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ALLUVIAL FAN FORMATION NEAR AKLAVIK, NORTHWEST TERRITORIES, CANADA

BY

R. F. LEGGET, R. J. E. BROWN AND G. H. JOHNSTON

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FORMATION D'UN CONE ALLUVIONNAIRE PRES D'AKLAVIK DANS LES TERRITOIRES DU NORD-OUEST, AU CANADA

SOMMAIRE

Lorsque le Gouvernement canadien décida de déplacer la ville d'Aklavik, située dans le delta du fleuve Mackenzie, Territoires du Nord-Ouest, la recherche d'un nouvel emplacement nécessita l'examen approfondi des quatre endroits qui semblaient convenir à cette fin. L'un d'entre eux se situait à la surface d'un cône alluvionnaire en pente douce encadré par les Monts Richardson et la bordure ouest du delta du Mackenzie. On constata que les prévisions basées sur l'observation des traits physiques de la surface et sur l'étude détaillée des photographies aériennes étaient erronées lorsque des sondages dans le pergélisol révèlent l'existence d'une couche de tangue d'une épaisseur d'au moins 40 pieds, mais non du sable, ni du gravier qu'on attendait. Les matériaux alluvionnaires proviennent de l'érosion du grès et du schiste des montagnes adjacentes datant du Crétacé. L'action du gel amorce probablement la désagrégation des roches et le courant tumultueux du torrent continue le processus d'érosion auquel semble contribuer en outre la pousse annuelle du carex et des herbes à croissance rapide sur la surface alluvionnaire située entre les méandres du torrent. La saison de croissance courte mais chaude amène la décomposition rapide de cette couverture herbeuse qui, mêlée aux couches annuelles de matériaux alluvionnaires, constitue des cônes composés principalement de tangue ne comprenant que de faibles quantités de matériaux à granulométrie grossière.

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Alluvial Fan Formation Near Aklavik, Northwest Territories, Canada

ANALYZED

Abstract: When the Canadian Government decided to relocate the town of Aklavik in the delta of the Mackenzie River, Northwest Territories, the search for a new site involved detailed site investigations of four prospective locations. One was on the gently sloping surface of an alluvial fan between the Richardson Mountains and the western rim of the Mackenzie Delta. Predictions from surficial evidence and from a detailed study of aerial photographs were invalidated when drilling in the perennially frozen ground disclosed at least 40 feet of organic silt and no sand or gravel as had been expected. The adjacent mountains of Cretaceous age supply materials eroded from sandstone and shales. The action of frost probably induces mechanical disintegration. Turbulent stream flow continues the erosion process, which appears to be still further aided by the annual growth of fast-growing sedges and grasses on the surface of the stream meanders. The short but warm growing season leads to rapid decay of this grass cover; this combined with the annual layers of stream-bed material results in the fans being composed predominantly of organic silt with only minor quantities of coarse-grained material.

CONTENTS

INTRODUCTION

Late in 1953 the Government of Canada decided that a new townsite should be found for the settlement of Aklavik, Northwest Territories, situated on the Peel Channel of the Mackenzie Delta. This decision was prompted by the ice content of the deltaic soils underlying the townsite that makes the soils unsuitable for building foundations, proper sanitation facilities, and airstrip construction. Danger from river flooding and the limited size of the site added to the local problems (Merrill and others, 1960).

A survey team under the auspices of the

Geological Society of America Bulletin, v. 77, p. 15–30, 7 figs., 4 pls., January 1966

3-4/2-606-3

Dept. of Northern Affairs and National Resources (Canada) was organized during the winter of 1953–1954 for the purpose of selecting a new site and was led by C. L. Merrill of that department. Personnel consisted of engineers and specialists in geography and geology from the staffs of the following Canadian federal departments: Northern Affairs and National Resources, Mines and Technical Surveys, Public Works, Transport, and National Health and Welfare, and from the Division of Building Research of the National Research Council.

Uncontrolled mosaics of aerial photographs covering the entire Mackenzie Delta and the adjacent uplands were assembled and studied in Ottawa during the winter of 1953–1954. Intensive study revealed that several potential sites existed on each side of the delta that merited investigation in the field.

Therefore, during the summer of 1954 detailed site investigations were conducted at each of the potential townsite areas. One of these areas consisted of a series of coalescing alluvial fans on the west side of the Mackenzie Delta, 12 miles southwest of Aklavik. Personnel of the relocation survey team conducted detailed soils and permafrost investigations on two of the alluvial fans.

The results obtained from this test drilling were unexpected in that the anticipated predominance of sand and gravel usually associated with alluvial fans was not found. The character of the soil formation thus revealed eliminated this site as a location for the new town, but at the same time raised questions regarding the formation of alluvial fans, which the writers have studied since the original field work was completed and upon which they now report.

DESCRIPTION OF ALLUVIAL FANS

Location

The coalescing alluvial fans form a plain tilted slightly downward to the east between the Richardson Mountains and the Husky Channel, a secondary channel that flows down the extreme west side of the Mackenzie Delta in northwestern Canada (Fig. 1; Pl. 1, fig. 1). The southern extremity of the Mackenzie Delta lies 90 miles north of the Arctic Circle. The delta is a low flat area approximately 40 miles wide and 130 miles long, covering an area of about 4700 square miles. It consists of silts, with some fine sand and clay, and is interlaced by many river channels and spotted with thousands of stagnant lakes (Mackay 1956; 1963). The Richardson Mountains rise to approximately 2000 feet above sea level on the western flank of the delta overlooking the alluvial fans. Thirteen miles to the southeast, at the southern end of the alluvial plain, the mountains rise to more than 2800 feet. To the west of this flank they rise to more than 5000 feet (Pl. 1, fig. 1).

The fan selected as the most suitable for a townsite area is the most northerly of the coalescing series and is 1 mile west of the junction of the Peel and Husky channels. Most of the observations were made on this fan (hereafter referred to as the "willow fan"; *see* description of fan vegetation) which is 1.75 miles long from the apex to the toe and 2.5 miles wide. Six miles to the south observations were made on another fan (hereafter referred to as the "spruce fan"; *see* description of fan vegetation) of about the same dimensions.

Climate

For more than 30 years there has been a weather station located in the delta at Aklavik. The climate in the region of the alluvial fans may vary slightly from that of Aklavik because of their location at the base of the Richardson Mountains but it can reasonably be assumed to be very similar to that of Aklavik.

Although the Mackenzie Delta reaches the arctic coast of Canada, its climate is essentially continental in character, with long cold winters and short, warm summers. Combined with the low elevation of the Mackenzie River valley and the protection afforded by the mountains to the west, the local climate is one of the factors associated with the extension of the tree line in the delta to within 20 miles of the arctic coast.

Study of the records (1931–1960) gives the following temperature information:

	°F
Mean January daily temperature	−19.9
Mean January daily minimum temperature	−26.9
Mean January daily maximum temperature	−12.9
Mean July daily temperature	56.5
Mean July daily minimum temperature	48.0
Mean July daily maximum temperature	64.9
Mean annual temperature	15.6
Mean annual minimum temperature	8.1
Mean annual maximum temperature	23.1

Extreme lowest recorded temperature since 1921	−62
Extreme highest recorded temperature since 1921	93

Particularly notable are the low mean annual temperature (in contrast with the mean July daily maximum of 64.9°F), showing clearly the relatively short duration of high summer and the long duration of the steadily cold winter.

At Aklavik, the average frost-free period each summer is only 66 days, from June 15 to August 20. It has been as short as 32 days and as long as 102 days. The dates of the last frost in spring and the first frost in autumn vary by about 1 month on each side of the average dates given. During most of June, July, August, and early September the temperature remains above freezing, giving an average total of 105 days without frost. On the average, however, only 66 of these would occur in succession.

The oscillation of the air temperature around the freezing point (32°F) during the year is relevant to the subject of this paper. According to Fraser (1959), who suggested that a freeze-thaw cycle is represented by a rise to 34°F following a drop to 28°F, the average number of freeze-thaw cycles occurring annually at Aklavik is 25. Examination of temperature records throughout Canada shows that the average annual frequency of freeze-thaw cycles decreases steadily with increasing latitude through central Canada. For example, Regina, Saskatchewan (lat. 51°N.), has an annual average of 60 cycles; Fort Smith, Northwest Territories (lat. 60°N.),

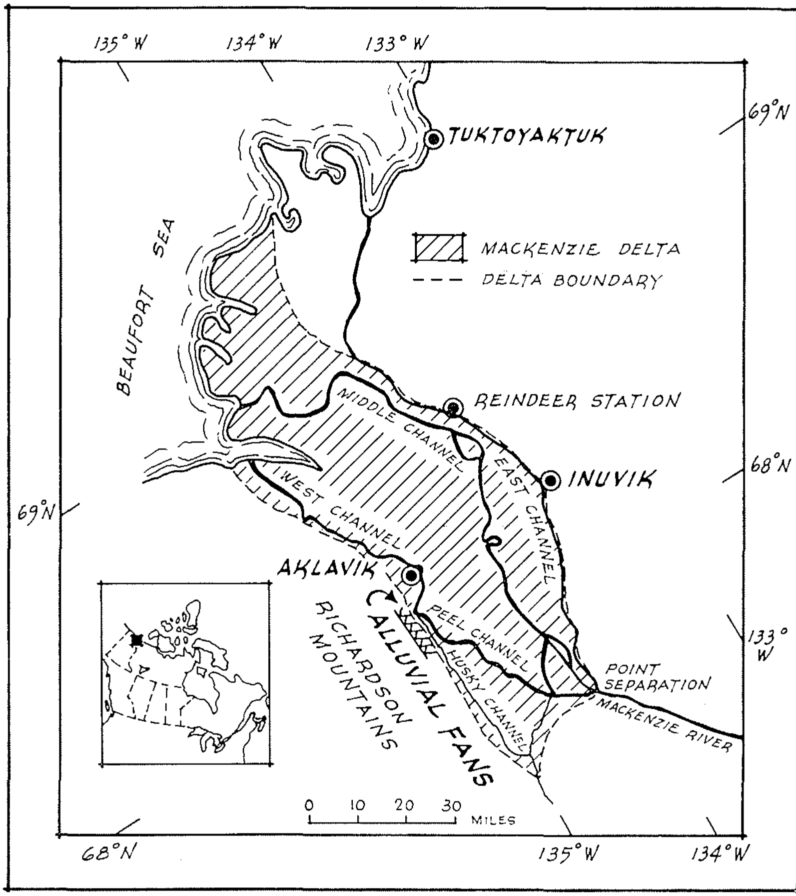

Figure 1. Map of Mackenzie Delta, Canada, showing location of alluvial fans

has 48; and Eureka, Northwest Territories (lat. 80°N.), has 12. Although the annual frequency of freeze-thaw cycles decreases toward the north, the duration of the freezing part of the cycle increases, and the minimum below-freezing temperatures become lower.

average less than 5 miles per hour. For almost half the time, the wind comes from the north or northwest, blowing inland from the Beaufort Sea, and for about one-third of the time it is from the south or southeast.

The hythergraph of the climate at Aklavik is

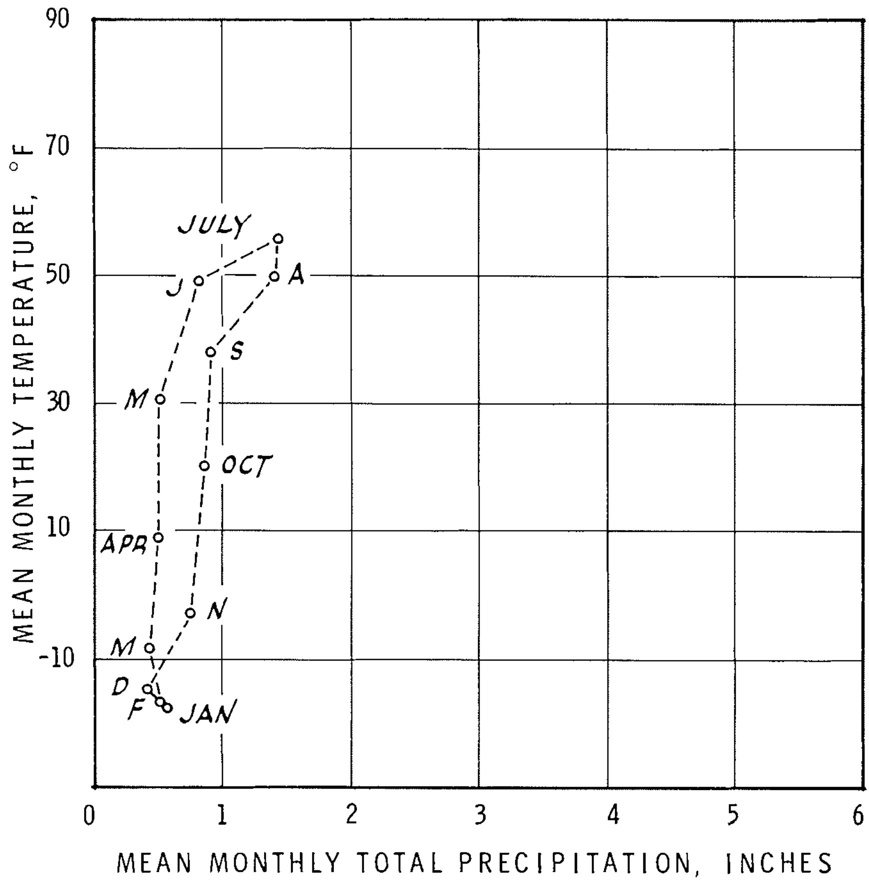

Figure 2. Hythergraph of Aklavik, Northwest Territories, Canada

The mean annual precipitation at Aklavik is 8.84 inches, the mean annual rainfall is 3.90 inches, and the mean annual snowfall is 49.4 inches. Rain has never been reported in the 4 months from November to February and is rare in March and April. Snow has fallen in all months of the year, although it rarely falls in July.

Aklavik is not very windy compared to the country as a whole. The strongest winds occur in June, with an average of only 8 miles per hour. In November and December the winds

shown in Figure 2. The main features of the climate are the short, warm summers; the long, cold winters; the low number of annual freeze-thaw cycles; the low annual precipitation; and the low wind speeds.

Surface Features

PHYSICAL GEOLOGY AND RELIEF: The western limit of the Keewatin Ice Sheet appears to have been in the delta area, the ice being blocked on the west by the barrier of the Richardson Mountains. Moving north along

Figure 1. Aerial view of alluvial fans looking south from an altitude of 20,900 feet. Mackenzie Delta on left with meandering Husky Channel at toe of fans. Note V-shaped valleys in Richardson Mountains on right. Borehole location shown by x. (RCAF air photo T5-10L, August 1944)

Figure 2. Stereo pair of willow fan situated between Mackenzie Delta (bottom of photographs) and Richardson Mountains (top of photographs). (RCAF A 12861–182 and 183) x, borehole location; 1, Hole no. 1; 2, Hole no. 2; 3, Hole no. 3

AIR PHOTOGRAPHS OF ALLUVIAL FANS, NORTHWEST TERRITORIES, CANADA

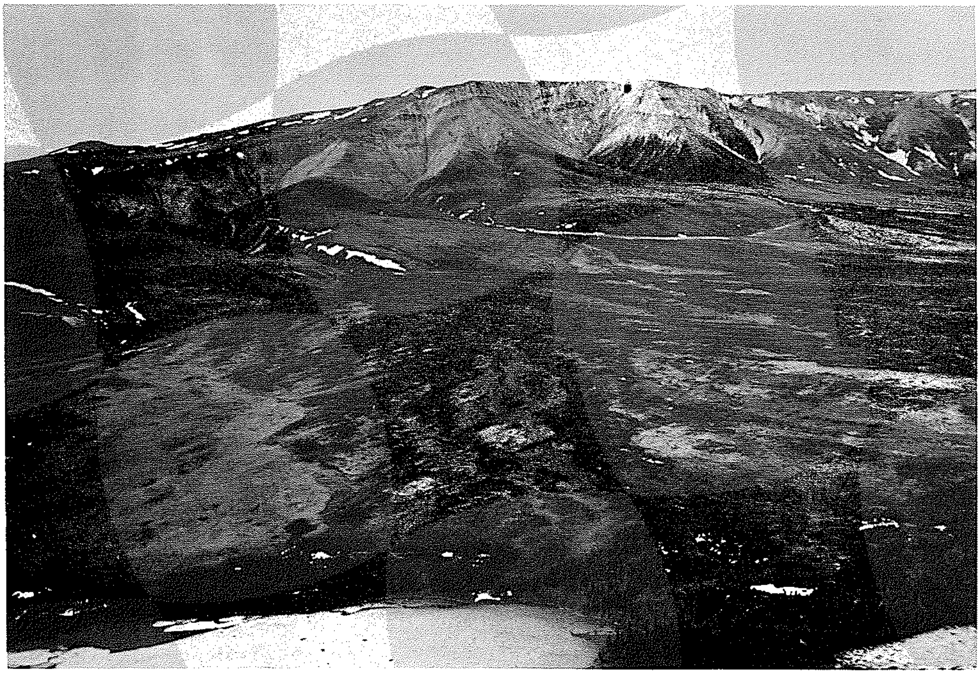

Figure 1. Aerial view of willow fan looking northwest (June 1954)

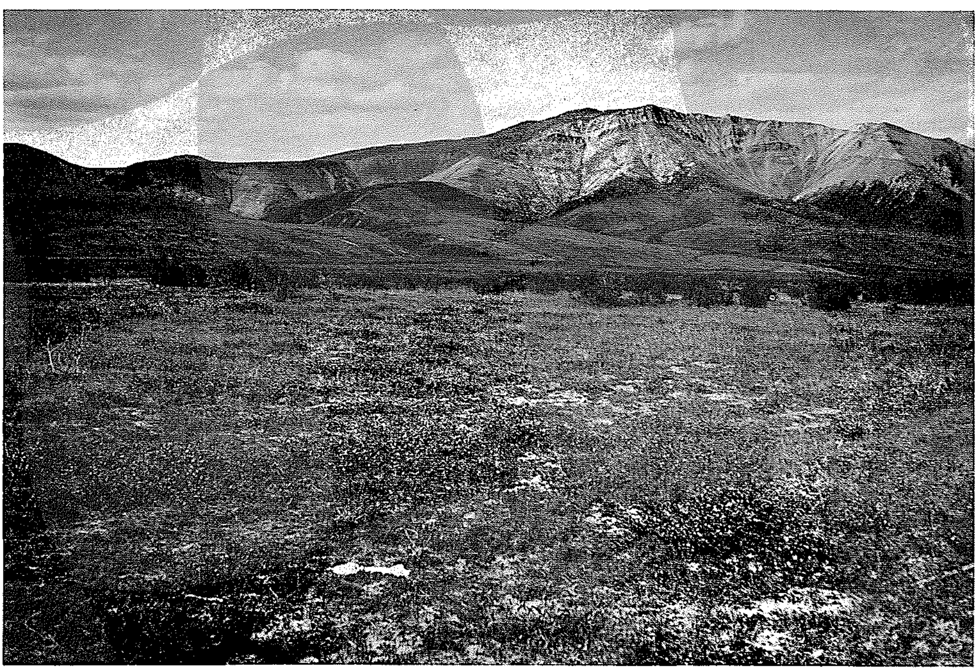

Figure 2. Ground view of willow fan (August 1954)

ALLUVIAL FANS NEAR AKLAVIK, NORTHWEST TERRITORIES, CANADA

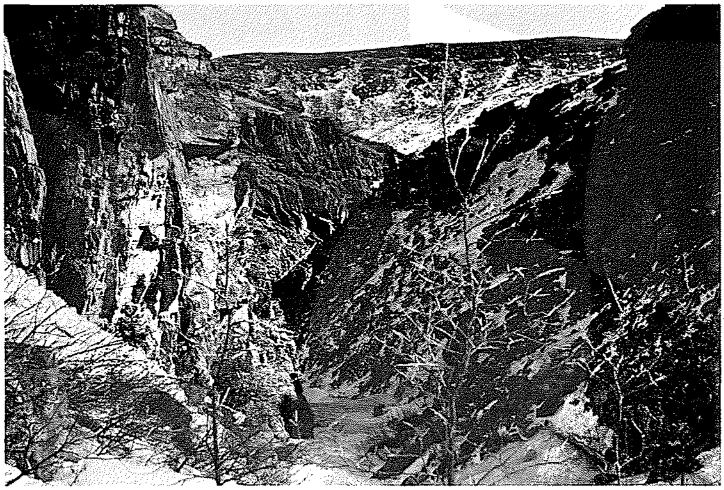

Figure 1. Willow fan gully (April 1954)

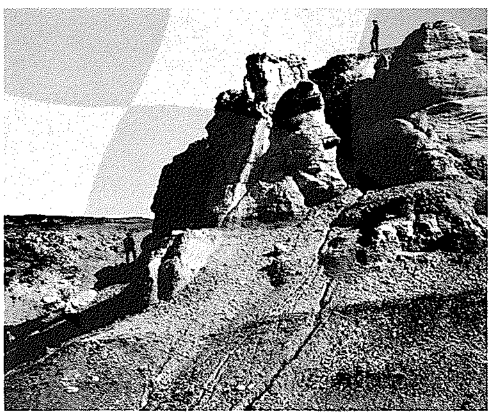

Figure 2. Sandstone bluffs at entrance of willow fan gully (August 1960)

Figure 3. Weathered shale blocks in Richardson Mountains (April 1954)

SOURCE OF MATERIAL COMPRISING ALLUVIAL FANS NEAR AKLAVIK, NORTHWEST TERRITORIES, CANADA

LEGGET AND OTHERS, PLATE 3

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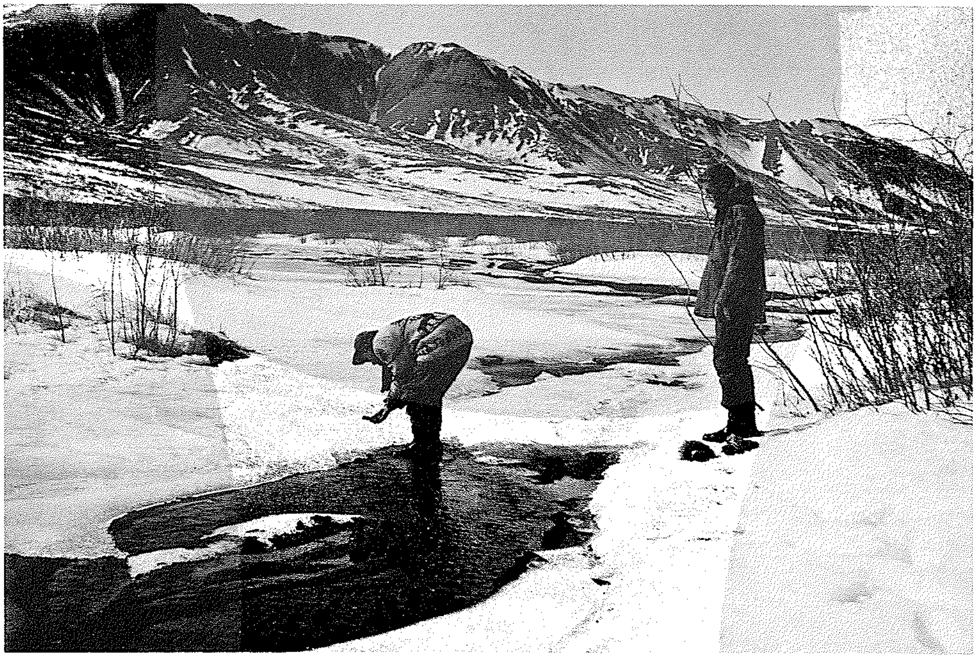

Figure 1. Stream flowing on willow fan, 2000 feet southeast of Hole no. 3 (May 1954)

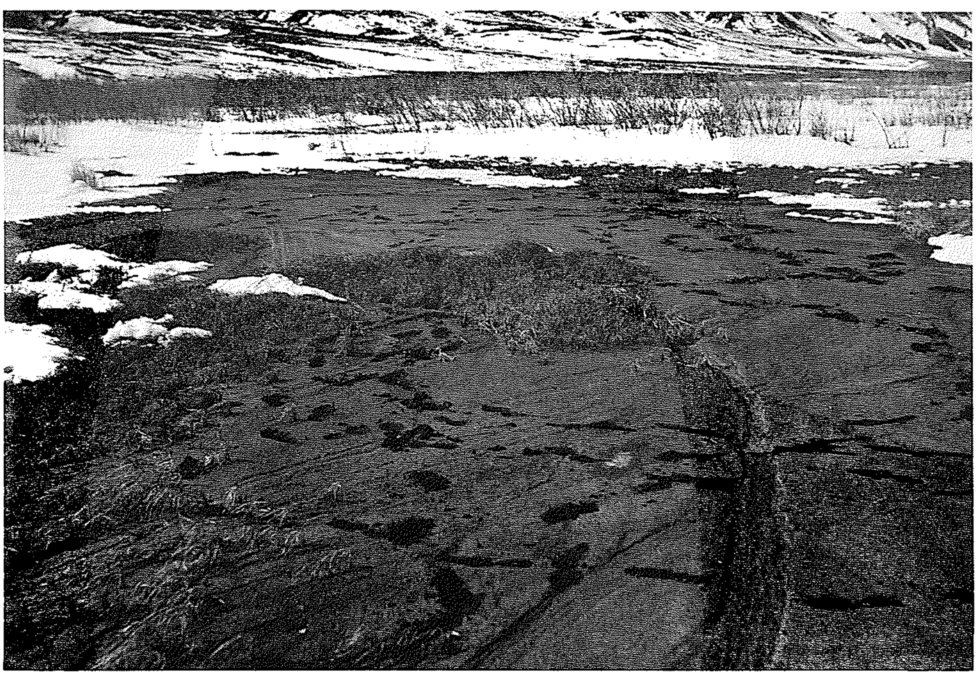

Figure 2. Freshly deposited material on willow fan, 2000 feet southeast of Hole no. 3 (May 1954)

SURFACE OF ALLUVIAL FANS NEAR AKLAVIK, NORTHWEST TERRITORIES, CANADA

LEGGET AND OTHERS, PLATE 4

the trough now occupied by the Mackenzie Delta, the ice straightened and smoothed off the eastern scarp of the mountains. Deposits and land forms associated with glaciation, such as till, kames, moraines, and melt-water channels, abound on the eastern slopes, and erratics occur to elevations of 3000 feet above the fans. West of the eastern scarp the relief is that of a rolling plateau dissected by many V-shaped valleys (Mackay, 1963).

The alluvial fans have been formed from disintegrated and decomposed products from the Richardson Mountains. Both the fans and the surface deposits of the Mackenzie Delta are believed to be predominantly postglacial. Two distinct grades were present on each of the fans investigated (Riccio, 1962). The first, relatively steep, extends from the apex of the fan downward for a distance of from one-third to one-half the length of the fan; on the willow fan this grade is 1.9 per cent and on the spruce fan, 6.1 per cent. The second grade, to the deltaic deposits at the toe of the fan, is longer and lower; at the willow fan it is 1.3 per cent and at the spruce fan, 2.3 per cent.

VEGETATION: The low elevation of the Mackenzie River valley, which is flanked by protecting mountains over much of its course, favors a northward extension of the great northern coniferous forest into the delta to about 20 miles south of the arctic coast. In the forested part of the delta spruce is dominant; poplar, birch, and thickets of alder and willow are also present. In many places, however, there are open patches of meadows unable to support any tree growth. North of the tree line the vegetation consists of mosses, grasses, sedges, and heaths, with widely scattered scrub willow and alder.

The tree growth on the willow fan, consisting of willow and alder thickets up to 15 feet high, is typical of the north half of the alluvial plain (Pl. 2, fig. 2). These thickets are interspersed with open meadow-like areas in which sedge (predominantly *Carex aquatilis Wahl*) and grass grow to a height of about 15 inches in only a few weeks every summer. There are some areas of bare (new) soil and an increasing number of sedge and grass tussocks toward the toe of the fan. Other ground plants include Sphagnum and other mosses, lichen (*Cladonia sp.*, *Cetraria sp.*), Labrador tea, juniper, blueberry, and wintergreen. The over-all pattern of the vegetation appears to trace the past movements of the discharge from the creek and thus intensifies the braided appearance of the fan when viewed from the air or by means of aerial photographs (Pl. 1, fig. 2; Pl. 2, fig. 1).

The tree growth on the spruce fan is typical of the southern half of the alluvial plain. Its vegetation is similar to the willow fan previously described with the addition of spruce trees, which reach a maximum height of 25 feet. The average height and density of the tree growth exceeds that on the willow fan, and hence the braided effect seen from the air is more pronounced.

The boundary between the fans and delta is fairly well delineated by vegetation. This is true even on the spruce-covered fans where the height and density of trees are somewhat less than those on the adjacent delta. The factors that allow these fans in the south half of the alluvial plain to support spruce growth in contrast to the scrub willow and alder growth of the northern fans present a problem beyond the scope of this paper.

FROST PHENOMENA: The ground surface of all fans is characterized by the following microrelief forms: polygons in local depressions surrounded, or partly surrounded, by raised rims up to 5 feet in height; complete and partial polygons about 30 feet in diameter delineated by troughs of depths measured in inches; and frost mounds up to 5 feet in diameter and 1 foot high. There are numerous signs of intensive frost action throughout the entire fan area. Large areas contain frost mounds, and polygonal cracks are found everywhere. Permafrost is continuous and extends to depths of several hundred feet.

Soils

BOREHOLE LOCATIONS: Subsurface investigations were carried out by drilling and sampling methods (Pihlainen and Johnston, 1954) to obtain undisturbed cores of the perennially frozen soils. Three holes were drilled in the willow fan and one on the spruce fan (Pl. 1, fig. 1; Pl. 1, fig. 2; Fig. 3; Pihlainen and others, 1956).

Hole no. 1, located at the toe of the willow fan, was advanced to a depth of 32 feet with core recovery of more than 90 per cent. Drilling difficulties were experienced at Hole no. 2, located part way up the fan. Two core barrels froze in at depths of 5 and 12 feet; samples were obtained only to a depth of 5 feet, and the hole had to be abandoned in order to recover the core barrels. Hole no. 3, located near the apex of the fan, was advanced to a depth of 38 feet with core recovery averaging 50 per cent. Hole no. 4, located near the middle of the spruce fan, was drilled to a depth of 29 feet, with core recovery averaging 60 per cent. (Detailed soil profiles are shown in Fig. 4.)

TEST RESULTS: Undisturbed samples were examined for ice segregation characteristics, and laboratory tests were carried out to identify the various soils found. Although the observations reported in this paper pertain mainly to the willow fan, some results of investigations on the spruce fan are included as supplementary material.

The soils consist predominantly of a light-brown to light-gray silt-sized soil, with varying amounts of organic material, thin layers (1 inch to 1 foot) of friable mudstones, and some more resistant sandstone pebbles. Twenty-three samples were analyzed for grain-size distribution. Figure 5 shows envelopes of the graphical records of the test results; samples from the toe of the willow-covered fan are all smaller than fine sand (0.2 mm). Grain-size distribution limits for samples from the top of this fan show larger particle sizes grading down from approximately the coarse-sand size (less than 2.0 mm). Samples from the middle of the spruce fan (with a higher surface gradient) show a grain-size distribution envelope similar to that at the top of the willow-covered fan except that more silt- and clay-size particles are present.

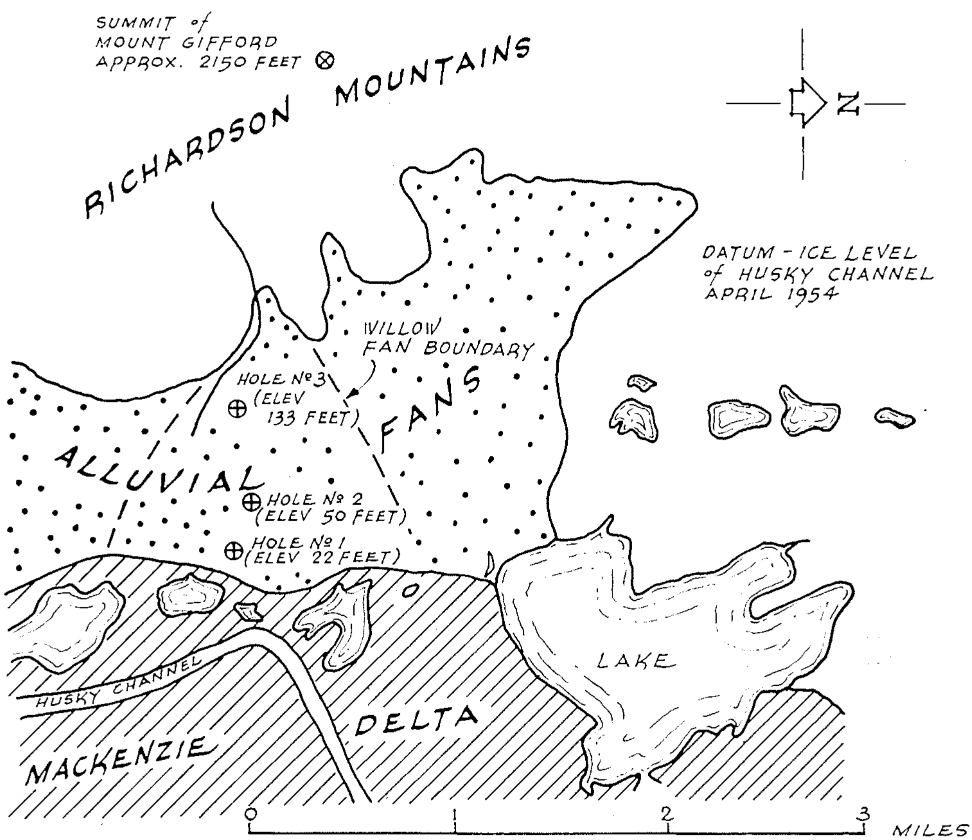

Figure 3. Map of willow fan area near Aklavik, Northwest Territories, Canada

In general, the soils found were nonplastic. Atterberg limit tests, by which the plasticity of a soil is determined, were conducted on a number of samples, but plasticity-index values for only nine were obtained. The test results are listed in Table 1, and a plot of plasticity index *vs.* liquid limit is shown in Figure 6. The graph shows that the points lie along the A-line[1] and

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[1] A-line represents the empirical boundary between typical inorganic clays (which are generally above the A-line) and plastic materials containing organic colloids.

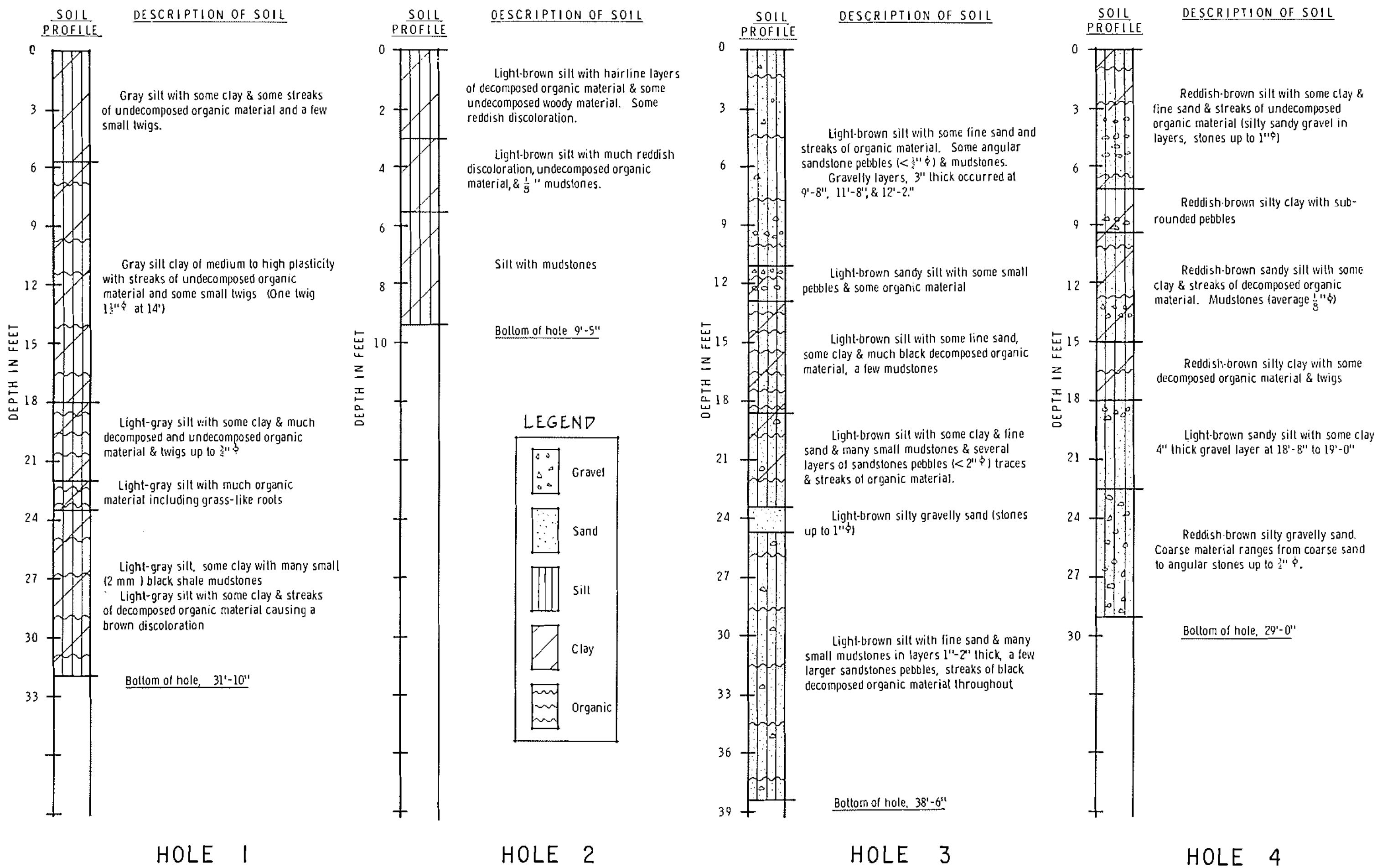

Figure 4. Detailed soil profiles from alluvial fan boreholes near Aklavik, Northwest Territories, Canada

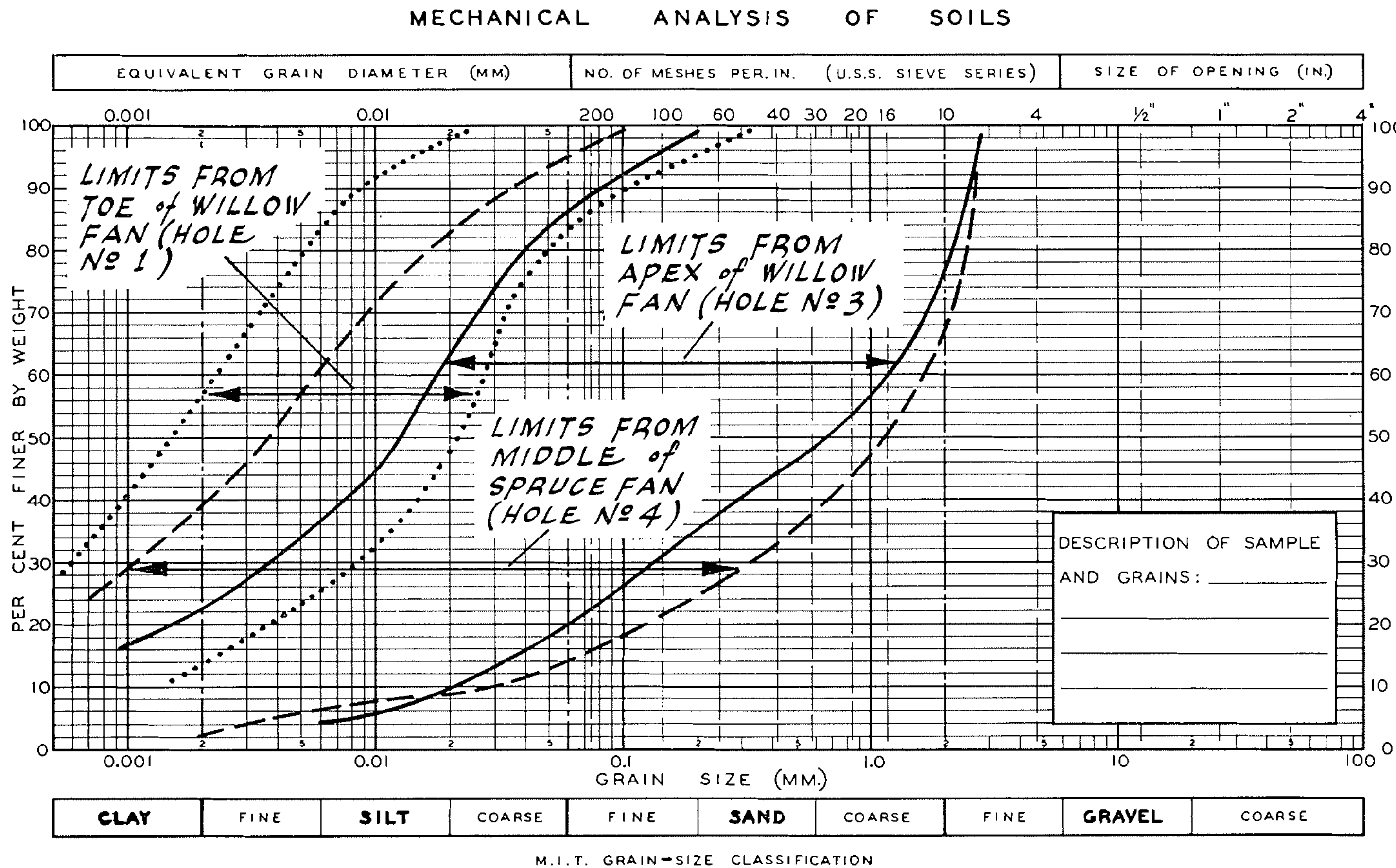

Figure 5. Envelopes of grain-size distribution curves for fan soil samples from near Aklavik, Northwest Territories, Canada

that the soils are predominantly organic and inorganic silts and silt clays (Casagrande, 1948).

A number of soil samples were examined under the microscope. Many angular quartz particles were observed in the soils from the upper part of the fan, indicating a sandstone origin. A reddish discoloration caused by the ferruginous deposits was quite prominent in these soils, but was not noticeable in those from the toe of the fan.

Thirty samples were taken from depths between 2 and 31 feet in Hole no. 1 for determining moisture (ice) content; this is expressed as a percentage of the weight of dry soil in the sample. Moisture contents averaged 85 per cent and ranged from 27 to 154 per cent. Ice segregation consisted of horizontal layers ranging in thickness from hairline (less than 1/32 inch) to ¾ inch, and averaging 1/16 inch. In ten samples taken from depths of 1.5 to 5 feet, in Hole no. 2 the moisture contents averaged 74 per cent, ranging from 31.2 to 193.9 per cent. Horizontal ice layers varied in thickness from hairline to ½ inch. Moisture content samples were taken about every 2 feet in Hole no. 3. In 25 samples from depths of 7 to 38 feet moisture contents averaged 72 per cent, ranging from 17.1 to 299.1 per cent. Ice segregation consisted predominantly of horizontal layers ranging in thickness from hairline (less than 1/32 inch) to ¾ inch, and averaging 1/16 inch. In Hole no. 4 moisture content samples were taken at least every 2 feet of penetration. In 28 samples from depths of 3 to 23.5 feet moisture contents averaged 83 per cent, ranging from 20.0 to 253.3 per cent. Ice segregation consisted of horizontal layers ranging in thickness from hairline (less than 1/32 inch) to ¾ inch, averaging 1/16 inch.

POLLEN ANALYSIS: In an attempt to determine the past vegetation associated with the fan deposits, samples from the four boreholes were examined by Dr. N. W. Radforth of the Department of Biology, McMaster University, Hamilton, Ontario. A pollen analysis showed that all major groups of plants were represented in the microfossils. Those commonly occurring in existing northern peats were present in all four boreholes, including microfossils of the three main peat types—amorphous-granular, fine-fibrous, and coarse-fibrous. It is impossible to reconstruct the distribution of the original plant cover, but variations in microfossil type frequency, indicating a predominance of shrubs, sedges, grasses, and lichens, suggest that the original plant cover was similar to that of the present.

TABLE 1. PLASTICITY AND ACTIVITY OF SOIL SAMPLES FROM ALLUVIAL FANS NEAR AKLAVIK, NORTHWEST TERRITORIES, CANADA

Location	Sample depth (in feet)	Atterberg limits: Liquid limit	Plastic limit	Plasticity index	Clay fraction per cent < 0.002 mm	Activity PI/per cent clay
Willow fan						
Hole no. 1	8	49.8	31.1	18.7	53	0.353
	14.5	55.1	32.3	22.8	48	0.475
	17	47.0	26.3	20.7	24	0.863
	22	47.3	28.8	18.5	43	0.430
Hole no. 3	21	40.1	30.9	9.2	16	0.575
Spruce fan						
Hole no. 4	7.5	43.7	28.3	15.4	39	0.395
	8.5	37.1	23.4	13.7	39	0.352
	16	40.3	25.5	14.8	35	0.423
	21	51.5	30.4	21.1	40	0.527

SOURCE OF FAN MATERIAL

The willow fan has evidently been formed from the deposition of disintegrated materials derived from the Richardson Mountains and transported through the gully at the apex of the fan. The rocks cut by the gully are mainly interbedded buff to brown fine- and coarse-grained sandstones, light- to dark-gray shales, and light-brown to dark-gray silty and sandy siltstones of Cretaceous age (Jeletzky, 1958) (Pl. 3, fig. 1). All are subject to severe frost action, as is indicated by the shattered appearance of many of the outcrops. The fine-grained sandstones are the more resistant, and sandstone pebbles found in the boreholes on the fan are predominantly of this material. The coarse-grained sandstones are friable and appear to disintegrate much more rapidly, particularly during the snow-melt period when they are easily eroded by the run-off (Pl. 3, fig. 2). In general, they are completely disintegrated by the time they are deposited on the fan by the gully stream. The siltstones and shales, also fine- and coarse-grained, are somewhat more resistant but do break down fairly quickly under frost and water action, resulting in deposition as individual particles or as small "mudstones," the latter being found even in Hole no. 1 at the toe of the fan. Many of the layers of siltstone have been cemented by a ferruginous coating up to 1/8 inch thick that has penetrated joints and fractures in the rock.

Sandstone boulders up to several feet in diameter can be seen on the high talus slopes rising above the narrow gorge of the gully. Some have clearly been disintegrated by natural weathering into flat subangular fragments. Disintegration appears to be more intense on the north-facing slope than on the south-facing slope, the gully being oriented approximately east-west. Resistant shale outcrops form distinct ridges on a saddle above the fan (elevation 1180 feet); these form steps, each about 2 feet high. The surface of the shale is severely weathered and cracked by frost, giving a series of small, friable round-topped blocks (Pl. 3, fig. 3). Between the ridges the shale is darker in color and has weathered to flakes approximately 1/8 inch in size. Distinct polygonal cracking producing polygons about 8 feet in diameter is evident in this black shale.

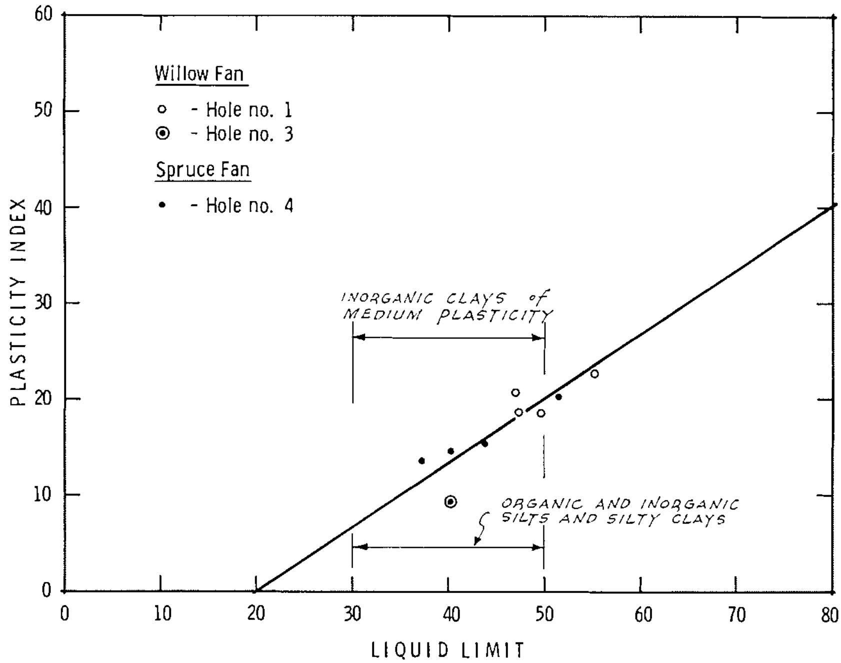

Figure 6. Plasticity chart for alluvial fan soils from near Aklavik, Northwest Territories, Canada

There are soil slumps at an elevation of 800 feet above sea level on a north-facing ridge. The almost vertical slip faces are spaced about 10 feet apart and range in height from 2 to 6 feet. The exposed soil is a light-brown silt with friable mudstones in the top 2 feet and streaks and flakes of organic material throughout the face of the exposure.

The gully from which the fan-forming stream emerges is about 150 feet deep close to its mouth and is V-shaped, with side slopes very steeply graded and in places at angles exceeding 45 degrees (Pl. 3, fig. 2). Material in the bed of the gully varies in size from silt-sized fines to boulders several feet in diameter. Many outcrops of the buff to dark-brown sandstone, weathered to white, and of red-stained siltstone are evident. Rock outcrops and boulders all exhibit severe surface weathering characteristics, which is particularly noticeable in the boulders of shale that clearly come from the uppermost beds above the gully.

FORMATION OF FANS

Introduction

As an immediate result of the disclosure in all three boreholes that the fans were underlain by silt with high ice content similar to that at the existing site of Aklavik, the site had to be abandoned as a prospective location for the new town. The existence throughout the fans of fine-grained soils derived from weathering of solid rock in the adjacent mountains suggests active disintegration of the parent rock material.

A literature search revealed that specific references to alluvial fan deposits or formation appear to be limited. The only paper on alluvial fans in polar regions describes fan development in an adjacent area in Alaska (Anderson and Hussey, 1962). It deals only with surficial features, however, for the authors have apparently not undertaken subsurface investigations. (A listing of papers on alluvial fans is given in the Bibliography.) No publication has been found that is relevant to the problem reviewed in this paper, a fact that explains the limited list of references.

What factors contribute to the breakdown of parent rock into the materials forming the fans? The nature of the parent rocks is clearly a first determinant, but the local climatic conditions and weathering to which the rocks are subjected are equally important. The process of transportation and deposition must be considered, and vegetation on the fans may be of some significance. Detailed study of the properties of the soil samples obtained from the boreholes could assist in the elucidation of the problem.

Freeze-Thaw Tests

The role of alternate freezing and thawing in the disintegration of rock material in northern regions is somewhat difficult to assess or to separate from the role of other physical processes. Although the concept of strongly predominant mechanical weathering in northern regions has been widely accepted, it is suggested that the fact that shattered rock is more evident in northern than in southern Canada is not solely the result of lower temperature or of high frequency of freeze-thaw cycles. (In fact, the frequency of freeze-thaw cycles decreases with latitude, as has already been mentioned.) The evident abundance of shattered rock may derive to an important degree from the absence of a concealing and insulating mantle of snow and vegetation in the north and may therefore be a secondary effect of the climatic factors of low annual temperature and precipitation (Fraser, 1959).

Determination of the number of freeze-thaw cycles that actually occur in nature for comparison with laboratory freeze-thaw tests is not an easy or convenient climatic analysis. The total amount of shattering appears to depend not only on the number of cycles, but also on the length and intensity of each cycle and on the removal of the debris so that fresh rock becomes available (Tricart, 1956). Experiments carried out with many rapid cycles to simulate the influence of thousands of years produced only a small thickness of frost-shattered material. Nonetheless, in an effort to obtain some idea of the role of alternate freezing and thawing on the formation of the fine-grained fan soils, laboratory tests were conducted on sandstone and shale fragments from the gully above the willow fan. Rock fragments were subjected to two daily freeze-thaw cycles (dry during freezing part of cycle), one cycle consisting of 6 hours of freezing down to 28°F and 6 hours of thawing up to 34°F. Between October 1956 and July 1957 the fragments were subjected to 400 cycles. This would be roughly equivalent to the number of cycles naturally occurring over a 16-year period (25 per year at Aklavik, *according to* Fraser, 1959). Grain-size distribution before and after the test are shown in Figure 7; in the range from about 0.1 to 10 mm the material finer by weight increased by about 10 to 20 per cent. In the range from about 1.0 to 3.5 mm a similar increase was noted.

On the basis of this testing alone it is virtually impossible to assess the relative importance of freeze-thaw cycles in nature on the disintegration of the source rock material. In view of the disintegration observed in the laboratory tests, however, it appears that the process is significant; it is possibly of paramount importance in the initial stages of mechanical breakdown.

Process of Deposition

Flow from the postglacial gully onto the fan is intermittent. For most of the year winter conditions result in complete freezing, and it is only

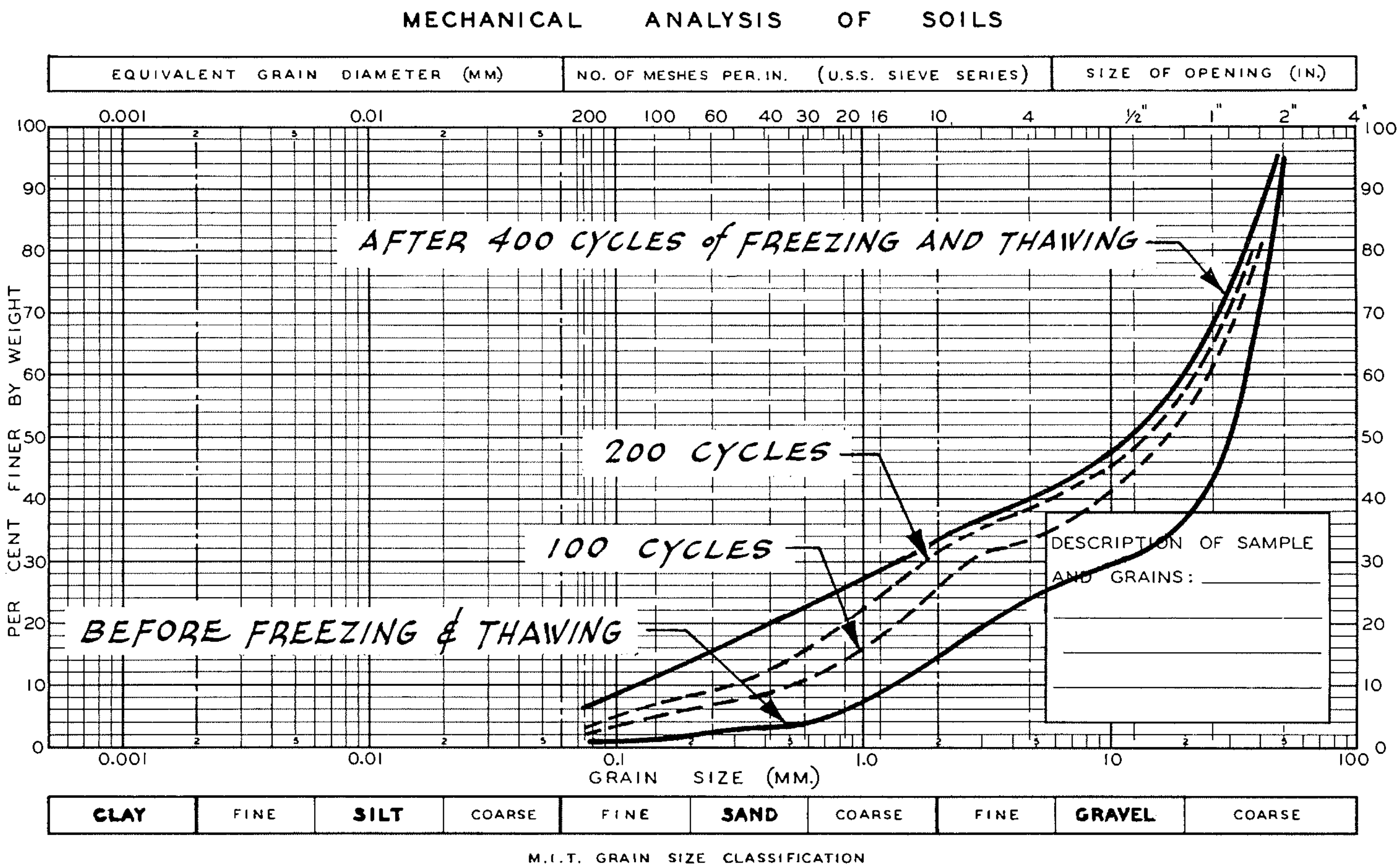

Figure 7. Disintegration of rock sample from willow fan gully near Aklavik, Northwest Territories, Canada, by freeze-thaw cycling in laboratory (Test no. 1)

with the advent of the very short summer season that the snow cover begins to melt and provide any stream flow. Drifting of snow in the gully, due to winter winds, results in an appreciable local storage of water despite the low annual precipitation for the region. Relatively slow melting of the snow drifts, especially those on the north-facing slopes, leads to a moderate regulation of run-off, with the result that there is usually some flow from the gully as late as August.

Emerging from the gully in the spring, and carrying a heavy bed-load of freshly disintegrated rock fragments with some silt, the stream has cut a trench about 6 feet wide and up to 6 feet deep in the loose scree deposits. Within half a mile of the end of the gully, however, the stream bed begins to flatten out and the stream itself takes on a braided pattern. As the entire region is underlain by permafrost, it is not until the end of August that the very shallow active layer has thawed even to a depth of about 18 inches. By that time, stream flow has almost ceased. Practically all the flow from the gully, therefore, debouches onto a fan of solidly frozen material. Accordingly, once the apex of the fan is passed, the stream flow spreads out rapidly, its velocity falls quickly, and its load of solid material is deposited in thin sheets on the particular area over which the stream happens to be flowing.

So complete is the control exercised by the frozen character of the material onto which the stream discharges that for no greater distance than half a mile from the end of the gully is there a properly defined stream bed; the course followed by the stream is diverted from side to side of the fan area by any unusual (and quite random) accumulation of deposited bed-load material. It is this irregular process of deposition and change of route that gives the upper part of the fan surface its characteristic braided appearance.

The intermittent character of the flow even in what may appear to be regular stream beds is indicated by the dense growth of scrub willow over the upper part of the fan (Pl. 4, fig. 1), and by the occurrence of small open sedge and grass meadows interspersed between the willow thickets.

Examination of the exposed mud-flats (Pl. 4, fig. 2) shows that the deposited material consists mainly of light-gray silt-sized particles, with many black streaks close to the surface suggestive of decomposing organic material. Shale and sandstone pebbles, subrounded to subangular and rarely more than 1 inch in diameter, lie scattered over the surface. Where there is any accumulation of these coarser particles, random counts showed less than one-third to consist of the more resistant materials.

Along the south side of the fan, in its upper reaches, is a levee-like ridge which generally follows the most southerly line of stream deposition. It is about 3 feet high and from 10 to 30 feet wide. There is a similar land form on the north side of the fan, but it is not nearly so well defined. The character of these ridges and the distribution of willow and meadow vegetation, described previously, suggest great variation in the stream flow from the gully from year to year, with occasional major changes in the pattern of flow over the fan, probably in years when there is unusually heavy run-off.

Disintegration of Material

Disintegration of the fan material appears to begin with weathering of the sandstone and shale beds into which the gully has been cut. Frost action and alternate freezing and thawing combined with water action are the initial weathering agents contributing to the breakdown of the material. The melting snow provides erratic stream flow from the gully onto the fan, concentrated in the early part of the short summer when the fan material onto which the flow discharges is still completely frozen. The stream flow spreads out over the frozen surface of the fan, resulting in rapid deposition of its bed and suspended loads. The upper part of the fan is composed of relatively coarser material resulting from the deposition of heavier sand particles and more resistant fine-grained sandstone pebbles. The soils in the lower third of the fan are made up of predominantly silt-sized particles with few, if any, pebbles.

After deposition on the fan, further alteration of the material is possible, and if so, it appears to be associated with organic material. Examination of the character of the near-surface deposits in areas of bare, fresh soil and in some of the grass and sedge meadows on the fan, as well as discussions with botanists who have visited the Mackenzie Delta, suggest that only sedges and grasses can be considered as potential factors in any further breakdown of the material, if such occurs. (The presence of undecomposed twigs of alder and willow in the boreholes to considerable depth tends to confirm the negligible effect of these larger organic features.) The sedges, predominantly *Carex aquatilis Wahl*, and grasses grow rapidly in the short but warm summer and