Stratigraphy of the Mackenzie River delta, Northwest Territories, Canada
Johnston, G. H.; Brown, R. J. E.

Publisher's version / Version de l'éditeur:
https://doi.org/10.1130/0016-7606(1965)76[103:SOTMRD]2.0.CO;2
Geological Society of America Bulletin, 76, 1, pp. 103-112, 1965-01

NATIONAL RESEARCH COUNCIL
CANADA
DIVISION OF BUILDING RESEARCH

Stratigraphy of the Mackenzie River Delta, Northwest Territories, Canada

By G. H. Johnston and R. J. E. Brown

REPRINTED FROM

THE GEOLOGICAL SOCIETY OF AMERICA BULLETIN
Volume 76, Number 1, January 1965, p. 103–112

RESEARCH PAPER NO. 235
OF THE
DIVISION OF BUILDING RESEARCH

PRICE 10 CENTS OTTAWA NRC 8280

January 1965

SOMMAIRE

Une enquête a été effectuée en avril 1961 dans le but de déterminer la répartition du permagel sous un petit lac et autour de lui dans le delta du Mackenzie près du nouveau centre urbain de Inuvik dans les Territoires du Nord-Ouest. Les dépôts ont fait l'objet d'un échantillonnage par forage jusqu'à la roche mère à une profondeur d'environ 230 pieds. C'est la première fois, semble-t-il, qu'on ait effectué une étude complète sur les dépôts de ce delta.

On n'a pas trouvé de permagel dans le trou foré sous le centre du lac mais on en a trouvé dans l'épaisseur des dépôts dans chacun des trois trous forés aux abords du lac (à moins de 500 pieds de sa rive). Environ 180 pieds de limons stratifiés, de sable fin et de matériaux organiques recouvrent 50 pieds d'argile limoneuse dense déposée sur la roche mère. Les résultats des essais effectués au laboratoire sur les sédiments échantillonnés portent à croire que la partie inférieure de la couche dense d'argile limoneuse qui contient des galets est probablement un dépôt erratique provenant de la couche de glace qui recouvrait la région durant le Wisconsin. La partie supérieure de la couche d'argile limoneuse qui ne contient pas de galets a probablement été déposée dans des conditions glacio-marines ou estuairiennes. Les sédiments qui recouvrent la couche argileuse sont d'origine deltaïque et ont été déposés par le Mackenzie actuel et ses prédécesseurs post-glaciaires.

Short Notes

G. H. JOHNSTON
R. J. E. BROWN

STRATIGRAPHY OF THE MACKENZIE RIVER DELTA, NORTHWEST TERRITORIES, CANADA

Abstract: An investigation was carried out in April 1961 to determine the distribution of permafrost under and adjacent to a small lake in the Mackenzie River delta near the new townsite of Inuvik, Northwest Territories, Canada. Using drilling methods, deposits were sampled to bedrock at a depth of about 230 feet, and it is believed that this is the first study in which a complete section of the deltaic deposits has been obtained.

Perennially frozen ground was not found in the hole bored under the center of the lake but was found in the total thickness of deposits in each of three holes drilled adjacent (within 500 feet) to the lake. About 180 feet of stratified silts, fine sand, and organic material overlie 50 feet of dense silty clay deposited on bedrock. Results of laboratory tests on the sediments sampled suggest that the lower portion of the dense silty-clay layer, which contains pebbles, is probably till deposited by the ice sheet that covered the area during the Wisconsin. The upper portion of the silty-clay layer, containing no pebbles, was possibly deposited under glaciomarine or estuarine conditions. The sediments overlying the clay layer are of deltaic origin and were deposited by the present Mackenzie River and its postglacial predecessors.

Introduction

The Mackenzie River valley is old; one or more drainage systems existed during interglacial periods of the Pleistocene Epoch. Major changes in land-sea relationships since the retreat of the last glacier have resulted in a complex history of deposition in the region of the Mackenzie River delta. The modern delta (Fig. 1) is a low, flat area, approximately 50 miles wide and more than 100 miles long, that is interlaced by many river channels and spotted with thousands of lakes and ponds. To the west it is bordered by the Richardson Mountains consisting predominantly of sedimentary formations of Mesozoic age; to the east by Richards Island, the Caribou Hills, and the uplands south of Inuvik consisting of extensive formations of Palaeozoic age covered in places with glacial drift and moraine deposits; and to the northeast by older deltaic or fluvial deposits (Mackay, 1963).

In April 1961 members of the Division of Building Research of the National Research Council, Canada, carried out an investigation to determine the distribution of permafrost under and adjacent to a small lake in the delta near the settlement of Inuvik, Northwest Territories (lat. 68° 21′ N., long. 133° 44′ W.). Holes were drilled, and deposits were sampled to bedrock at a depth of about 230 feet (Johnston and Brown, 1964). Previous subsurface investigations in the delta and adjacent areas (Pihlainen and Johnston, 1954; Pihlainen and others, 1956) were to shallow depths not exceeding 40 feet. This paper records the results of the study in which, as far as the authors know, deltaic deposits were penetrated for the first time. Some comments on the geological history of the delta area are included.

Location and Description of Area

The investigation was conducted at a small, shallow lake about 5 miles southwest of the new townsite of Inuvik, Northwest Territories (Fig. 1), which lies on the East Channel that forms the well-defined eastern boundary of the Mackenzie River delta. The banks of the channels and lakes in the delta are low (5–20 feet); flooding caused by ice damming in the main channels apparently occurs every few years but not every year. White spruce is the dominant tree species; some specimens grow to heights of 50 feet. The vegetation cover also includes

Geological Society of America Bulletin, v. 76, p. 103–112, 7 figs., January 1965

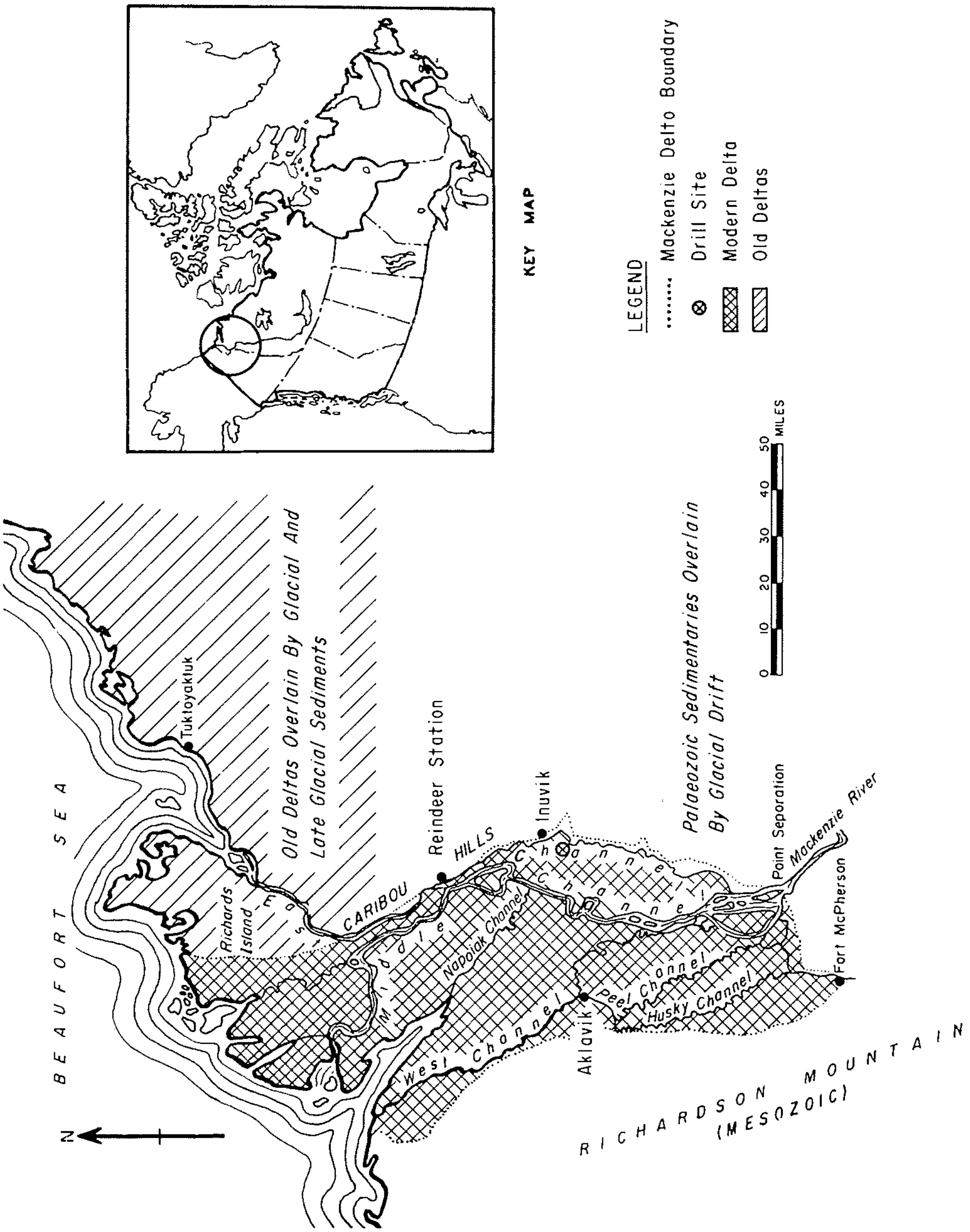

Figure 1. Mackenzie River delta, Northwest Territories, Canada

black spruce, willow and alder, and scattered stands of tamarack. Moss occurs as a very thin ground cover throughout the area.

Stratigraphy

Four holes were drilled to various depths at the site. Hole No. 1, at the center of the lake, was drilled to bedrock at 230 feet. The three other holes were bored immediately adjacent to the lake: No. 2 to 115 feet; No. 3 to 196 feet; and No. 4 to bedrock at 260 feet. Core drilling was carried out for the full depths of holes Nos. 1 and 3, and good, undisturbed cores of most of the materials penetrated were obtained. A typical section at this location in the delta is as follows:

0–100 feet—thinly stratified sandy silt with layers of decomposed organic material throughout; content of organic material particularly high at bottom of unit.

100–180 feet—fine-to-medium sand with thin layers of organic material spaced at irregular intervals throughout full depth.

180–230 feet—very dense silty clay containing scattered small pebbles from 206 to 221 feet and a high concentration of pebbles in the bottom 9 feet above bedrock; no pebbles in the top 26 feet of the clay layer.

230 feet—bedrock (dolomitic limestone).

Figure 2 shows a detailed log of the materials. At hole No. 3 the ground surface that is 12 feet above the ice level of the East Channel at Inuvik (April 1961) was used as datum. No geodetic elevation has been established at Inuvik. Little information is available on the general geology of the immediate area, but the bedrock in the hole appears similar to the dolomite, magnesian limestone and slaty shale exposed about 8 miles south of Inuvik (Kellaway, 1956).

Perennially frozen ground was not found in the hole bored under the center of the lake, but it did occur for the full depth of each of the other holes. Visible ice segregation in the form of horizontal and irregularly oriented layers was confined mostly to the top 30 feet. Below this depth the deposits were solidly frozen; only thin ice layers occurring at random in predominantly silty or clayey beds were noted. Sandy material was well bonded by ice not visible to the eye.

Physical Properties of Sediments

Standard engineering tests to identify and classify the deposits were made on representative samples obtained from holes Nos. 1 and 3 and at various intervals in the other two holes.

Moisture content values decrease with depth in the upper 50 feet, as shown in Figure 3. From the surface to a depth of 35 feet the moisture content averaged 38.2 per cent, and from 35 to 180 feet it averaged 28.9 per cent. Only a few values were obtained below 180 feet, and these were less than 20 per cent.

The deposits can be subdivided into four main groups according to grain size, as shown in Figure 4. Of the 11 samples in group 1 (silty clay), seven were from the dense clay layer occurring below 180 feet; the other four were from random depths within the top 80 feet. Of the 38 samples in group 2 (silt with some fine sand and clay), seven were from between 100 and 180 feet, 28 between 40 and 100 feet, and three from between the ground surface and 40 feet. Of the 15 samples in group 3 (sandy silt), 13 were from between 0 and 100 feet. Of the 18 samples in group 4 (fine sand), seven were from between 0 and 100 feet; the other 11 were from the 100- to 180-foot layer.

The plasticity characteristics of several of the samples were determined by means of Atterberg Limit tests[1]; the results are tabulated in Table 1. *Plasticity* which is an important property of fine-grained sediments may be defined as the range in moisture content over which the material remains plastic or capable of being moulded. Although the *limits* are somewhat empirical in nature, they are extremely useful as an indication of the plastic characteristics of any given clay and for comparison with other clays (Casagrande, 1948). For example, grain-size distribution can be misleading in comparing chemically and mechanically derived clay-sized particles, but the plasticity characteristics will show the inherent differences markedly. The relationship between the plasticity index, which is equal to the liquid limit minus the plastic limit, and the liquid limit is shown in Figure 5. All values fall in a band slightly above and parallel to the A-line[2] wherein most glacial clays lie.

The *activity*, which indicates the swelling and

[1] Liquid limit is the water content at which the material has such a small shear strength that it flows to close a groove of standard width when joined in a specified manner. Plastic limit is the water content at which the material begins to crumble, rather than to distort plastically, when rolled into threads of one eighth inch diameter.

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

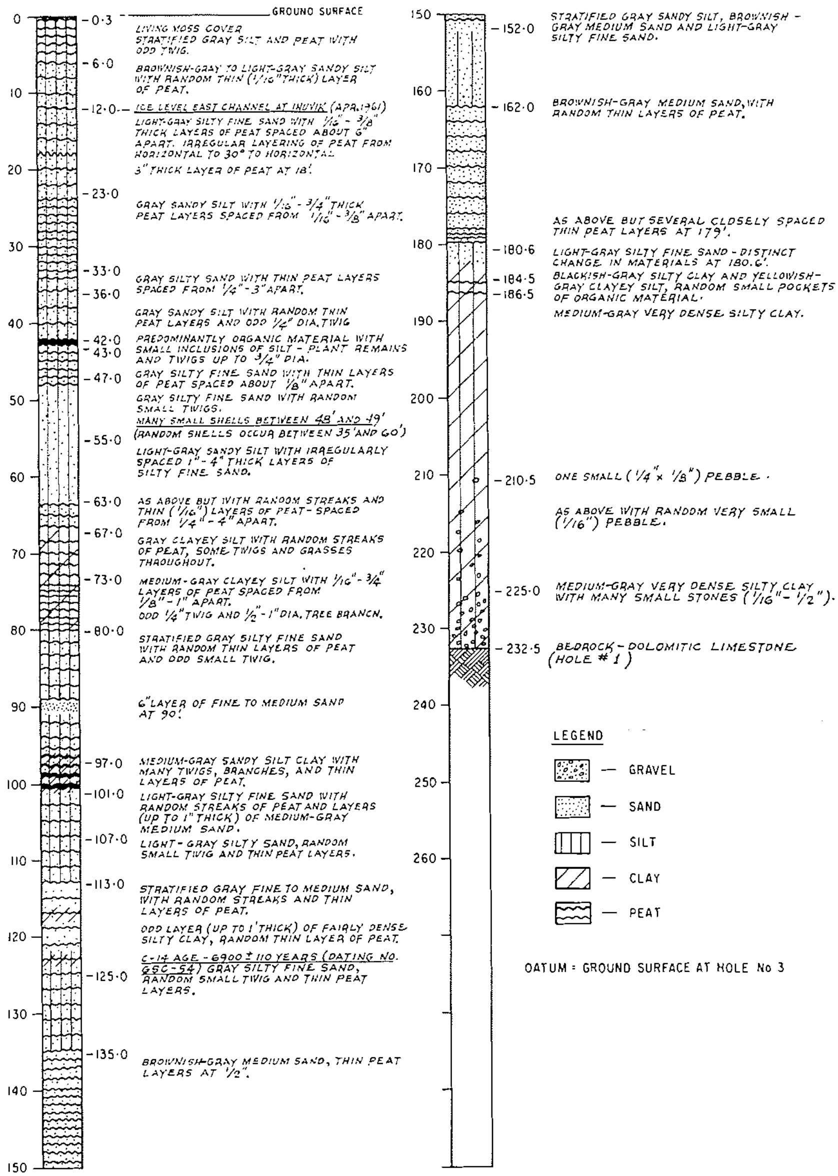

Figure 2. Mackenzie River delta combined soil log boreholes Nos. 1 and 3, Northwest Territories, Canada

shrinking properties of a clay, is another important characteristic and relates the plasticity index to the percentage of clay-sized particles (Fig. 6). Typical values for samples taken at various depths are given in Table 1. Some degree of correlation has been found between *activity* and the mineralogy and geological history of a clay (Skempton, 1953 p. 58). One or more of the following seem to characterize *inactive* clay (activity less than 0.75): (1) Predominance of either kaolinite or mechanically derived particles of clay size; (2) Deposition in fresh water; (3) Deposition in salt water but subsequent leaching by percolation of fresh water.

Clays combining (1) and (2) or (1) and (3) form the least active group (*i.e.* less than 0.5). Apart from kaolin, typical members of this group are derived largely by mechanical erosion of nonargillaceous rocks by ice sheets and then deposited in ice-dammed lakes. They are also derived from postglacial marine deposits which have been leached by fresh water usually following isostatic uplift. Clays formed by normal weathering and deposited in fresh water usually have activities between about 0.5 and 0.75. As will be noted from Table 1 the values for the silty-clay material (below 180 feet) fall mainly in this group.

The pore water was extracted from several samples of the dense silty clay, and the salt concentration was determined. As shown in Figure 7, the salt content is low to about 180 feet but increases below that depth from about 3 g/*l* to about 28 g/*l* at 220 feet.

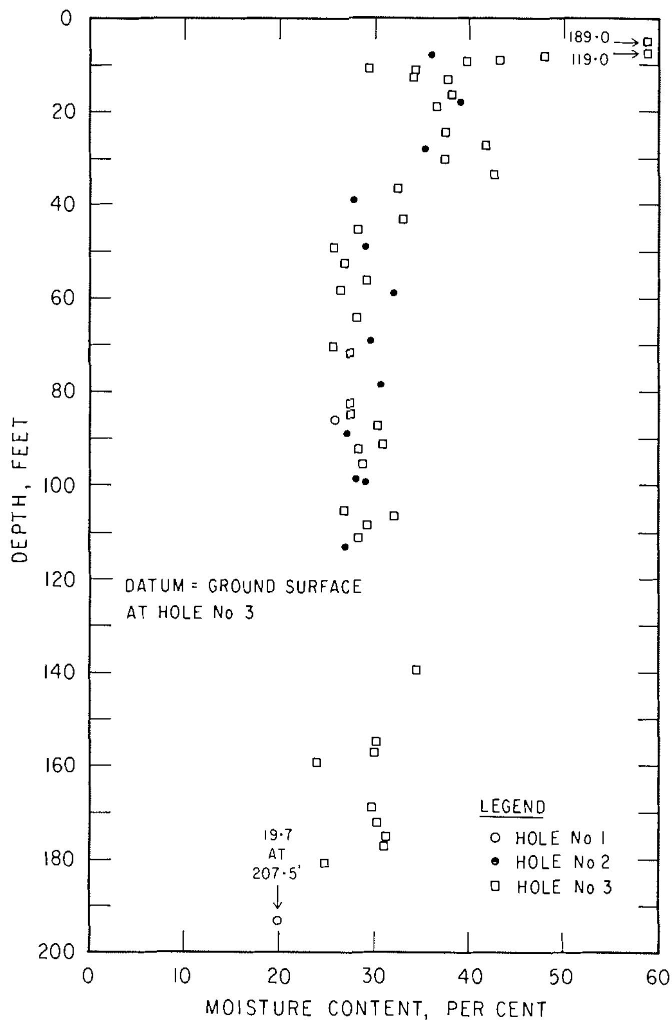

Figure 3. Mackenzie River delta soils—moisture content versus depth

Several samples taken from between 35 and 60 feet contained fossil remains. These shells, examined and identified by Dr. F. J. E. Wagner of the Geological Survey of Canada as Pelecypoda (*Pisidium* sp.), Gastropoda (*Succinea* sp.(?), *Gyraulus* sp.), and Ostracoda (*Bythocypris* sp., *Cardona* sp., *Ilyocypris* sp., and

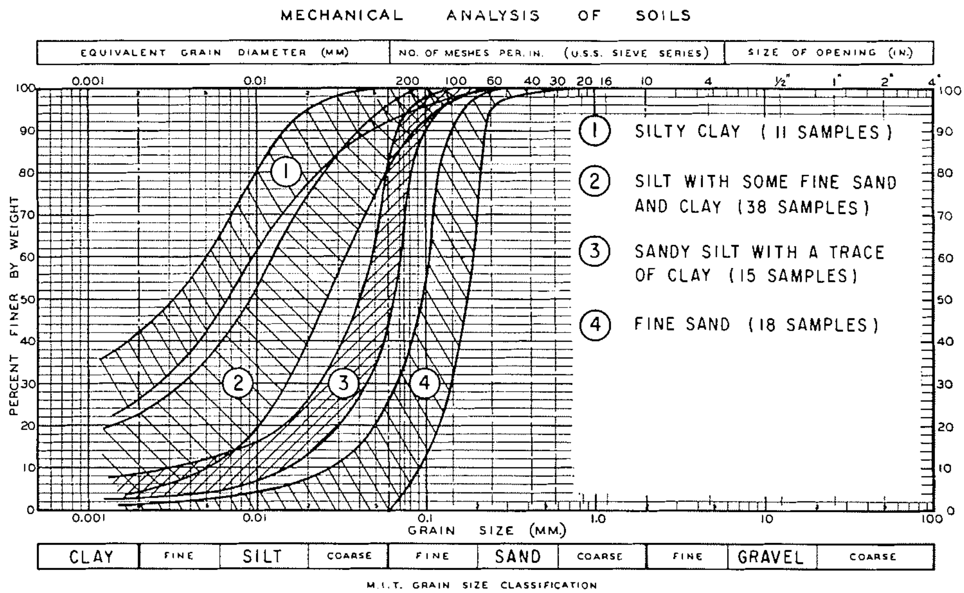

Figure 4. Mackenzie River delta soils—grain size envelopes

Limnocythere sp.), represent fresh-water conditions. No shells were found in the dense clay layer.

Suggested Origin of Deposits

During the last (Wisconsin) glaciation, the Laurentide ice sheet extended westward across the delta to the front of the mountains according to O. L. Hughes (personal communication, 1963). Presumably, the area was ice-free by about 12,000 years ago (Muller, 1962, p. 284; Mackay, J. R., and Terasmae, Jaan, personal communication, 1963).

The basal pebbly part of the dense silty layer

TABLE 1. PHYSICAL PROPERTIES OF SOME MACKENZIE RIVER DELTA SOILS

Sample* depth	Sample no.	Atterberg limits: Liquid limit	Atterberg limits: Plastic limit	Atterberg limits: Plasticity index	Clay fraction per cent <0.002 mm	Activity plasticity index / per cent clay
12	MD1 8	32.1	24.1	8.0	11	0.727
42	38.5	57.8	31.8	26.0	28	0.929
49	45	55.2	31.7	23.5	31	0.758
54	50	35.5	23.0	12.5	18	0.694
55	MD2 55.5	35.0	23.6	11.4	17	0.671
58	58	37.5	22.6	14.9	17	0.877
68	68	37.3	25.7	11.6	13	0.893
75	75	39.1	21.5	17.6	27	0.652
76	MD1 72	41.1	25.4	15.7	21	0.748
78	MD2 78	41.3	21.7	19.6	27	0.726
97	97	49.8	28.2	21.6	20	1.080
116	116	34.3	22.3	12.0	21	0.572
185	185	38.2	19.5	18.7	35	0.534
190	190(b)	40.0	20.3	19.7	31	0.636
194	MD1 190(d)	40.4	19.1	21.3	35	0.609
195	191	38.4	19.2	19.2	35	0.548
195	MD2 195	39.1	18.3	20.8	35	0.594
204	MD1 200(a)	35.2	18.4	16.8	35	0.480
219	215.5	34.4	17.7	16.7	37	0.451

* Datum—Ground surface at hole No. 3.

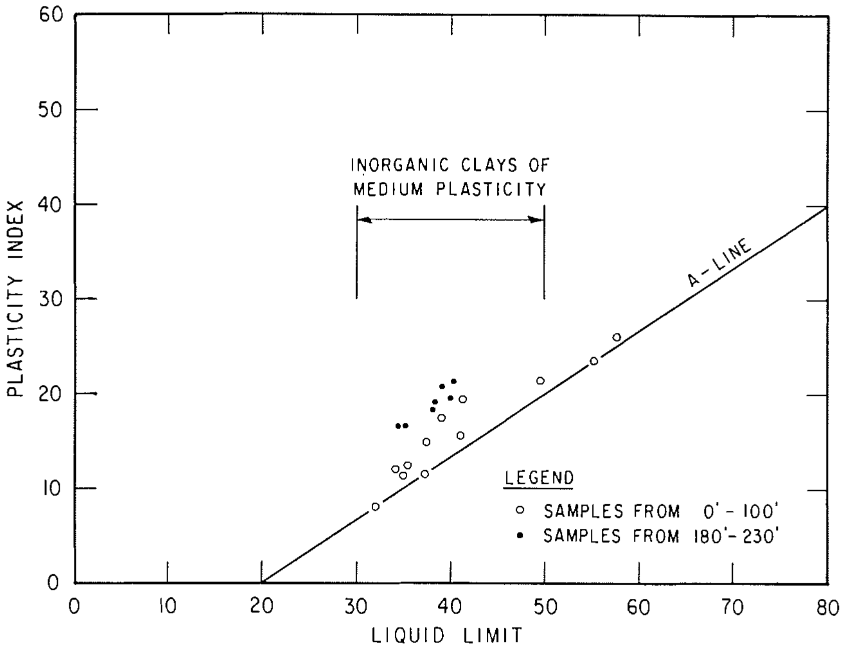

Figure 5. Mackenzie River delta soils—plasticity chart

from the 206-foot depth is probably till deposited by the ice sheet. Although no distinct boundary within the clay layer is evident from the data, the upper portion, which contained no pebbles, was possibly deposited under glaciomarine or estuarine conditions. Relatively quiet water conditions would be necessary for deposition of these fine-grained sediments. Their plasticity values and location on the plasticity chart (Fig. 5) indicate that the material is an inorganic clay of medium plasticity and of glacial origin. In addition, their activity suggests that they were deposited in fresh water and contain mostly mechanically derived clay-sized particles. Postglacial marine submergence might be inferred, however, from the present location of the area near the sea coast and the salt content of the clay. The apparent decrease in activity (to values less than 0.5) with depth in this layer suggests that the sea encroached

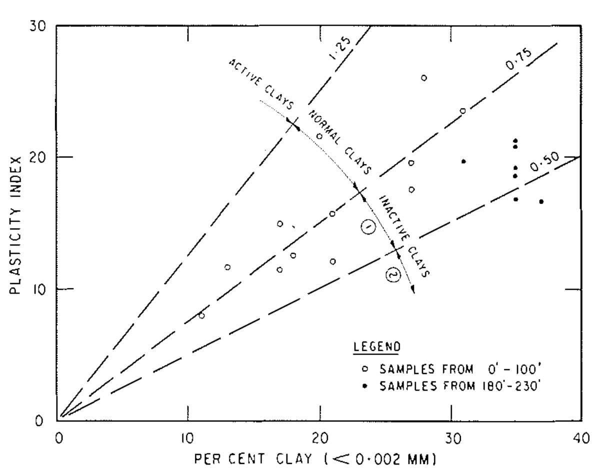

Figure 6. Mackenzie River delta soils—activity

on the till as the glacier retreated and the lowest portion of the pebble-free layer (*i.e.* about 200 feet) was deposited in sea water. The remainder of the layer (to about 180 feet) was probably deposited in water that became less brackish with time due to the increased volume of water from the melting glacier and isostatic readjustment (uplift). No microfossils or other potential indicators of age or conditions were observed in this material. The abrupt change from clay to sand in the profile suggests that environmental conditions underwent radical alteration at that time, although changes in major channels in this large delta could produce rapid local extensions of the delta.

It appears that all the sediments above the silty clay are of deltaic origin deposited by the present Mackenzie River and its postglacial predecessors. The stratified fine- to medium-sized sand from the 100- to 180-foot depth was probably deposited by a larger volume and faster flow of water, perhaps by a local stream or river flowing into the delta from the east near the location of Inuvik. It could also be a result of a change in stream gradient at this location or to erosion of fresh drift.

The Geological Survey of Canada dated a wood fragment from the 125-foot depth at 6900 ± 110 years B.P. (dating no. GSC-54). It appears, therefore, that deltaic deposition has occurred (at least from that depth to the surface) at an average rate of about 1/5 inch per year. Above the 100-foot depth the sand merges into sandy silt, indicating a decreased flow of water similar to the present rate. The concentration of organic material at the 100-foot depth might be the result of some major climatic change that may have occurred about 5500–5000 years ago (Terasmae, 1961). The deposition of this material, however, could also be the result of local terrain conditions not related to climatic fluctuations, *e.g.*, erosion and undercutting of a channel bank. Vegetation was well-established at this time and for some time previously, as is indicated by the woody and peaty remains found in the drill cores and by the results of other investigators (Muller, 1962 p. 284; Mackay, J. R., and Terasmae, Jaan, personal communication, 1963).

The formation and existence of permafrost is closely associated with climate and its fluctuations. Although we know little of the climatic regime 12,000 to 8500 years ago, recent palynological studies in this area indicate a rather cool, dry climate 8500 to 7500 years ago (compared with the present) according to J. R. Mackay and Jaan Terasmae (personal communication, 1963). Further evidence suggests that this was followed by a period of warmer climate than that of the present—the postglacial thermal maximum, which occurred about 6000–5000 years ago (Terasmae and Craig, 1958; Muller, 1962 p. 284; Mackay, J. R., and Terasmae, Jaan, personal communication, 1963). The formation of many of the pingos in the region is associated with the

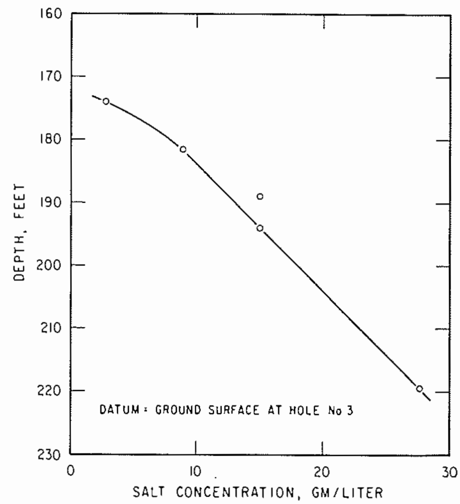

Figure 7. Mackenzie River delta soils—salt concentration versus depth

marked cooling of the climate that followed the postglacial thermal maximum. The formation of permafrost probably began with the initiation of subaerial deltaic deposition because it could not have started during the previous postglacial, marine submergence or estuary-forming period. No observations were made, however, establishing the time at which permafrost formation actually began. The formation of some pingos could have begun 10,000–7000 years ago (Muller, 1962). If this is the case, permafrost must have existed at that time and through the thermal maximum to the present.

These comments are based on the results of a rather limited investigation carried out at one location in the Mackenzie River delta. Future investigations at other locations will help to clarify the complex sequence of events that took place in this area.

Acknowledgments

The authors are grateful to Dr. J. R. Mackay, University of British Columbia, and Drs. J. G. Fyles, O. L. Hughes, and Jaan Terasmae of the Geological Survey of Canada, who reviewed and commented on the results of the investigation. Shells, pollen, and wood fragments of the study area were examined by personnel of the Geological Survey of Canada whose assistance is gratefully acknowledged.

References Cited

Casagrande, Arthur, 1948, Classification and identification of soils: Trans. Am. Soc. Civil Eng., v. 113, p. 901–991

Johnston, G. H., and Brown, R. J. E., 1964, Some observations on permafrost distribution at a lake in the Mackenzie Delta, Northwest Territories, Canada: Arctic, v. 17, no. 3, p. 163–175

Kellaway, G. A., 1956, Notes on the geology of the Mackenzie delta (Abstract): The Canadian Geographer, no. 7, p. 12

Mackay, J. R., 1963, The Mackenzie Delta area, Northwest Territories, Canada: Dept. Mines and Tech. Surveys, Geog. Br. Memoir No. 8, 202 p.

Muller, Fritz, 1962, Analysis of some stratigraphic observations and radiocarbon dates from two pingos in the Mackenzie delta area, Northwest Territories: Arctic, v. 15, no. 4, p. 279–288

Pihlainen, J. A., and Johnston, G. H., 1954, Permafrost investigations at Aklavik 1953 (drilling and sampling): Natl. Research Council, Canada, Div. Bldg. Research, NRC 3393, 47 p.

Pihlainen, J. A., Brown, R. J. E., and Johnston, G. H., 1956, Soils in some areas of the Mackenzie River delta region: Natl. Research Council, Canada, Div. Bldg. Research, NRC 4096, 51 p.

Skempton, A. W., 1953, The colloidal "activity" of clays: Third Internat. Conf. on Soil Mech. and Found. Eng. Proc., v. 1, p. 57–61

Terasmae, Jaan, 1961, Notes on Late-Quaternary climatic changes in Canada: Annals of the N. Y. Acad. of Sci., v. 95, art. 1, p. 658–675

Terasmae, Jaan, and Craig, B. G., 1958, Discovery of fossil Ceratophyllum Demersum L. in Northwest Territories, Canada: Canadian Jour. Botany, v. 36, p. 567–569

Division of Building Research, National Research Council, Ottawa, Canada
Manuscript Received by the Society January 16, 1964
Contribution of the Division of Building Research, National Research Council, Ottawa, Canada
Published with the Approval of the Director of the Division