Fort Simpson, N.W.T. engineering site information: soil and permafrost conditions

Pihlainen, J. A.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20331580
Technical Paper (National Research Council of Canada. Division of Building Research), 1961-08

NATIONAL RESEARCH COUNCIL
DIVISION OF BUILDING RESEARCH
CANADA

FORT SIMPSON, N.W.T. - ENGINEERING SITE INFORMATION; SOIL AND PERMAFROST CONDITIONS ANALYZED

BY

J. A. PIHLAINEN

TECHNICAL PAPER NO. 126

OF THE

DIVISION OF BUILDING RESEARCH

OTTAWA

AUGUST 1961

PRICE 25 CENTS

NRC 6452

NATIONAL RESEARCH COUNCIL

CANADA

DIVISION OF BUILDING RESEARCH

FORT SIMPSON, N.W.T. - ENGINEERING SITE INFORMATION; SOIL AND PERMAFROST CONDITIONS

by

J. A. Pihlainen

Technical Paper No. 126

of the

Division of Building Research

OTTAWA

August 1961

PREFACE

The significance of the existence of permafrost at a site for engineering construction lies mainly in the possibility that if soil is frozen it will contain large quantities of ice. The difficulties encountered in engineering construction when this situation occurs can be serious. Beyond this special problem of the North there is the general requirement for the best possible soils information to assist in the proper planning and design of engineering works.

Reliable soils and permafrost information on Northern Canadian townsites is often difficult and costly to obtain, and can seldom be gathered on short notice. The detection of ground ice requires special drilling and sampling techniques to produce frozen cores for observation. The Division has therefore undertaken as one of its responsibilities, and as a contribution to Northern development, the collection and publication of engineering site information on Northern settlements as the opportunities arise. A request for assistance with a soils investigation for the foundation of a new hostel at Fort Simpson provided the opportunity to extend the investigation to a general survey of soils and permafrost conditions. The information obtained is now reported in the hope that it will be of use in future planning.

The author, now in private consulting practice, was for ten years a research officer with the Division involved in studies of Northern terrain conditions and associated engineering problems.

Ottawa
August 1961

N. B. Hutcheon
Assistant Director

TABLE OF CONTENTS

FORT SIMPSON, N.W.T. - ENGINEERING SITE INFORMATION; SOIL AND PERMAFROST CONDITIONS

by

J. A. Pihlainen

SUMMARY

Thirty boreholes were drilled from 18 August to 4 September 1958 at various locations throughout the island on which the town of Fort Simpson, N.W.T. is located. One-third of the boreholes were associated with the construction of a hostel for the Department of Northern Affairs and National Resources; the remainder were located in areas where the land-clearing dates, some extending back to the nineteenth century, were known.

The occurrence of a gravelly stratum encountered at depths from 20 to 30 feet below the ground surface restricted the depths of the boreholes. Soil sampling was not carried out at each borehole but enough samples were taken at random locations and depths to describe the soil types adequately. Land use history, the occurrence of permafrost, and the soils at the borehole locations are described.

THE LOCALITY

The settlement of Fort Simpson is located at the junction of the Liard and Mackenzie Rivers at 61° 52' N latitude and 121° 22' W longitude (Fig. 1). Physiographically Fort Simpson is in the Mackenzie Lowlands which are bounded by the Precambrian Shield on the east and the Mackenzie Mountains of the Cordillera on the west. In general, the relief of this lowland is level ranging in elevation from 500 to 1000 feet above sea level. Much of the region is covered by glacial deposits which are underlain by relatively undisturbed sedimentary rocks of Devonian age. Lacustrine and alluvial deposits are also found in the region.

The town of Fort Simpson is on an island approximately 3 miles long and 2/3 mile wide, with its long axis oriented northwest to southeast. It is separated from the mainland by a channel 600 feet wide that functions only at high water levels (spring break-up). The width of the Mackenzie River at Fort Simpson is about 1 mile (Fig. 2).

The northeasterly edge of the island, along which the town has developed, is about 40 feet above the water level of the Mackenzie River and there is a general slope down to the flood channel. The relief of the island is characterized by three terraces or stages in the formation of the island. The highest of these flats contains the buildings of the Hudson's Bay Company and Anglican Church of Canada. Its boundary is emphasized by a 5-foot-high escarpment south of the Hudson's Bay buildings, but its slope to the northwest is relatively long and gradual. The second highest terrace contains most of the cultivated fields of the Roman Catholic Mission and the Experimental Farm of the Department of Agriculture. The areal extent of this flat is sharply defined by a 5- to 10-foot escarpment which runs generally northwest to southeast along its southern boundary. The only major discontinuity in the flat to gently undulating relief is an old channel scar in the northern portion of the R.C. Mission fields. Approximately 75 per cent of these two alluvial flats has been cleared and is now occupied.

The third and largest relief stage of the island is lowest in elevation. It is undulating to rolling and contains old channel scars and sloughs. At the most only 10 per cent of this area has been cleared (at time of writing - March 1959). The predominant trees are aspen and birch with white spruce and a dense brush undergrowth. The forest floor has a litter of semi-decomposed organic matter which varies in thickness from 2 to 5 inches. No low, moss-like vegetation was noted. Thick stands of balsam poplar as well as willow and alder fringe the perimeter of the island, especially in the vicinity of the flood channel.

Climate

The climate of the region is continental and is characterized by a long cold winter, a short fairly warm summer and quite low precipitation. For 35 recorded years during 1910 to 1957 the mean annual temperature ranged from 20.5 to 29.1°F., averaging 25.0°F. In 41 recorded years the total precipitation ranged from 5.56 to 19.07 inches, averaging 12.36 inches. Approximately 39 per cent of the precipitation was in the form of snow - an average of 47.7 inches. These records, supplied by the Meteorological Branch, Department of Transport, are shown graphically in Fig. 3.

History and Land Use

Fort Simpson is the oldest settlement still occupied on the Mackenzie River. The site was occupied first by the Northwest Company in 1804 when it was known as "Fort of the Forks" (1). The name was changed to Fort Simpson about 1821

after the union of the Northwest Company and the Hudson's Bay Company. The Anglican Church of Canada established a mission there in 1858 and a church in 1866; both have since been rebuilt.

For about 60 years prior to 1888 York boats were used for freight and passenger transportation on the Mackenzie River. Since Fort Simpson was the headquarters for the Mackenzie District of the Hudson's Bay Company, it accommodated the chief factor with a relatively large permanent staff and a large seasonal transient population. Accordingly the provision of fire wood and garden produce would be on such a scale that some of the effects of occupation on permafrost conditions could have been initiated during the latter part of this period.

About 1888, when the Hudson's Bay Company's steamer "Wrigley" came into service along the Mackenzie River, the demand for logs was such that suitable wood was not available on the island. It is interesting to note that several tree ring counts of large spruce, which are now relatively scarce on the island, gave ages of about 75 years. Disuse of the York boats also meant that a number of brigade men settled around the Simpson area either as Hudson's Bay Company employees or as trappers. Until the twentieth century Fort Simpson remained a small collection of buildings with little cleared area. Camsell (1) describes Fort Simpson in the 1880's as a "..... world in itself, a few acres of cleared land, a few people huddled together in a few houses, a small, very small segment of civilization surrounded by the endless northern forest and completely isolated from the world".

Significant effects of occupation on permafrost conditions probably started early in the 1900's. Local residents report a major forest fire which razed a portion of the island at that time. The Roman Catholic Church, which had established a mission in 1894 near the Hudson's Bay Company post, started construction of a hospital in 1913 (2). The mission moved to the hospital area at this time and began land clearing that has continued steadily to the present day. The R.C. hospital burned in 1930 and was replaced in 1931 by the present structure.

The Royal Canadian Mounted Police established a detachment at Fort Simpson in 1913 and the Royal Canadian Signals started operations in 1924, moving to their present quarters in 1928. More recently the most northerly unit of the Experimental Farms Service of the Department of Agriculture began research at Fort Simpson in 1947 (3). During 1958, construction began on two hostels and a day school for the Department of Northern Affairs and National Resources. A summary of the land occupation history is shown in Fig. 4.

THE OCCURRENCE OF PERMAFROST

The occurrence of permafrost on the island of Fort Simpson is widespread although not continuous. In general, permafrost was encountered at some depth, except in relatively recent alluvial deposits and in some areas that had been cleared for approximately 25 years or more. Observations on the occurrence of permafrost, notes on the existing terrain, and the land use history for the areas investigated with boreholes have been summarized in Table I.

Areas Without Permafrost

In 10 of the 30 boreholes permafrost was not encountered to the depth drilled (see Fig. 5 for borehole locations). Proximity of a large body of water and its warming effect is illustrated by borehole S-1. This hole located on the edge of the Mackenzie River and started approximately 1 foot above the water level (September 1958) showed no frozen ground to a drilled depth of 45 feet. Boreholes S-11, -12 and -13, in relatively recent alluvial deposits, also showed no permafrost. The clearing and occupation of areas investigated with boreholes S-5, -15, -18, -22, -23 and -24 is suggested as the reason why no permafrost was encountered to the depth drilled at these locations. It may be that these locations did not have permafrost originally, but it is considered improbable for all of these widely scattered locations.

Areas With Permafrost

The depths to permafrost observed in the remaining 20 boreholes ranged from 3.5 to 18.0 feet. At natural sites where no large scale clearing has taken place for the last 75 years the depth to permafrost ranged from 3.5 to 5.0 feet (boreholes S-8, -9 and -10). In areas now regrown, where some clearing had been carried out, the depth to permafrost is somewhat dependent on the time and extent of clearing. Borehole S-25, in an area cleared extensively 75 years ago, showed permafrost at a depth of 15 feet. At borehole S-30, where a smaller area of trees had been cleared or burned about 1930, the depth to permafrost was 10.5 feet.

Depths to permafrost in areas which have been cleared and maintained principally for pasture or cultivation show some dependence on the date of clearing, although they are extremely variable. For example, areas cleared or occupied about 1915 (boreholes S-3, -4, -5, -6 and -14) show depths to permafrost that range from 10 feet at borehole S-3 to that of borehole S-5 where permafrost was not encountered to the drilled

depth of 22 feet. The depths to permafrost and the dates of clearing in the vicinity of the boreholes are shown graphically in Fig. 6. This plot of the observations serves to summarize the effects of occupation on permafrost conditions at Fort Simpson.

The Formation of Permafrost at Fort Simpson

Climate is the principal variable in the formation of permafrost. Absence of permafrost in relatively recent alluvial deposits might suggest that the present climate at Fort Simpson is not forming permafrost. At two borehole locations (S-20 and S-25) however, alternating layers of frozen and thawed soil occurred between depths of 7 and 15 feet over perennially frozen soil. Both these areas had been cleared but are again regrown with grass, brush or trees. Since one winter's frost penetration to such depths is not common and not in evidence at other boreholes it appears that these layers of frozen soil are seasonal frost remnants which have persisted because of the regrowth of vegetation in the area. By definition this may be called "permafrost." Accordingly, it is suggested that the present climate at Fort Simpson is such that permafrost can be formed, and that the physical environment provided by the vegetative cover is an important factor for its present day formation.

THE SOILS AT FORT SIMPSON

The soil at Fort Simpson is predominantly a series of stratified silts, fine sands and some organic materials. Strata of coarse grained soils (sands and sandy gravel) are also found and are usually first encountered at a depth of from 20 to 30 feet. Water wells in the settlement confirm the predominantly fine grained soils with coarse grained strata to a depth of 45 feet. When frozen, the fine grained soils are usually cemented into a well-bonded mass in which the ice is not visible to the eye. Ice contents are relatively low for perennially frozen fine grained soils, but higher than is usually encountered with such soils in the unfrozen state.

The following detailed information on soils is based on samples taken at random from 30 borehole locations throughout the island. It is intended to illustrate the general properties of the Fort Simpson soils to a depth of from 20 to 30 feet. Occurrence of a gravelly stratum at this depth prevented sampling at greater depths.

Grain Size Distribution

The grain size distribution of the 26 samples of fine grained soil fall between narrow limits (Fig. 7).

These soils are predominantly silt-sized with varying amounts of fine sand and clay-sized particles and are similar to those reported at Aklavik (1).

The grain size distribution range of 6 samples of grey fine sand, which is usually associated with the gravel stratum, is also shown in Fig. 7. It was not possible to sample the gravels, but some exposures near the edge of the Mackenzie River suggest that it is a graded sandy gravel.

The grain size distribution of samples from borehole S-1 are shown in Fig. 8. This borehole was located on the gravelly beach approximately 1 foot above the September 1958 water level of the Mackenzie River and approximately 40 feet below the starting elevation of boreholes in the settlement area. The soil from borehole S-1 was found to be an inorganic clay of intermediate plasticity with silt lenses. The frequency of the silt lenses increased at depths below 30 feet; this is well illustrated in Fig. 8.

Ice Contents

Most of the ice observed in the perennially frozen soil at Fort Simpson bonded the soil particles into a solid, almost rock-like mass in which the ice was not visible by eye. Ice contents (weight of ice divided by the weight of dry soil) of 101 samples ranged from 22.1 to 49.6 per cent and averaged 35 per cent. These values of ice content are low compared with the ice contents of Aklavik silt (4) which ranged from 20 to 340 per cent (Fig. 9). At Aklavik correlation of ice content with depth was possible for the first 10-foot deep layer, but at greater depths the ice contents were constant at 54 per cent. At Fort Simpson there is no correlation of ice content with depth. Appreciable differences in the ice contents of the Aklavik and Fort Simpson silts do, however, suggest a difference in the formation or the environment of the deposits.

In only a few instances was ice in the frozen drill cores visible by eye. This type of ice was usually in the form of horizontal layers or lenses which ranged from hairline to 1/32 inch thick. It was not encountered at depths below 7 feet from the ground surface and in most case could be the ice of seasonally frozen ground. The ice content of 11 such samples ranged from 47.4 to 116.7 per cent and averaged 67.7 per cent. This form and ice content are similar to those of the Aklavik silts. It is interesting to note that the occurrence of frozen soil with visible ice at Fort Simpson is restricted to locations where there is a relatively shallow seasonal thaw and where there is a surface covering of semi-decomposed forest litter at least 3 to 4 inches thick. An organic surface cover is not common at Fort Simpson, but it is at Aklavik where it consists of moss-like vegetation and peat.

In one or two boreholes frozen soil was observed in which the ice cemented the soil particles very poorly. The result was that the 2-inch diameter drill cores were friable and easily crumbled by hand. The well bonded or friable property of the drill core was used to differentiate between permafrost and seasonal frost respectively. Only three samples of frozen soil in the poorly bonded condition were obtained and ice contents of 23.6, 37.4 and 53.2 per cent were recorded. This range of ice contents suggests that there may be no appreciable difference in the ice contents of seasonal frost and permafrost at Fort Simpson.

Moisture contents of thawed soil at Fort Simpson ranged from 12.8 to 33.9 per cent and averaged 25.5 per cent. In general, the moisture content increased with depth and approached the ice content at the permafrost or seasonal frost level. Since the details of environment, permafrost level and occupation history vary considerably at Fort Simpson, no correlation was attempted. Representative moisture content distribution with depth in an area where permafrost was and was not encountered are shown in Fig. 10.

Plastic Soils

Only three samples from 26 random grain size distribution samples of the Fort Simpson fine-grained soils were suitable for plasticity tests. The liquid limit ranged from 34 to 40 per cent and the plasticity index from 12 to 15 per cent. Borehole S-1 at the edge of the Mackenzie River encountered a grey clay with silt lenses at a depth of 10 feet below the September 1958 water level. Plasticity characteristics of the deposit are shown in Fig. 8.

CONCLUSIONS

1. The occurrence of permafrost at Fort Simpson is widespread but not continuous.

2. The climate at Fort Simpson is such that permafrost can be formed and that the physical environment such as the vegetative cover is an important factor for its present day formation.

3. The seasonal thaw in natural sites at Fort Simpson ranges from 3 to 6 feet.

4. The effect of occupation on permafrost at Fort Simpson has been to thaw the permafrost to depths of at least 30 feet in areas occupied 75 years or more. The depths to permafrost in cultivated areas show some dependence on the date of clearing but are extremely variable.

5. The soil at Fort Simpson is predominantly a series of stratified silts, fine sands with some clay and organic material. Strata of coarse-grained soils are usually first encountered at a depth of from 20 to 30 feet. Water wells in the settlement confirm the predominantly fine-grained soils with gravelly strata to a depth of 45 feet.

6. When frozen the soils at Fort Simpson are usually cemented into a well-bonded mass in which the ice is not visible to the eye. The ice contents are relatively low for perennially frozen fine-grained soils, but higher than is usually experienced with such soils in the unfrozen state. The ice content must be investigated and appraised for each construction project.

ACKNOWLEDGMENTS

The assistance given by all of the people at Fort Simpson must be recorded. In particular, the close cooperation of the late Mr. J. A. Gilbey, Superintendent, Department of Agriculture, Experimental Farm Substation, Mr. Don Hepburn, Principal, Fort Simpson Day School, Department of Northern Affairs and National Resources, and Reverend Father S. Lesage, O.M.I., Superior, Sacred Heart Mission, was especially appreciated.

REFERENCES

1. Camsell, C. Son of the North. Toronto Ryerson Press, 1954.

2. Lesage, Rev. Father S., O.M.I. Sacred Heart Mission, A Historical Sketch. Sacred Heart Mission, Fort Simpson, 1958.

3. Gilbey, J. A. Progress Report 1947-1953; Fort Simpson, N.W.T., Dominion Experimental Substation. Experimental Farms Service, Department of Agriculture, Ottawa, 1954.

4. Pihlainen, J. A. and G. H. Johnston. Permafrost Investigations at Aklavik: 1953. National Research Council, Canada, Division of Building Research, NRC 3393, January 1954.

TABLE I

FORT SIMPSON DEPTHS TO PERMAFROST AND AREA OCCUPATION NOTES

Borehole Number	Depth of Borehole ft in.	Depth to Permafrost ft in.	Area Occupation Notes
S-1	45 - 0	> 45 - 0	Edge of Mackenzie River - borehole started approximately 1 foot above September 1958 water level
S-2	32 - 0	6 - 6	6 feet from edge of 40-foot high Mackenzie River bank
S-3	30 - 0	10 - 0	N.A. and N.R. school property at present - probably cleared and occupied 1915
S-4	21 - 6	18 - 0	N.A. and N.R. school yard at present - probably cleared and occupied 1915
S-5	22 - 0	> 22 - 0	General area stripped of vegetation 1957 but effect of adjacent R.C. property cleared 1915 has thawed permafrost
S-6	25 - 6	11 - 0	Adjacent to R.C. property cleared 1915
S-7	22 - 6	5 - 0	Area stripped of vegetation 1957
S-8	26 - 0	5 - 0	Natural site - heavy spruce and birch tree growth with brush. Decomposed forest litter approximately 4 in. thick
S-9	21 - 0	4 - 0	Natural site - heavy spruce, birch and brush growth, forest litter approximately 6 in. thick
S-10	21 - 6	3 - 6	Natural site - heavy spruce, birch and brush growth, forest litter approximately 4 in. thick
S-11	17 - 6	> 17 - 6	Natural site - in balsam poplar stand on western edge of island near slough
S-12	13 - 0	> 13 - 0	Natural site - in willows which fringe western edge of island near slough
S-13	21 - 0	> 21 - 0	R.C. field cleared 1956-57 on western edge of island near slough
S-14	22 - 6	15 - 0	R.C. field stripped and occupied 1915
S-15	17 - 6	> 17 - 6	R.C. field stripped and occupied 1933
S-16	21 - 6	4 - 0	R.C. field stripped and occupied 1953
S-17	23 - 0	16 - 0	R.C. field stripped and occupied 1920 to 1923, now cultivated field
S-18	23 - 0	> 23 - 0	R.C. field stripped and occupied 1927 to 1935, now cultivated field
S-19	25 - 0	10 - 0	R.C. field stripped and occupied 1921 to 1924, now cultivated field
S-20	28 - 0	12 - 0	Reported to be an old potato field in 1945 - local opinion area occupied in 1930, now in transmitter area
S-21	15 - 6	5 - 6	Cleared for transmitter tower construction in 1945
S-22	30 - 6	> 30 - 6	In area of Hudson's Bay Company post occupied since 1804
S-23	23 - 0	> 23 - 0	In Hudson's Bay Company field cultivated since at least 1888 and perhaps since 1804
S-24	22 - 0	> 22 - 0	In Hudson's Bay Company field cleared since at least 1905 and perhaps since 1888
S-25	22 - 6	15 - 0	Natural site at present - no trees in area observed older than 75 years, probably cleared 1888 and abandoned 1905 or later
S-26	10 - 6	3 - 6	Edge of road approximately 30 feet from Mackenzie River bank, area occupied since 1913 (?)
S-27	18 - 6	5 - 6	Dominion Experimental Farm barn area - cleared 1935 (?)
S-28	21 - 0	5 - 0	Experimental Farm field - in slough pasture, cleared 1935 (?)
S-29	21 - 0	8 - 0	Experimental Farm area cleared 1950 to 1957
S-30	22 - 0	10 - 6	Natural site north of Experimental Farm - adjacent area cleared 1930

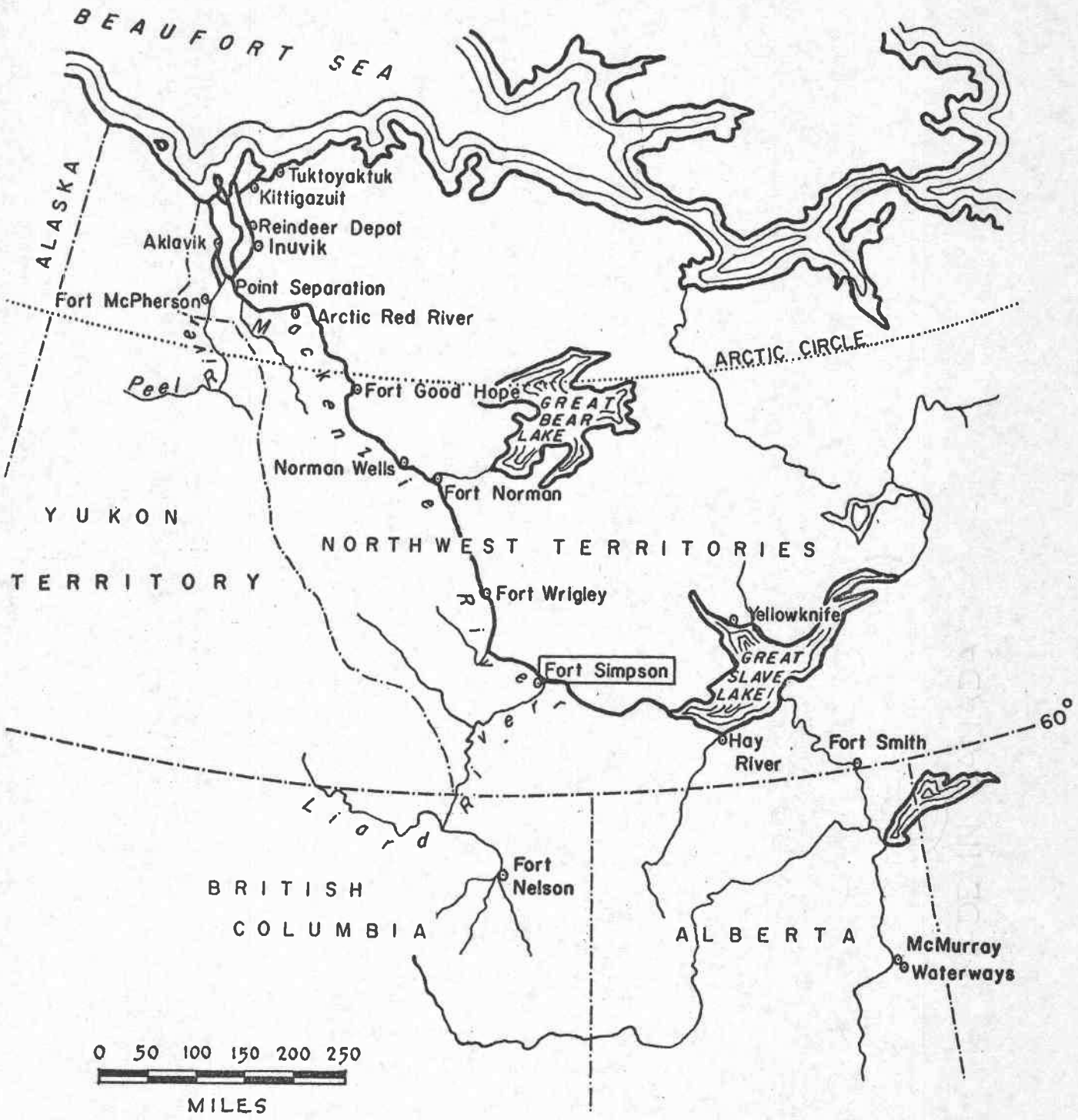

FIGURE 1

THE MACKENZIE WATERWAY

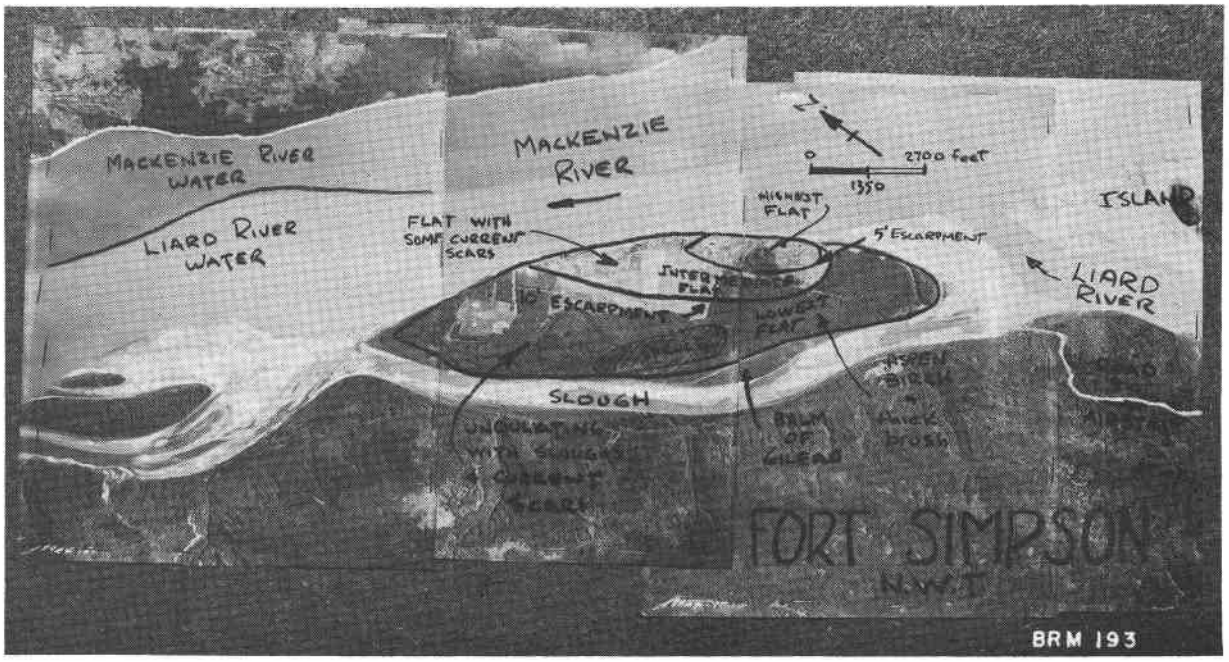

FIGURE 2 Relief and terrain features at Fort Simpson, N.W.T. (R.C.A.F. Air Photographs A8924)

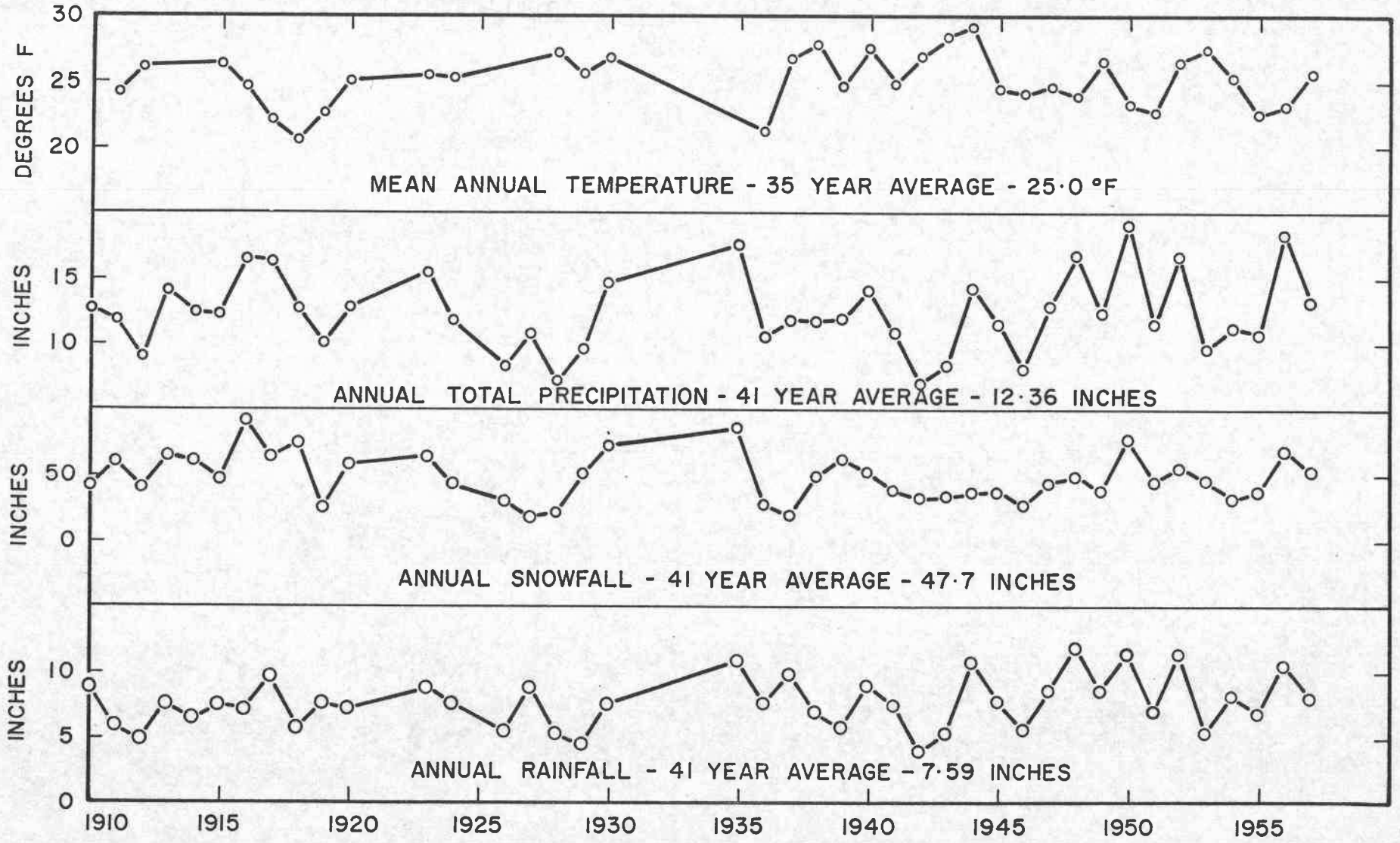

FIGURE 3

FORT SIMPSON METEOROLOGICAL DATA 1910-1957

(SUPPLIED BY THE METEOROLOGICAL BRANCH, DEPARTMENT OF TRANSPORT)

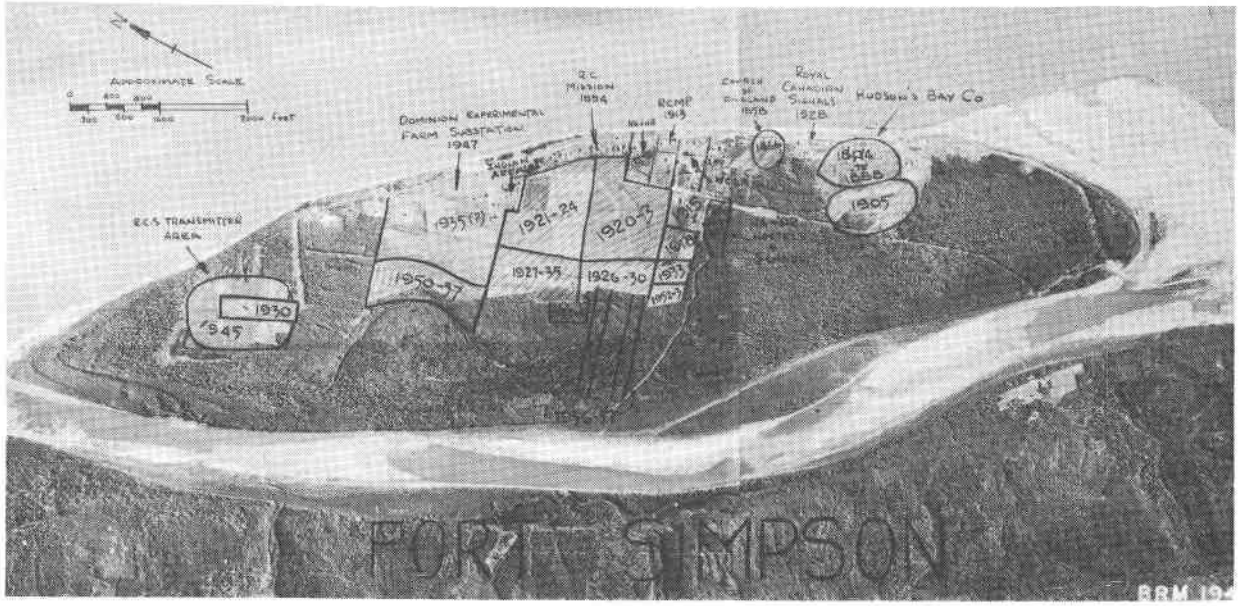

FIGURE 4 Land occupation history at Fort Simpson, N.W.T.

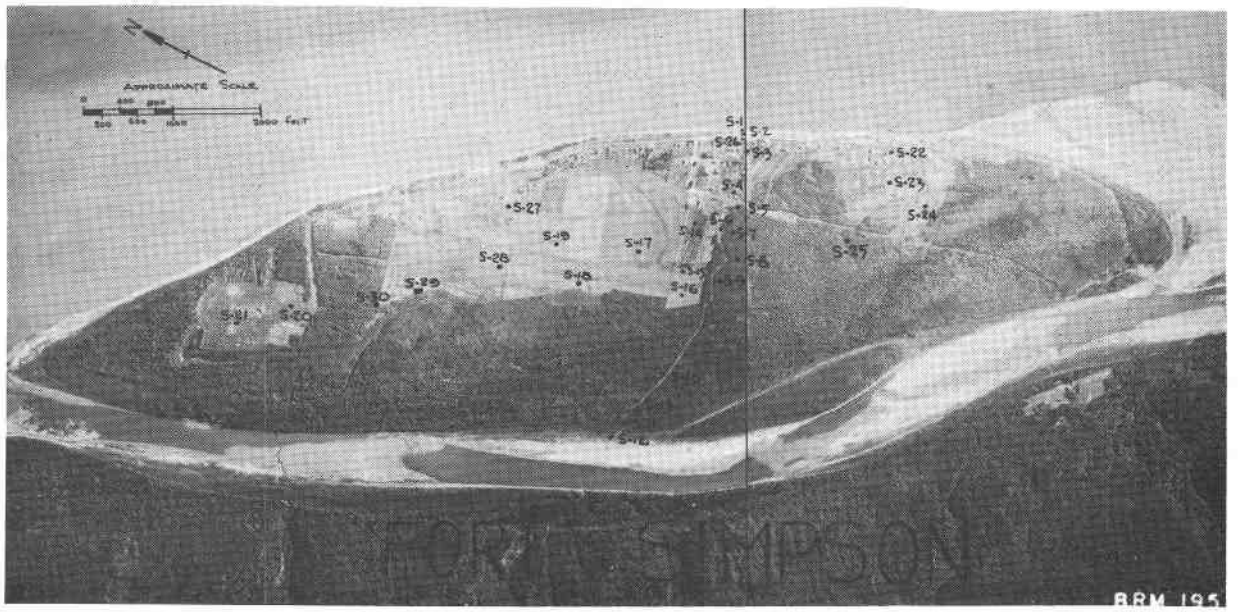

FIGURE 5 Borehole locations, Fort Simpson, 1958.
(R.C.A.F. Air Photographs A8924)

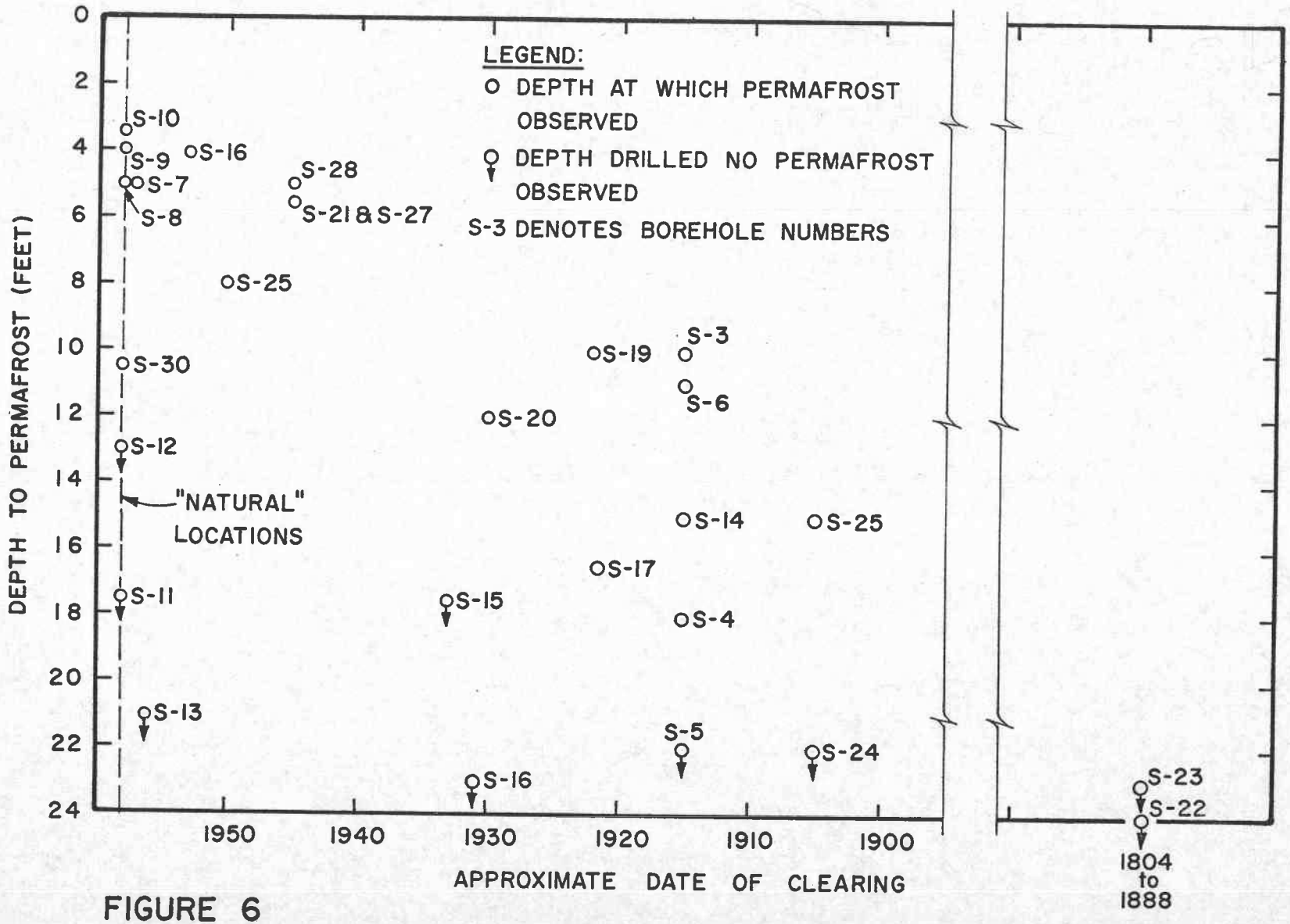

FIGURE 6

DEPTH TO PERMAFROST AND THE APPROXIMATE DATE OF CLEARING AT FORT SIMPSON, N.W.T.

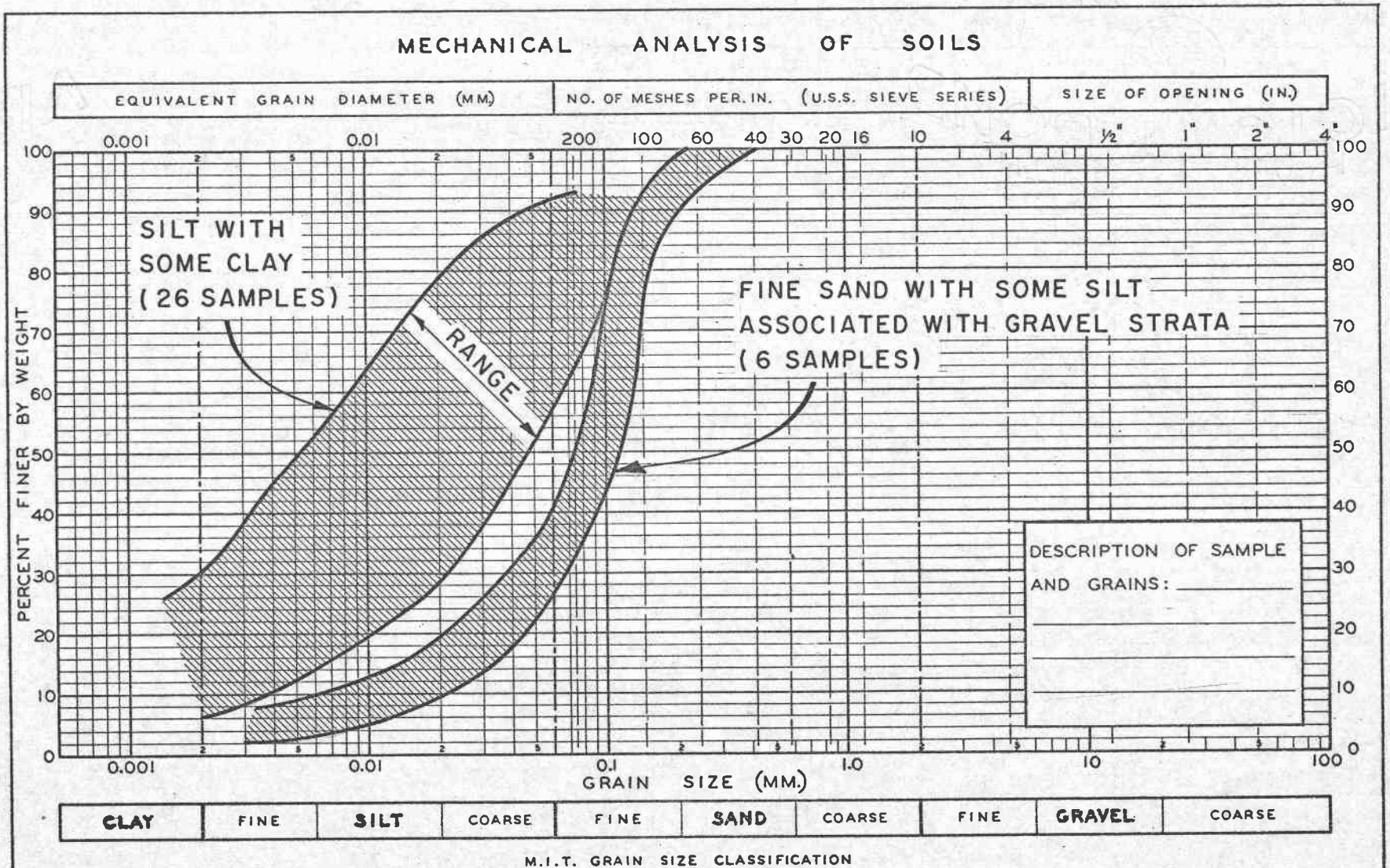

FIGURE 7

GRAIN SIZE DISTRIBUTIONS OF FORT SIMPSON ALLUVIAL SOILS

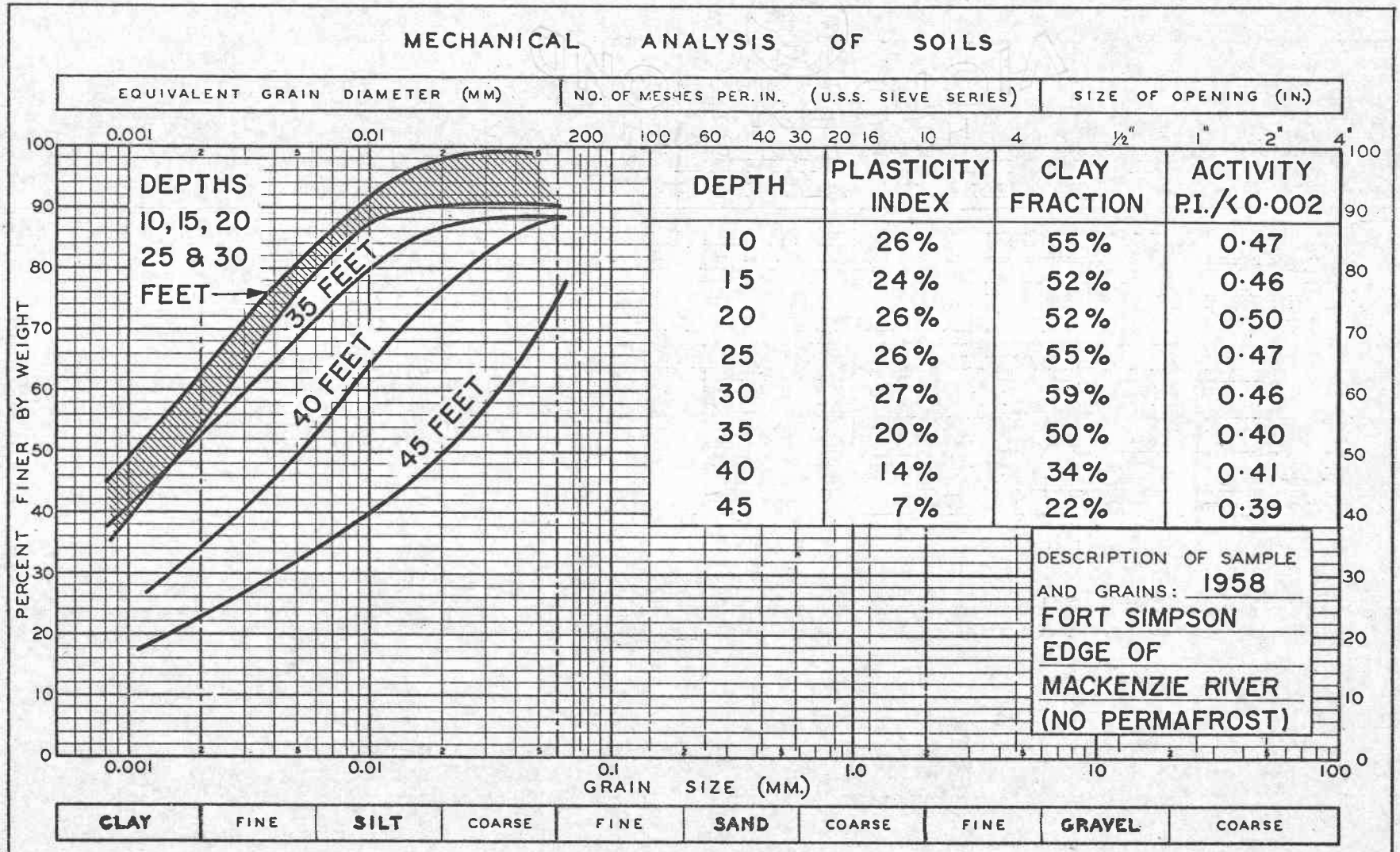

FIGURE 8

GRAIN SIZE DISTRIBUTIONS AND PLASTICITY CHARACTERISTICS OF SAMPLES FROM BOREHOLE S-1, FORT SIMPSON, N.W.T.

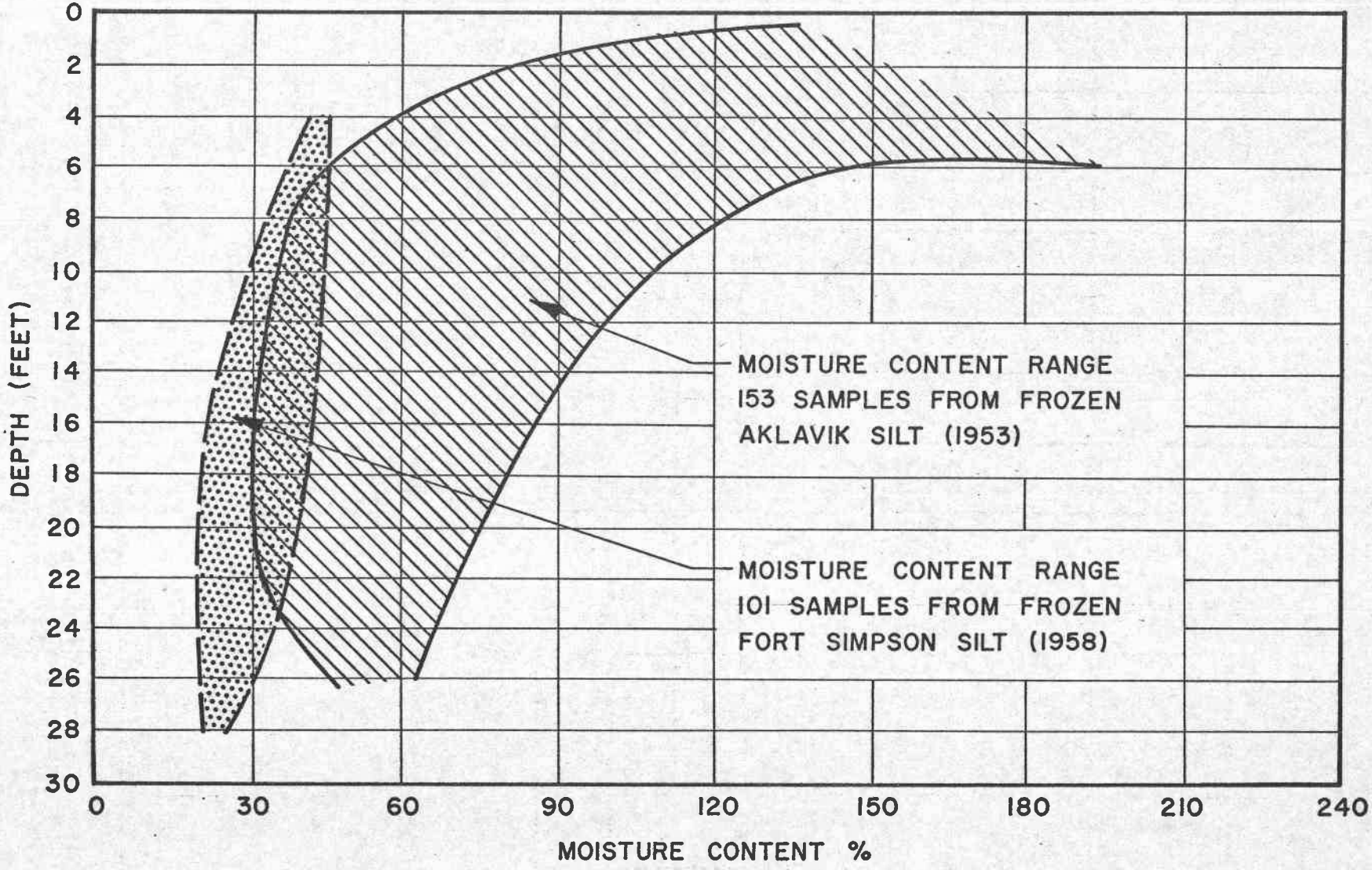

FIGURE 9

COMPARISON OF MOISTURE CONTENTS VS DEPTH FOR AKLAVIK & FORT SIMPSON

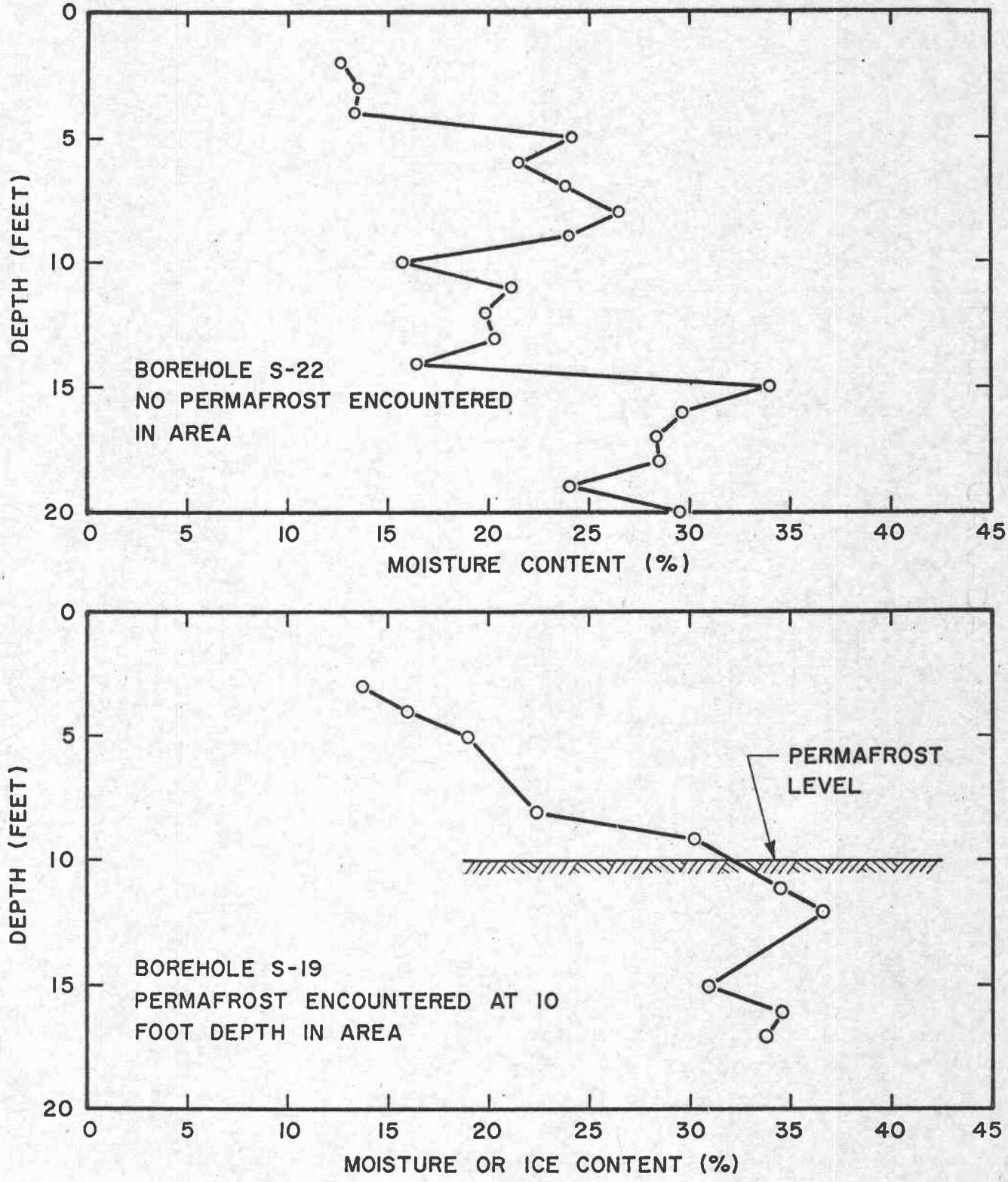

FIGURE 10
REPRESENTATIVE MOISTURE CONTENTS
FORT SIMPSON, 1958