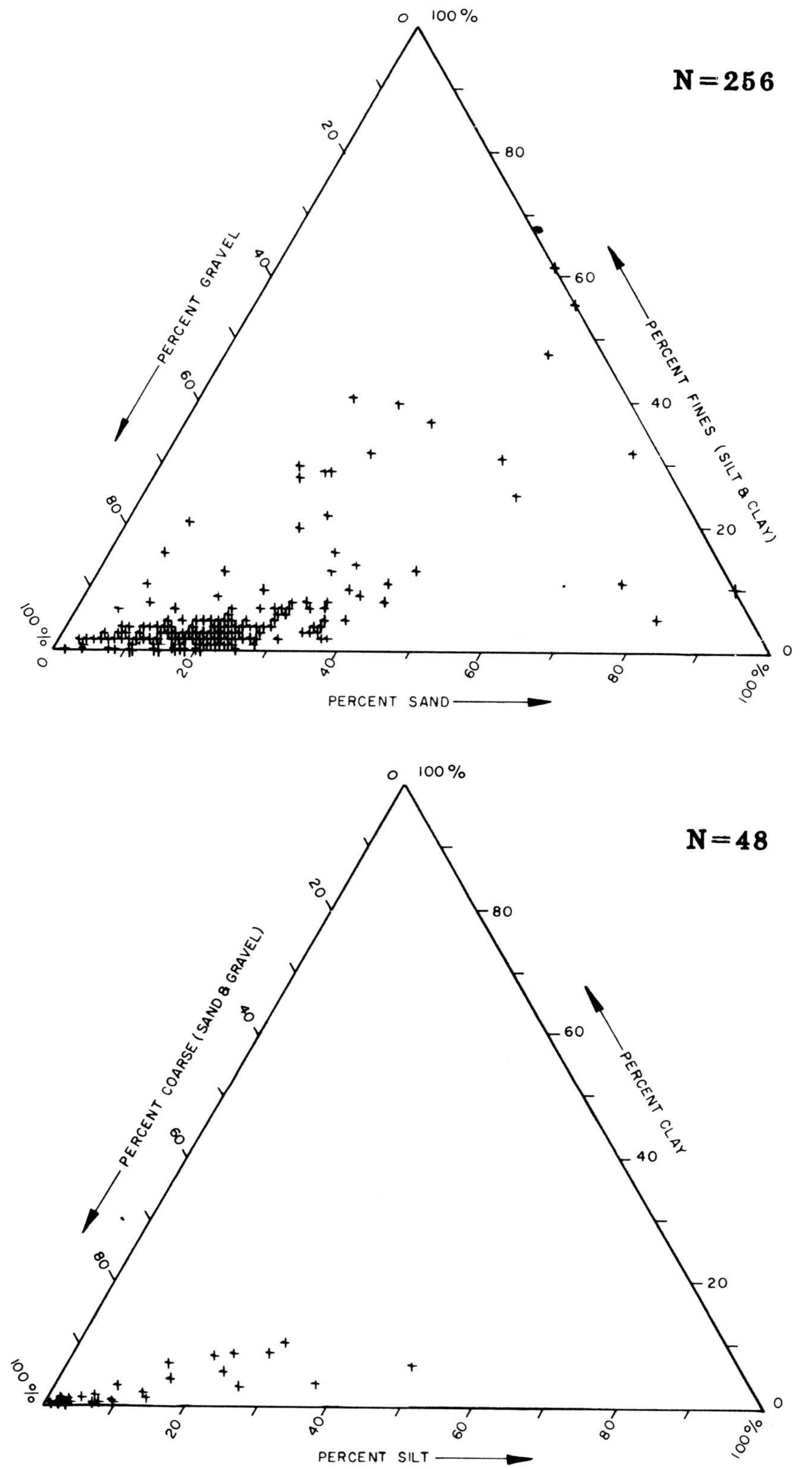


Figure 25. Textural triangle plots of braided flood-plain alluvium [Fpb-r] along the TAPS route through the Arctic Foothills and Arctic Coastal Plain (route segments I and J, table 5).

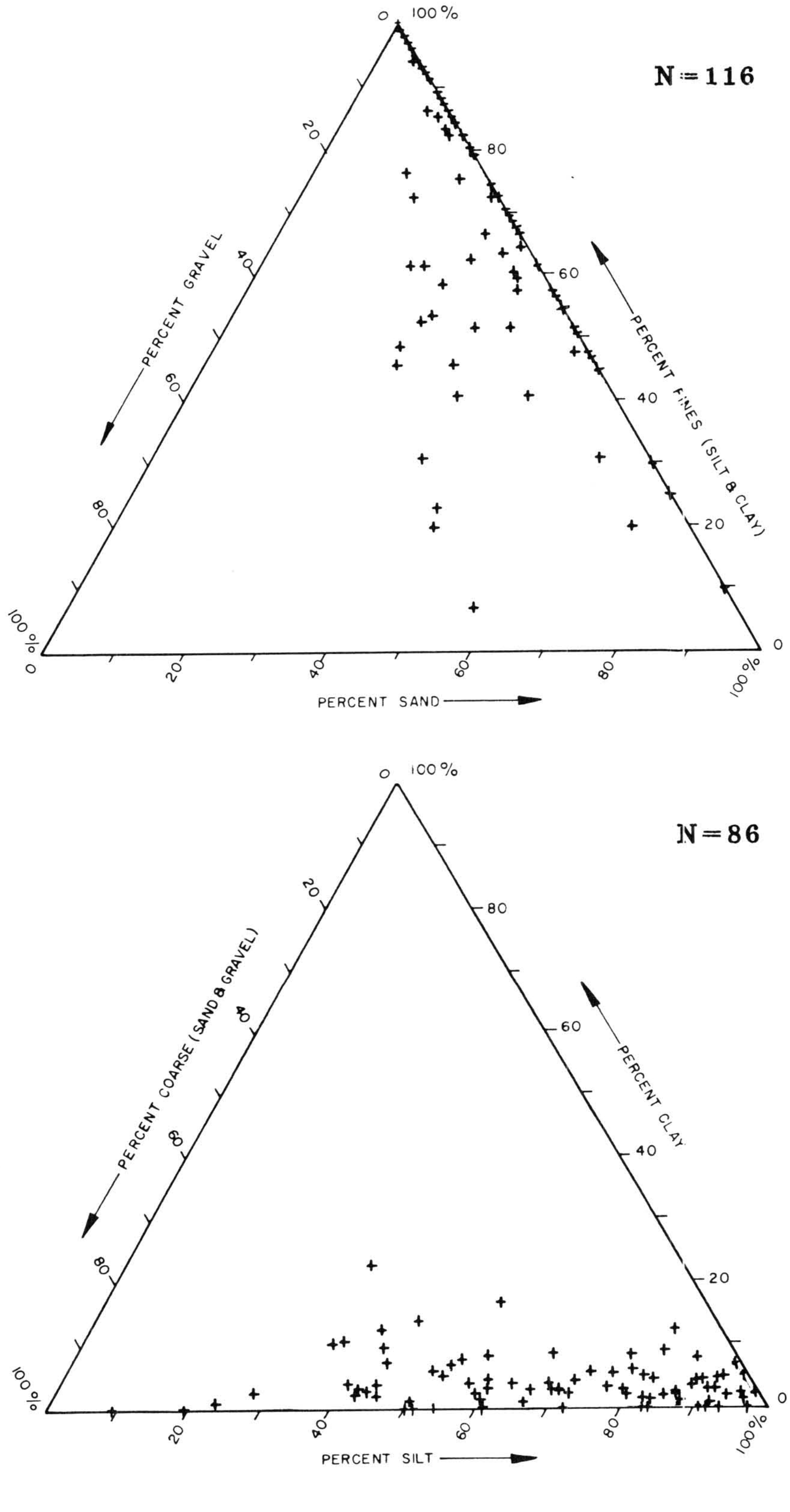


Figure 26. Textural triangle plots of retransported deposits [Fs] along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5).

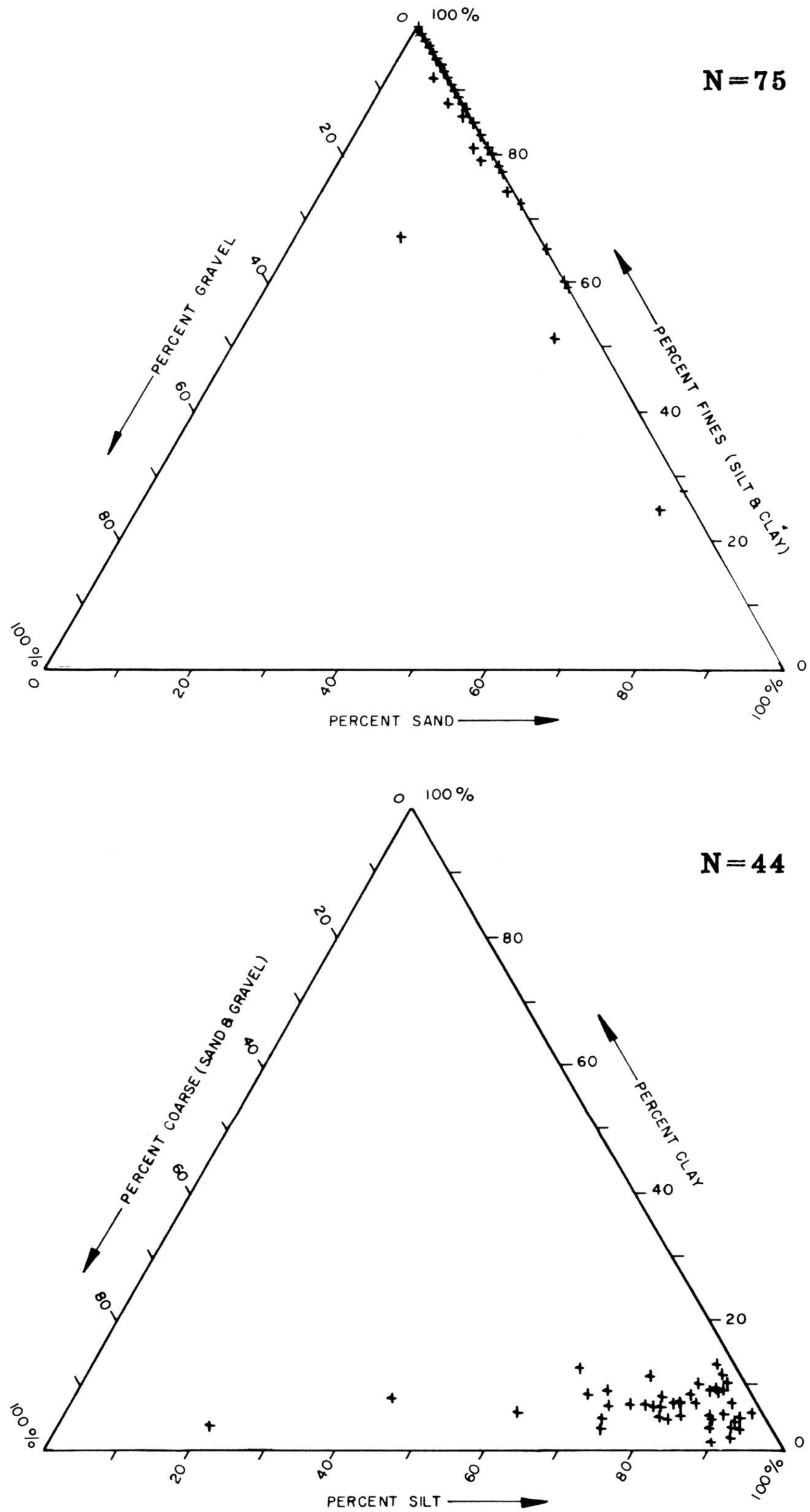


Figure 27. Textural triangle plots of retransported deposits [Fs] along the TAPS route through the central and northern Kokrine-Hodzana Highlands (route segment F, table 5).

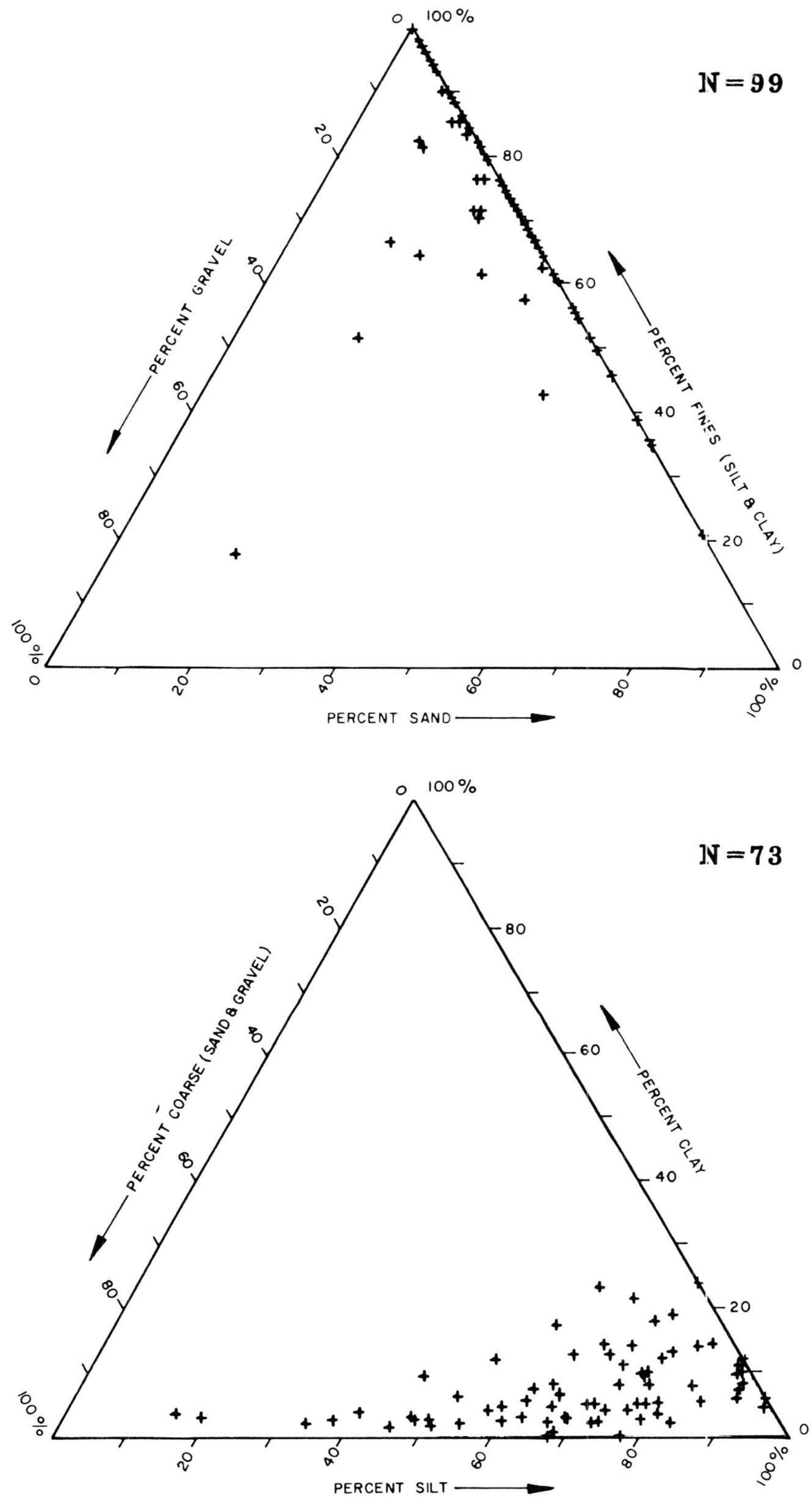
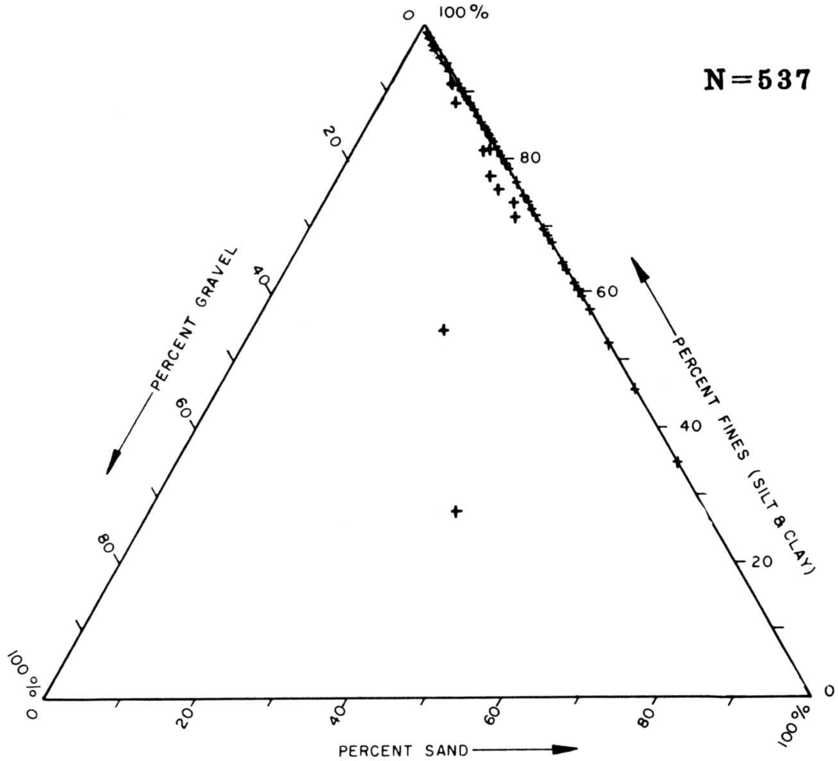


Figure 28. Textural triangle plots of retransported deposits [Fs] along the TAPS route through the Ambler-Chandalar Ridge and Lowland physiographic unit and Brooks Range (route segments G and H, table 5).



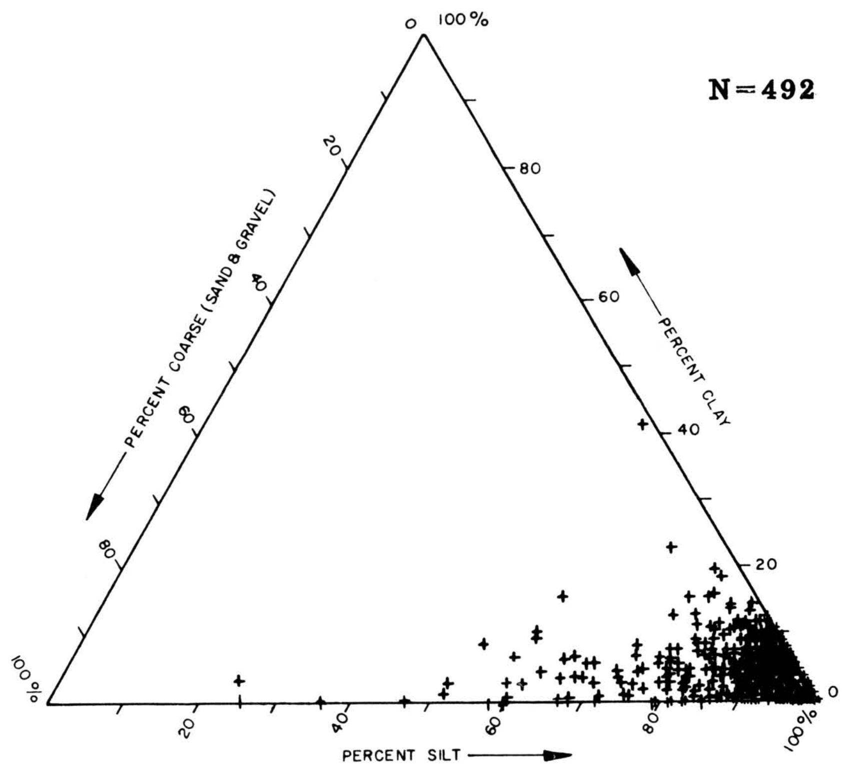
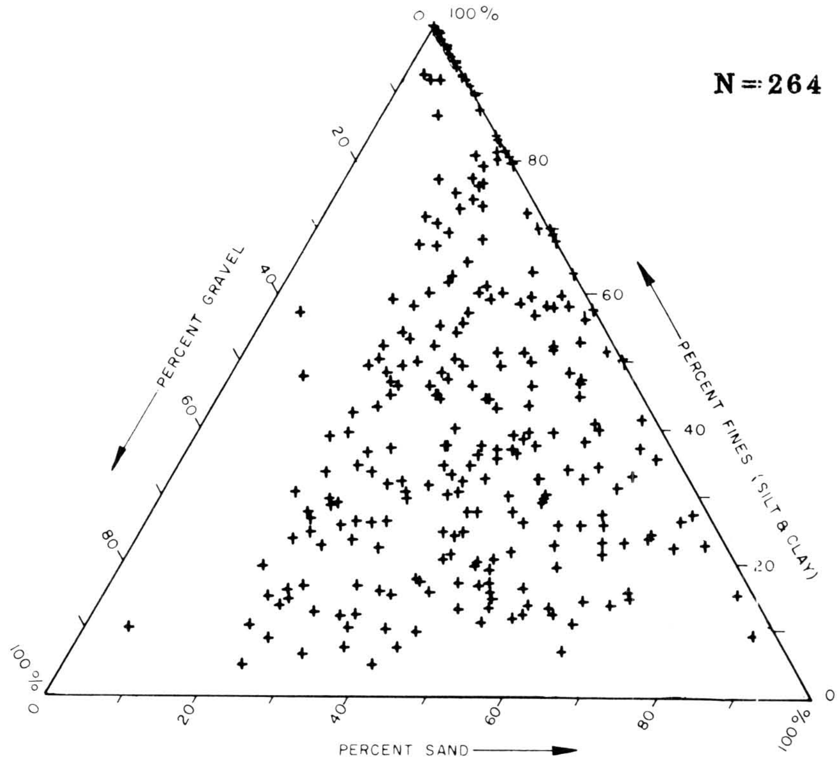


Figure 29. Textural triangle plots of retransported silt [Fss] along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5).



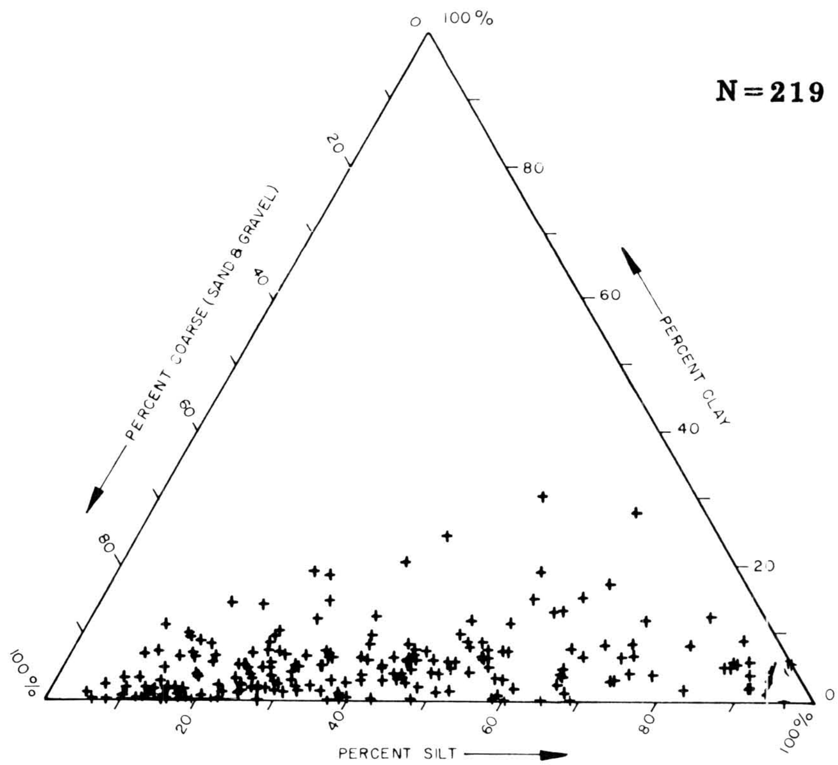
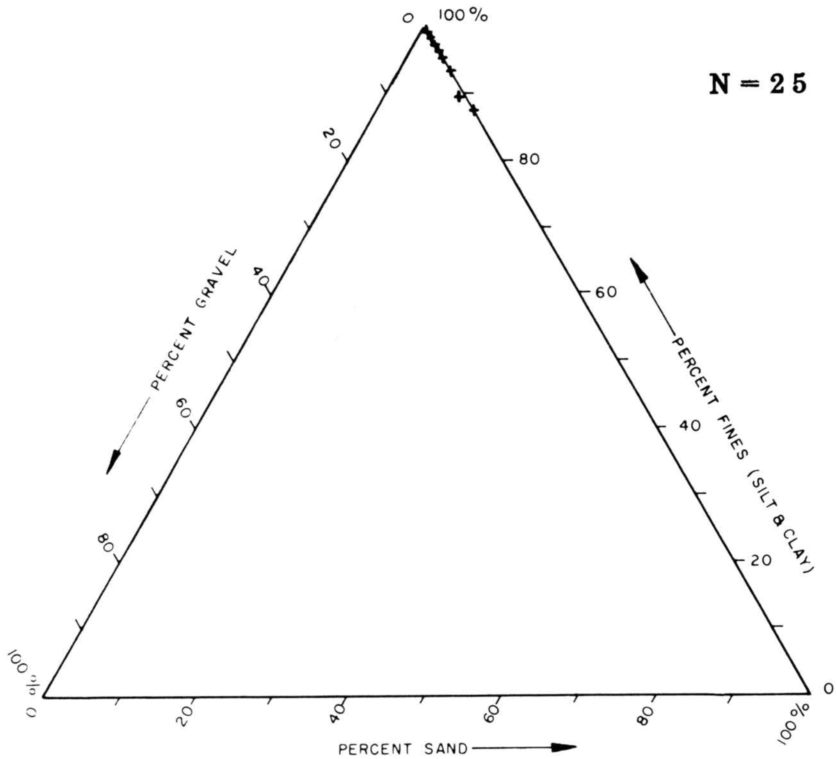


Figure 30. Textural triangle plots of colluvium [C] along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5).



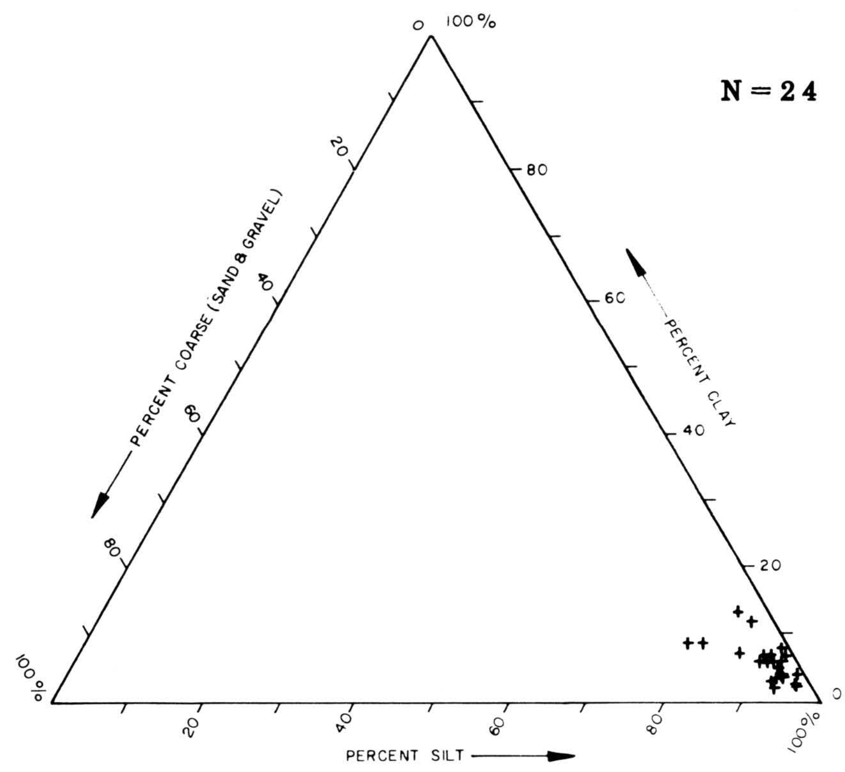


Figure 31. Textural triangle plots of upland loess [Elu] along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5).

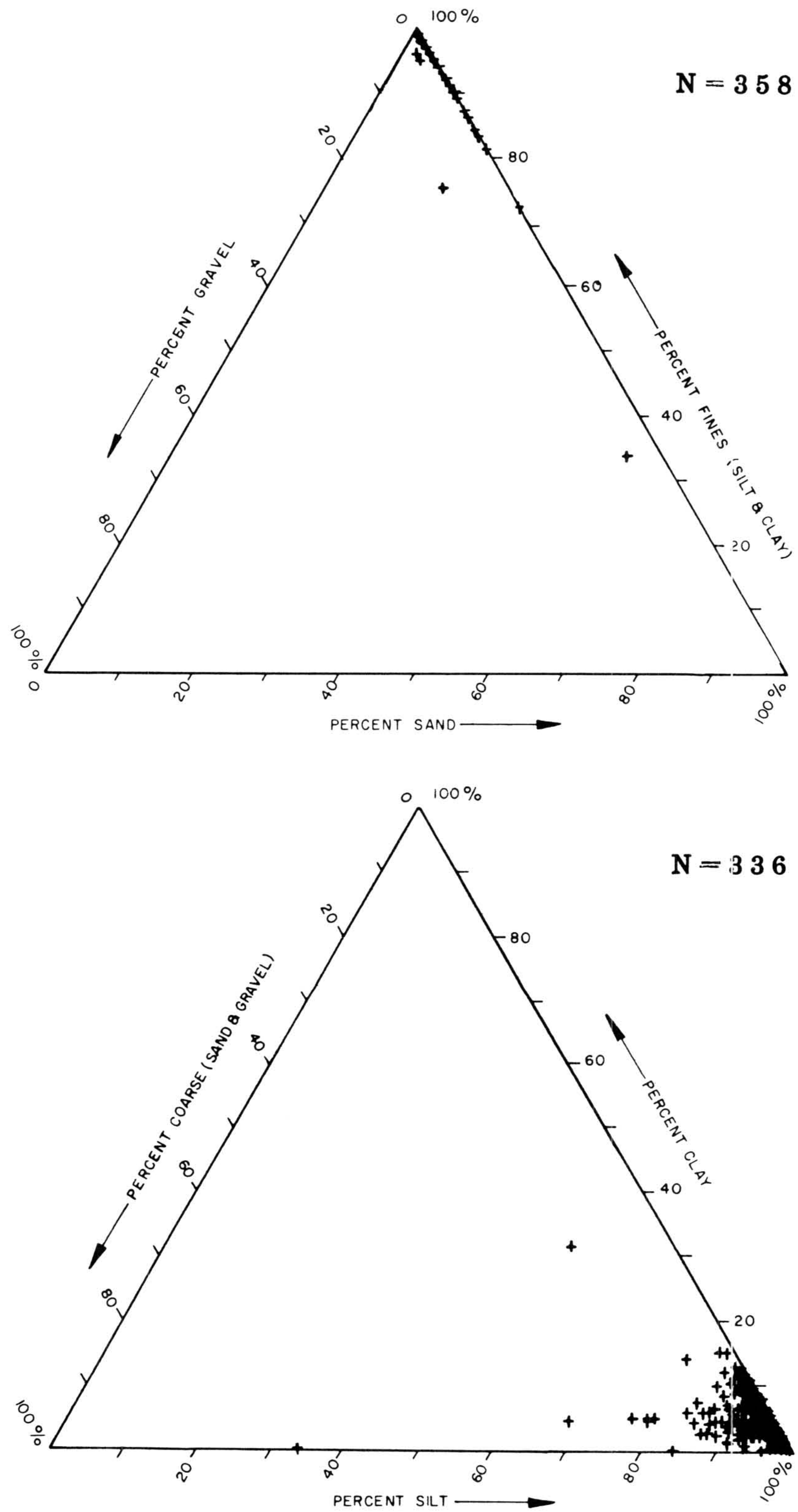
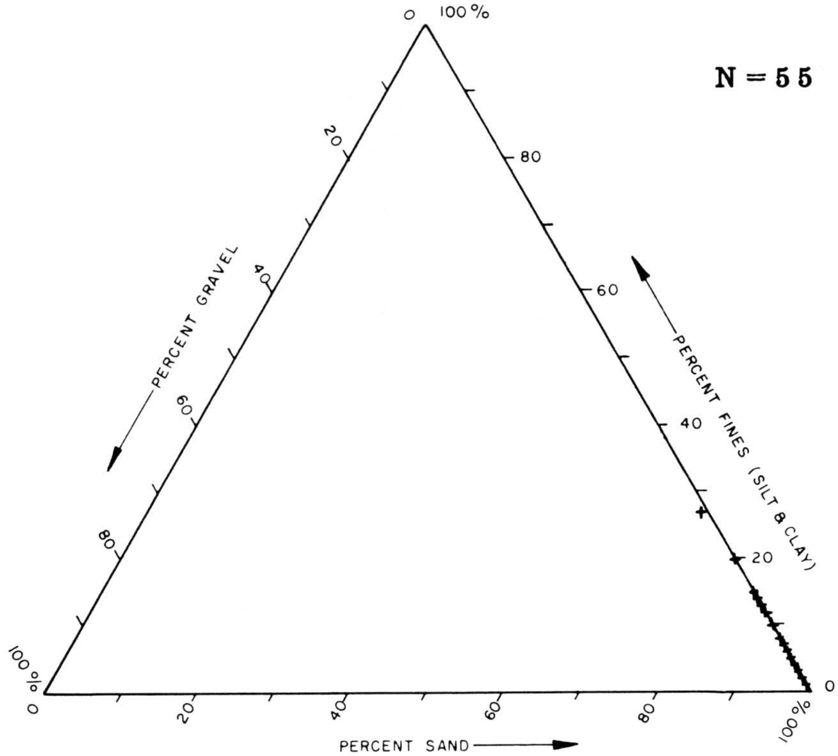


Figure 32. Textural triangle plots of frozen upland loess [Elx] along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5).



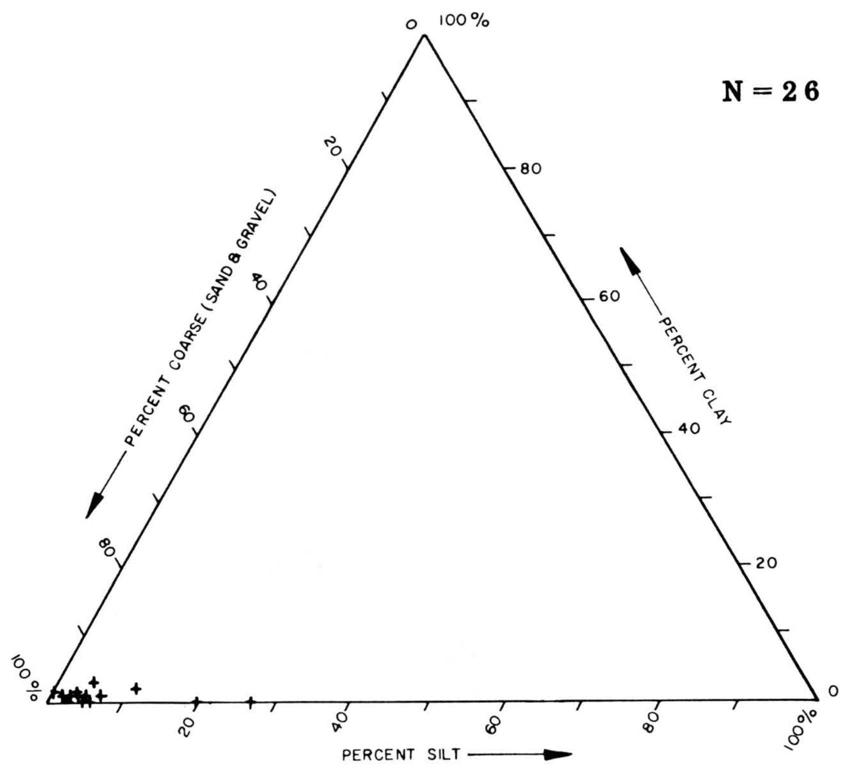


Figure 33. Textural triangle plots of dune sand [Es] along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5).

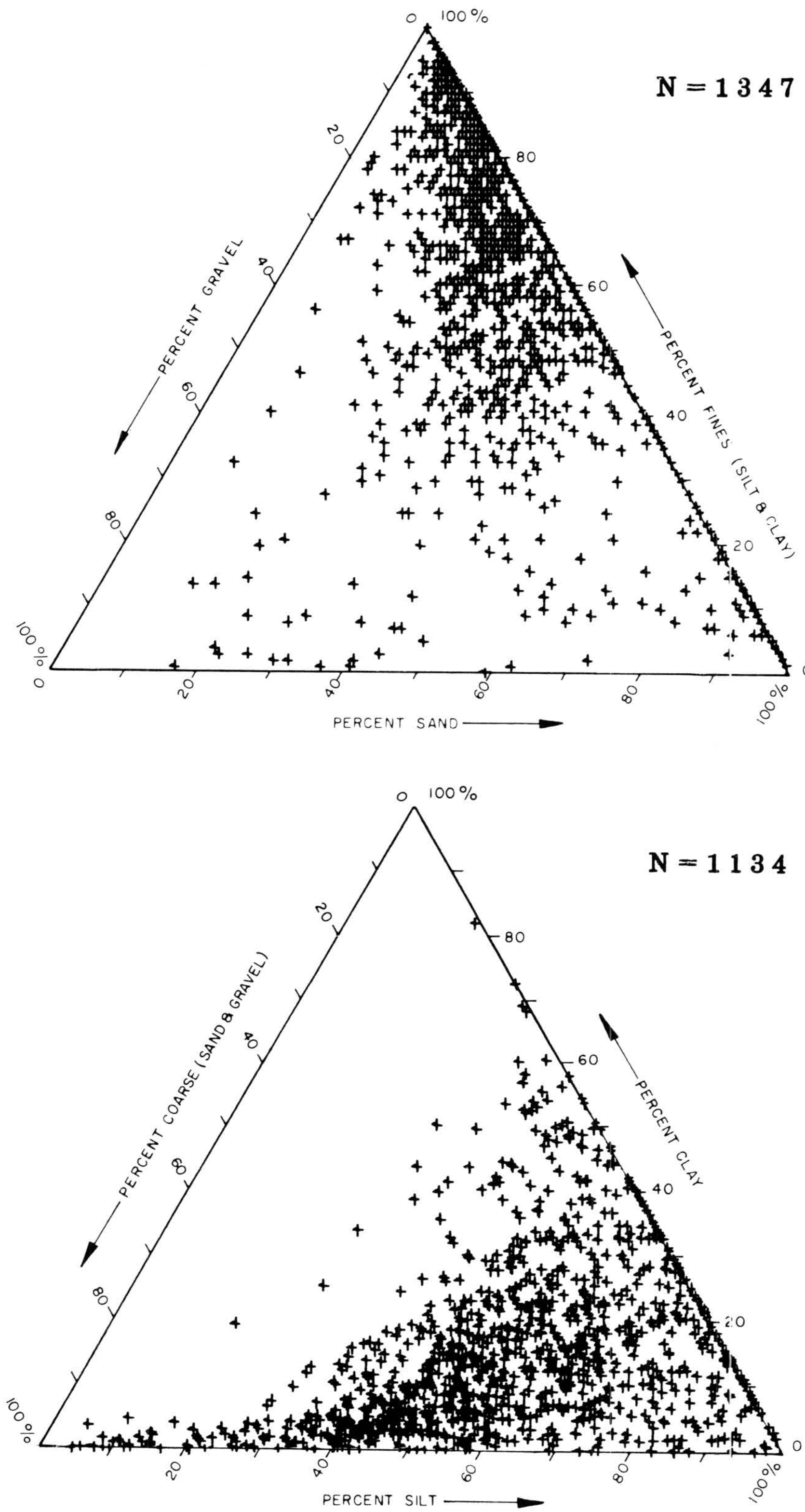
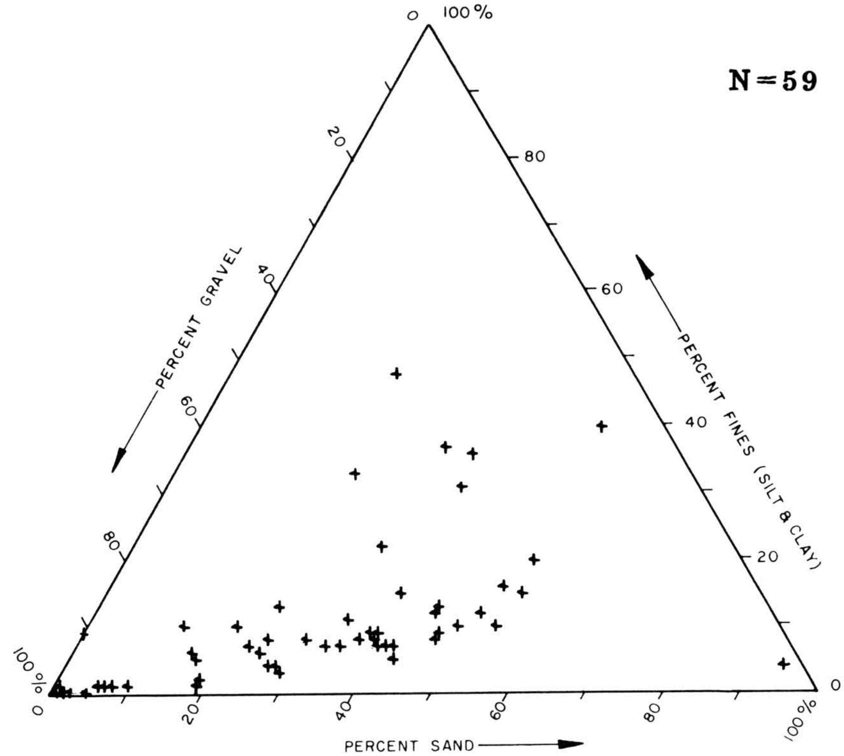


Figure 34. Textural triangle plots of glaciolacustrine deposits [G+L] along the TAPS route through the Copper River Lowland (route segments B and C, table 5).



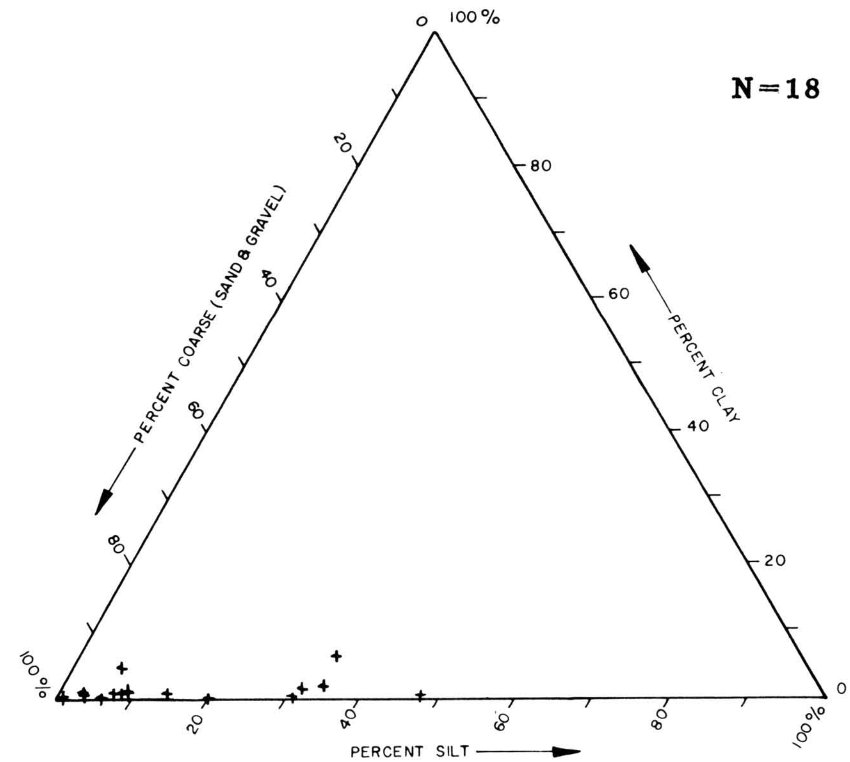


Figure 35. Textural triangle plots of outwash [GFo] along the TAPS route through the Gulkana Upland and Alaska Range (route segment D, table 5).

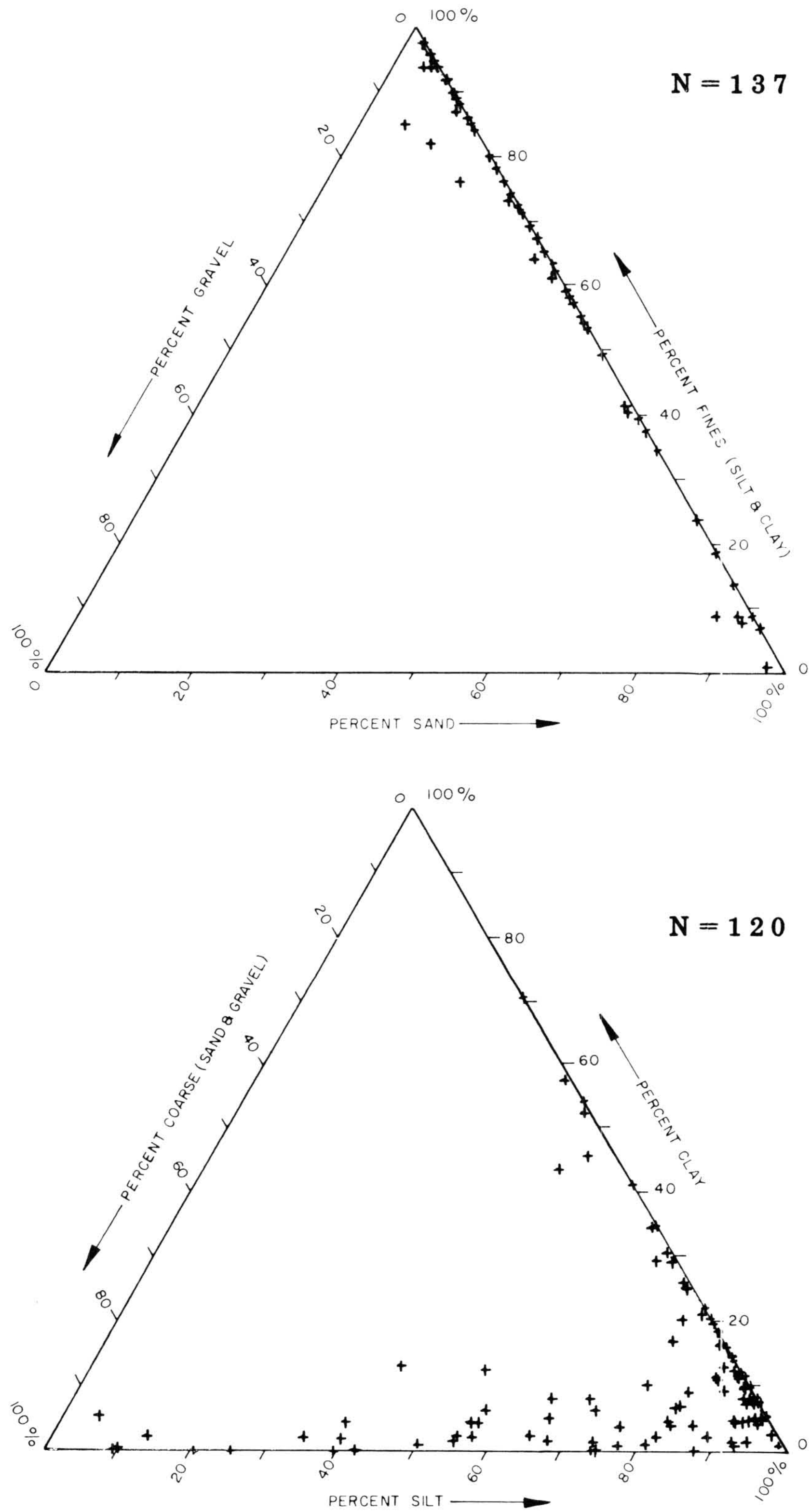
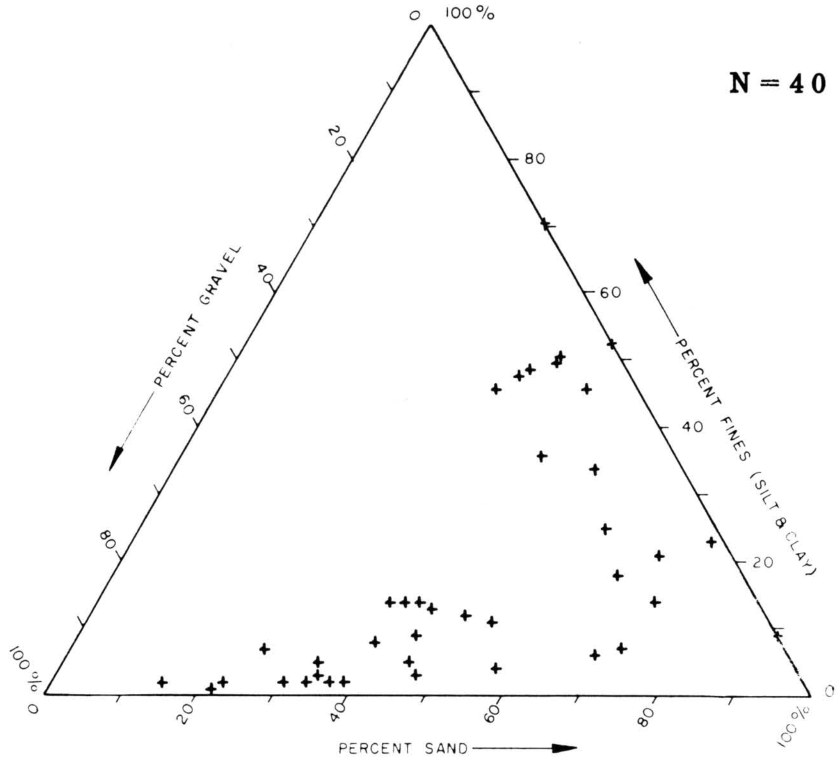


Figure 36. Textural triangle plots of lacustrine deposits [L] along the TAPS route through the Ambler-Chandalar Ridge and Lowland physiographic unit and Brooks Range (route segments G and H, table 5).



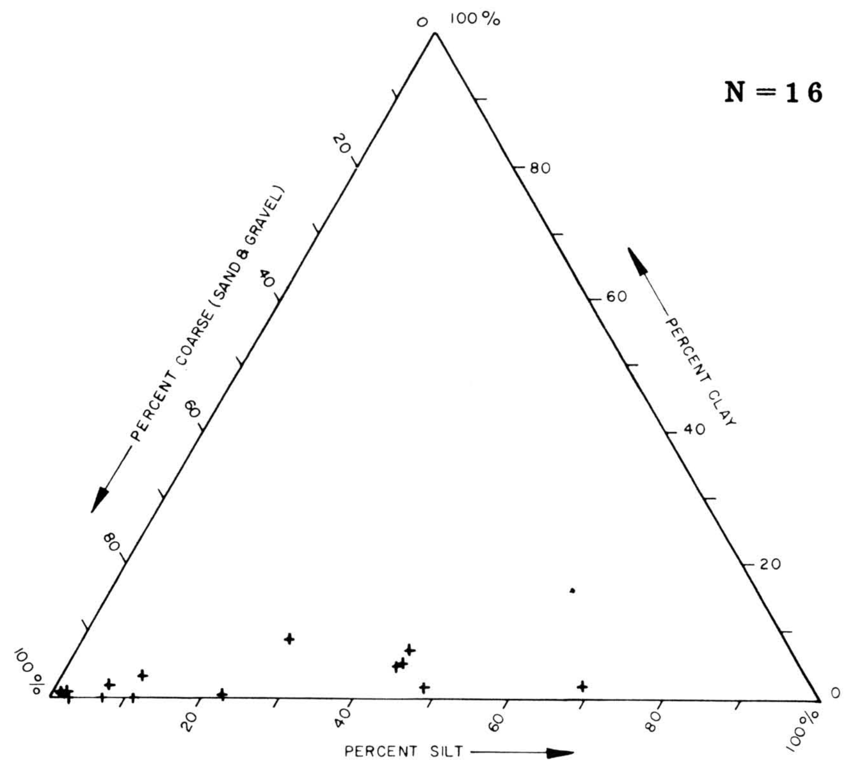


Figure 37. Textural triangle plots of coastal-plain sediments [Mc] along the TAPS route through the Arctic Coastal Plain (route segment J, table 5).

APPENDIX B

Comparisons of the moisture content of landforms along the route of the Trans-Alaska Pipeline System (TAPS)

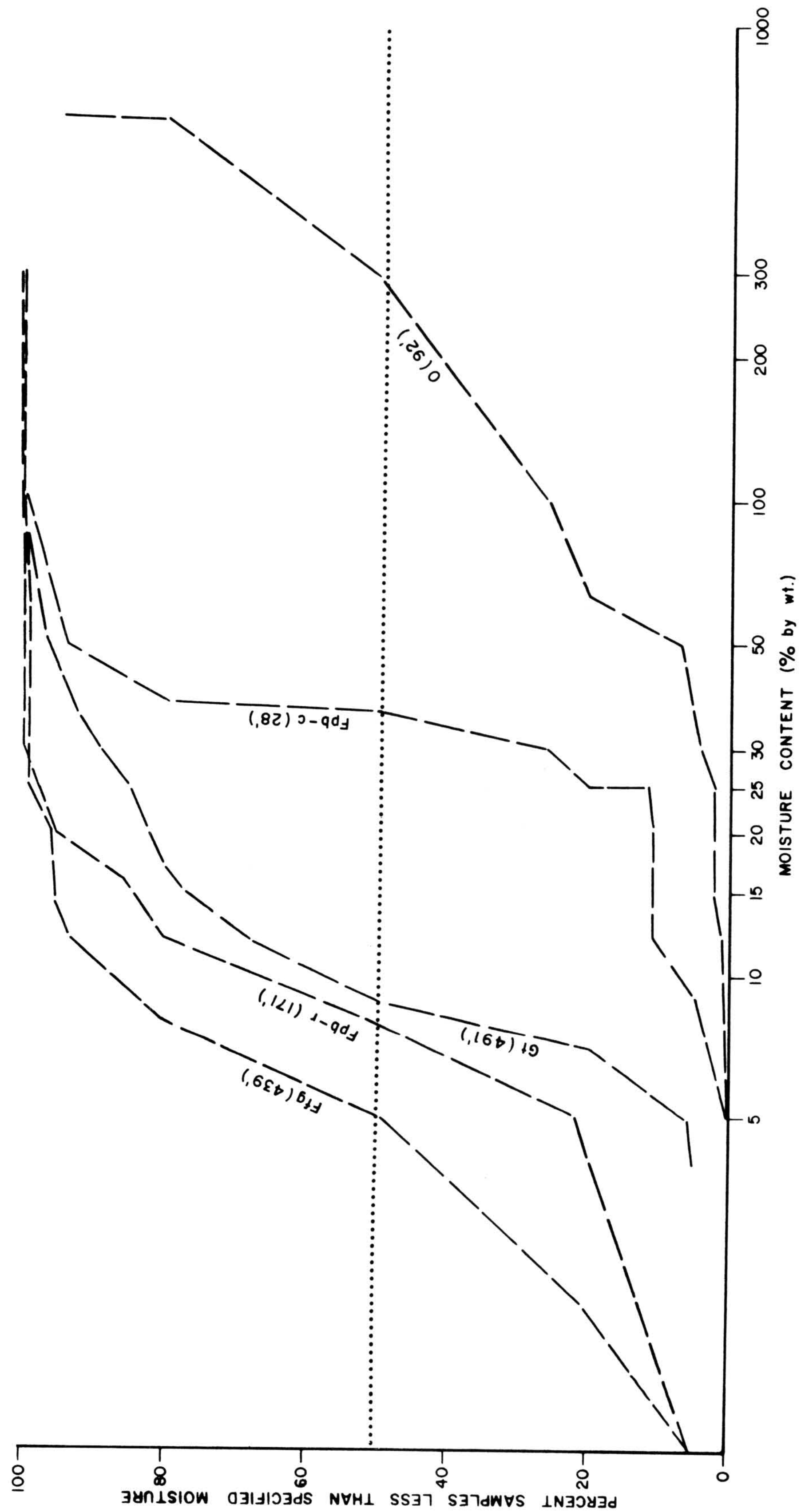


Figure 38. Comparison of the moisture content of five landforms along the TAPS route through the Chugach Mountains (route segment A, table 5); number of feet of test hole drilled in parentheses.

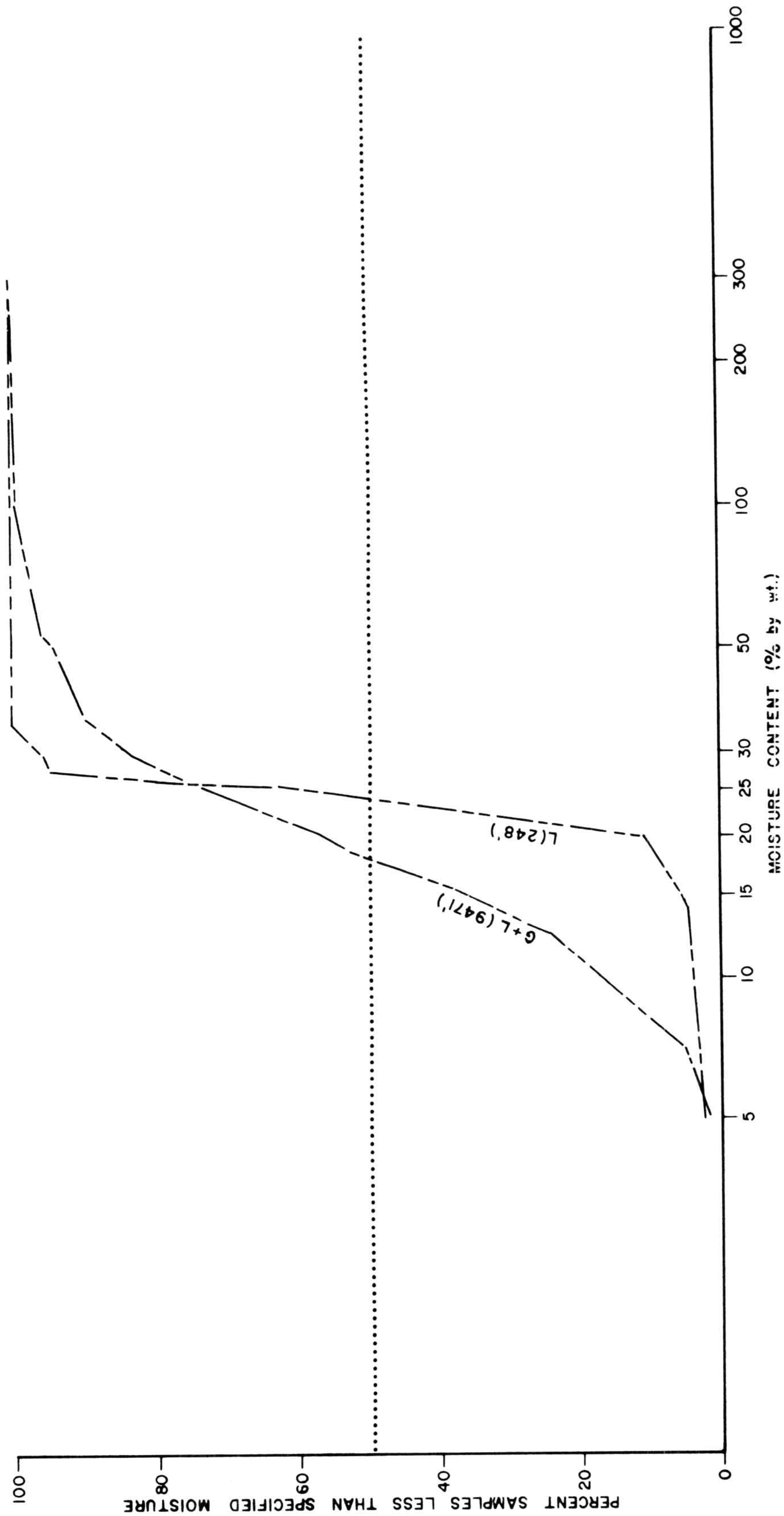


Figure 39. Comparison of the moisture content of glaciolacustrine deposits [G+L] and lacustrine sediments [L] along the TAPS route through the Copper River Lowland (route segments B and C, table 5); number of feet of test hole drilled in parentheses.

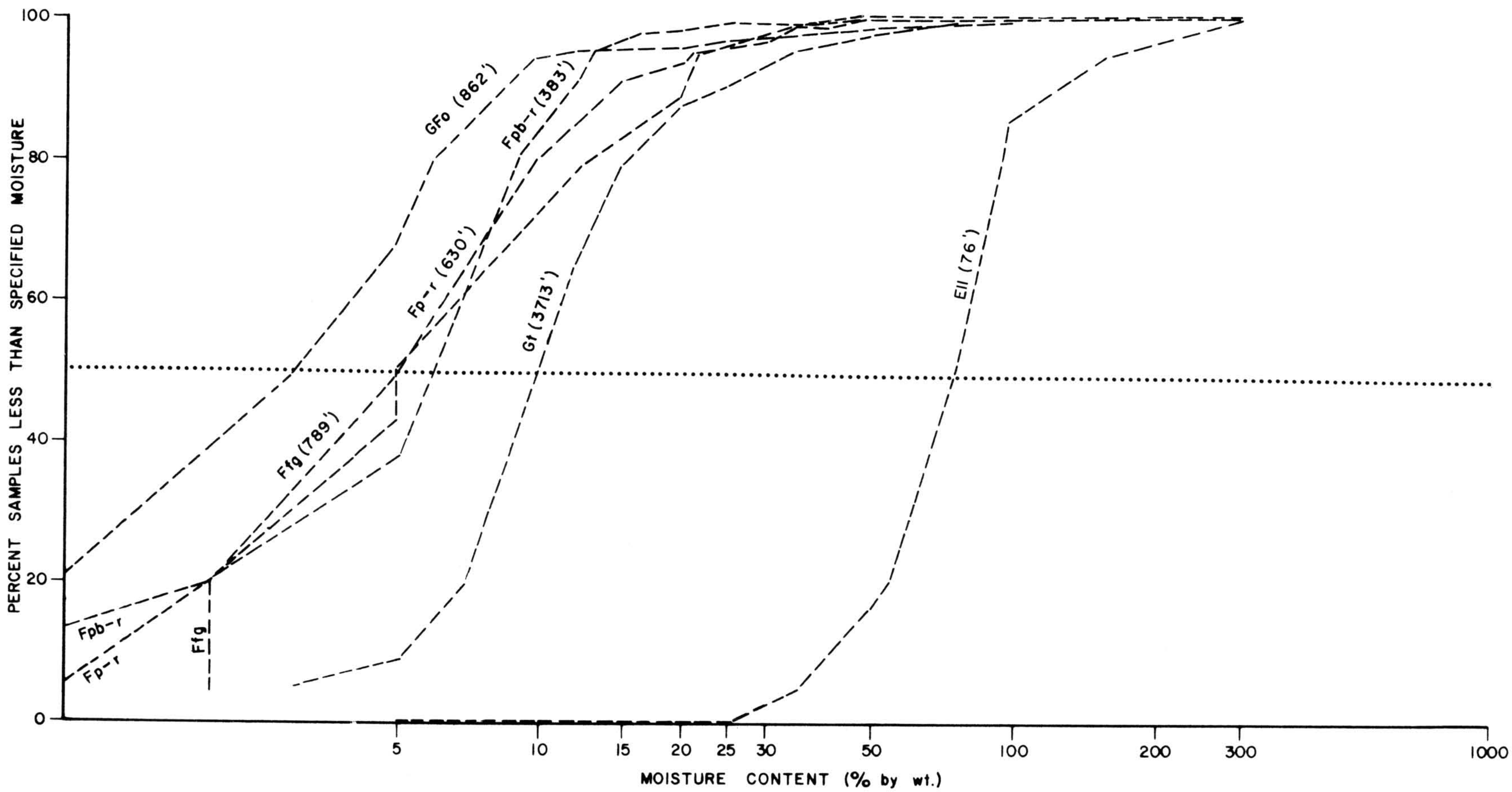


Figure 40. Comparison of the moisture content of six landforms along the TAPS route through the Gulkana Upland and Alaska Range (route segment D, table 5); number of feet of test hole drilled in parentheses.

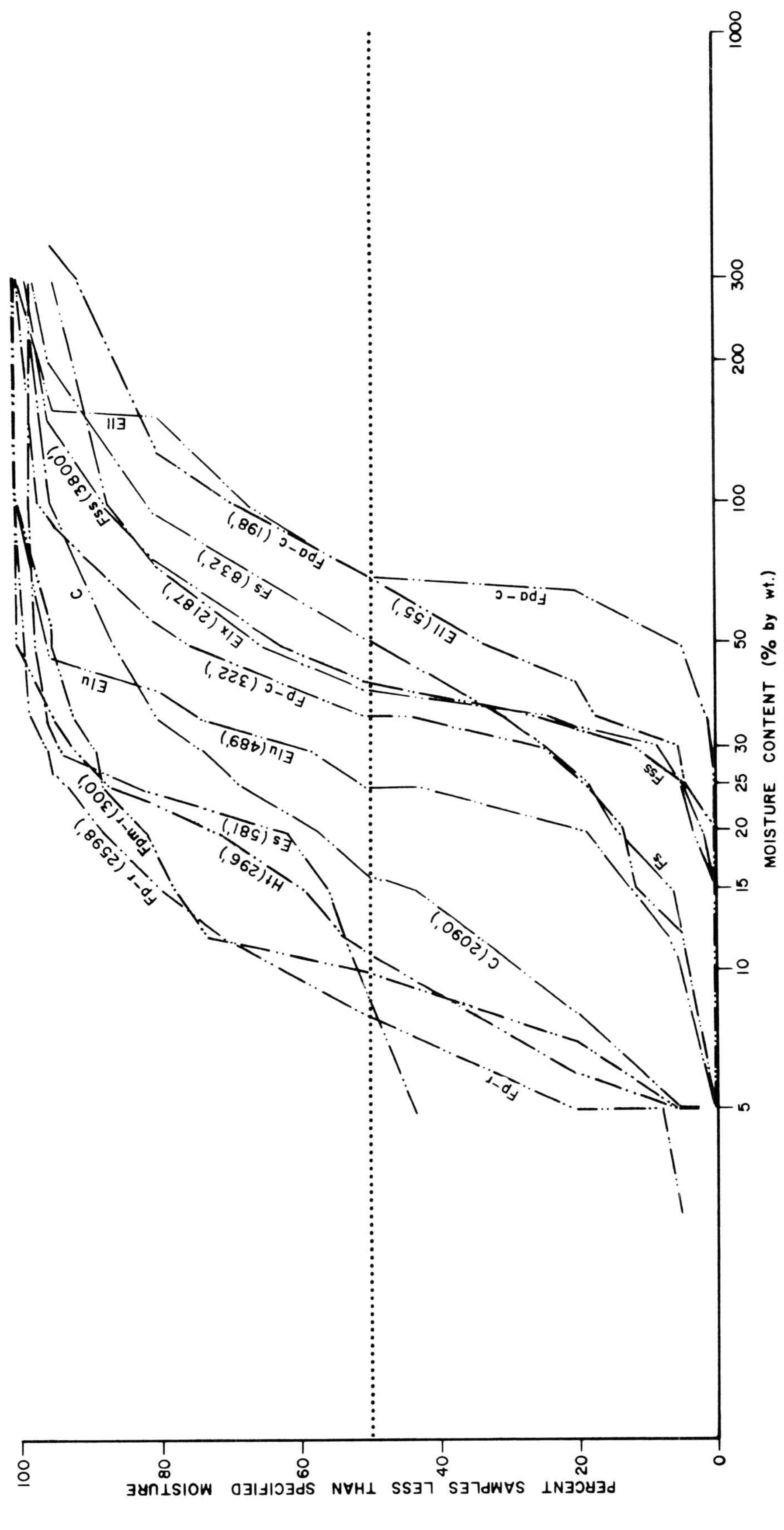


Figure 41. Comparison of the moisture content of 12 landforms along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5); number of feet of test hole drilled in parentheses.

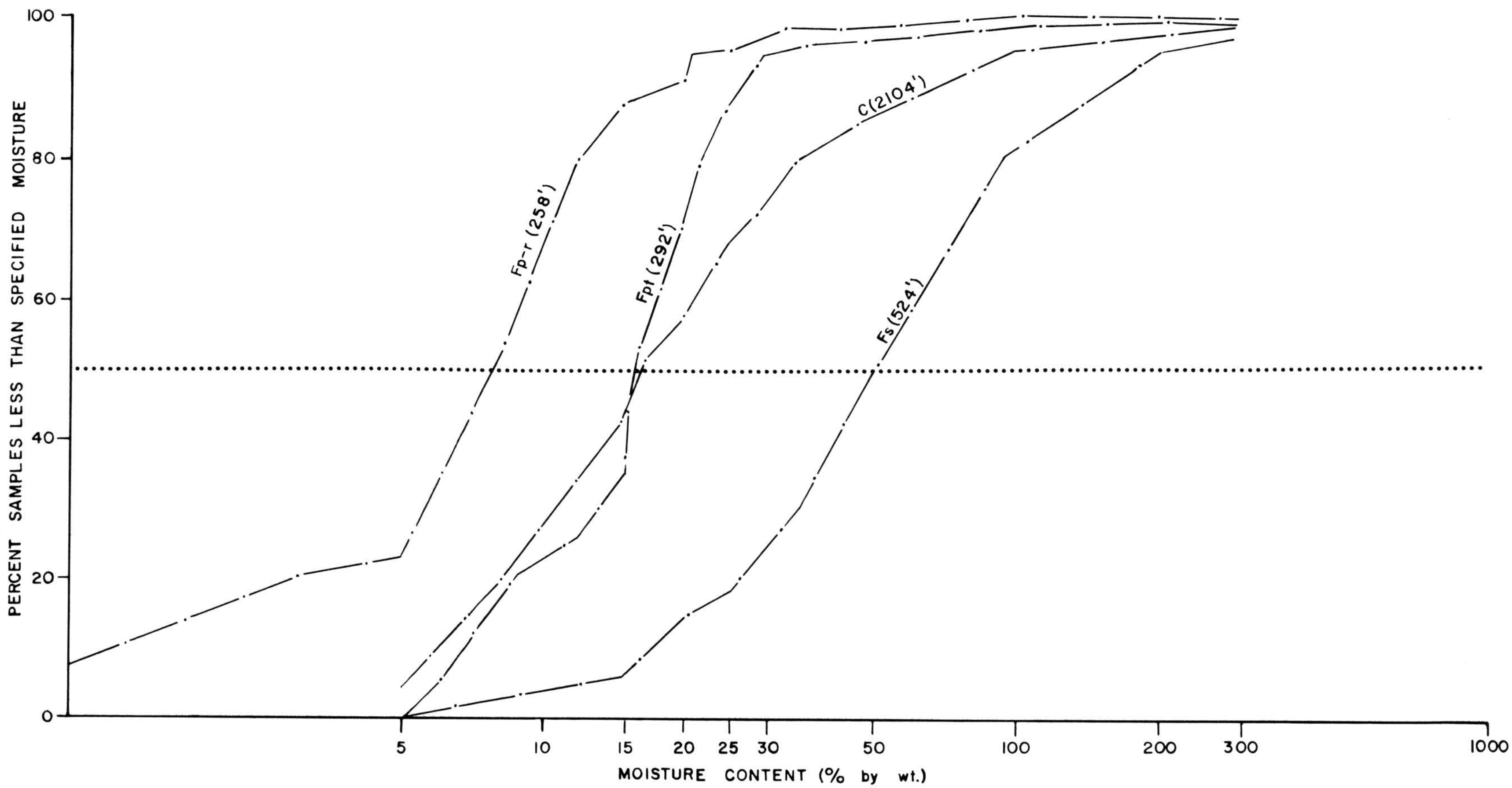


Figure 42. Comparison of the moisture content of four landforms along the TAPS route through the central and northern Kokrine-Hodzana Highlands (route segment F, table 5); number of feet of test hole drilled in parentheses.

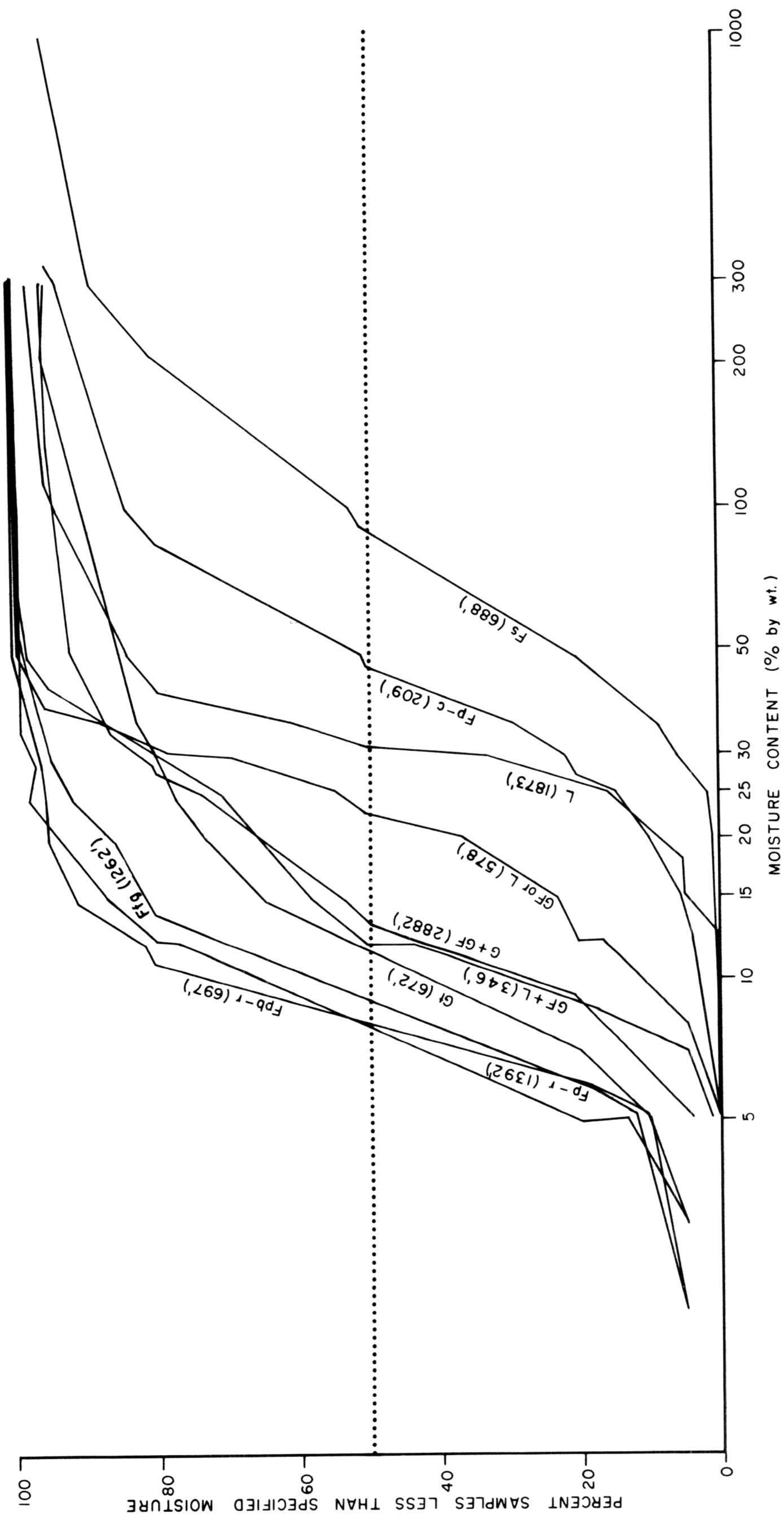


Figure 43. Comparison of the moisture content of 10 individual and composite landforms along the TAPS route through the Ambler-Chandalar Ridge and Lowland physiographic unit and Brooks Range (route segments G and H, table 5); number of feet of test hole drilled in parentheses.

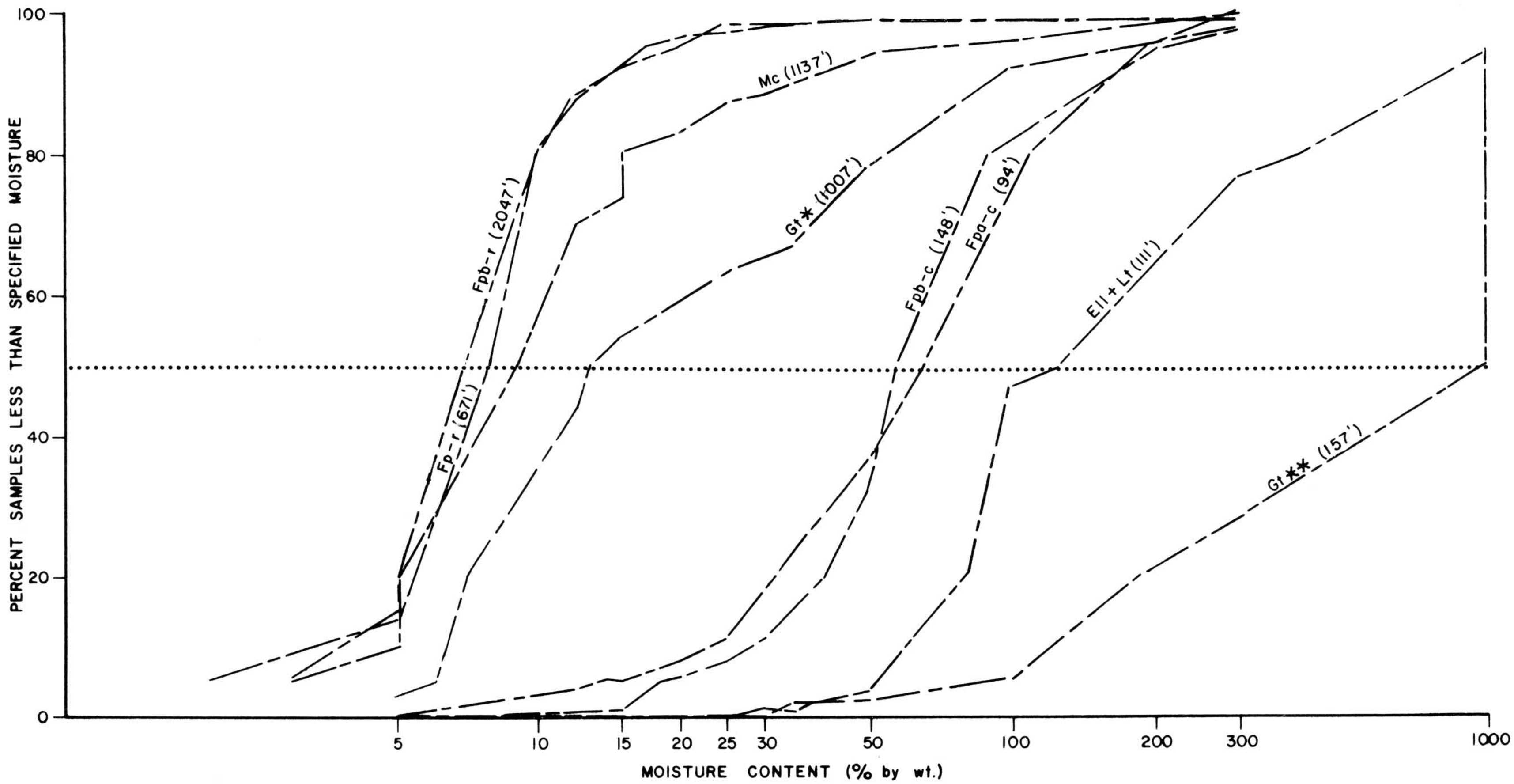


Figure 44. Comparison of the moisture content of eight individual and composite landforms along the TAPS route through the Arctic Foothills and Arctic Coastal Plain (route segments I and J, table 5); number of feet of test hole drilled in parentheses. *Itkillik Till of late Wisconsin age (Hamilton and Porter, 1975). **Upper 20 ft of mid-Pleistocene(?) till (Sagavanirktok Glaciation of Detterman and others, 1958, or Sagavanirktok River Glaciation of Hamilton, 1978b, 1978c.

APPENDIX C

Comparison of the thaw strain in 12 landforms in several route segments of the Trans-Alaska Pipeline System (TAPS)

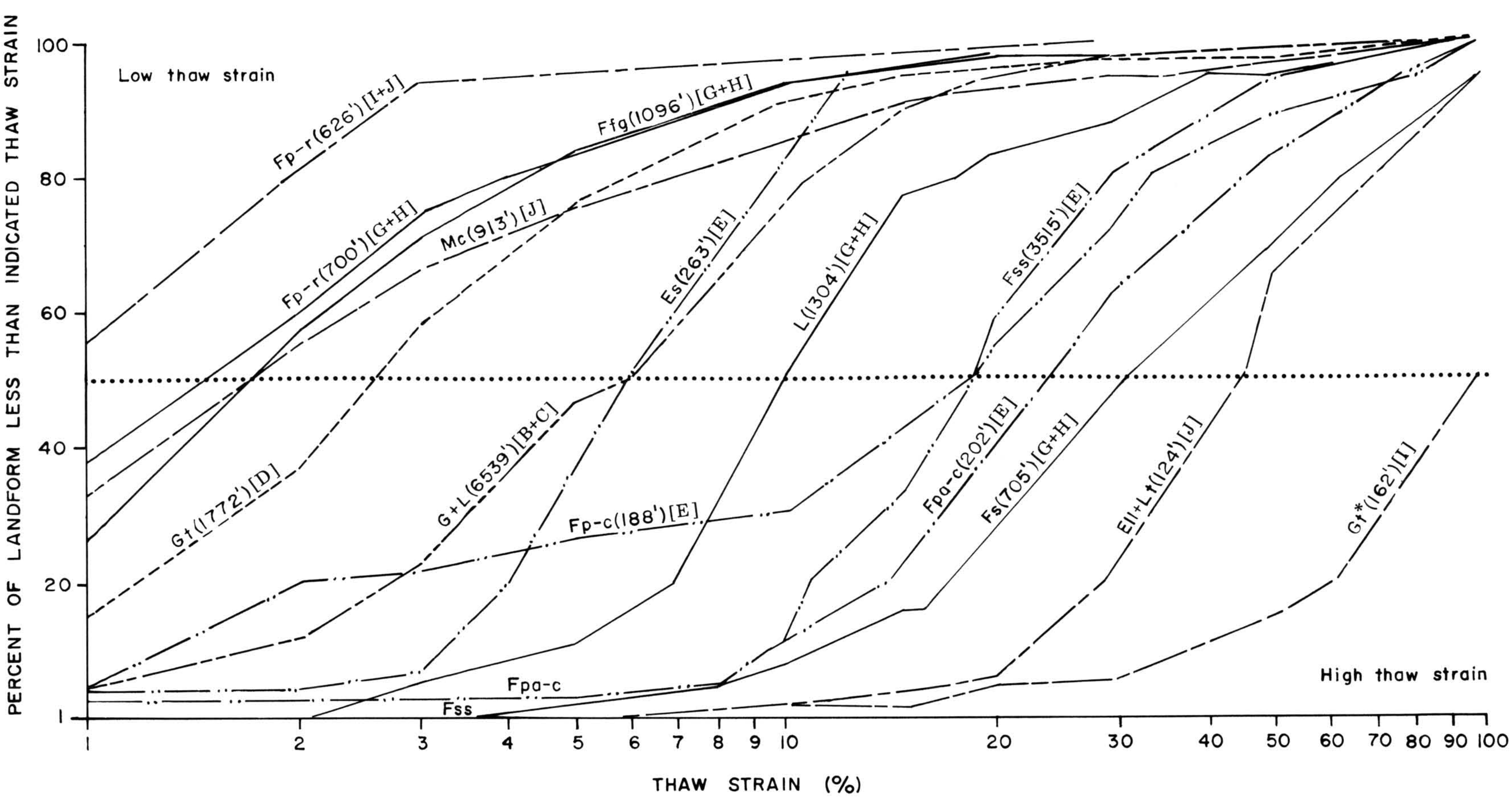


Figure 45. Comparison of the thaw strain in 12 landforms in several segments of the TAPS route; segments (table 5) in brackets, number of feet of test hole drilled in parentheses. *Ice- and organic-rich sediments comprising upper 20 ft of mid-Pleistocene(?) till of Sagavanirktok Glaciation (Detterman and others, 1958; Sagavanirktok River Glaciation of Hamilton, 1978b, 1978c).

APPENDIX D

Comparisons of the dry density of landforms along the route of the Trans-Alaska Pipeline System (TAPS)

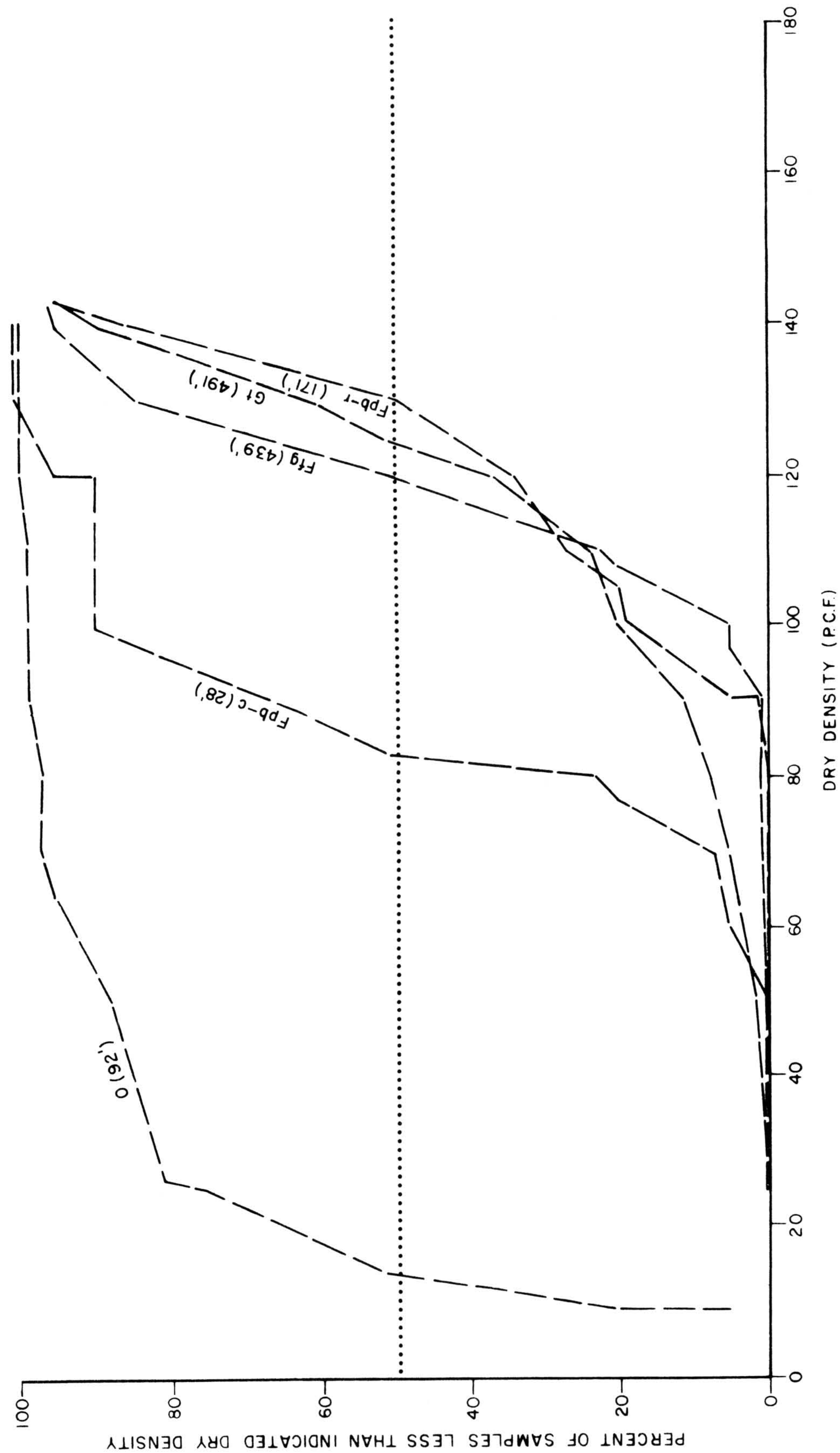


Figure 46. Comparison of the dry density of five landforms along the TAPS route through the Chugach Mountains (route segment A, table 5); number of feet of test hole drilled in parentheses.

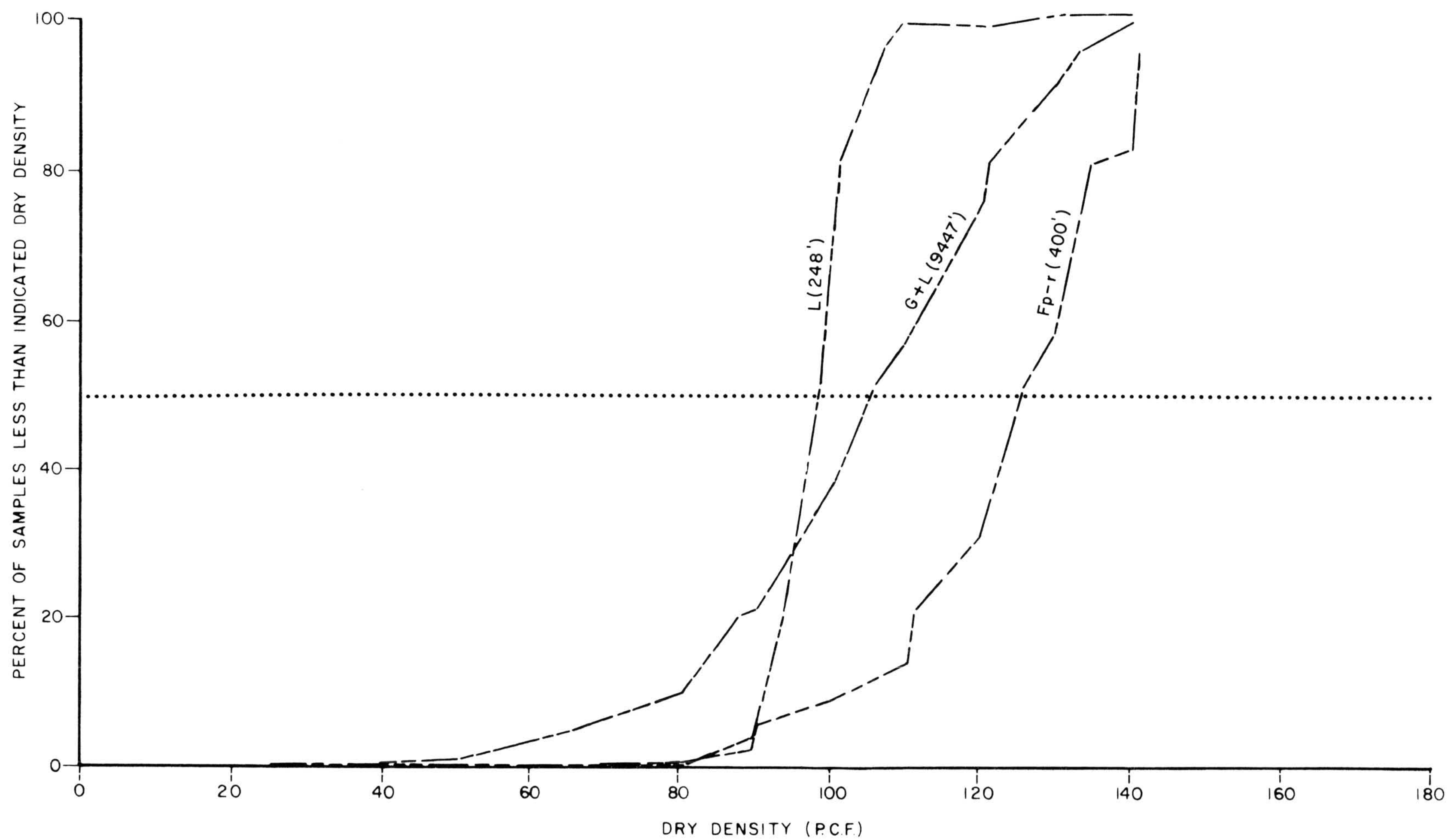


Figure 47. Comparison of the dry density of three landforms along the TAPS route through the Copper River Lowland (route segments B and C, table 5); number of feet of test hole drilled in each landform in parentheses.

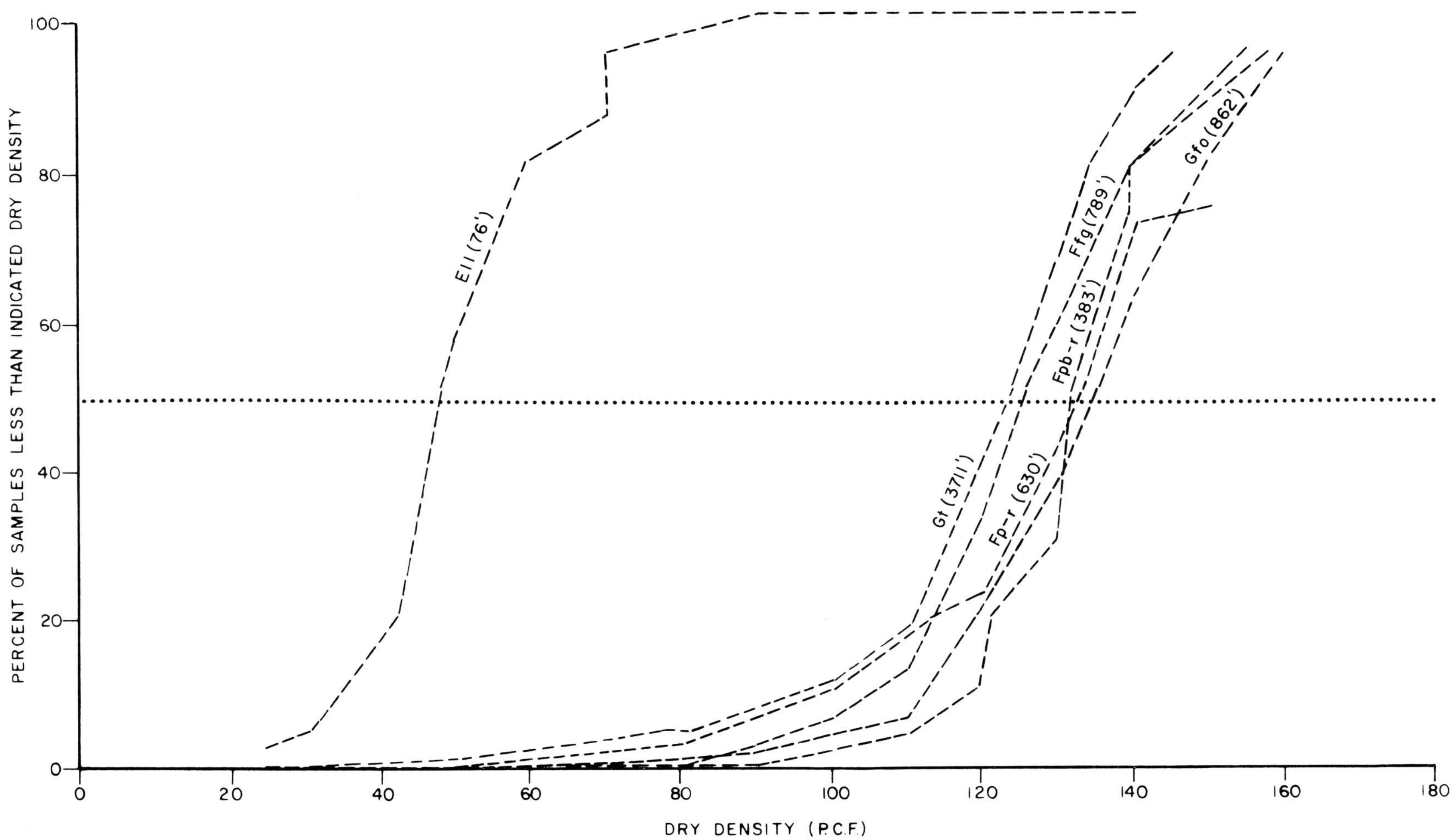


Figure 48. Comparison of the dry density of six landforms along the TAPS route through the Gulkana Upland and Alaska Range (route segment D, table 5); number of feet of test hole drilled in parentheses.

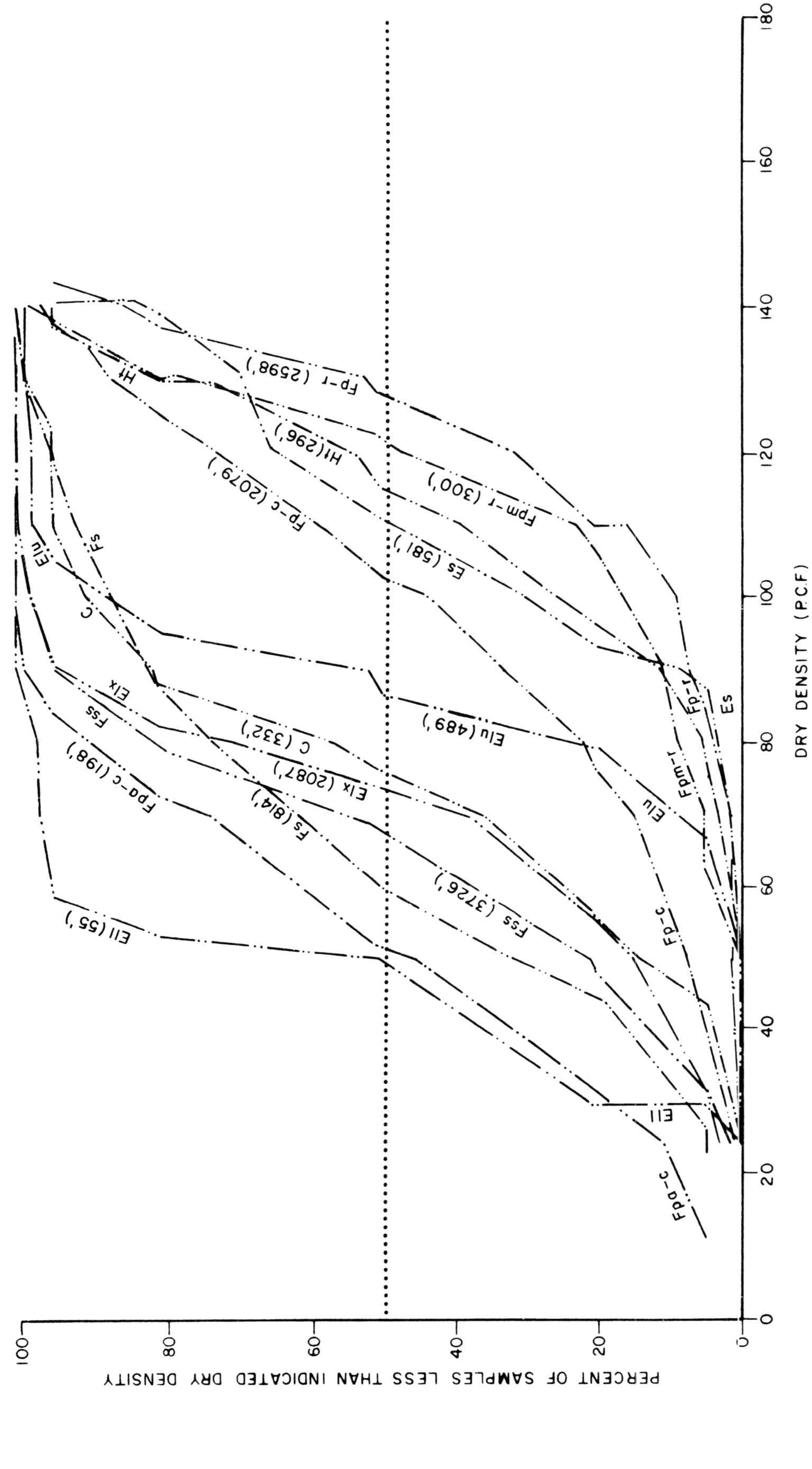


Figure 49. Comparison of the dry density of 12 landforms along the TAPS route through the Tanana-Kuskokwim Lowland, Yukon-Tanana Upland, Rampart Trough, and southern Kokrine-Hodzana Highlands (route segment E, table 5); number of feet of test hole drilled in parentheses.

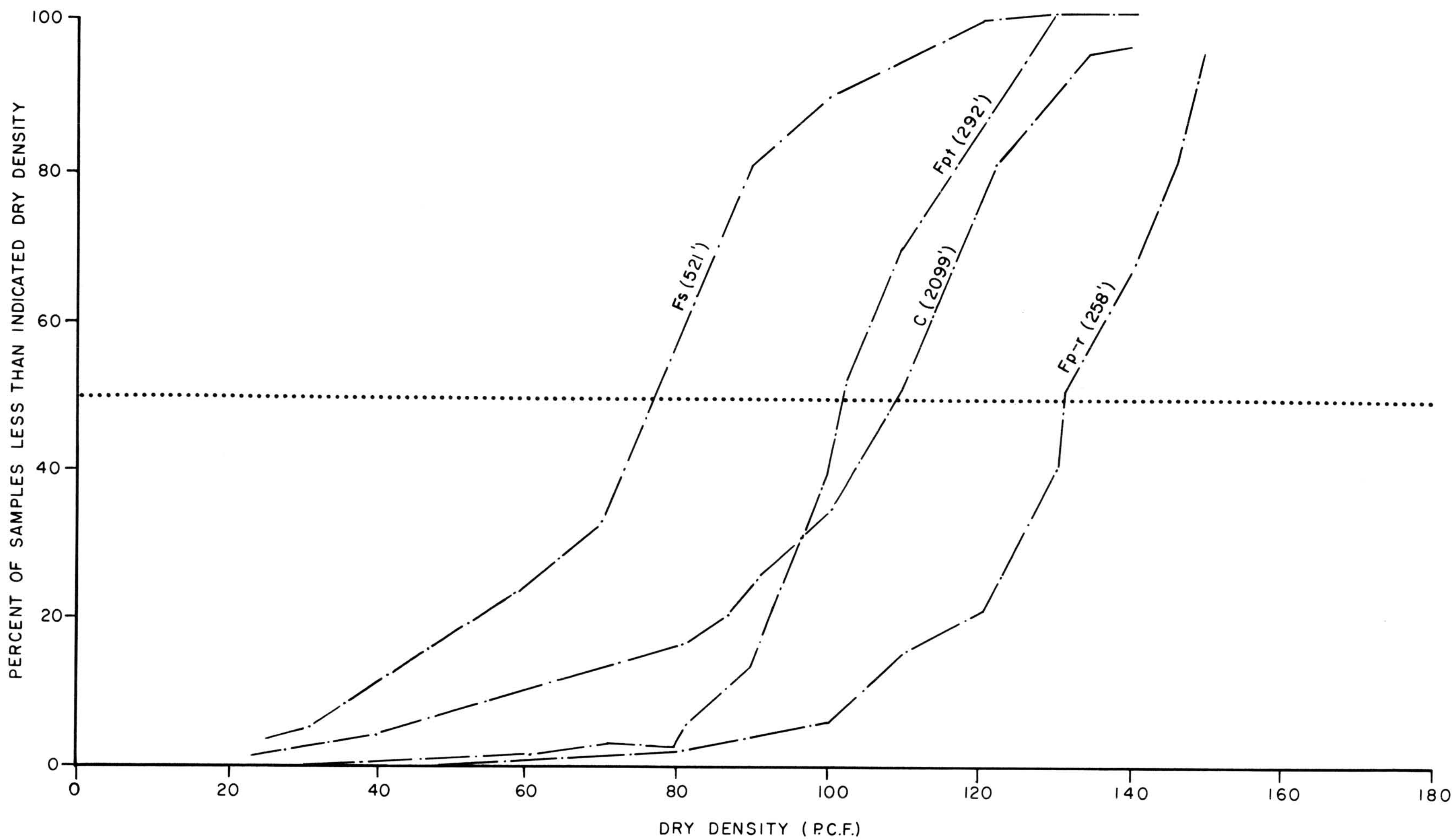


Figure 50. Comparison of the dry density of four landforms along the TAPS route through the central and northern Kokrine-Hodzana Highlands (route segment F, table 5); number of feet of test hole drilled in parentheses.

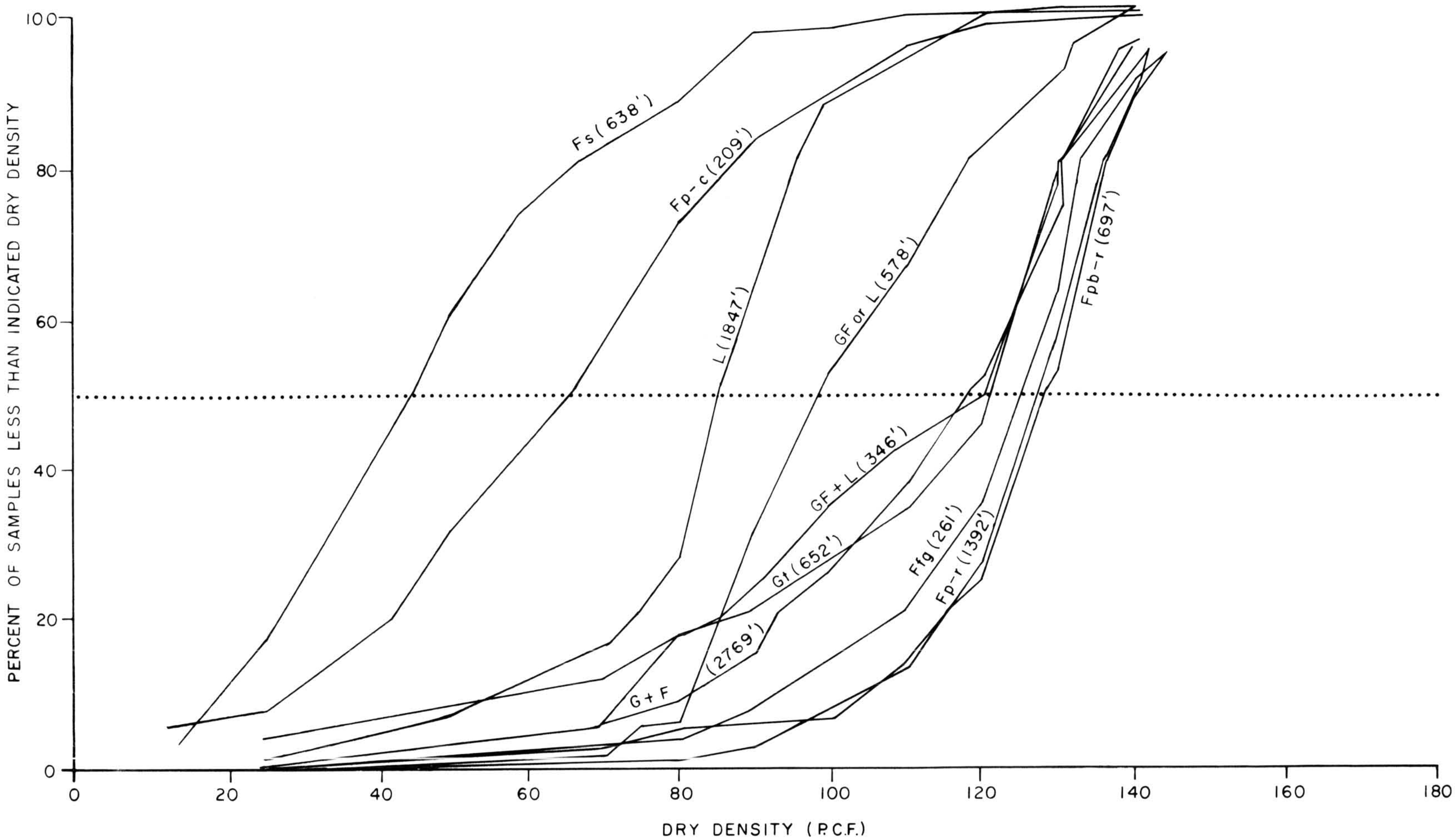


Figure 51. Comparison of the dry density of 10 individual and composite landforms along the TAPS route through the Ambler-Chandalar Ridge and Lowland physiographic unit and Brooks Range (route segments G and H, table 5); number of feet of test hole drilled in parentheses.

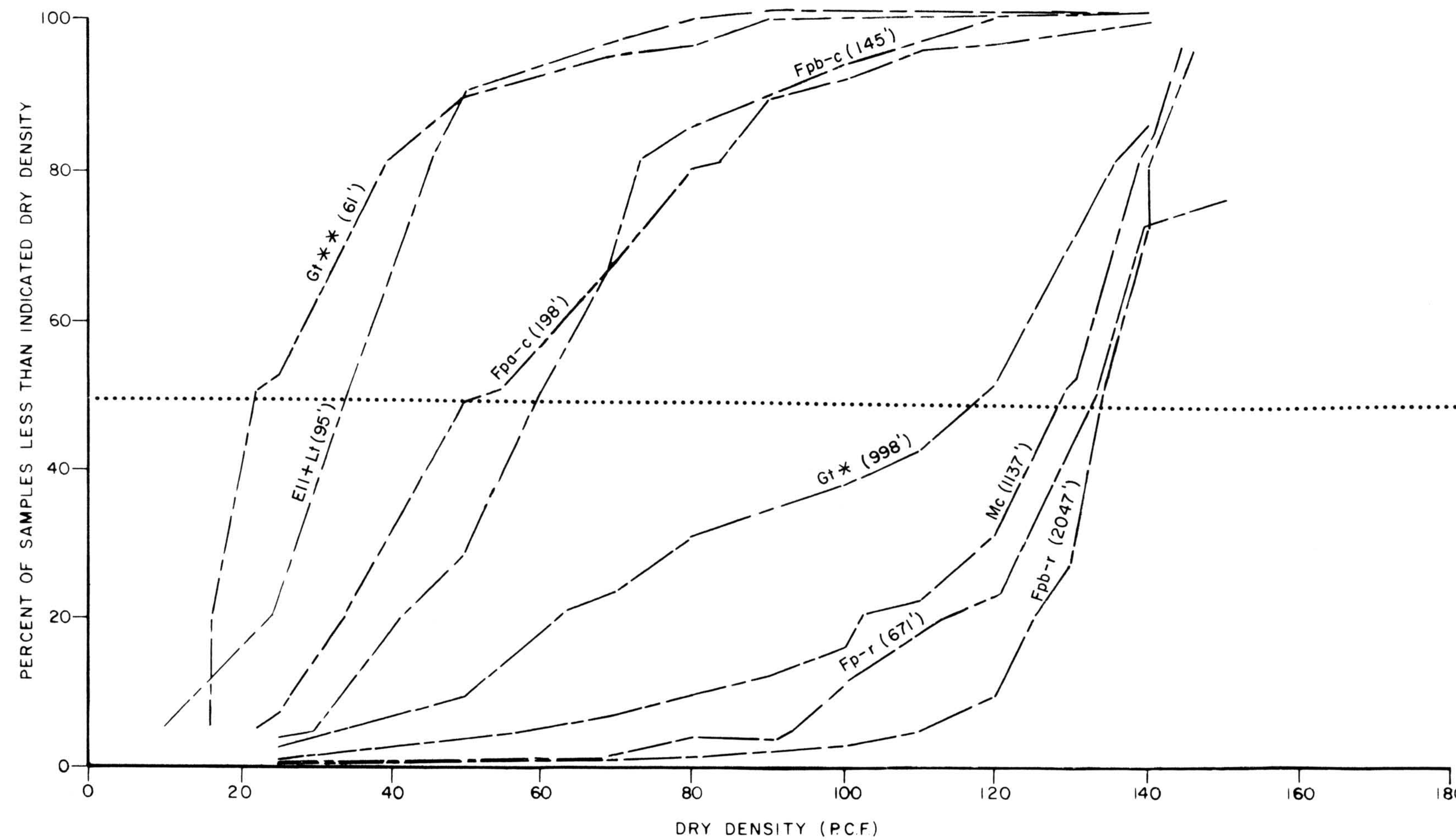


Figure 52. Comparison of the dry density of eight landforms along the TAPS route through the Arctic Foothills and Arctic Coastal Plain (route segments I and J, table 5); number of feet of test hole drilled in parentheses. *Itkillik Till of late Wisconsin age (Hamilton and Porter, 1975). **Upper 20 ft of mid-Pleistocene(?) till of Sagavanirktok Glaciation (Detterman and others, 1958; Sagavanirktok River Glaciation of Hamilton, 1978b, 1978c).