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CANADA

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BY

J. A. PIHLAINEN, R. J. E. BROWN AND G. H. JOHNSTON

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PREFACE

During the summer of 1953, the Permafrost Research staff of the Division of Building Research carried out an extensive investigation of soil conditions at Aklavik, N.W.T. This program was carried out jointly with the Department of Northern Affairs and National Resources, in conjunction with the construction of a 10-room school and an 8-apartment teacherage. The investigations revealed that the soils at Aklavik are silts and fine sands having an extremely high ice content that makes construction costly. In view of an anticipated large Government construction program at Aklavik, this information formed part of the basis for considering the relocation of the town.

At the request of the Department of Northern Affairs, personnel from the Permafrost Research Station, together with other interested federal departments, formed a survey team to gather field information during 1954 on the possibility of locating a more suitable townsite in the Mackenzie River Delta. Mr. C.L. Merrill, Department of Northern Affairs and National Resources, was leader of the team.

All information collected during the survey has been reported to the Department of Northern Affairs and National Resources in unpublished reports of the Division of Building Research. In view of the growing interest in the Mackenzie River Delta region, it was thought advisable to summarize this information. This report presents the first compilation of soils data for the Mackenzie River Delta region. Comments and additional information will be welcomed by the Division.

Ottawa,
October, 1956.

R.F. Legget,
Director.

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SOILS IN SOME AREAS OF THE MACKENZIE RIVER DELTA REGION

by

J.A. Pihlainen, R.J.E. Brown
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I. THE MACKENZIE RIVER DELTA REGION

More than 100 miles before it empties into the Beaufort Sea, the Mackenzie River divides into a series of channels that flow through its delta (Fig. 1). Unlike a typical delta which fans out from its source, this one is long and narrow, approximately 100 miles long and 50 miles wide. Its shape is controlled by the adjacent upland and curves from the south to the northwest. On the west, the steep fault scarp of the Richardson Mountains rises abruptly and confines the delta plain. These mountains extend to the northwest and are predominantly sandstone and shale of the Cretaceous age. The east side of the delta is confined by the Caribou Hills, morainic hills, and extensive exposures of Palaeozoic limestones, sandstones, and shale.

At the southern extremity of the delta, near Point Separation, the Mackenzie River divides into three major channels. The main or Middle Channel flows through the middle of the delta, and the Peel Channel branches from the Middle Channel and flows down the west side. Approximately half-way to the coast, the Peel Channel becomes the West Channel. The town of Aklavik is situated on a sharp bend in the Peel Channel, 3 miles upstream from the beginning of the West Channel. The East Channel branches from the Middle Channel and flows down the east side of the delta.

These principle channels are interconnected by many meandering smaller channels, forming numerous islands and thousands of lakes. The banks are low, built of alluvial material and forested with spruce and willow. Northward from Aklavik, the banks diminish in height, forest growth decreases and finally disappears.

Camsell and Malcolm report that the Mackenzie River is characterized by the comparative purity of its water, and because it carries relatively little sediment for its size, its delta is not being built up as rapidly as that of its great counterpart, the Mississippi (1). The large lakes within its drainage basin not only act as sedimentation basins but also serve to regulate the flow of the stream. Its volume, therefore, does not show much seasonal variation. Rough measurements by McConnell place the discharge at a medium stage of water at about 500,000 cubic feet per second.

Continued weather data for the region have been confined to observations at Aklavik, and show a mean annual air temperature of 15°F. with a July mean of 56°F. The mean annual rainfall is 4 inches and the mean annual snowfall is approximately 5 feet (Fig. 2).

II. DELTAIC SOILS

SCOPE OF REPORT

The relatively incomplete knowledge of the soils in the delta region of the Mackenzie River necessitates the reporting of data based on a geographical rather than a physical division of the region. Although a broad division of the region into two physical units, i.e., the delta proper and the adjoining upland, is possible, further subdivision must await more detailed soils information.

Soils and soil conditions typical of the delta proper are described first. Most of this information was collected during 1953, but data obtained in succeeding years also are included. Soils information also is given on areas investigated on the western edge of the delta along the Husky Channel and farther north.

On the eastern edge of the delta, detailed exploratory soil surveys for the Aklavik Relocation Project were carried out at two potential townsite areas approximately 35 miles east of Aklavik. Notes on soils at Kittigazuit and in the Caribou Hills, are also included. Wherever it may prove helpful, soil information is augmented by typical aerial photographs, borehole logs, and ground photographs.

TOPOGRAPHY AND VEGETATION (3)

The Mackenzie River Delta is characterized by a flat plain, with many meandering channels and numerous lakes. Bank erosion is severe so that undermined trees are a frequent sight along the channels. In spite of a gradual diminution in the size of spruce trees from south to north, the timberline is abrupt at about 68° 45' north latitude (2). Each year during break-up the Mackenzie River rises in flood; excess water overflows from the channels into the deltaic lakes causing favourable conditions for marsh vegetation.

Many stretches of balsam poplar border the waterways. Poplars in this climate are more stunted than spruce, and paper birch is virtually absent. Other plants, such as sedges, low and high willows, and alders form a definite zonation on the inner banks of the channel meanders. These are reflected in air photographs by grey colour tone changes.

SOILS AND PERMAFROST

During 1953, 16 boreholes (average depth 25 feet were drilled at the proposed sites of some large buildings in Aklavik. Although only this one location in the delta was investigated, the results of sampling and testing approximately 300 soil samples suggest that the data are representative of the delta.

Soil at Aklavik, to a depth of 35 feet, is predominantly a series of stratified fine sands, silts, and organic material. The absence of coarser particles was remarkable; not even a pebble was encountered in the 16 drilled holes. Organic material ranged from black, hairline streaks to strata 2 feet thick and was composed of a heterogeneous mixture of decomposed and partly decomposed matter. Plastic soils were scarce and, when found, were usually associated with organic deposits. Ice segregation in these fine-grained soils consisted mainly of horizontal ice lenses (in thickness from hairline to 3/4 inch), although small, random vertical ice formations were also observed.

Grain Size Distribution

The grain size distributions for 95 samples tested fall between narrow limits, and almost all grain sizes are below the No. 60 sieve size. The limits of grain size distribution, representative samples, and the frequency with which they occur are shown in Fig. 3. Soils in the silt size occur most often and the absence of coarse or medium sand particles is notable.

Ice Contents

Generally, the form of ice in the delta soils observed was of two types:-

(1) ice which bonded individual particles but was not always discernible to the unaided eye; and

(2) ice which segregated or formed layers, lenses, and dikes, from hairline to 3/4 inch in thickness.

The ice contents (per cent of ice to dry soil, on a weight basis) plotted at sample depths are shown in Fig. 4. These data were analysed by statistical methods and it was found that for the first 10 feet, ice content varies linearly with depth, or

$$Y = 172.11 - 12.35\ X$$

where Y is the moisture content in per cent at X, the depth of the sample from the ground surface, in feet. The correlation ratio for this regression is low however, and should be used only as an approximation.

Ice contents at depths greater than 10 feet are "statistically" constant at 54 per cent (Fig. 4). This depth is too low to be the limit of yearly thaw and refreeze, but could be the depth at which yearly temperature effects are no longer felt or reflected by ice formations in the soil.

Unit Weights

The mass and dry unit weights of some typical delta soils are shown in Table 1.

The results, averaging 92 lb/ft^3 and 52 lb/ft^3 for the mass and dry unit weights respectively, are relatively low. For example, typical unit weight values for thawed, loose uniform sand in the natural state are 118 lb/ft^3 in the saturated state and 90 lb/ft^3 in the dry state. Only one sample (AB15-12, Table 1) approaches these values. The low unit weight values are explained by the expansion due to freezing of water, the high ice contents, and the presence of bulky but lightweight organic material.

TABLE 1

Unit Weights of Some Aklavik Soils

Sample number	Soil description	Moisture content %	*Dry unit weight lb/ft^3	*Mass unit weight lb/ft^3
AB15-12	Sandy silt	54	76	116
AB1-7	Silt with trace of fine sand and some clay	63	59	96
AB1-23	Silt with organic material	62	54	88
AB1-22	Silt and stratified organic material	69	53	90
AB6-2	Organic material with silt	43	51	73
AB1-9	Silt with clay and organic material	87	47	88
AB3-3	Silt and stratified organic material	87	47	87
AB6-6	Silt with some fine sand	117	41	88
AB3-8½	Silty sand with organic material	150	39	98
		Average	52	92

* The mass unit weight is the weight per unit volume of a soil in its natural state; the dry unit weight is the "dried" weight per unit of original volume.

Plastic Soils in the Delta

Plastic soils were scarce at Aklavik; the ones noted in Table 2 were all that were encountered. Average values for the liquid and plastic limits were 38.0 and 28.4 per cent; the plasticity index averaged 9.6 per cent. All natural moisture (ice) contents are in excess of the liquid limit, i.e., although the soil has a solid form when frozen, it is transformed into a "liquid" or "slurry" if the contained water melts.

TABLE 2

Atterberg Limits of Some Aklavik Soils

Sample number	Natural moisture content %	Liquid limit %	Plastic limit %	Plasticity index %
AB1-5	62.5	39.8	28.9	10.9
AB3-5	123.1	37.3	26.9	10.4
AB4-23	48.6	37.9	32.0	5.9
AB5-10	45.8	39.0	29.1	9.9
AB6-5	91.4	39.4	26.9	12.5
AB6-7	66.6	38.8	29.2	9.6
AB6-20	55.0	40.4	29.7	10.7
AB12-26	55.8	36.8	27.5	9.3
AB16-21	48.1	33.2	25.6	7.6
	Average	38.0	28.4	9.6

Organic Contents

Present methods of reporting organic contents in soils are based on a weight basis, i.e., the organic content is defined as a ratio of the weight of combustible material to the weight of incombustible material expressed as a percentage. Since the difference in relative weights of organic material and mineral particles is large, organic contents expressed as percentages are low. Furthermore, significant visual differences in organic contents are not reflected proportionately in the results of organic content test. Thus the organic content of a sample described as a "mixture of flakey and stringy dark-brown to black organic material, well bonded with ice but with no visible ice segregation containing small pockets of silt" was 19.1 per cent Another sample described as "silt, one foot from ground surface, with no organic material discernible visually" had an organic content of 8.4 per cent.

III. WESTERN EDGE OF MACKENZIE RIVER DELTA

Soil investigations along the western edge of the Mackenzie River Delta region were conducted in two general areas during 1954:

(i) On the alluvial fans of the Richardson Mountains approximately 12 miles southwest of Aklavik and parallel to the Husky Channel (Fig. 5); and

(ii) Approximately 25 miles north of Aklavik immediately adjacent to the West Channel area where the Richardson Mountains' benchlands intercept the channel (Fig. 9).

HUSKY CHANNEL AREA

The Husky Channel area is approximately 12 miles south-west of Aklavik and 2 miles west of the junction of the Husky and Peel Channels. Access to the region is by the Husky Channel, approximately 300 feet wide (Fig. 5).

A camp was established in this area to carry out site investigations in an attempt to locate a townsite and airstrip (Fig. 5). Using air photographs the area was subdivided into three distinct landforms: the Richardson Mountains; the alluvial fans of the Richardson Mountains; and the delta of the Mackenzie River (Fig. 6). The boundaries of these landforms were located in the field and soil sampling was carried out at selected or representative portions of each landform. The Mackenzie River Delta landform was not sampled in this area because of its similarity to the Aklavik area which was sampled during the previous year.

Field reconnaissance confirmed that the alluvial fans of the Richardson Mountains were similar to those farther south, so that reliable predictions of any fan could be made on the findings of the fans investigated. Thus the area actually covered was about 8 miles long by 1½ miles wide.

Richardson Mountains

The Richardson Mountain landform is of interest because it supplied the material for the alluvial fans. In this area, the Richardson Mountains have a north-south trend and lie 2 to

3 miles west of the Husky Channel whose course is generally parallel to the mountains (Fig. 7). The mountains rise approximately 2,000 feet above the delta although Black Mountain, 10 miles south of the investigated area, rises over 2,800 feet.

The mountains are comprised mainly of sandstone, shale, and conglomerate, in either a weakly or strongly cemented state. Frost action seems to play a large part in the erosional process as shown by the many frost cracks and foliations in the exposed bedrock. West of the camp at an elevation of 1000 feet, abundant fossil imprints of cretaceous pelecypods and brachiopods were observed in the weathered shaley conglomerate.

One reference only can be made to soil conditions since the observations were made in winter. Soil slumps were noted at an elevation of 800 feet on a north-facing ridge west of the camp. The almost vertical slip faces were spaced about 10 feet apart and ranged in height from 2 to 6 feet. The soil was a light brown silt with friable "mudstones" in the top 2 feet with streaks and flakes of organic material throughout the face of the exposure.

Low-Lying Richardson Mountain Area

An area which appears superficially similar to the Richardson Mountains but which is lower in elevation begins approximately 2 miles north of the camp. It has been found to differ distinctly from the alluvial fans and the deltaic deposits. This landform has been called the low-lying Richardson Mountain area.

Topography and Vegetation

The area, a series of flat bench or "plateau-like" projections of the mountains, was covered with frost mounds averaging 2 feet in diameter and 8 inches in height. Vegetation consisted of sphagnum and reindeer moss, Labrador tea, wintergreen, and knee-high brush.

Soils and Ice Segregation

A drill hole (AB20) was advanced to a depth of 22 feet between the two lakes shown in Fig. 6. At the drill hole location

10 feet above the lakes, the soil for a depth of 12 feet is a silt clay of intermediate compressibility. Decomposed organic material and roots of hairline thickness occur in the silt-clay from the surface to a depth of 7 feet.

Ice segregation in the first 7 feet consists of lenses varying in thickness from hairline to 3/16 inch, averaging 1/16 inch. From 7 to 12 feet ice segregation is predominantly composed of large individual horizontal lenses up to 3/4 inch thick.

From 12 to 17 feet the soil is a silt clay of intermediate compressibility with angular and subrounded friable "mudstones" up to 1 inch in diameter. At the 17 foot depth, a reddish-brown silty clay (resembling a glacial till) with unsorted angular and subrounded stones was encountered. Although the material was described in the field as "unfrozen" because of no apparent ice, it may have been below 32°F. It was possible to break the core by hand although the material was compact and dense. The hole was abandoned at the 22-foot depth because drill penetration was very slow and hard on equipment.

Alluvial Fans

The alluvial fans in the Husky Channel area form a north-south band, 1 to 3 miles wide at the base of the Richardson Mountains. The deposition of fan material is confined mainly to the spring when melt water from the Richardson Mountains reaches the almost level grade of the fan. The changing courses of the creeks are reflected by the vegetation and gentle slope of the fans. Heavy willow thickets stand side by side with open grassy areas, depending on the past history of the creeks. In general, the first impression of the alluvial fans is that of a gently tilted plain with random streaks and blotches of low vegetation and scrubby brush.

Vegetation

The alluvial can be subdivided into two distinct types on the basis of vegetation. For convenience these two types of fans will be referred to as:

(a) brush covered fans; and

(b) forested fans.

(a) Brush Covered Fans: Vegetation on a brush covered fan consists of willow and alder thickets (maximum 15 feet high), open grass meadows, grass tussocks, sphagnum moss with patches of reindeer moss frequently covering frost mounds 1 foot high. The vegetation seems to trace the past movements of the supporting creeks and this gives the fan a "braided" appearance when viewed from the air or on aerial photographs.

(b) Forested Fans: Vegetation on the forested fans is essentially similar to that on the previously described brush covered fan, with the addition of spruce trees which reach a maximum height of 25 feet. The "concentration" and average over-all height of vegetation exceeds that on the brush covered fan and hence the braided effect from the air is more pronounced (Figs. 8 and 9).

Topography

The alluvial fans occupy a position between the Richardson Mountains and the low-lying delta plain. Aerially, they appear as a slightly tilted plain. The merging of the fan into the deltaic deposits is imperceptible and generally only discernible by vegetation changes.

Two distinct grades were observed on the fans investigated (Fig. 10). The first is a relatively steep grade which extends downward from the base of the mountains for a distance of one-third to one-half the length of the fan. This grade was 1.9 per cent on the campsite fan and 6.1 per cent on the forested fan. The second grade to the deltaic deposits is longer and lower, 1.3 per cent of it on the campsite fan and 2.3 per cent on the forested fan.

The ground relief is characterized by the following phenomena: polygons in local depressions surrounded by peripheral mounds up to 5 feet high; polygonally oriented cracks with depths measured in inches enclosing areas 30 feet in diameter; creek levees up to 5 feet high; and frost mounds up to 5 feet in diameter and 1 foot high.

Soils and Permafrost

As expected, the soils of the fans show characteristics of the weathered portion of the Richardson Mountains from which they have been derived. Thus, the campsite brush covered fan derived from the adjacent mountain material of friable shale and sandstone, is composed predominantly of a light-brown, silt-sized soil with varying amounts of organic material, thin layers (1 inch to 1 foot thick) of friable "mudstones", and some more resistant sandstone pebbles. This point is more strikingly shown by the forested alluvial fan investigated which, built up by gullies containing thick beds of a reddish conglomerate, has a surface layer of reddish soil.

Grain Sizes: More than half the thirty samples tested for grain size distribution had particles smaller than the medium sand size (0.06 mm.). Although pebbles up to 1 inch in diameter were noted in the field, these broke down into coarse to fine sand sizes when soaked in water.

Grain size distribution limits or "envelopes" are shown in Fig. 11. Samples from the toe of the brush 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 forested fan (with a higher surface grade) show a grain size distribution envelope similar to the top of the brush covered fan except that more silt and clay-sized particles are present.

Ice Segregation: Ice segregation in the alluvial fan was predominantly horizontal layers or lenses ranging in thickness from less than 1/32 inch to 3/4 inch. The over-all average moisture content of ninety-four samples to a depth of 38 feet was found to be 81.1 per cent with a standard deviation of 55.4 per cent. The mean moisture contents for the various drill hole locations did not differ significantly for a confidence level of 99 per cent. This is due to the large scattering or range of the moisture contents.

Black Mountain

The section of the Richardson Mountains west of the Husky Channel is divided by local inhabitants into two sections - Red Mountain and Black Mountain. The Red Mountain area, characterized by reddish shale and sandstone conglomerates, extends from north of the brush covered alluvial fans to about 2 miles south of the forested alluvial fans. The most prominent landmark of the Black Mountain area is a high promontory rising over 2,800 feet above the delta. Between Black Mountain and the delta is the continuation of the series of coalescing alluvial fans extending eastward to the Husky Channel.

The face of Black Mountain indicates that it consists of horizontal strata of buff- and darker-coloured sandstone and shale. The cap rock of the mountain is resistant sandstone below which are long steep talus slopes. The top of this mountain area is smooth and almost undissected. There is a gradual decrease in elevation to the west where the land becomes slightly undulating.

The soil cover formed in situ on the top of the mountain is only a few inches thick over bedrock. It consists of a mixture of fines with many angular and subangular stones of sandstone, shale and granite. The vegetation is grass a few inches high, and moss. There is enough forage to support a flock of Dahl mountain sheep.

The exposed rock on the steep face of Black Mountain is fractured by frost action. Further down on the colluvial slopes are evidences of earth slides and ripple-like soil lobes. In the stream beds at the base of the mountain are angular shale and sandstone boulders several feet in diameter.

On the alluvial fans below Black Mountain is an area of knobby hills about 60 feet high covering about 1 square mile. They support spruce trees up to 40 feet high, generally larger than those on the forested fans to the north. Other trees include willow, poplar, and alder. The ground vegetation consists of a thick cover of green sphagnum moss and low-lying broad-leafed plants.

On the side of one of the knobby hills, a landslide occurred exposing some massive ground ice under overhanging vegetation. The ice forms several parallel bands about 1 foot thick lying almost horizontally. The soil is a silt and clay mixture with random pebbles, and a large angular boulder 2 feet in diameter was observed (Fig. 12).

Among the knobby hills is a network of stream channels where water is either flowing or ponded in local flat areas. The top few inches of the silty soil are thawed; below this the ground is frozen. The streams are loaded with fine-grained sediments. The vegetation in these low areas is coarse grass up to 2 feet high.

In the area of knobby hills are several "pingo-like" structures of which three were examined (Fig. 13). One is part of a spruce covered knobby hill, and resembles a pingo consisting of friable stratified grey silt and fine sand. The west side is about 20 feet high, the east side about 60 feet high, and the sides have a slope of 30 degrees. The crater contains a circular lake 40 feet in diameter and 20 feet above the level of the alluvial fan. The vegetative cover consists primarily of coarse grass 2 feet high, and a few stunted spruce growing on the sides of the hill and on the lip of the crater.

A second structure of silt was examined at the base of Black Mountain. It is saucer-shaped about 4 feet high at the rim and gradually sloping in to the centre from all sides. Its dimensions are approximately 50 feet (north-south) by 35 feet (east-west). There is a circular crack along the rim about 2 feet wide by 1 foot deep. In the centre is a circular lake about 25 feet in diameter. There are two run-off trenches at the south end and a small stream bed leads in from the north.

The third structure resembles the one just described. There is a ridge around the outside about 100 feet in diameter, varying in height from 4 feet on the east side to 12 feet on the west. The soil is silt with angular stones of sandstone and shale up to 6 inches in diameter. The vegetation consists of scattered, stunted spruce 6 feet high, and coarse grass 2 feet high. Water from the lake in the centre overflows into a low part of the ridge to the east. It is coloured a bright rusty-red by algae.

The origin of the area of knobby hills at the top of the alluvial fans below Black Mountain is uncertain. One theory suggests that it may be the result of soil slides from the steep face of the mountain.

WEST CHANNEL AREA

The West Channel area is situated approximately 24.5 air miles (28.2 channel miles) north of Aklavik immediately adjacent to the West Channel area where the Richardson Mountain benchlands intercept the channel. The area investigated was approximately 3 miles long bordering the channel, by 1½ miles wide inland to the west of the channel (Fig. 15). To the north and south, it is separated from the channel by deposits of the Mackenzie Delta.

Local Relief

The benchlands bordering the West Channel, rise in a fairly steep bank varying in height from 10 to 40 feet. To the west there is a slight but continual rise in elevation within which the local relief is undulating to rolling with scattered low-lying flat depressions, swales, and rounded knolls (Fig. 15). A network of shallow V-shaped gullies cuts through this country. Although there are minor local differences in relief, drainage, vegetation, and other features, the benchland area is generally homogeneous and will be considered as such in this discussion.

Bedrock Outcrops

The underlying bedrock is exposed in a few scattered outcrops approximately 2 miles inland from the West Channel and does not affect directly the nature of the site (Fig. 14). One of the outcrops forms a series of subdued ridges extending away from, and perpendicular to, the sides of the gully. Another is a localized outcrop, a few square yards in area, on the side of a hill.

The rock is grey sandstone. It is not well cemented as individual grains can be scraped off easily. The surface rock has been fractured into large rectangular blocks and smaller fragments by frost action. No rock outcrops were seen anywhere along the shore of the West Channel in the vicinity of the investigated area.

Drainage

The area drains to the West Channel through a roughly parallel series of shallow V-shaped gullies (Fig. 14). Where the site area borders the channel, there are three main gullies that enter the channel approximately 3/4 of a mile apart. Between these are several much smaller gullies.

The major gullies vary in depth from 20 to 50 feet, and become shallower toward the headwaters of the streams cutting them. The streams flow at approximately 10 miles per hour; the water is clear, indicating a lack of suspended soil material. It is probable that they diminish in size or even dry up later in the summer when the snow has disappeared from the higher land to the west. The presence of willow and alder thickets in the stream beds appears to substantiate this.

There are only a few small shallow lakes in the area, the largest being about 300 yards in diameter; they drain through the gullies to the West Channel. Generally, the lakes lie in poorly drained depressions whose surfaces are covered with polygons. The water in these lakes is coloured with iron salts and organic material.

Ground Surface Features

(a) Shore Deposits

There is a thin layer of gravel lying along the shore of the West Channel where it flows adjacent to the site area, that appears to have been washed out from the bank above it. The rounded and subrounded stones are of sedimentary and igneous origin and range up to approximately 6 inches in diameter.

(b) Polygons

Polygons and polygonal cracks are prevalent throughout the site becoming more numerous inland from the West Channel. In most cases they are associated with the poorly drained areas around the lakes and headwaters of the streams.

There are both depressed and raised centre polygons varying in diameter from 20 to 50 feet. The interstices vary in width from a few inches to 3 or 4 feet and are filled with water. The centres of the depressed centre polygons are partially filled with water. In some cases where there are polygonal cracks rather than well defined polygons, they are defined by shallow moss-filled trenches.

(c) Frost Mounds and Frost Boils

Apart from the areas of polygons and polygonal cracks, most of the site area is covered with frost mounds, frost boils and grass tussocks. The mounds vary in diameter from approximately 2 to 4 feet and rise approximately 1 foot above the bottom of the interstices.

(d) Soil Slumping

Many of the slopes exhibit areas of soil slumping. These slumps are especially pronounced on the slopes of the deeper V-shaped gullies 2 to 3 miles inland from the West Channel.

Individual slumps are generally 2 to 3 feet in height and are especially prominent on the slopes facing north. The slumps are covered with a ground vegetation of grass and moss.

Vegetation

The main feature of the vegetation in this area is the comparative lack of tree growth. Tree growth is confined to sheltered gullies and is densest on the south-facing slopes and along the water courses. The trees are willow and alder reaching a maximum height of approximately 8 feet. Interspersed with this thicket growth is ground birch to a height of about 3 feet. In the deeper gullies, 2 to 3 miles inland, are parallel lines of this mixed tree growth extending from the tops of the gullies down-slope to stream beds containing willow and alder thicket. As the gullies become shallower toward the headwaters of the streams, the trees become more stunted.

The ground vegetation throughout the area is generally uniform, typical of the Arctic tundra. It consists of closely-spaced grass tussocks, reindeer and sphagnum moss. Other plants include Labrador tea and some flowering and berry plants. There are areas of ground birch, dwarf alder, and willow, attaining heights of 2 to 3 feet.

Snow Cover

The snow cover of this site area reaches a maximum depth of 3 to 4 feet and is characteristic of the Mackenzie Delta and adjacent upland regions. The area extends in a north-south direction and is devoid of any tree growth except in the sheltered gullies. The snow cover is modified therefore, by the prevailing wind, which sweeps across this area from the north.

Generally, the higher areas between the gullies are covered with snow to a depth of 1 to 2 feet, the surface of which is packed and glazed by the wind. Heavy drifts of snow accumulate in the gullies especially on the south-facing (i.e. north) slopes, which are oriented in a perpendicular direction to the prevailing wind. Some sections of the gullies are completely filled with snow. The snow cover on the ground between the gullies usually is melted by the third week in June but the heavy drifts on the north slopes of the gullies remain until late July.

Soils Data

Accessibility of the site and distance to a source of wash water dictated the location of the exploratory boreholes on this West Channel site. Since the area closest to the channel consists of low hills sloping gently upwards from the channel and dissected by several shallow V-shaped gullies, it appeared that drill holes placed in a low spot and on top of a ridge would indicate, generally, the soil conditions of the whole area.

Both a low and a high spot were adjacent to the camp-site located in the southern third of the proposed site area and next to the channel. The location of the two exploratory boreholes, AB28 and AB29, is shown in Fig. 14.

Core recovery averaged about 50 per cent in AB28 and about 33 per cent in AB29. Whenever stones are struck while drilling, poor core recovery may be expected.

Borehole AB28 was drilled, in the low area, to a total depth of 32 feet. From the ground surface to a depth of 10 feet, the soil is a blackish-brown organic material, fibrous in structure with undecomposed material and twigs up to ½ inch in diameter. Ice segregation, when discernible, is in the form of fine ice lenses parallel to the ground surface and averaging less than 1/32 inch in thickness.

Between 10 and 19 feet below the surface the soil is a light brown silt with many angular and some rounded stones up to 1 inch in diameter. Some layers of light brown medium-sized sand, and fine sand with pebbles up to 1/4 inch in diameter were noted. Ice segregation consists of irregularly oriented ice lenses ranging in thickness from 1/32 inch to 3/8 inch although discernible ice segregation was not noted in the sands.

Between 19 and 31 feet below the surface the soil is a brownish-grey silt clay of low compressibility with angular and subangular stones up to 1 inch in diameter.

The last foot, between 31 and 32 feet below the surface is a grey sandy silt with many subangular stones up to 3/4 inch in diameter. The slow rate of drill penetration here suggests that the material is relatively compact and dense.

Borehole AB29 was drilled on top of a knoll. From the ground surface to 4 feet below the surface the soil is an organic material similar to drill hole AB28.

Between 4 and 12 feet below the surface the soil is a brownish-grey silt clay of low compressibility with random specks of brown discoloration, some hairlike roots, and some pebbles up to 2 inches in diameter. Ice segregation consists of horizontal ice lenses averaging 1/8 inch thick. Between 12 and 22 feet, the soil is a grey sandy silt with many granite and sandstone stones 1/4 inch to 1/2 inch in diameter. Ice segregation consists of horizontal ice lenses averaging 1/16 inch thick.

IV. EASTERN EDGE OF MACKENZIE RIVER DELTA

Soil investigations were carried out at various locations along the eastern fringe of the Mackenzie River Delta. Exploratory soil surveys were carried out during 1954 at two locations east of Aklavik, East Three and East Four. Notes on soil conditions are included for Kittigazuit and the Caribou Hills, which are situated on the East Channel north of East Four.

EAST SITE FOUR

East Site Four is approximately 36 air miles (57.6 channel miles) northeast of the present town of Aklavik. The area investigated runs approximately 4 miles along the East Channel and extends inland for about one mile (Fig. 18).

Topography

The northern portion of the site is generally flat with terrace-like undulations rising to a gully at the east (Fig. 17). The southern portion is a series of rounded hills and knolls with a general rise to the northeast.

A striking surface feature of almost the entire area is the hummocky ground. Many hummocks are as large as 5 feet in diameter with separating trenches 2 to 3 feet deep. Some have frost cracks several inches wide while others are bare of vegetation and expose brown clayey-silt with some fine sand. Most of the hummocks have a vegetative cover.

Vegetation

Scattered birch up to 30 feet high predominate on the northern portion of East Four. The long slope with a terrace-like undulation rising to the gully at the east is covered predominantly with birch. Scattered spruce up to 30 feet high become more sparse up the slope. Most of the ground is covered with dense willow, alder, and ground birch. Many dead and burned trees, mostly spruce, were observed. The ground cover consists of hummocks and grassy tufts. The vegetation on the better drained areas in the southern portion of scattered knolls and swales is birch, up to 20 feet high, with scattered spruce. The undergrowth is dense ground birch and the ground surface is hummocky.

Soils Data

The locations of exploratory boreholes were dictated largely by the availability of wash water and accessibility. Fortunately, representative areas in the north and south portions of the area were close to the East Channel and back packing of sampling and drilling equipment over hummocky terrain and through dense undergrowth was kept to a minimum.

Exploratory borehole AB24 on the northern portion of the East Four area was advanced to a depth of 32 feet (Fig. 16). To a depth of 11 feet, the soil is a dark grey clay of intermediate compressibility with many small stones and random patches of undecomposed organic material. Between 11 and 30 feet the soil is a light grey clay of intermediate compressibility. Between 30 and 32 feet the light grey clay is compacted and dense with no discernible ice segregation.

Exploratory borehole AB25 on the southern portion of East Four area was advanced to a depth of 37 feet (Fig. 16). The soil is a greyish clayey-silt of low compressibility with some stones up to $\frac{1}{2}$ inch in diameter. At a depth of 18 to 20 feet there appears to be more stones up to 1 inch in diameter.

A bank of exposed soil was observed on the shore of Lake 3 (Fig. 16). Soil samples were obtained from a trench along the face of the exposure. The exposure is in a soil slumping area that occurs in many places along the eastern fringe of the lake. The trench at this location revealed the soil to be a series of sand, silt, and graded sandy gravel for the first 4 feet. From this depth down to approximately 16 feet the soil is a graded silty-gravel with boulders up to 18 inches in diameter. The observations were made in thawed soil and there were no water seepages.

Grain Size

Grain size distribution limits for the two borehole locations are shown in Fig. 18. Soil in the northern area has more clay-sized particles and is more compressible than that in the southern area. Considerable difficulty was experienced in attempting to disperse the soil during testing and many samples flocculated to such an extent that testing by the hydrometer method was not possible.

Ice Contents

In the northern area, soil for a depth of 10 feet has ice or moisture contents above the liquid limit of thawed soil. At depths greater than 10 feet, moisture contents are relatively low (average moisture content 23.5 per cent, standard deviation 7.2 per cent) and only slightly above the plastic limit of thawed soil. Ice segregation in the first 10 feet of soil is composed of horizontal lenses or ice layers varying in thickness from 1/32 inch to 1/8 inch. Below 10 feet, soil is well bonded or cemented by ice not discernible to the eye.

In the southern area, ice segregation, for a depth of approximately 6 feet, is in horizontal lenses or layers up to 3/4 inch thick. The ice contents are well above the liquid limit of the thawed soil.

Between 6 and 30 feet below ground surface, ice segregation is in irregularly-oriented layers varying in thickness up to 1 inch. Again, moisture contents are all considerably higher than the liquid limit of the thawed soil. At a depth between 32 and 37 feet (bottom of hole) moisture content tests show soil to be only slightly above the plastic limit of the thawed soil, although there were haphazardly-oriented ice lenses averaging 1/8 inch thick and spaced approximately every 3 inches.

Plasticity

In the northern area, the clays are of intermediate compressibility having an average liquid limit of 41.7 per cent (standard deviation 6.3 per cent) and a plasticity index of 20.4 per cent (standard deviation 7.2 per cent). In the southern area, the clays are of low compressibility having a liquid limit of 33.8 per cent (standard deviation 7.7 per cent) and a plasticity index of 16.1 per cent (standard deviation 4.5 per cent). Clays at both locations have activity values of less than 0.50 and are therefore in an inactive group.

EAST SITE THREE

An area 4 miles long, 34.5 air miles (70.7 channel miles) east of the present town of Aklavik was investigated during 1954. This general area was known as East Site Three and was later chosen as the new townsite for Aklavik (Fig. 19).

Topography

The area at East Site Three may be divided into three smaller regions (Fig. 20). The first, the northern region, consists of terrace-like steps which rise and finally merge with the upland. These steps are low, rounded, and separated by smooth swale-like depressions. The second is the middle portion of the area which is predominantly low and intermediate in elevation between the deltaic deposits and the "terraces" to the north. Large areas of undrained depressions are randomly interrupted by low rounded hills. The third is the southern region consisting of parallel, northwest-southwest rounded hills with large lakes between them.

Vegetation

Vegetation throughout the area is so varied that only generalities will be reported. Relatively steep slopes, such as the terraces of the north, Boot Creek Gully, and the parallel ridges, support birch growth. The "terrace" flats and lower slopes generally have sparse spruce growth with some birch and thickets. The middle-low region supports stunted spruce or thickets which merge into open areas of sphagnum and reindeer moss. Local depressions in all regions appear to merge into these open areas.

Soils Data

The inaccessibility of many portions in the area curtailed exploratory drilling. An exposure at Twin Lake suggested the occurrence of gravel in the northern portion of the area (Fig. 19). Accordingly, exploratory borehole AB26 was drilled on top of the steep slope north of Boot Lake. Gravelly material was encountered 2 feet below ground surface and as no samples are possible in gravel, the hole was abandoned at 14 feet 9 inches to avoid possible damage to the light drill rig. Exploratory borehole AB27 was subsequently drilled approximately 1/2 mile south of the gravel exposure. Gravelly material was again encountered after 2 feet of silt was penetrated. Again no sampling was possible and the hole was abandoned at 12 feet because of the possibility of damaging the drill rig.

Having proved the presence of granular materials, 24 test pits were located at anticipated construction areas of the site in an attempt to map and sample the soils. At first the test pits were advanced merely by removing the thawed soil periodically. In order to bring the test pits to a depth of at least 5 feet before the season ended, local labourers were hired to pick the remaining few feet of soil in unfinished pits. An engineering soils map was prepared based on the soils data obtained at East Site Three (Fig. 21).

Grain Size Distribution

The grain size distribution limits for four areas at East Three are shown in Fig. 22. The lower townsite "terrace" and its associated low knolls are graded gravels with fine sand or silt. In contrast, the upper townsite terrace soils are mainly silts with clay and some sand. The soils of the rounded ridges or "drumlinoids" of the Long Lake area are predominantly fine-grained and plastic. The extensive flats or low areas between the rounded ridges consist mainly of fine-grained soils with sand and gravel-sized particles.

Ice Contents

Ninety moisture or ice content samples were taken from various areas at East Site Three. The samples were taken to a depth of 5 feet and ranged from 20 to 1019 per cent. The attempt to correlate moisture content with depth, grain size, and form of ice segregation failed because variances were not homogeneous for a 95 per cent significance level.

Plasticity

Plasticity data for three locations at East Site Three are shown in Fig. 23. The plastic soils at East Three are predominantly silts or clays of low compressibility. The Long Lake ridges and flats have clay-sized soils of intermediate to high compressibility.

THE CARIBOU HILLS

The Caribou Hills extend for about 30 miles along the east side of the Mackenzie Delta about half-way between Point Separation and the Beaufort Sea. They form a steep southwest-facing slope overlooking the East Channel, and rise to their maximum height of between 500 and 600 feet south of Reindeer Depot. (Fig. 24).

Topography

The top of the hills extends eastward in a slightly rolling plateau which merges with the barren lands to the east. Northward, their altitude diminishes and they terminate against the undulating and hummocky tundra which stretches to the Arctic coast.

Vegetation

There are variations in vegetation on the Caribou Hills. In the gullies separating the faceted spurs of the hills are birch, alder, ground birch, berry plants, and moss. On the upper, gentler slopes are scattered willow, alder, and ground birch with a ground cover of reindeer moss and Labrador tea. The flatter areas have stands of white spruce up to 40 feet high, and scattered, stunted stands of spruce extend to the top of the hills. On top of the Caribou Hills, 500 feet above the delta, is tundra vegetation of reindeer moss, ground willow and alder, and other ground plant species.

Soils

The soil of the Caribou Hills consists of silty clay and fine sand with some pebbly or gravelly sand capping the hills locally. Beds of lignite and very thin layers of ironstone are exposed. Where the lignite has been burned out, reddened patches and bands appear on the steep hill slopes.

At the south end of the Caribou Hills, where the East Channel borders the steep southwest-facing slope, a traverse was made from the delta to the top. At the bottom of the hills, there is a sand beach with angular and subangular sandstones and claystones up to ¼ inch in diameter.

A steep bank of soil about 100 feet high with a 40-degree slope, rises from the beach. The only vegetation on this bank is a few scattered patches of grass near the top. On either side are similar banks, not as high, but covered with grass and a few stunted willow and alder shrubs.

The soil in these steep faces is a fragmented, brown clayey-silt with fine sand. On the surface of the steep bank covered in the traverse are scattered patches, several square feet in area and about 12 inches deep, of leached soil. In the banks are layers of crumbly sandstone and ironstone, and tiny concretions about ¼ inch in diameter filled with orange-brown sand. There are several rounded boulders up to 3 feet in diameter in the side of the bank. The soil is dry on the surface and moist beneath, which, combined with its crumbly nature, causes continual slumping.

Above these steep banks, the general slope of the hills is about 20 degrees. The soil consists of clay, silt, and sand-sized particles with rounded and subrounded stones of sedimentary and igneous origin. Near the edge at the top of the hills are several blowouts and washouts about 10 feet in diameter.

The origin of the Caribou Hills is not completely known, although several theories have been advanced. Dr. G.A. Kellaway, Geological Survey of Great Britain, suggests that the lower, steeper slopes consist of a shale core covered with residual soil formed in situ, or glacial drift of an epoch prior to the Pleistocene (4). The upper slopes consist of pleistocene glacial drift (personal communication).

KITTIGAZUIT

During the summers of 1953 and 1954 brief visits were made to an abandoned site at Kittigazuit, approximately 80 miles northeast of Aklavik on the east side of the Mackenzie River Delta north of the Caribou Hills. The main purpose of these visits was to investigate the conditions of footings for a 600-foot high tower which had been founded on permafrost.

Topography and Vegetation

The tower and camp buildings are located approximately one-half mile east of the East Channel. The banks rise sharply to a height of 100-150 feet along the East Channel and then slope steadily downward away from the Channel. Inland the general relief is undulating, with the depressions containing small lakes or low marshy areas (Fig. 25). The low areas are predominantly hummocky and poorly drained; shallow trenches filled with stagnant water separate the small mounds.

The camp buildings stand on a small knoll separated from the East Channel bank by a low-lying area. A prominent feature of this low area is the presence of large polygons, 20 to 40 feet in diameter. Vegetation throughout the area consists of grasses, mosses, and low brush with no tree growth.

Soils and Permafrost

The soil of the area is a fine grey silty-sand covered with black organic material from 9 to 18 inches thick. Frozen soil is first encountered from 9 to 36 inches below ground surface (August) depending on the moss cover. The high east bank of the channel is predominantly a fine- to medium-sized sand which, in places, has drifted into dunes.

CONCLUSION

The Mackenzie Delta and adjacent upland in which all these soils investigations were conducted, lie in the zone of continuous permafrost, approximately 500 miles north of the southern boundary of permafrost. Throughout this area, the summer thaw penetrates from only a few inches to 3 or 4 feet into the ground depending upon vegetation, soil type and other local factors.

These studies were made at locations selected for practical reasons. The investigations in the delta at Aklavik in 1953 were conducted to obtain data for the erection of a new federal school and teacherage. Since similar physical conditions prevail throughout the delta, it is assumed that the soils and permafrost conditions encountered at Aklavik are typical for the entire delta area.

Subsequent studies conducted during the summer of 1954 on the upland adjacent to the delta were made in areas selected as possible sites for the new town of Aklavik. Great variety was encountered in soils and permafrost (ice segregation) because of the differences in physiography, topography, and vegetation. Therefore, the data collected can be considered typical only of the immediate areas in which the investigations were conducted.

This study is a start in the collection of soils and permafrost data in the Mackenzie Delta area. It is the hope of the authors that this paper will stimulate further investigations in this important region of northern Canada.

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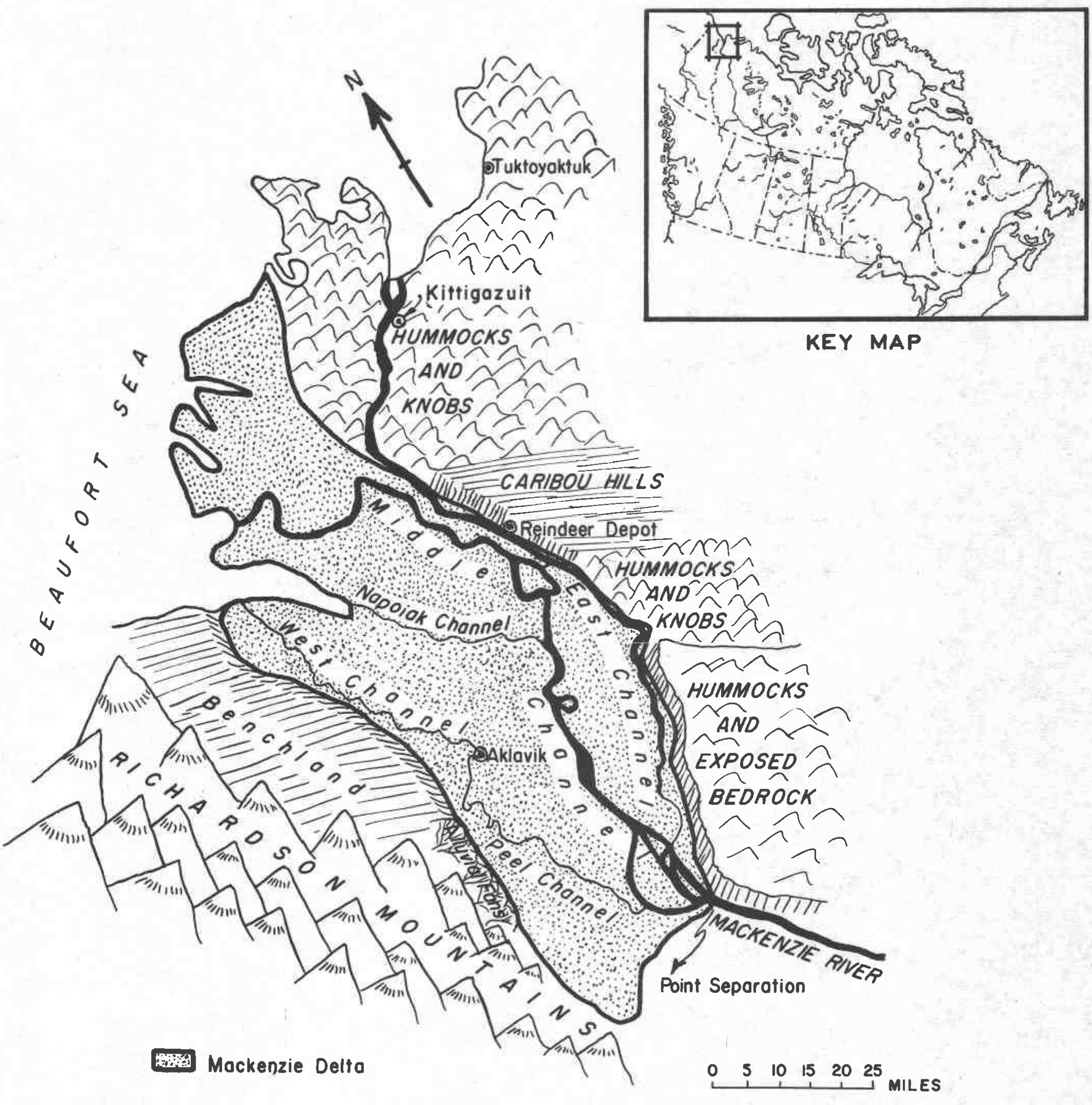


FIGURE 1

PHYSIOGRAPHIC DIAGRAM OF THE MACKENZIE DELTA AND ADJACENT UPLAND

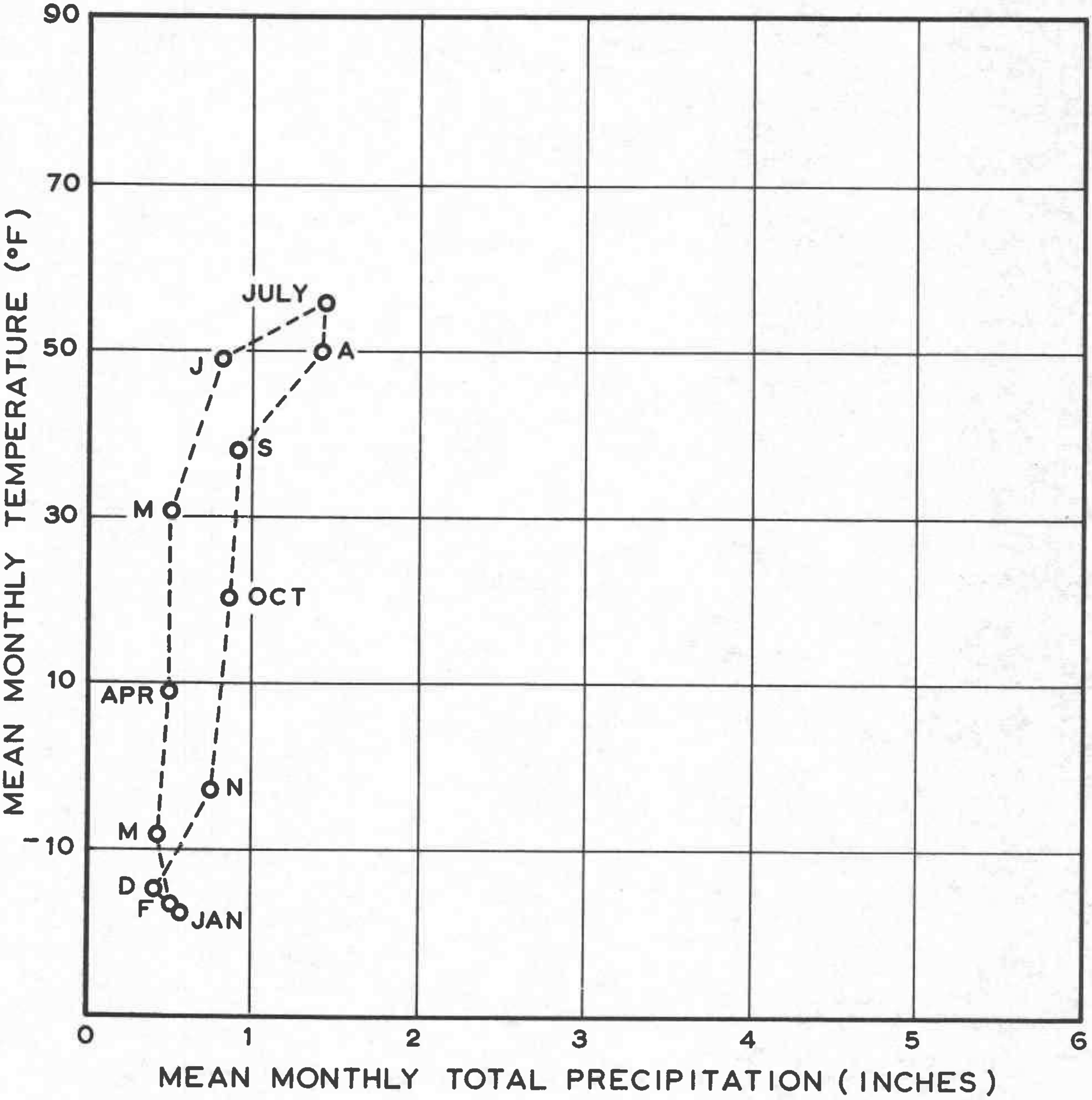


FIGURE 2

HYTHERGRAPH OF AKLAVIK, N.W.T.

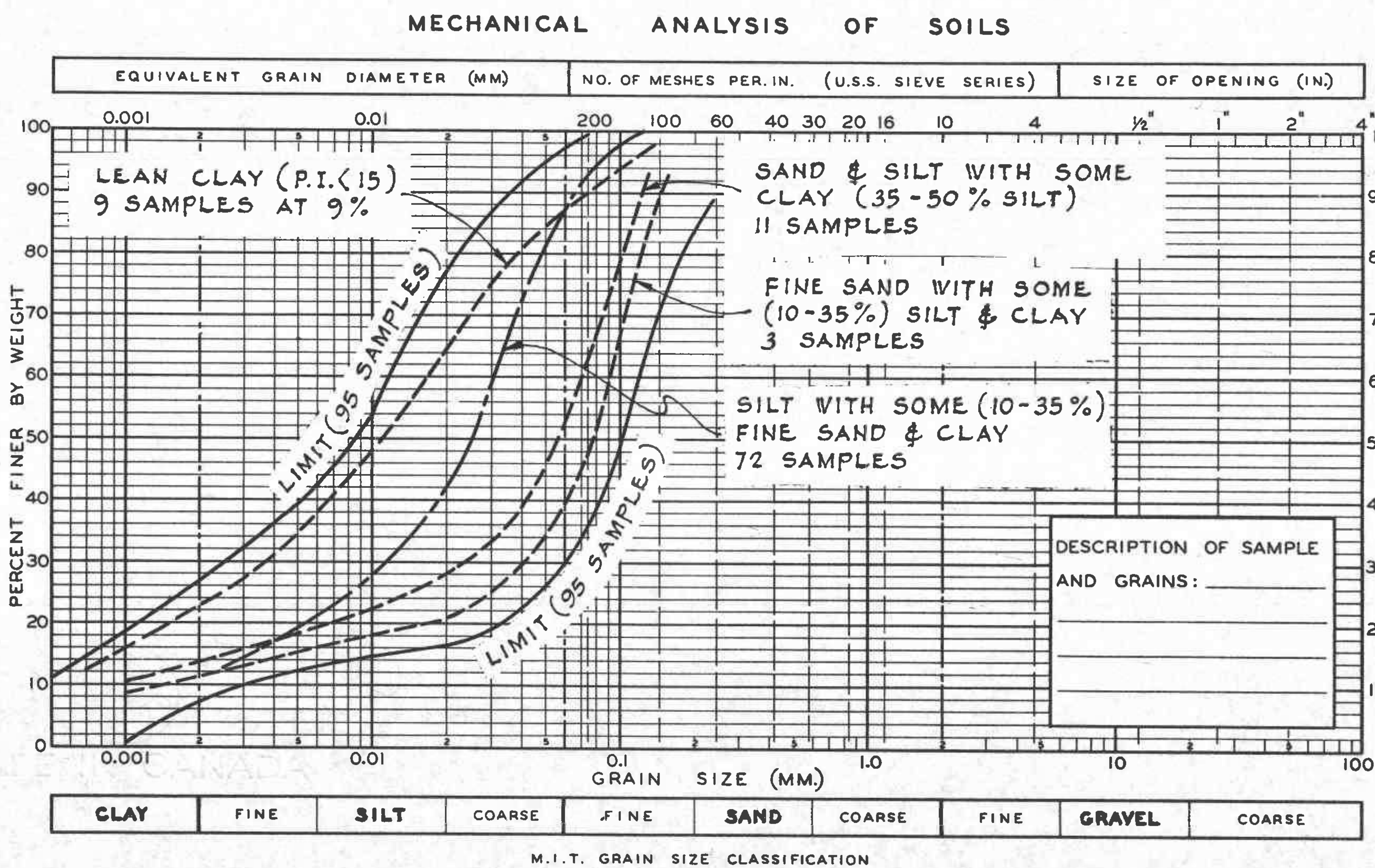


FIGURE 3 AKLAVIK PERMAFROST INVESTIGATIONS (1953)

REPRESENTATIVE GRAIN SIZE DISTRIBUTION CURVES, LIMITS, & FREQUENCY OF OCCURRENCE

D.B.R. TECH. PAPER No. 43.

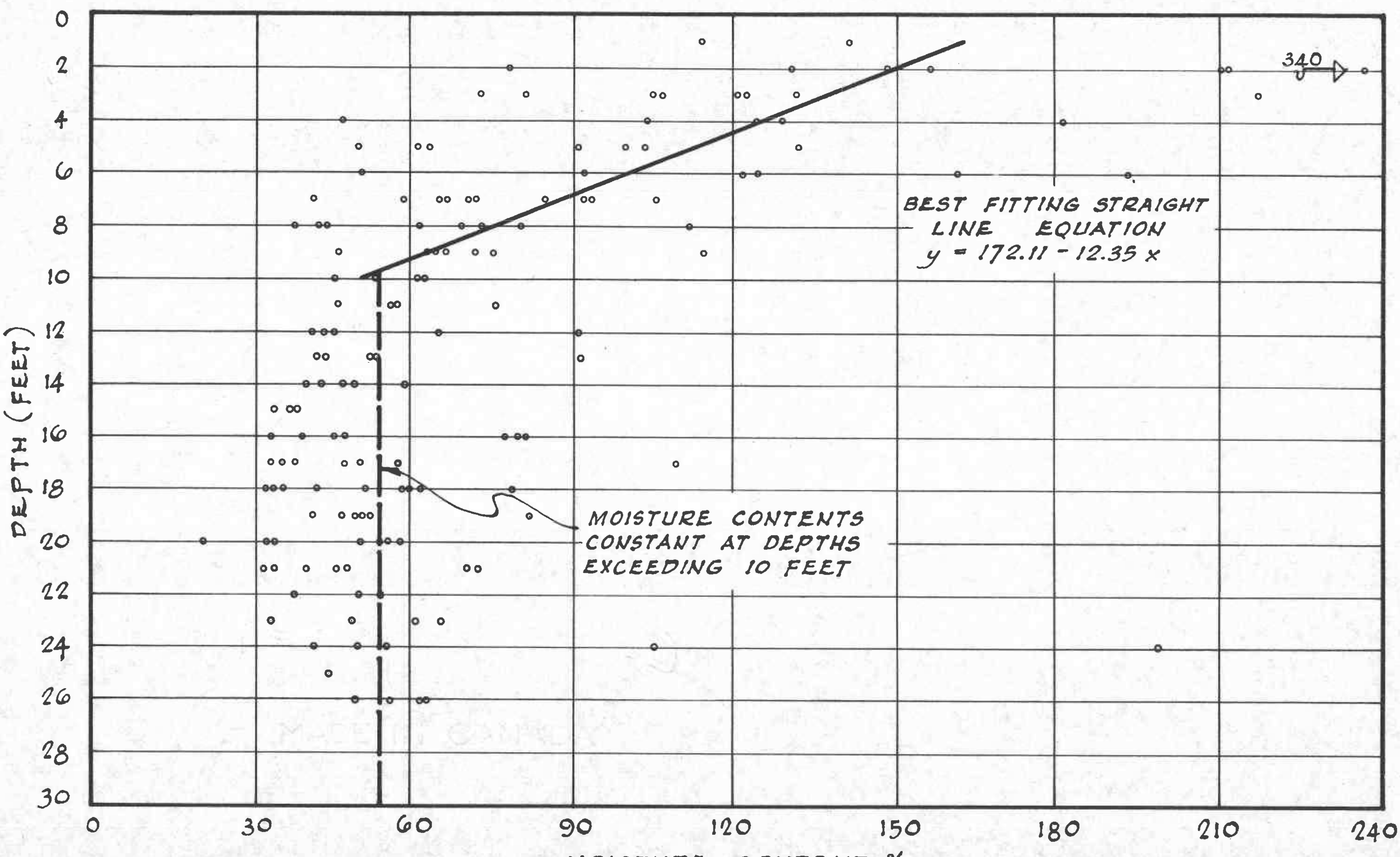


FIGURE 4

AKLAVIK PERMAFROST INVESTIGATION 1953 MOISTURE CONTENT VERSUS DEPTH

(16 HOLES, 153 SAMPLES)

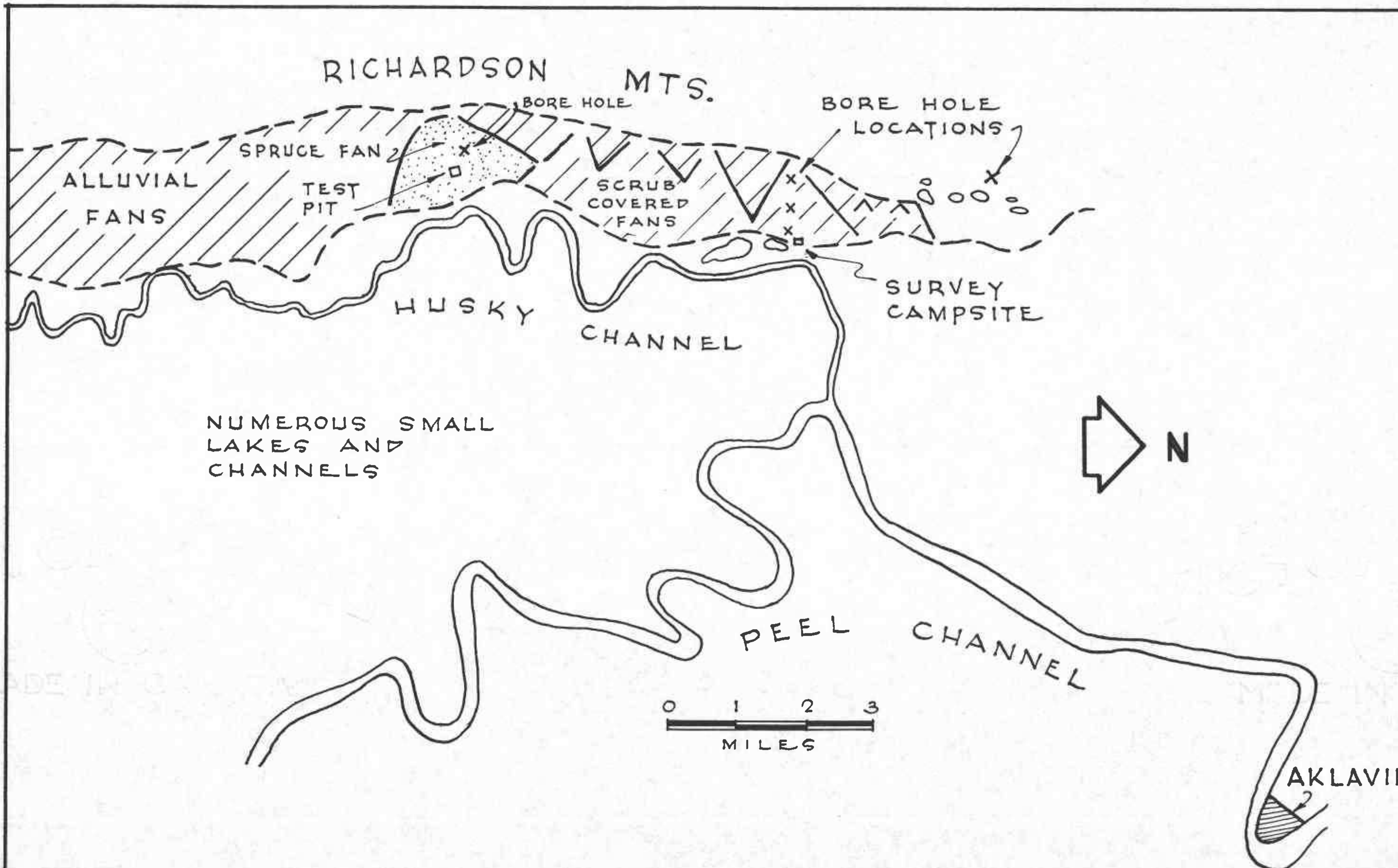
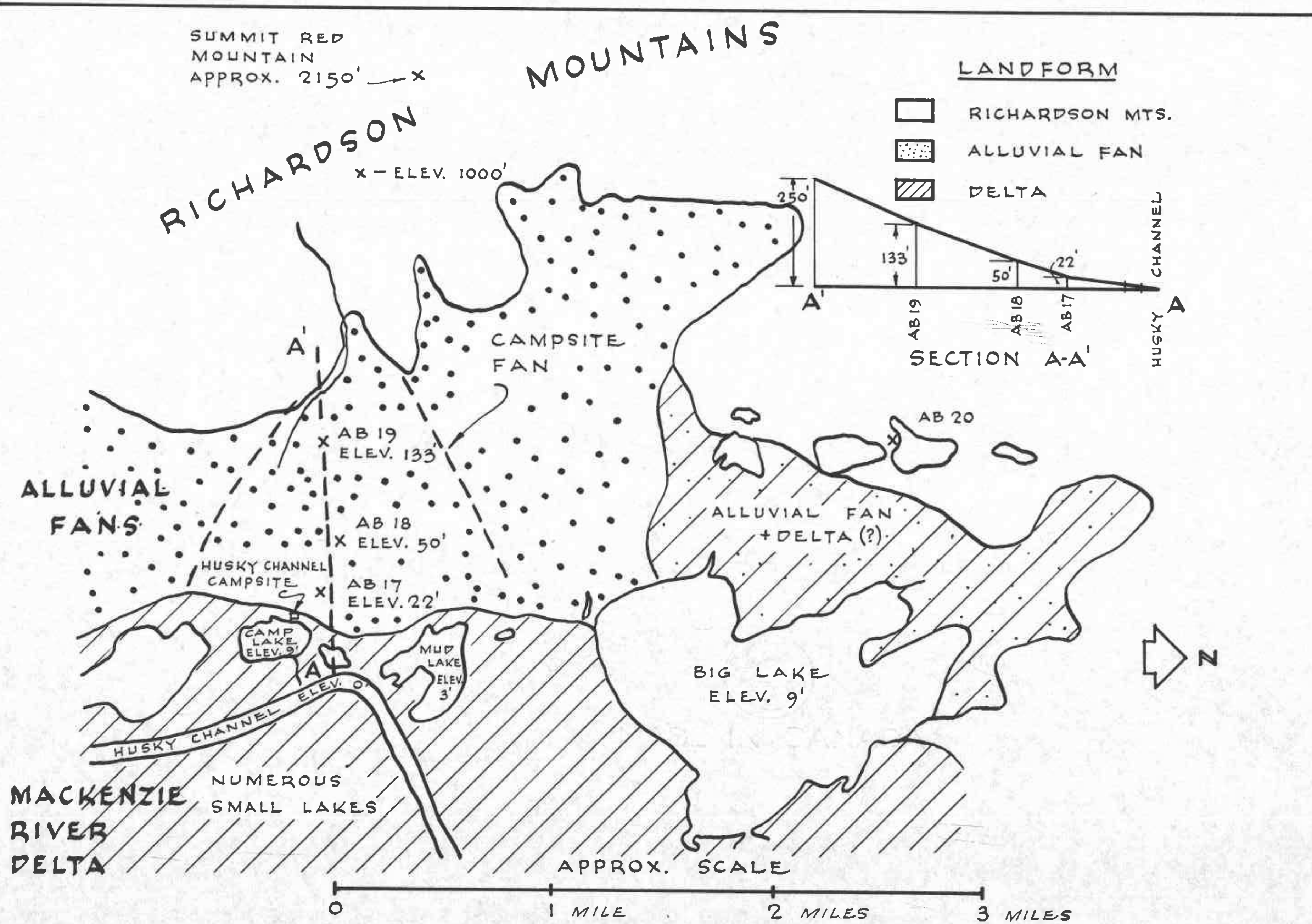


FIG. 5 HUSKY SITE AREA

(FROM RCAF AIRPHOTOS)

T.N.B. JULY 54

D.B.R. TECH. PAPER 43



FROM RCAF PHOTO A12861-182

FIG. 6 CAMPSITE FAN AREA

D.B.R. TECH. PAPER 43

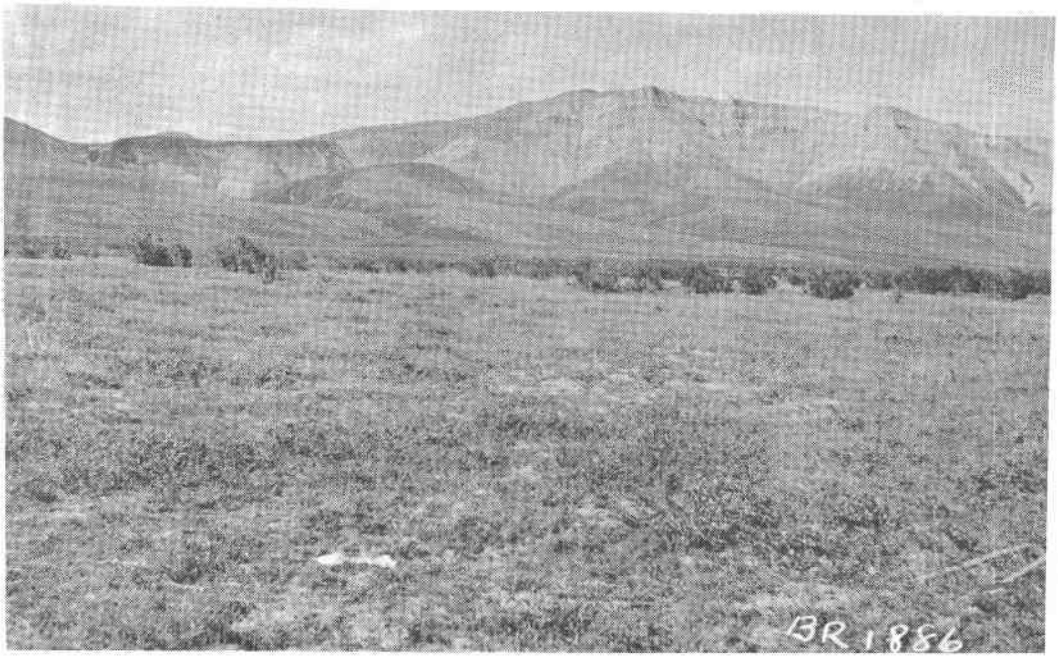


Figure 7 Red Mountain of the Richardson Mountains as seen from borehole 17 at the edge of the campsite alluvial fan

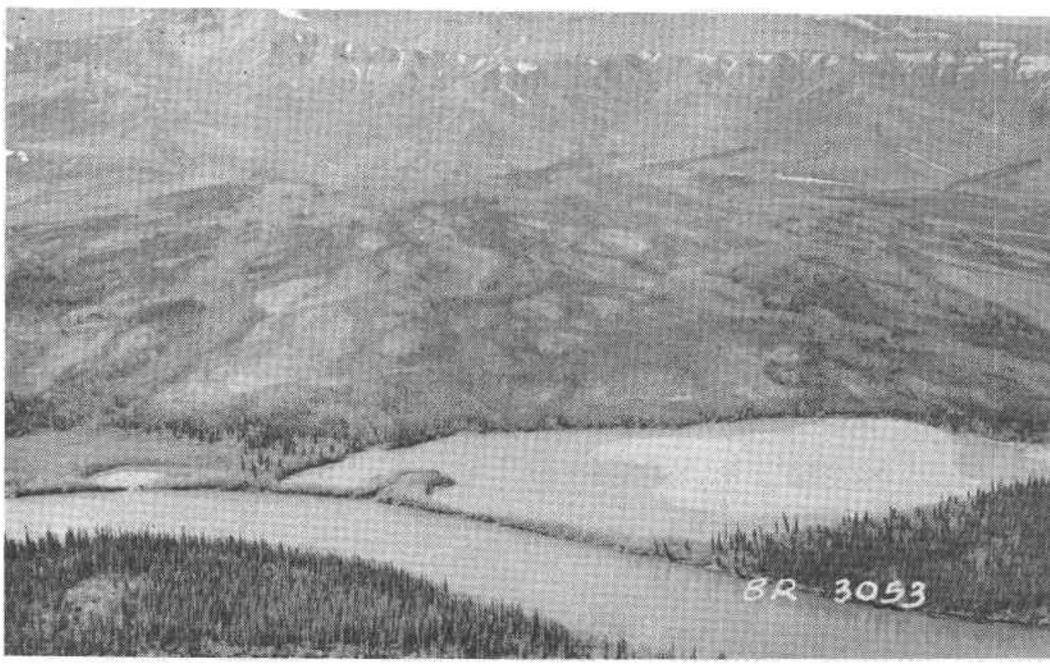


Figure 8 The "Spruce Fan" a typical forested alluvial fan as seen from an altitude of 500 feet. Note the pronounced "braided" or mottled appearance

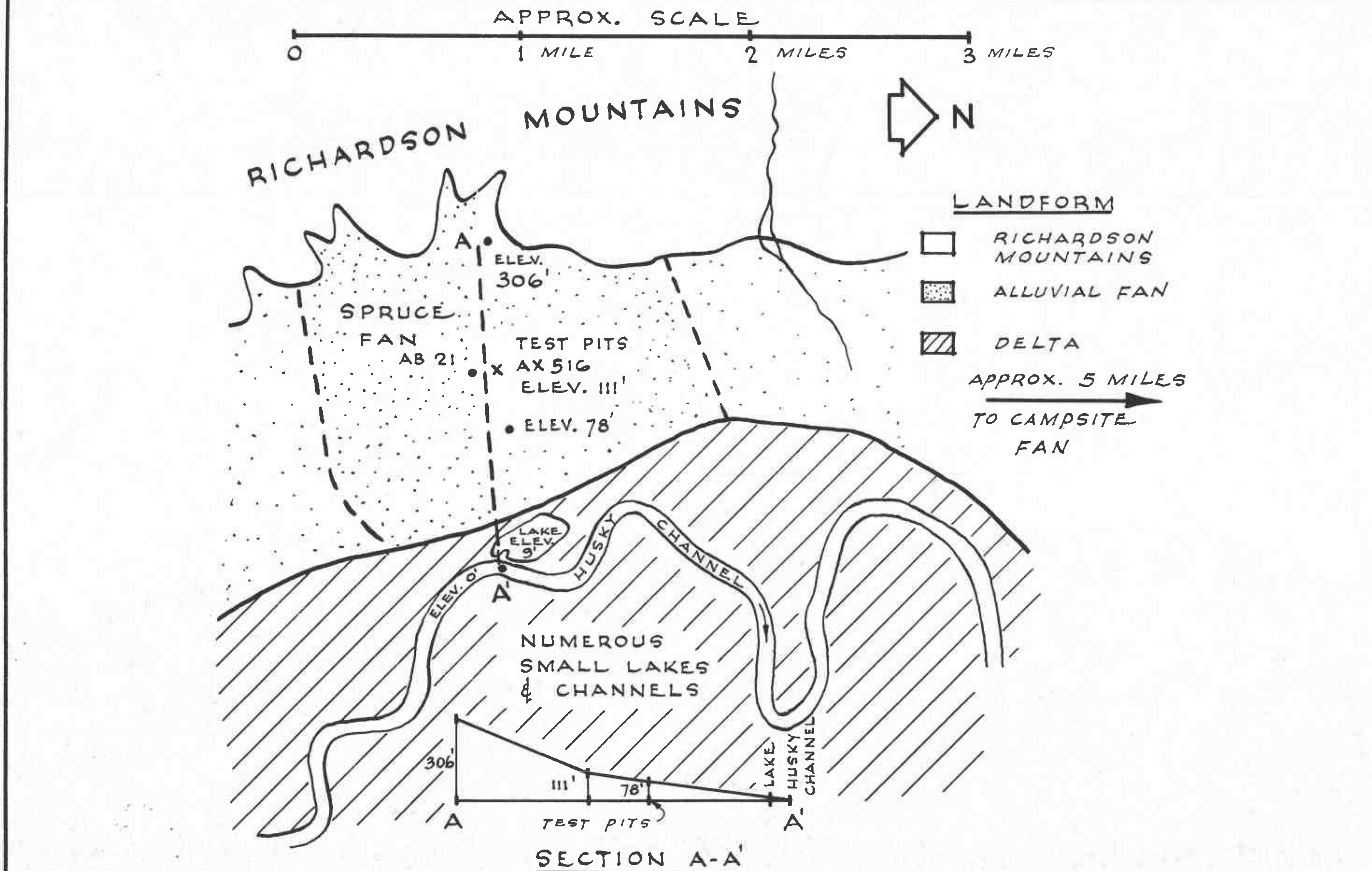


FIG. 9 SPRUCE FAN AREA

FROM R.C.A.F. PHOTO A12861-185

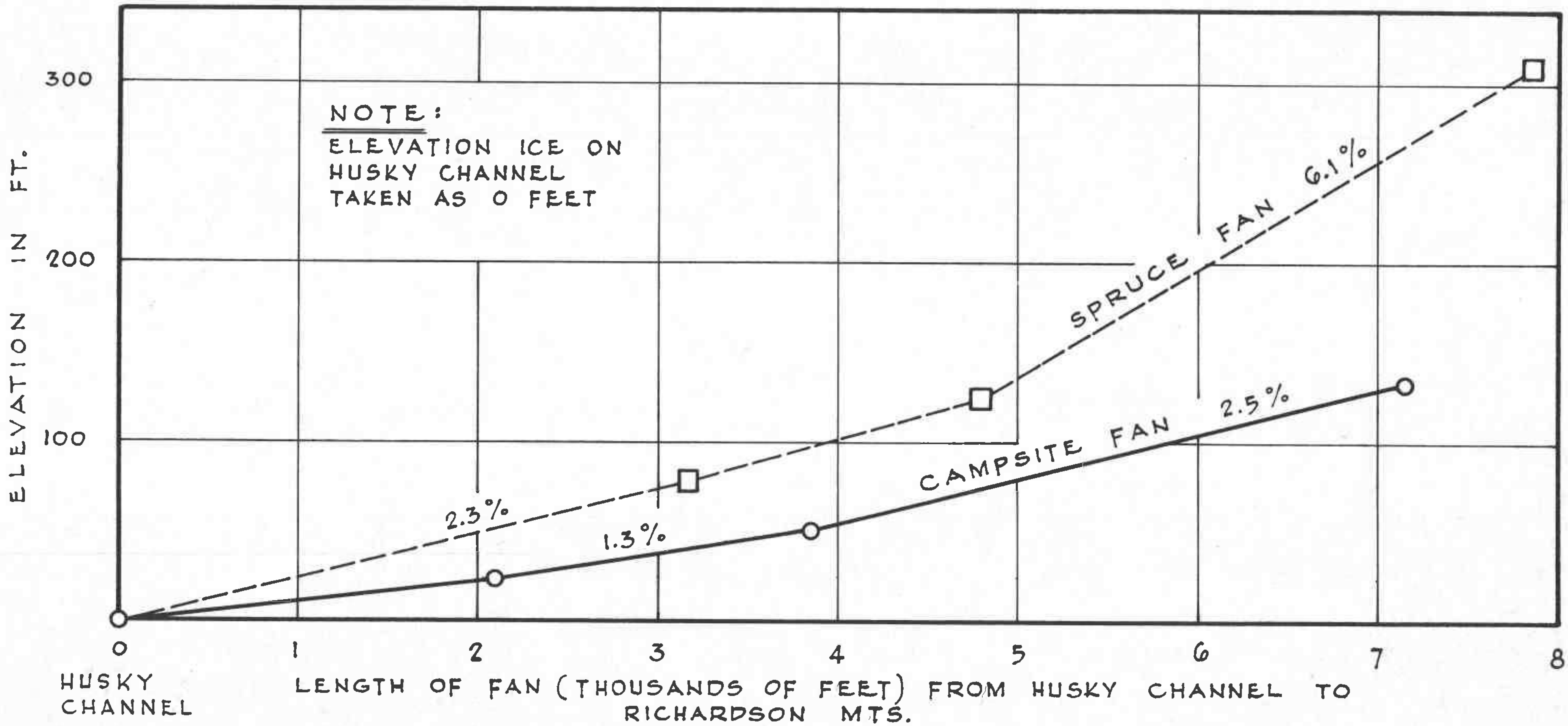


FIG. 10 TYPICAL ALLUVIAL FAN GRADIENTS

A.B. JULY 54

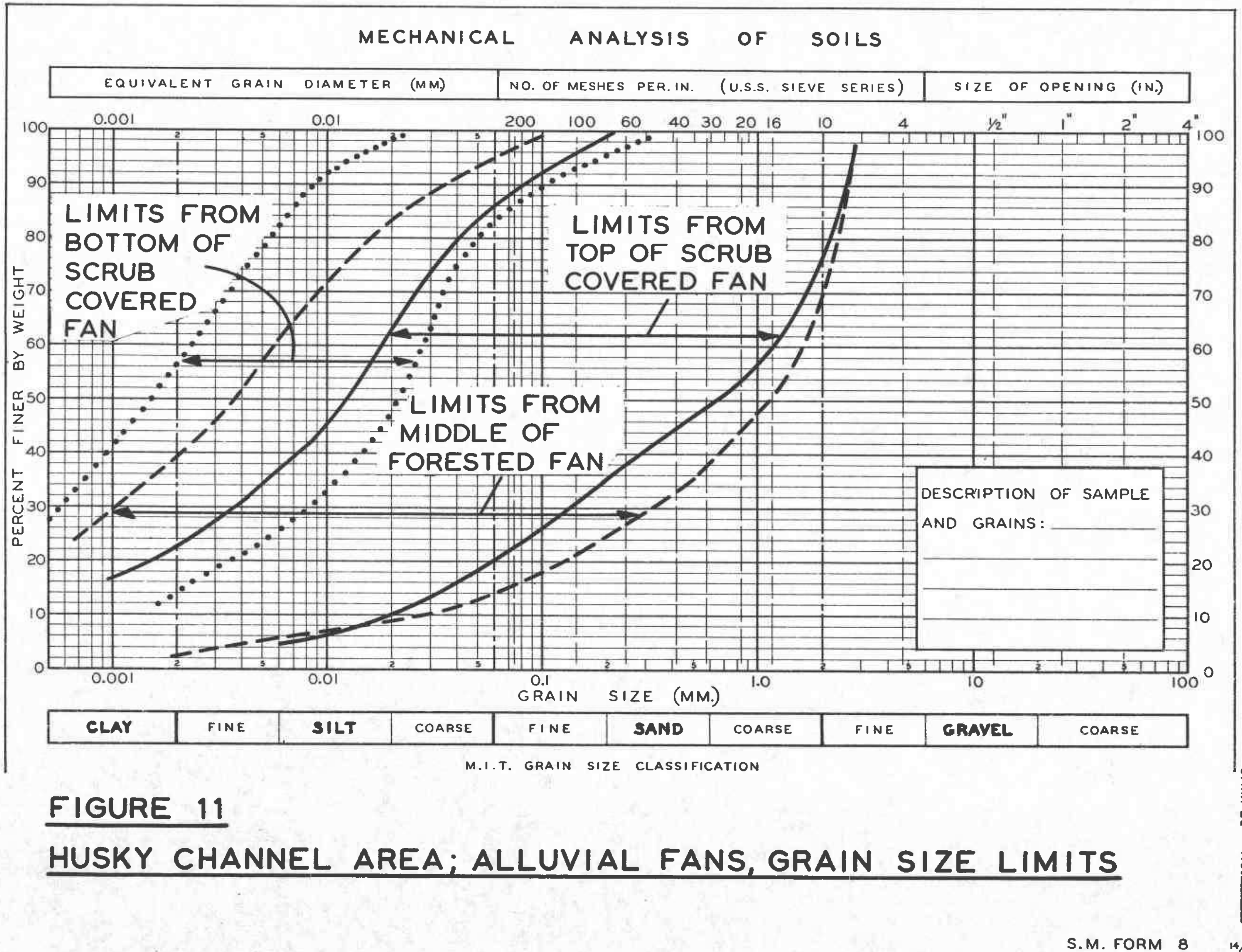


FIGURE 11

HUSKY CHANNEL AREA; ALLUVIAL FANS, GRAIN SIZE LIMITS

Figure 12 Massive ice exposed by a landslide on some knobby hills at the foot of Black Mountain. Note the large angular boulder in the formation.

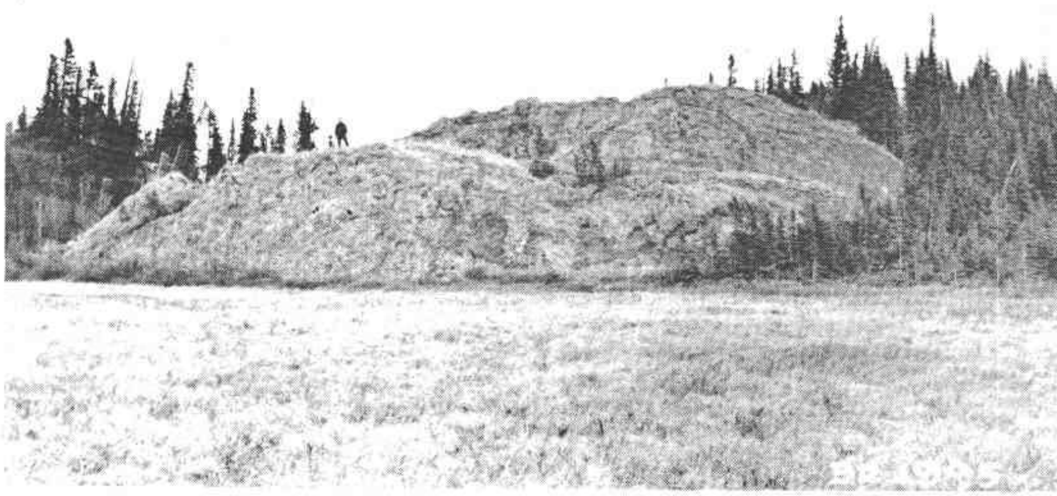


Figure 13 Knobby, "pingo-like" hills found at the base of Black Mountain

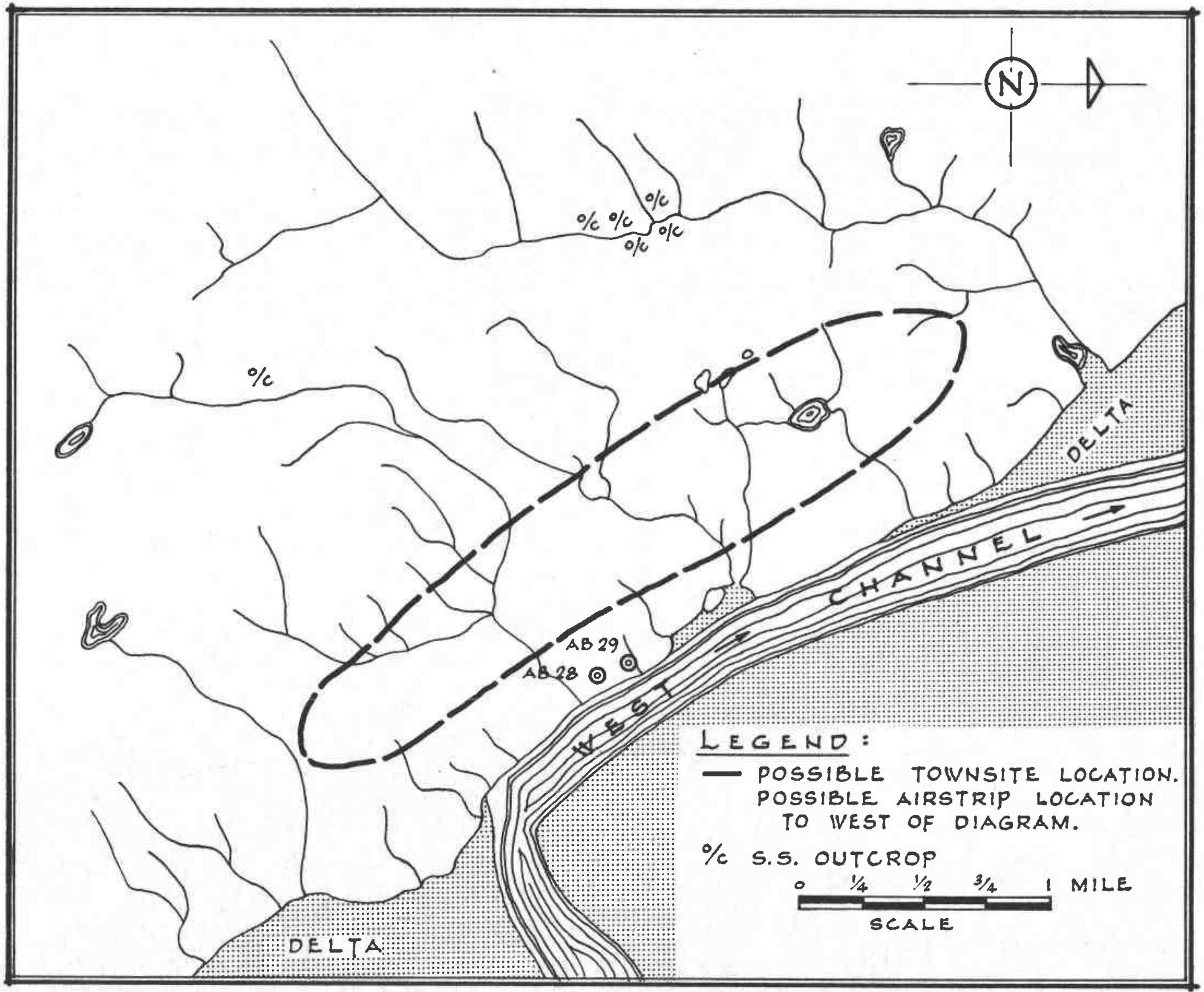


FIGURE 14

POTENTIAL WEST CHANNEL (FRASERVILLE) SITE SHOWING EXPLORATORY BOREHOLE LOCATIONS AND POTENTIAL SITE AREA

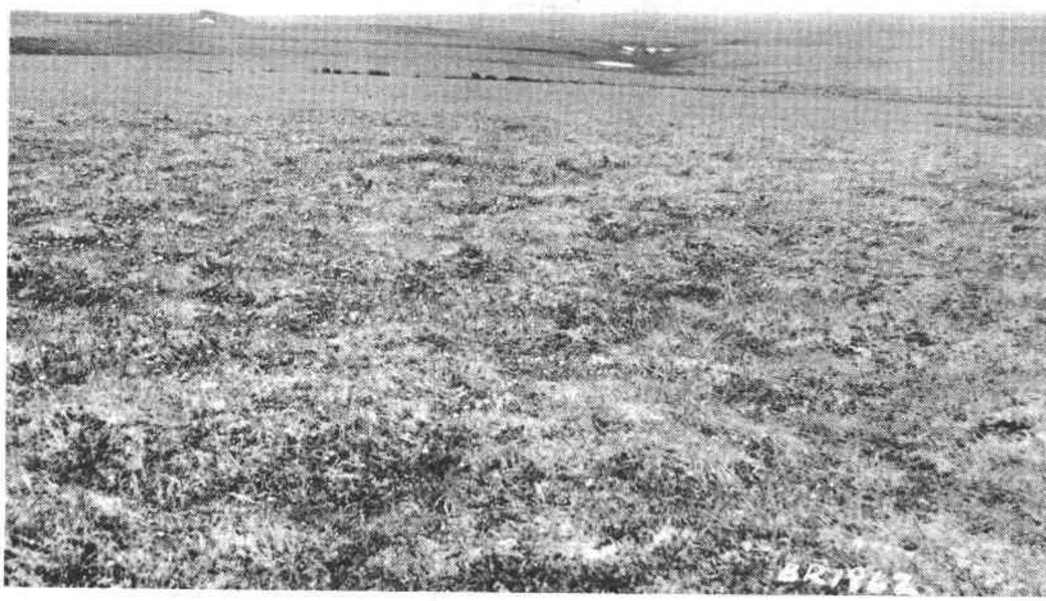


Figure 15 View of West Channel site illustrating the low relief with scattered flat depressions and swales

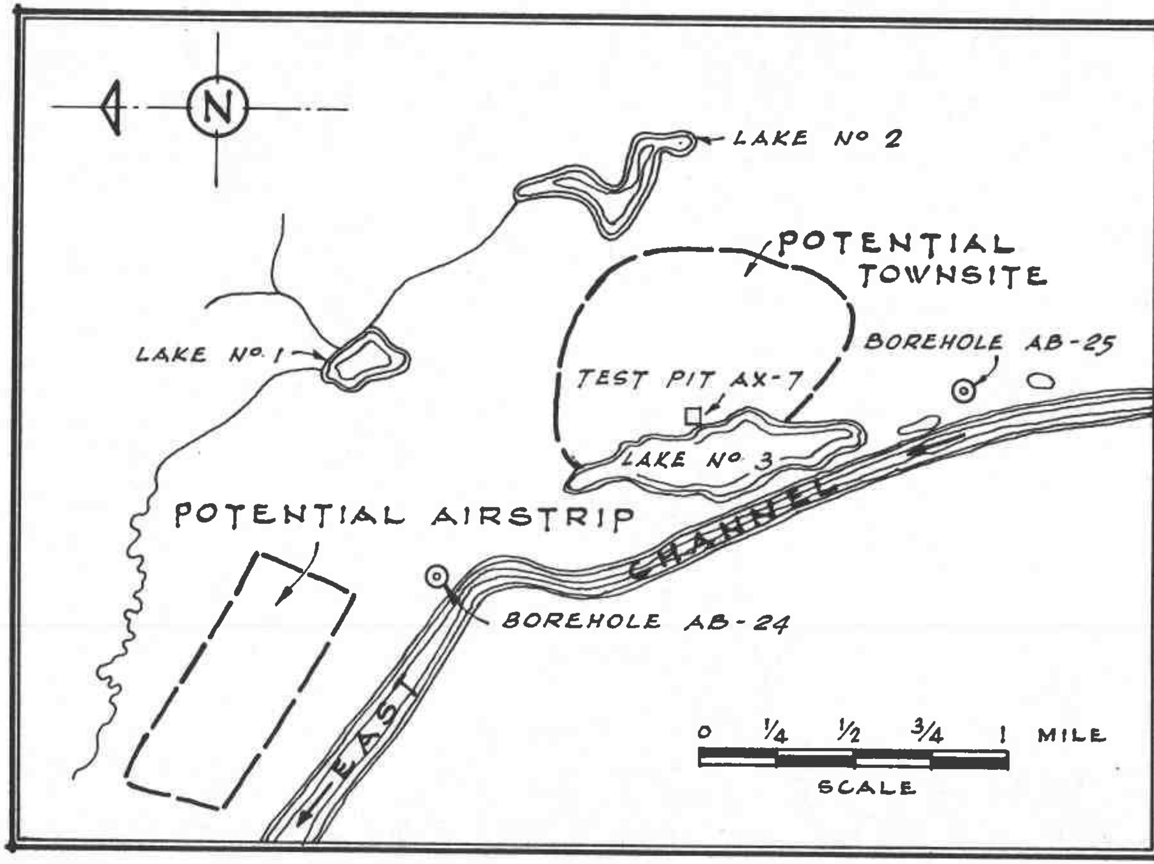


FIGURE 16

POTENTIAL EAST SITE No 4 SHOWING EXPLORATORY BOREHOLE LOCATIONS AND POTENTIAL SITES

Figure 17 Looking northwest at East Site Four showing the undulating area rising from the delta

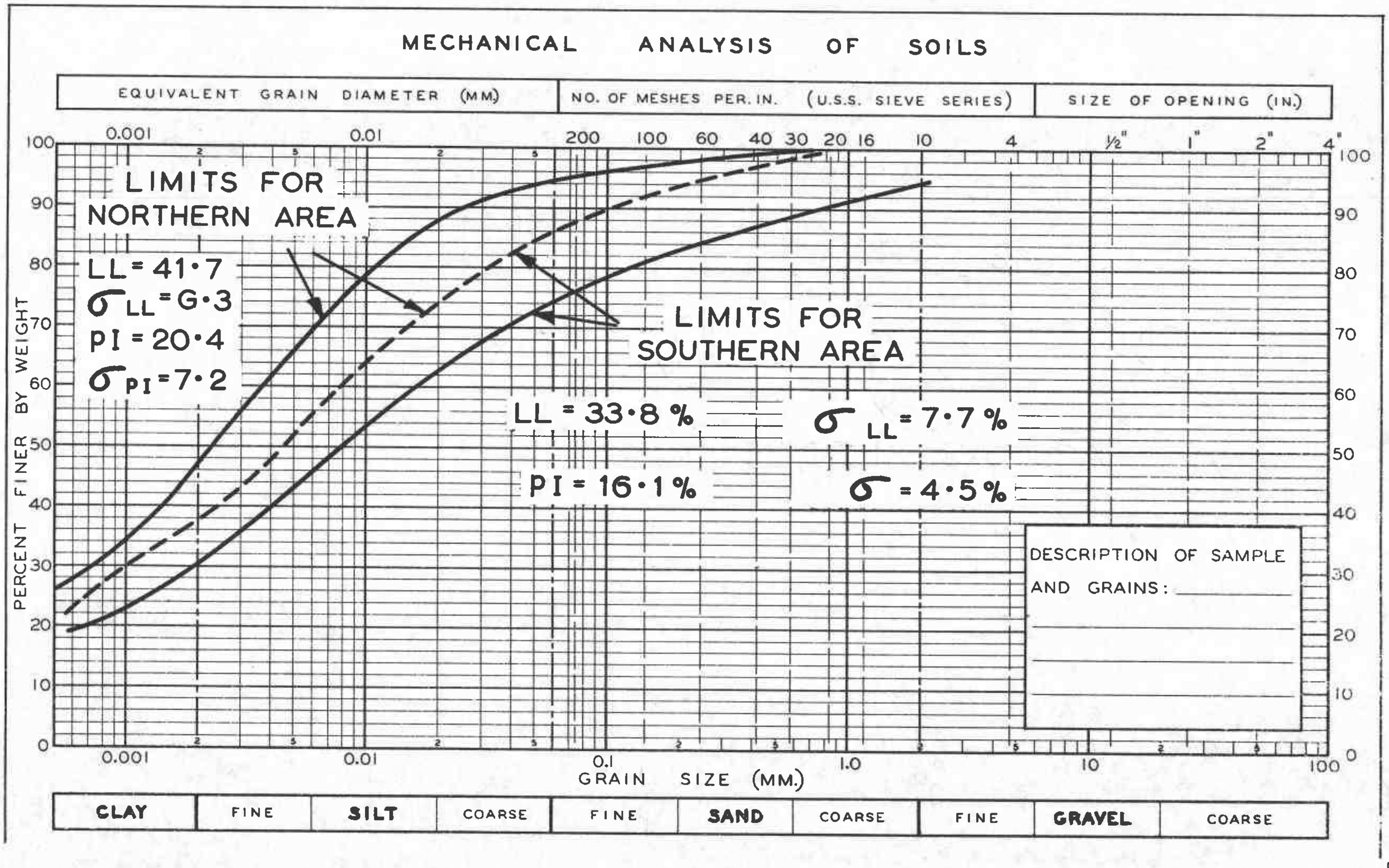


FIGURE 18

GRAIN SIZE LIMITS FOR 9 SAMPLES FROM EAST SITE 4

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S.M. FORM 8 14/2/48

BR 1193-4

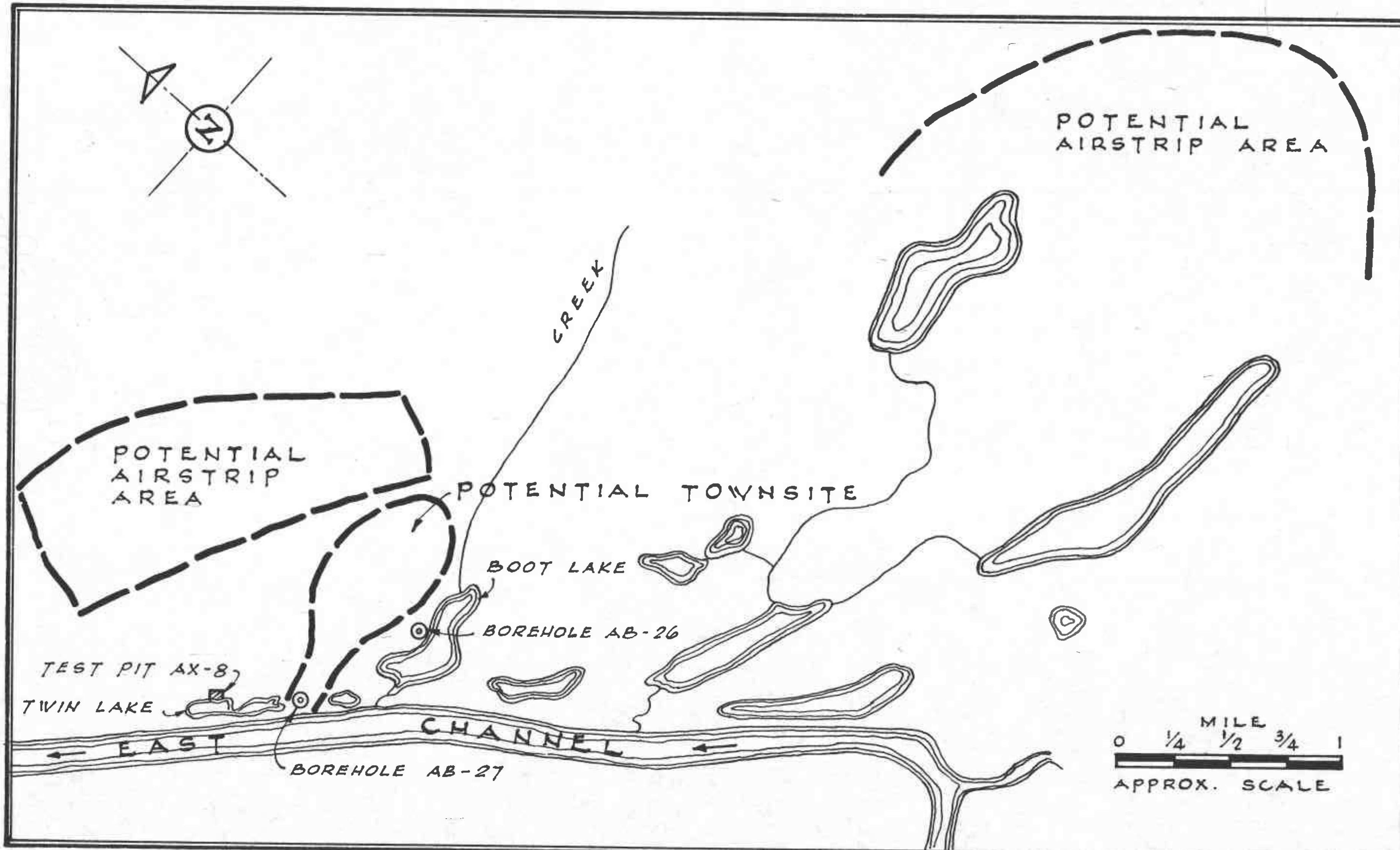
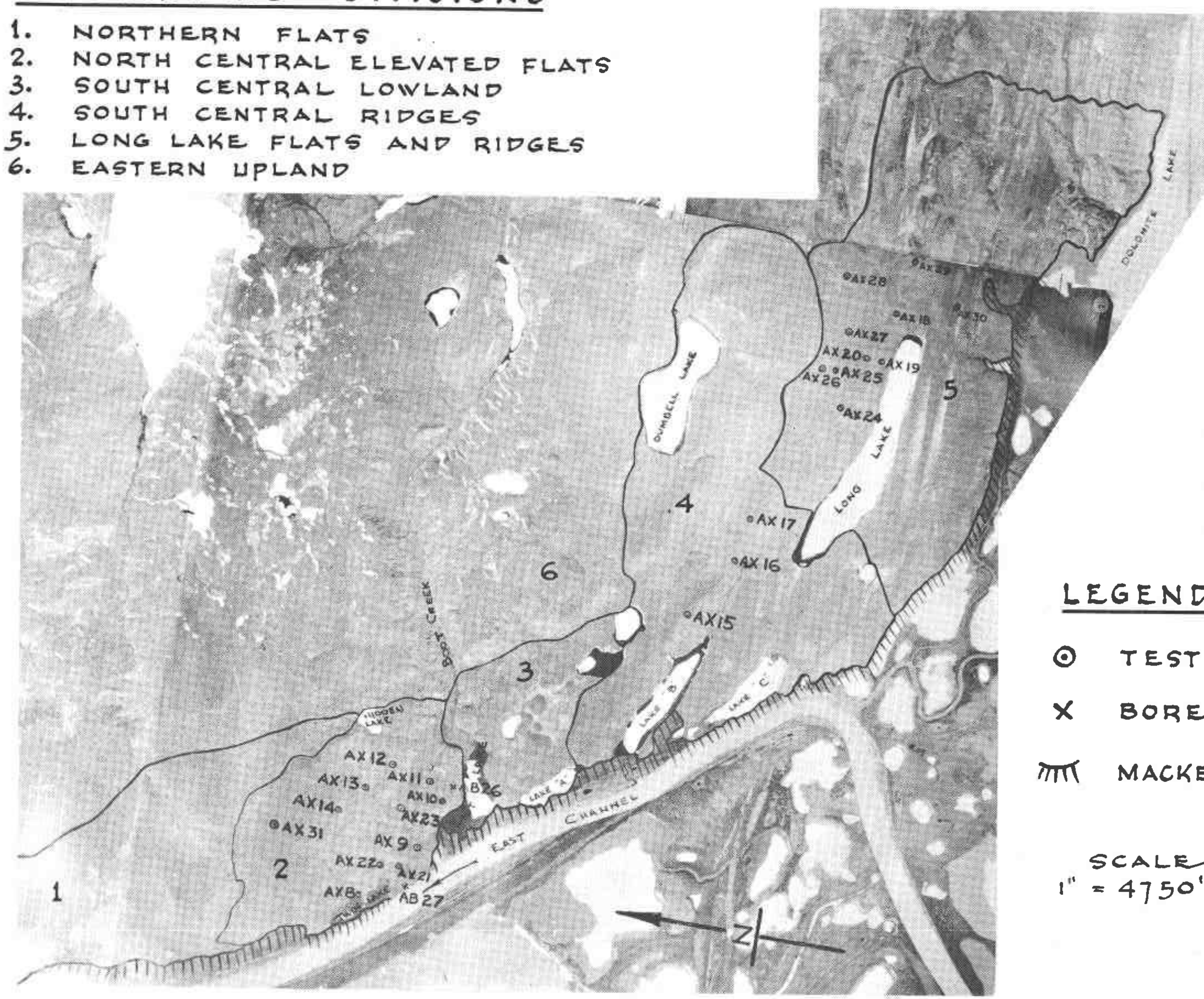


FIGURE 19

EAST SITE No 3 SHOWING BOREHOLE LOCATIONS AND POTENTIAL SITES

TOPOGRAPHIC DIVISIONS

1. NORTHERN FLATS
2. NORTH CENTRAL ELEVATED FLATS
3. SOUTH CENTRAL LOWLAND
4. SOUTH CENTRAL RIDGES
5. LONG LAKE FLATS AND RIDGES
6. EASTERN UPLAND



LEGEND:

⊙ TEST PIT

× BOREHOLE

MACKENZIE DELTA

SCALE:
1" = 4750' APPROX.

FIGURE 20 TOPOGRAPHIC DIVISIONS AND LOCATIONS of TEST PITS AT EAST THREE

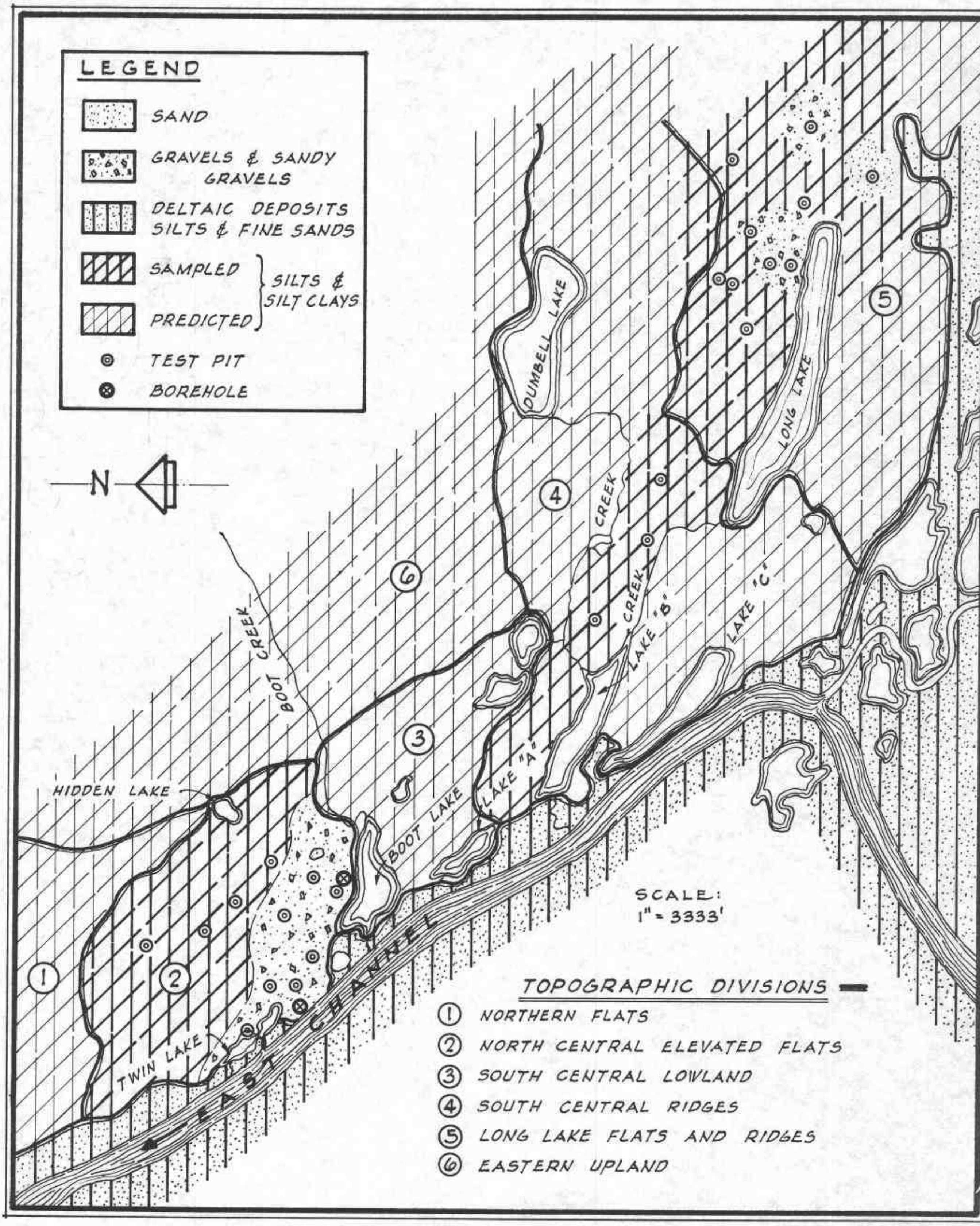


FIGURE 21 ENGINEERING SOILS MAP of EAST THREE

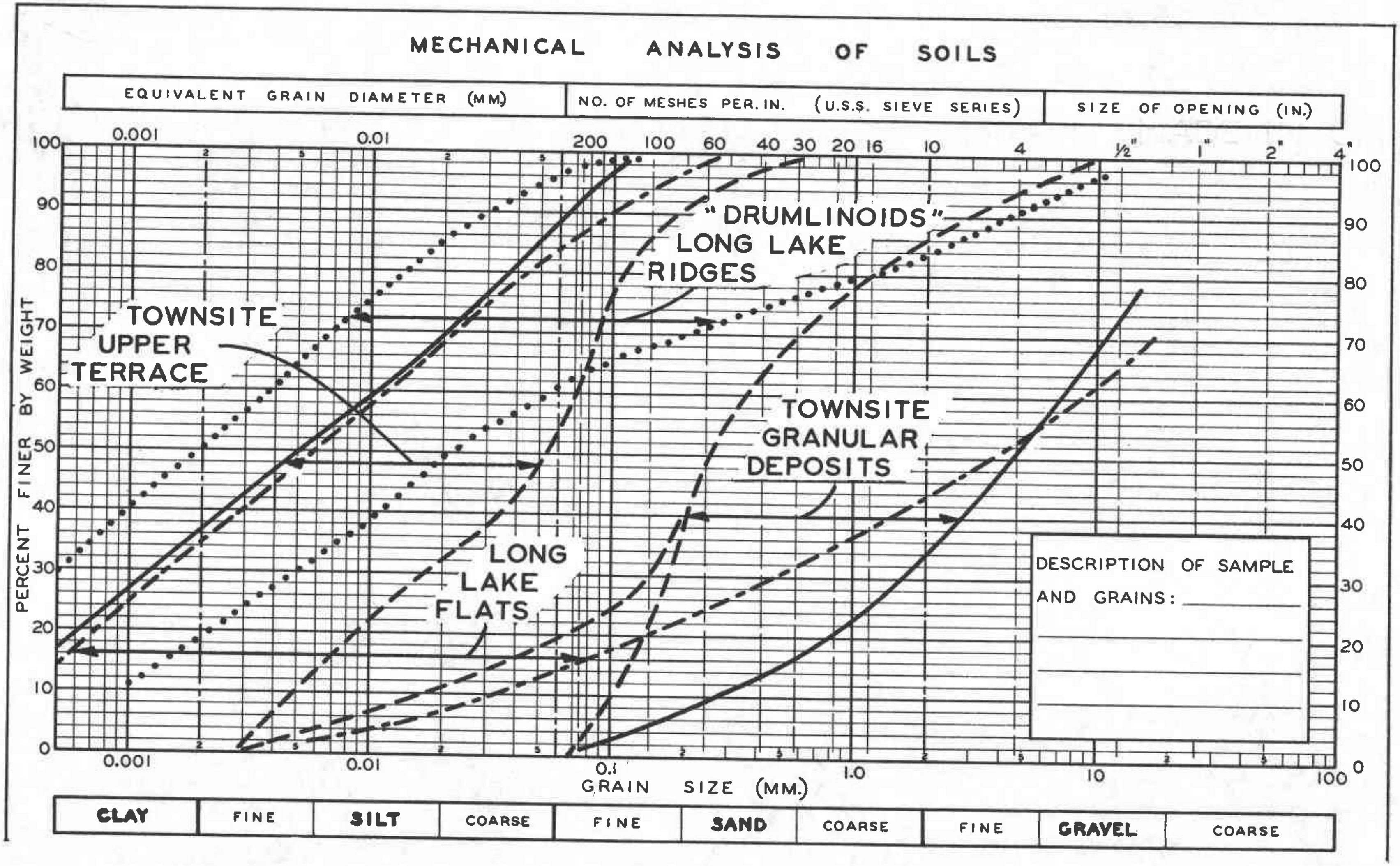


FIGURE 22

EAST THREE GRAIN SIZE DISTRIBUTION LIMITS

JAP 24/11/55

T.N.D.

BR-326 S.M. FORM 8 14/2/48

BR 1193-5

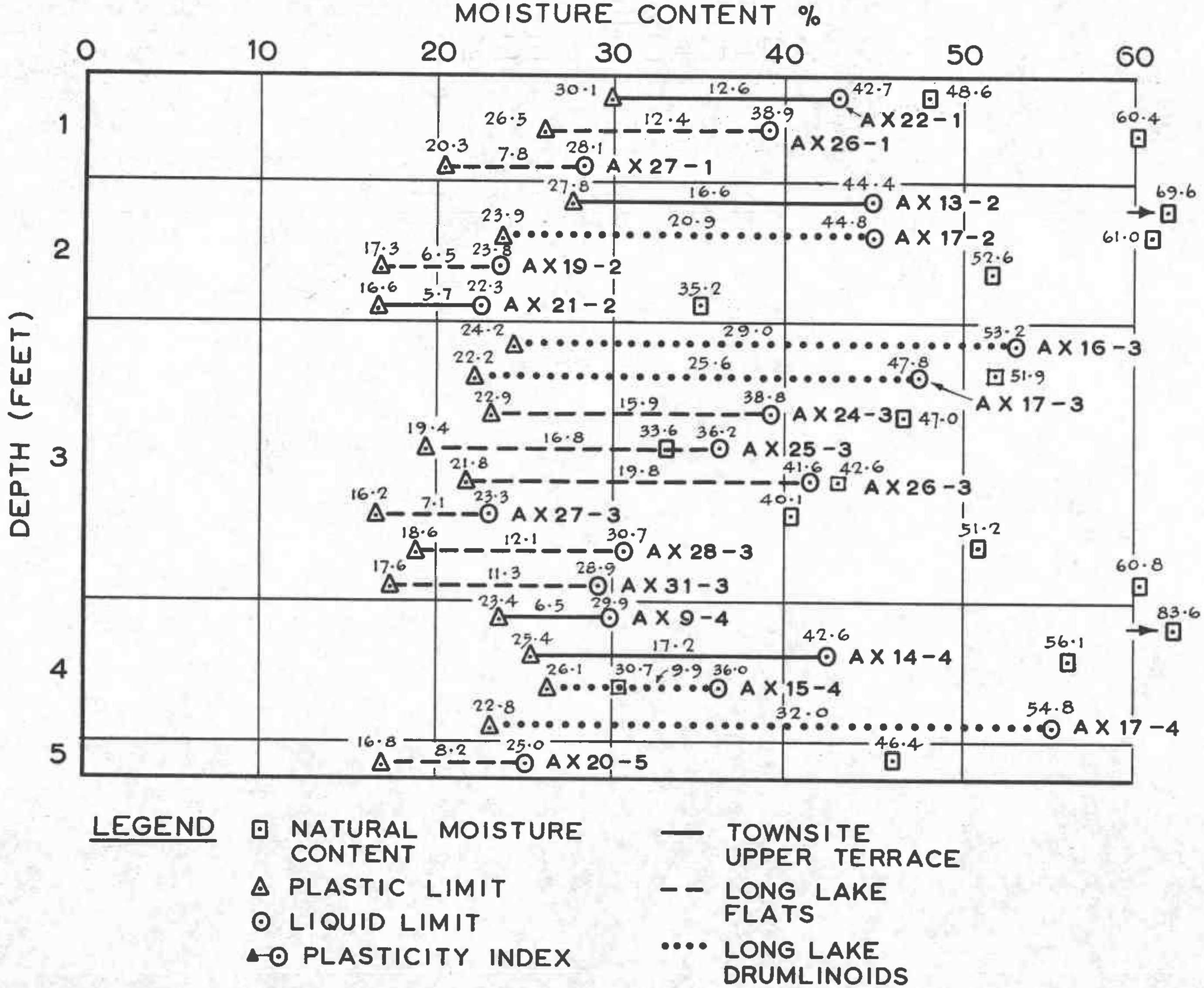


FIGURE 23

PLASTICITY DATA FROM THREE LOCATIONS AT EAST THREE PLOTTED VERSUS DEPTH

Figure 24 View of the Caribou Hills from the East Channel at the Reindeer Depot

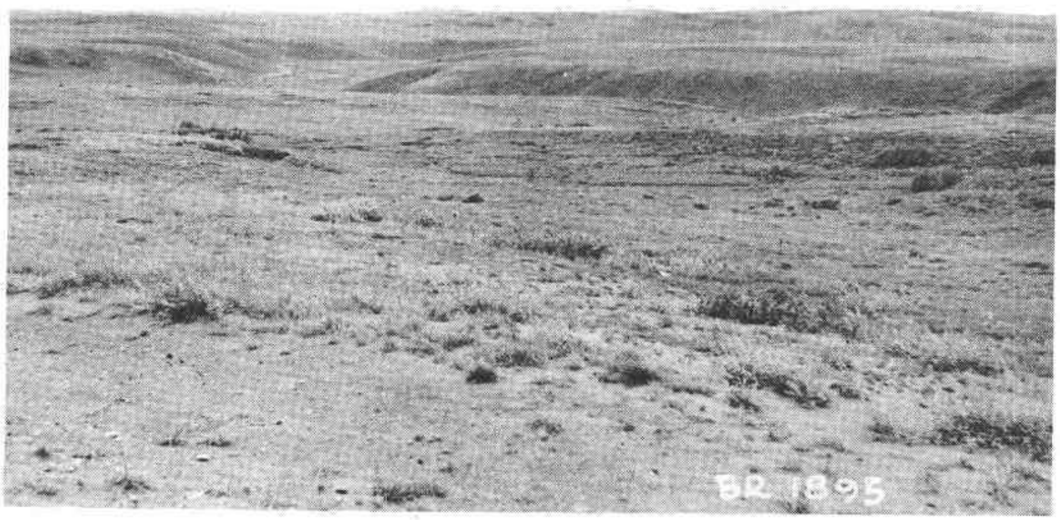


Figure 25 Terrain in the vicinity of the abandoned Loran station at Kittigazuit