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ENGINEERING GEOLOGY OF THE GREAT BEAR RIVER AREA, NORTHWEST TERRITORIES

K.W. Savigny

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"The information which they gave respecting the river...that it would require several winters to get to the sea, and that old age would come upon us before the period of our return: we were also to encounter monsters of such horrid shapes and destructive powers as could only exist in their wild imaginations. They added, besides, that there were two impassible falls in the river, the first of which was about thirty days march from us."[1]

[1] Mackenzie. (1971, p. 33-34) This is an account of conditions along Mackenzie River between Fort Norman, Northwest Territories, and the "Frozen" (Arctic) Ocean as related to Sir Alexander Mackenzie by natives at Fort Norman during his descent of the Mackenzie in July, 1789, Sir Alexander Mackenzie was the first explorer to visit the Fort Norman-Great Bear River area.

ENGINEERING GEOLOGY OF THE GREAT BEAR RIVER AREA, NORTHWEST TERRITORIES

Abstract

Great Bear River drains Great Bear Lake westward into Mackenzie River. Great Bear River valley is incised up to 50 m below the levels of Mackenzie and Great Bear plains. Quaternary sediments are exposed intermittently along the valley slopes. Rocks of Tertiary age are exposed more or less continuously along the lower reach of Great Bear River, and Mesozoic and Paleozoic rocks are exposed where the river crosses McConnell Range at St. Charles Rapids.

A single Laurentide till is present and is assumed to represent the Late Wisconsinan advance. The till generally rests on bedrock, but locally it overlies older alluvial and deltaic sediments. This advance was followed by a lacustrine phase over Mackenzie Plain. The lacustrine phase appears to have ended abruptly with progradation of a deltaic facies. Permafrost is widespread except beneath large lakes, streams, and rivers.

Postglacial entrenchment by Great Bear River appears to have begun on Mackenzie Plain about 10 000 years ago and approached its present level by approximately 2670 years ago.

Résumé

La Grande rivière de l'Ours achemine les eaux du Grand lac de l'Ours vers l'ouest jusque dans le fleuve Mackenzie. La vallée de la Grande rivière de l'Ours est encaissée jusqu'à 50 m sous le niveau de la plaine du Mackenzie et de la Grande plaine de l'Ours. Des sédiments du Quaternaire sont mis à nu par intermittence le long des flancs de la vallée. Des roches datant du Tertiaire affleurent de façon plus ou moins continue le long du cours aval de la Grande rivière de l'Ours, tandis que des roches mésozoïques et paléozoïques affleurent à l'endroit où la rivière traverse le chaînon McConnell, soit aux rapides St-Charles.

Un till Laurentidien unique est présent et représenterait l'avancée de la fin du Wisconsin. Ce till repose généralement sur la roche en place, mais à certains endroits, il est sus-jacent à des sédiments alluviaux et deltaïques plus anciens. Cette avancée a été suivie d'une phase lacustre sur la plaine du Mackenzie. Cette phase semble s'être terminée brusquement avec la progression d'un faciès deltaïque. Le pergélisol est généralisé, sauf sous les grands lacs et cours d'eau.

L'encaissement post-glaciaire de la Grande rivière de l'Ours aurait commencé il y a quelque 10 000 ans dans la plaine du Mackenzie et serait parvenu à peu près à son niveau actuel il y a environ 2670 ans.

SUMMARY

Great Bear River drains Great Bear Lake from its southwest end near Fort Franklin and flows westerly for 115 km to its confluence with Mackenzie River at Fort Norman. In the early 1970s, the hydroelectric potential of Great Bear River valley and several alternative pipeline, railroad, and road crossing locations were investigated by private agencies. The Geological Survey of Canada commissioned this study in order to obtain baseline engineering geology data that would assist regulatory authorities with their evaluation of alternative development schemes.

Most of the study area is situated in Mackenzie Plain. This is an area of low elevation and relief bordered on the northwest, north, and east by Franklin Mountains. Mackenzie Plain is underlain by flat-lying Tertiary and Cretaceous clastic rocks ranging from shale through siltstone, sandstone to conglomerate. Most are poorly indurated and some shales and silstones are bentonitic. Lignite to subbituminous coal beds and laminae are common.

Bedrock is generally overlain by a thick succession of Late Wisconsinan glacial sediments; however, older surficial deposits occur at two locations. At one site these deposits are interpreted to be preglacial alluvium and at the other they are considered the remnants of a glacial delta complex.

Till, which is assumed to have been deposited during Late Wisconsinan glaciation, is the lowest widespread deposit in the Quaternary section. This is overlain by glaciolacustrine silty clay and then glaciodeltaic sand, both of which are also widespread.

Radiocarbon dates indicate that deltaic sedimentation ceased at an elevation of about 100 m approximately 10 000 years ago, and that the rate of downcutting by Great Bear River was controlled by the local base level of Mackenzie River. This local base was approximately 70 m by 3290 ± 100 BP, and was below 68 m by 2670 ± 130 BP.

Holocene sediments are common throughout the area. Organic soils, lacustrine clay, silt, and sand, and eolian sand are present on the surface of Mackenzie Plain; alluvial silt, sand, and gravel are present on valley floors; and clayey to sandy colluvium covers valley slopes.

Permafrost is widespread but discontinuous beneath Mackenzie Plain. Ground ice is a significant component of fine grained soils and organic soils, and is also present in deltaic sands. Degradation of permafrost by ablation causes bimodal flows which are the most widespread form of mass movement; other forms include multiple retrogressive slides and creep.

Borrow resources for common fill are widespread, but all materials are frozen and contain ground ice. Time would have to be allowed for permafrost to melt and excess water to drain in order for these materials to be

SOMMAIRE

La Grande rivière de l'Ours évacue les eaux du Grand lac de l'Ours à l'extrémité sud-ouest de celui-ci, près de Fort-Franklin, puis coule vers l'ouest sur 115 km jusqu'à son confluent avec le fleuve Mackenzie à Fort-Norman. Au début des années 70, le potentiel hydroélectrique de la vallée de la Grande rivière de l'Ours ainsi que plusieurs emplacements de substitution pour les pipelines, chemins de fer et routes ont été étudiés par des bureaux privés. La Commission géologique du Canada a commandé la présente étude afin d'obtenir des données de base en géologie appliquée ; de telles données devraient faciliter le travail des organismes de contrôle dans leur évaluation d'autres schémas d'aménagement.

La plus grande partie de la zone d'étude est située dans la plaine du Mackenzie. Il s'agit d'une zone de faible altitude et à bas reliefs qui est bordée au nord-ouest, au nord et à l'est par les monts Franklin. La plaine du Mackenzie repose sur des roches détritiques du Tertiaire et du Crétacé disposées à l'horizontale et allant des schistes argileux jusqu'aux conglomérats, en passant par le grès et le siltstone. La plupart de ces roches ont mal durci, certains schistes argileux et siltstones étant même bentonitiques. Les couches de lignite et les laminites sont fréquentes.

Le substrat rocheux est généralement recouvert d'une épaisse succession de sédiments glaciaires datant de la fin du Wisconsin; on trouve toutefois des dépôts quaternaires plus anciens à deux endroits. Au premier, les dépôts seraient des alluvions préglaciaires, tandis qu'à l'autre il s'agirait plutôt des restes d'un complexe deltaïque d'origine glaciaire.

Du till qui aurait été déposé pendant la glaciation de la fin du Wisconsin constitue le dépôt généralisé le plus bas dans la coupe quaternaire. Le tout est recouvert d'argile limoneuse glaciolacustre, puis de sable glaciodeltaïque, ces deux matériaux étant aussi répandus que le till.

Les âges radiométriques obtenus indiquent que la sédimentation deltaïque a cessé à une centaine de mètres d'altitude il y a quelque 10 000 ans et que la régulation de la vitesse de creusement de la Grande rivière de l'Ours était assurée par le niveau du fond du fleuve Mackenzie à cet endroit. Ce fond était situé à environ 70 m vers 3290 + ou − 100 BP et il se situait sous les 68 km vers 2679 + ou − 130 BP.

Les sédiments holocènes sont courants à la grandeur de la zone. On trouve des sols organiques, de l'argile, du limon et du sable lacustres, ainsi que du sable éolien à la surface de la plaine du Mackenzie; on trouve du gravier, du sable et du limon alluvial sur les fonds de vallée, tandis que les flancs de ces mêmes vallées sont recouverts de matériaux colluviaux argileux à sableux.

Le pergélisol est répandu, mais discontinu sous la plaine du Mackenzie. La glace de sol constitue un important élément des sols à grain fin et des sols organiques et on en trouve aussi dans les sables deltaïques. La régression du pergélisol par ablation provoque des glissements régressifs dus au dégel qui sont la forme la plus répandue de mouvement de masse; dans les autres formes, qu'il suffise de mentionner les glissements régressifs multiples et de fluage du gélisol.

utilized. Considerable quantities of granular borrow are available in specific areas. Most of these are also expected to be within the permafrost zone, but thawing and drainage should be much more straightforward.

No evidence of groundwater discharge was observed from surficial materials with the exception of seepage through the active layer. Groundwater may be present below the permafrost table in Tertiary and Cretaceous bedrock. This condition may have an impact on exploration and development for oil and gas, and lignite deposits.

Les matériaux d'enfouissement pour le remplissage ou le remblayage ordinaires sont répandus, mais ils sont tous gelés et renferment de la glace de sol. Il faudrait laisser au pergélisol le temps de fondre et à l'excédent d'eau le temps de s'écouler avant de pouvoir se servir de ces matériaux. À certains endroits, on a accès à de grandes quantités de matériaux d'emprunt à l'état de granulats. La plupart de ces matériaux devraient aussi appartenir à la zone de pergélisol, mais le dégel et le drainage devraient y être plus simples.

Aucun signe de débit d'eaux souterraines n'a été observé à partir des matériaux de surface, si ce n'est le suintement à travers le mollisol. Il y a peut-être de l'eau souterraine sous le plafond du pergélisol dans le socle rocheux datant du Tertiaire et du Crétacé. Cette condition pourrait se révéler déterminante dans l'exploration et la mise en valeur de gisements de pétrole et de gaz, ainsi que de lignite.

INTRODUCTION

This report represents the results of an engineering geology study of the Great Bear River valley in the Northwest Territories. Great Bear River drains Great Bear Lake from its southwest end near Fort Franklin, flowing westerly for 115 km to its confluence with Mackenzie River at Fort Norman (Fig. 1). For most of its length, the river has a steep gradient and is deeply incised in a narrow valley. These topographic characteristics combined with the enormous reservoir capacity of Great Bear Lake make the valley attractive for hydroelectric development. Topographic characteristics and geographic location make it an obstacle to linear facilities following the Mackenzie Transportation Corridor (Hughes et al., 1973).

In the early 1970s, the hydroelectric potential of the Great Bear River valley and several alternative pipeline, railroad and road crossing locations were being investigated by private agencies. The Geological Survey of Canada considered it essential to obtain baseline engineering geology data for evaluation of alternative development schemes.

Engineering geology studies were initiated in 1973 as part of the Environmental-Social Program, Northern Pipelines. The surficial geology and some bedrock geology in the Great Bear River area were studied in 1973, with brief visits to specific locations in 1975, 1976, and 1977. All field work in 1973 was supported by boat from a logistics base in Fort Norman. Later field visits were supported by helicopter from Norman Wells. The information reported here is based primarily upon examination of stratigraphic sections exposed along Great Bear River and laboratory analysis of samples taken from the exposures. The main objectives of these studies were to describe the stratigraphy of surficial deposits and the general scheme of major Quaternary events. Subsurface data were provided by Northern Canada Power Commission, Hardy Associates (1978) Ltd., and Pemcan Services "72".

The author was a Research Assistant with the Terrain Sciences Division, Geological Survey of Canada, associated with the Environmental-Social Program during 1973. Engineering geology studies along Great Bear River were carried out independently by the author, and later formed the basis of a PhD dissertation for the Department of Civil Engineering, University of Alberta (Savigny, 1980).

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Field assistance was provided by J. Pilon, A. Rotman, M.C. Savigny, and D.C. Sego. M. Mendo, of Fort Norman, provided skilled boatsmanship through rapids to many natural exposures along Great Bear River. Many worthwhile discussions were held with O.L. Hughes in the field. Field visits after 1973 were supported in part by Northern Engineering Services and the National Research Council of Canada. Discussions with O.L. Hughes regarding the sequence of Quaternary events were of great value in delineating the geomorphic development. Critical comments on the manuscript were offered by D. Cook, O.L. Hughes, and S. Hopkins. Thurber Consultants Ltd. generously assisted in the preparation of the original manuscript.

HISTORICAL PERSPECTIVE

Early explorations in the Great Bear River area were carried out for geographical interest. The explorers included Sir Alexander Mackenzie, Sir John Franklin, and others of central importance in the history of the Canadian nation (Camsell and Malcolm, 1921; Robinson and Robinson, 1946; Hume, 1954).

Geological surveys of the area began in 1888 with investigations by R.G. McConnell of the Geological Survey of Canada. In 1914, J.O. Bosworth was the first to stake claims around local hydrocarbon shows. Since that time, exploration and development of the hydrocarbon deposits have provided a wealth of information on the local bedrock geology (Hume and Link, 1945; Hume, 1954).

Regional geological surveys were undertaken by the Geological Survey of Canada beginning in 1957. These concentrated on bedrock geology, but also included significant studies of surficial geology (Douglas and Norris, 1963;

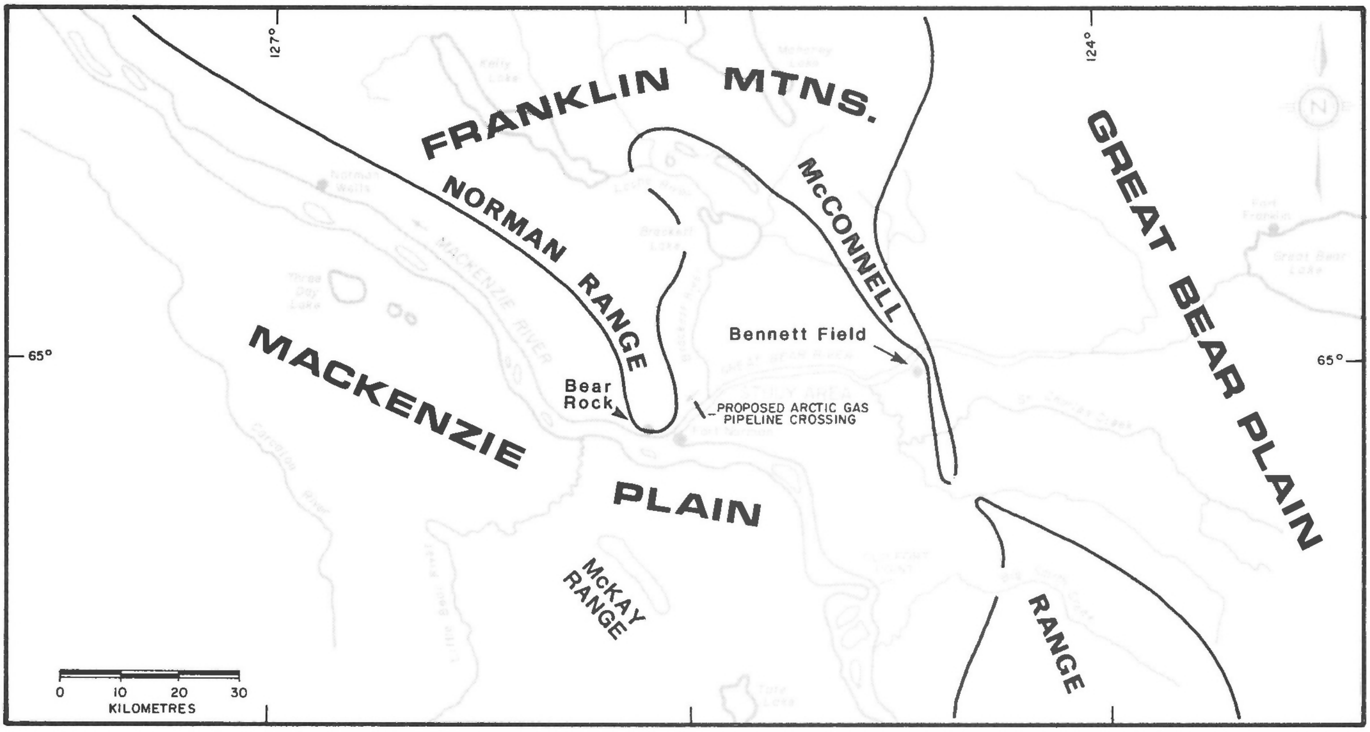


Figure 1. Physigraphic subdivisions of the Great Bear River area.

Norris, 1963; Aitken et al., 1969; Aitken et al., 1970; Cook and Aitken, 1971).

In 1968, the discovery of oil and natural gas on the North Slope of Alaska, together with encouraging results of wildcat drilling in the Mackenzie Delta, caused producers to look to the Mackenzie River valley for the location of pipelines to carry petroleum products to southern consumers. In the early 1970s, numerous studies were initiated to resolve engineering complexities associated with the construction of pipelines and support facilities. Geological investigations, which formed part of these studies, concentrated on surficial geology and involved mapping, describing and explaining the unconsolidated deposits, landforms, permafrost, ground ice, and organic (muskeg) terrain present in areas adjacent to Mackenzie River (Hughes et al., 1973; Hanley and Hughes, 1973).

Figure 2. View west from Mount St. Charles over Mackenzie Plain; Great Bear River flows from left to right in the background. 204698-29A

PHYSIOGRAPHY

Two physiographic regions are represented in the study area (Fig. 1): Mackenzie Plain, which is part of the Interior Plains, and Franklin Mountains, which is part of the Cordillera (Bostock, 1948). The part of each region that lies in the vicinity of Great Bear River is described below.

Mackenzie Plain

Mackenzie Plain is an area of low elevation and relief bordered on the northwest, north, and east by Franklin Mountains. It is drained by the Great Bear and two tributaries-Brackett River and St. Charles Creek; otherwise, drainage is poorly developed, with a myriad of small lakes, swampy interlake areas, and few well defined streams (Fig. 2).

Near the confluence of the Great Bear and Mackenzie, the plain is underlain by Tertiary clastic rocks. These outcrop along Great Bear River to above the confluence with the Brackett, and upstream along the Mackenzie almost as far as Old Fort Point. Elsewhere, the plain is underlain by undifferentiated Tertiary-Cretaceous clastic rocks which rarely outcrop (Cook and Aitken, 1976). Silty clay till overlies bedrock throughout Mackenzie Plain; the till is overlain by clay, silt, and sand of glaciolacustrine or glaciodeltaic origin. Glaciofluvial, alluvial, and eolian sediments are present in some locations.

Topographic elevations range from 52 m on the beach at Fort Norman to 150 m where Great Bear River crosses the trend of Franklin Mountains. Major streams are incised between 45 and 60 m below the featureless plain surface. Valley sides are commonly colluviated by active or remnant bimodal flows seated in ice-rich glaciolacustrine and, in places, morainic sediments.

Franklin Mountains

The Franklin Mountains region is represented by two mountain ranges: McConnell Range in the east and Norman Range in the west (Fig. 1). These merge north of Great Bear River, defining a crescentic northern limit to Mackenzie Plain. The chain of lakes extending northwest from Brackett Lake through Kelly Lake marks their common boundary.

Paleozoic carbonates and shales are the dominant lithologies. Interbedded salt, gypsum, and anhydrite are important components, but do not comprise significant thicknesses. Glacial drift is present throughout, but is thin or lacking in the highlands of Franklin Mountains.

McConnell Range is a narrow ridge where it is crossed by Great Bear River at St. Charles Rapids. South of the river there are other topographic lows by which drainage passes into Mackenzie Plain. The ridge is more contiguous north of the river. Relief is 410 to 425 m.

Norman Range is wider and more rugged than McConnell Range, and forms a continuous drainage divide within Mackenzie Plain. Relief is 520 to 550 m.

STRATIGRAPHY, LITHOLOGY, AND ENGINEERING PROPERTIES OF BEDROCK AND SURFICIAL MATERIALS

The bedrock geology of the Great Bear River area has been studied in detail during more than half a century of petroleum exploration. The stratigraphy of local rocks is well described in the literature and hence the following discussion is limited to specific properties which appear to affect the Quaternary stratigraphy.

Quaternary sediments are widespread throughout the area. They were examined in detail in the field and in the laboratory to facilitate understanding of their areal distribution and to provide insight into regional geomorphic development. The location of each measured section and drillhole from which data were obtained is given the code "GB" followed by a number. The numbers have no particular order along the river; thus, any site referred to in the text may be found by determining its kilometre[1] location from Table 1, and then referring to Figure 3 for the location. A summary description of each section and drillhole is given in Appendix 1.

Paleozoic and Mesozoic

Detailed study of Paleozoic and Mesozoic stratigraphy began soon after Bosworth's discovery of oil seeps in 1914. Camsell and Malcolm (1921) published the first detailed analysis, and Hume (1954) prepared what remains one of the most comprehensive. "Operation Norman" of the Geological Survey of Canada was aimed at updating geological knowledge and preparing 1:250 000 scale geological maps. Recent publications based on this program include: Aitken et al. (1969, 1970, 1973), Tassonyi (1969), Fritz (1970), Yorath (1970), Balkwill (1971), Aitken and Cook (1974), Norford and Macqueen (1975), and Cook and Aitken (1976). A stratigraphic column is given in Table 2.

Paleozoic rocks are best exposed in Norman and McConnell ranges (Fig. 4). Several hard, resistant carbonate formations make up most of the exposed rocks. Overlying shale formations outcrop on the west side of each range and are well exposed along streams. Soluble evaporitic rocks make up thick zones of the Saline River Formation and Bear Rock Formation (Tassonyi, 1969). Where the Bear Rock Formation is Quaternary subcrop, numerous sinkholes testify to Holocene, and probably Pleistocene, subsurface solution. Minor evidence of solution is also present in the Saline River Formation (Aitken and Cook, 1974).

Mesozoic rocks are made up of a succession of marine and nonmarine clastic rocks of Cretaceous age. They are exposed on the flanks of Norman and McConnell ranges and in many valleys on Mackenzie Plain. The rocks are composed of interbedded medium to fine quartz sandstone and clay shale. Lignite is common as a minor constituent. Bentonite laminae up to 25 mm thick are also common, and most clay shales have a significant bentonite component (Tassonyi, 1969; Yorath, 1970; Yorath in Aitken and Cook, 1974).

Cenozoic — Tertiary

Tertiary rocks underlie most of Mackenzie Plain in the Great Bear River area (Yorath, 1970; Yorath in Aitken and Cook, 1974). They constitute an eastward thinning wedge of clastic rocks that pinches out near the western flank of McConnell Range (Fig. 4).

The rocks are well exposed in the area of the Mackenzie and Great Bear confluence and for several kilometres upstream along both rivers. Those along Great Bear River may be subdivided into two units, referred to here as the "lower unit" and the "upper unit".

Lower unit

The lower unit consists of a complex, upsection transition from shale and siltstone, through sandstone to conglomerate. These rocks are exposed intermittently along Great Bear River from Fort Norman to a short distance above the confluence with the Brackett (Fig. 5).

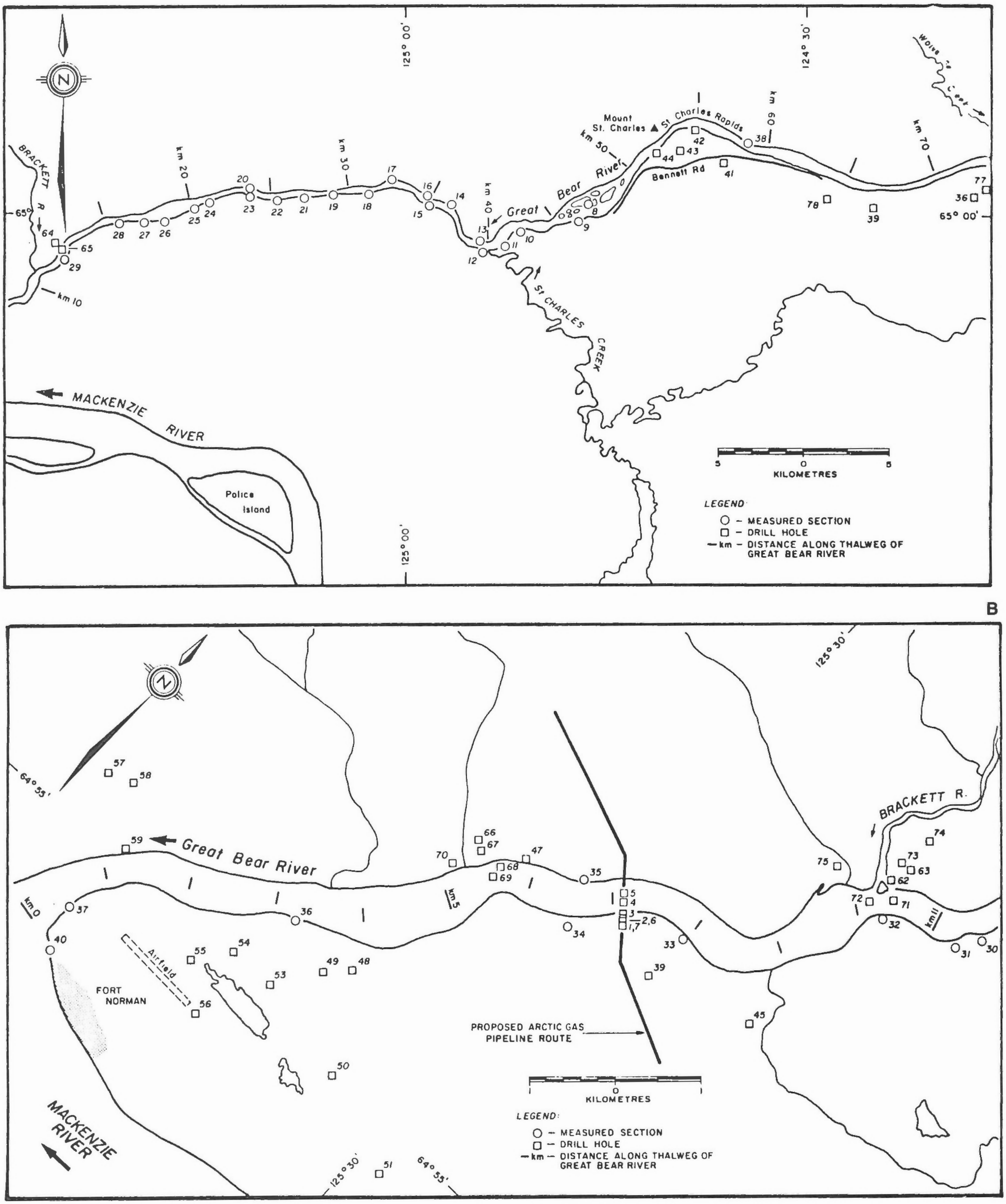
Shale and siltstone appearing at the base of the unit are medium to highly plastic and bentonitic. They show varying degrees of fissuring and are more like heavily overconsolidated soils than rocks. They are weakly indurated and may be excavated by hand and broken down with gentle finger pressure.

[1]Kilometre 0 is arbitrarily defined as the confluence of Mackenzie and Great Bear Rivers. The kilometres accumulate upstream along Great Bear River.

Table 1. Guide to the location of drillholes and measured sections along Great Bear River

Location code (cf. Fig. 3)	Kilometre location along river	Elevations (m) Nearest river level	Top of section or drill collar	Source S-Section DH-Drillhole CR-Consulting Rpt.
GB1	7.1	56.3	101.5	DH GB1, 1A, 1B
GB2	7.1	56.3	80.2	DH GB2
GB3	7.1	56.3	70.4	DH GB3, 3A
GB4	7.1	56.3	56.3	CR DH N74-303
GB5	7.1	56.3	56.3	CR DH N74-304
GB6	7.1	56.3	87.5	CR DH N74-307
GB7	7.1	56.3	101.6	CR DH N74-308
GB8	46.3	80.1	86.2	S WS-73-2
GB9	45.4	79.5	125.5	S WS-73-3
GB10	42.5	78.0	125.7	S WS-73-4
GB11	41.1	77.3	109.7	S WS-73-5
GB12	40.0	76.9	82.6	S WS-73-6
GB13	39.6	76.7	116.8	S AR-73-4
GB14	37.1	75.5	118.4	S WS-73-8
GB15	35.1	74.8	120.5	S WS-73-9
GB16	34.8	74.7	82.5	S AR-73-5
GB17	32.6	73.2	80.0	S AR-73-6
GB18	31.1	72.2	113.6	S WS-73-11
GB19	29.0	71.2	86.2	S WS-73-12
GB20	24.1	68.8	108.8	S WS-73-14
GB21	27.25	70.3	116.9	S WS-73-15
GB22	25.6	69.5	76.3	S WS-73-16
GB23	24.1	68.8	95.8	S WS-73-17
GB24	21.1	67.3	99.1	S WS-73-18
GB25	20.3	67.0	80.0	S WS-73-19
GB26	18.9	66.2	107.2 (top sand)	S WS-73-20
GB27	18.1	65.7	76.3 (top clay)	S WS-73-21
GB28	16.2	64.7	99.2	S WS-73-22
GB29	11.8	61.3	100.6	S AR-73-7
GB30	11.5	61.0	86.4	S WS-73-23
GB31	11.2	60.9	N/A	S WS-73-24
GB32	10.3	59.8	110.9	S WS-73-25
GB33	8.0	57.8	N/A	S WS-73-26
GB34	6.5	56.5	101.8	S AR-73-8
GB35	6.6	56.6	66.6	S AR-73-8
GB36	3.3	53.3	87.3	S WS-73-28
GB37	0.4	51.4	83.4	S WS-73-27
GB38	57.6	97.7	130.82	S WS-73-1
GB39	65.2	110.6	213.4	CR DH B-14
GB40	0 (Ft. Norman)	51.0	N/A	S WS-75-8
GB41	56.5	96.0	135.3	CR DH M20
GB42	54.9	91.4	128.0	CR DH B15
GB43	53.0	91.4	147.8	CR DH M2
GB44	51.9	84.8	84.8	CR DH R2
GB45	8.7	58.4	Unknown	CR DH 2FN13
GB46	8.0	57.8	Unknown	CR DH 1FN30
GB47	5.9	56.0	Unknown	CR DH 3FN10
GB48	3.9	54.2	Unknown	CR DH 112
GB49	3.8	53.9	Unknown	CR DH 113
GB50	N/A	N/A	Unknown	CR DH 107
GB51	N/A	N/A	Unknown	CR DH 122
GB52	N/A	N/A	Unknown	CR DH C32FN8
GB53	3.1	N/A	Unknown	CR DH 110
GB54	2.6	52.8	Unknown	CR DH 111
GB55	2.3	52.7	Unknown	CR DH 452
GB56	2.5	N/A	Unknown	CR DH 1FN14
GB57	1.2	N/A	Unknown	CR DH 465
GB58	1.4	N/A	Unknown	CR DH 461
GB59	1.3	N/A	Unknown	CR DH 522
GB60	outside map area	N/A	176.8	CR DH M14
GB61	outside map area	N/A	174.1	CR DH M18
GB62	10.4	59.9	61.1	CR DH R11
GB63	10.6	60.1	101.3	CR DH R21
GB64	12.3	61.4	102.3	CR DH R22
GB65	12.2	61.4	61.4	CR DH R20
GB66	5.5	55.8	97.5	CR DH R206
GB67	5.5	55.8	91.4	CR DH R207
GB68	5.7	55.8	57.3	CR DH R208
GB69	5.6	55.8	57.3	CR DH R209
GB70	5.2	55.4	91.4	CR DH R210
GB71	10.5	59.9	61.4	CR DH R201
GB72	10.2	59.6	61.4	CR DH R202
GB73	10.6	59.6	108.6	CR DH R203
GB74	10.7	N/A	111.2	CR DH R204
GB75	9.9	59.4	79.2	CR DH R205
GB76	71.0	N/A	234.8	CR DH M6
GB77	72.2	N/A	228.6	CR DH M7
GB78	61.2	N/A	182.9	CR DH M1

A



B

Figure 3. Field locations along (A) Great Bear River and (B) in the Fort Norman to Brackett River area.

Table 2. Exposed bedrock formation in the Great Bear River area

ERA	PERIOD		FORMATION and MAXIMUM THICKNESS (m)		LITHOLOGY
CENOZOIC	Eocene ?		UNNAMED	490	Gravel, conglomerate, sand, sandstone, minor beds of coal; nonmarine
Unconformity					
MESOZOIC	Cretaceous	Upper	LITTLE BEAR and EAST FORK FMS., undifferentiated	300+	Sandstone, shale, minor coal; marine and nonmarine
		Disconformity			
MESOZOIC	Cretaceous	Upper	SANS SAULT and SLATER RIVER FMS., undifferentiated	760	Shale, sandstone, local conglomerate at base; marine
Unconformity					
PALEOZOIC	Devonian	Upper	IMPERIAL FORMATION	1100	Shale, sandstone, minor limestone; marine
			Conformable Contact		
PALEOZOIC	Devonian	Upper	CANOL FORMATION	90	Shale, black, siliceous, bituminous; marine
		Disconformity			
PALEOZOIC	Devonian	Middle	HARE INDIAN FORMATION	130	Shale, minor siltstone and limestone; marine
			Conformable Contact		
PALEOZOIC	Devonian	Middle	HUME FORMATION	170	Limestone, fossiliferous; minor shale; marine
		Disconformity			
PALEOZOIC	Devonian	Lower	BEAR ROCK FORMATION	300	Dolomite, dolomite solution-breccia, anhydrite and gypsum; marine. Equivalent to the Camsell, Arnica, and Landry formations, jointly
		Relationships Uncertain			
PALEOZOIC	Devonian / Silurian	L / U	UNNAMED	200(?)	Dolomite, partly sandy or argillaceous; sandstone, dolomitic; marine. Equivalent to the Delorme Formation
		Unconformity			
PALEOZOIC	Silurian / Ordovician	L / U	MOUNT KINDLE FORMATION	310	Dolomite, fossiliferous, siliceous; minor chert; marine
		Unconformity			
PALEOZOIC	Ordovician / Cambrian	Lower / Upper	FRANKLIN MOUNTAIN FORMATION	460	"Cherty member": dolomite, chert, drusy; quartz marine "Rhythmic member": alternation of very finely crystalline dolomite with finely to medium crystalline dolomite; marine "Cyclic member": dolomite, conglomeratic, stromatolitic, and argillaceous, shaly; marine "Basal redbeds": sandstone, red shales, conglomerate, dolomite, chert; marine and (?) nonmarine
		Conformable Contact			
PALEOZOIC	Cambrian	Mid.	SALINE RIVER FORMATION	841(?)	Redbeds: shale, siltstone, sandstone, salt, gypsum, anhydrite, dolomite; marine
		Unconformity			
PALEOZOIC	Cambrian	M-L	MOUNT CAP FORMATION	108	Shale, thin bedded limestone, sandstone, siltstone; marine

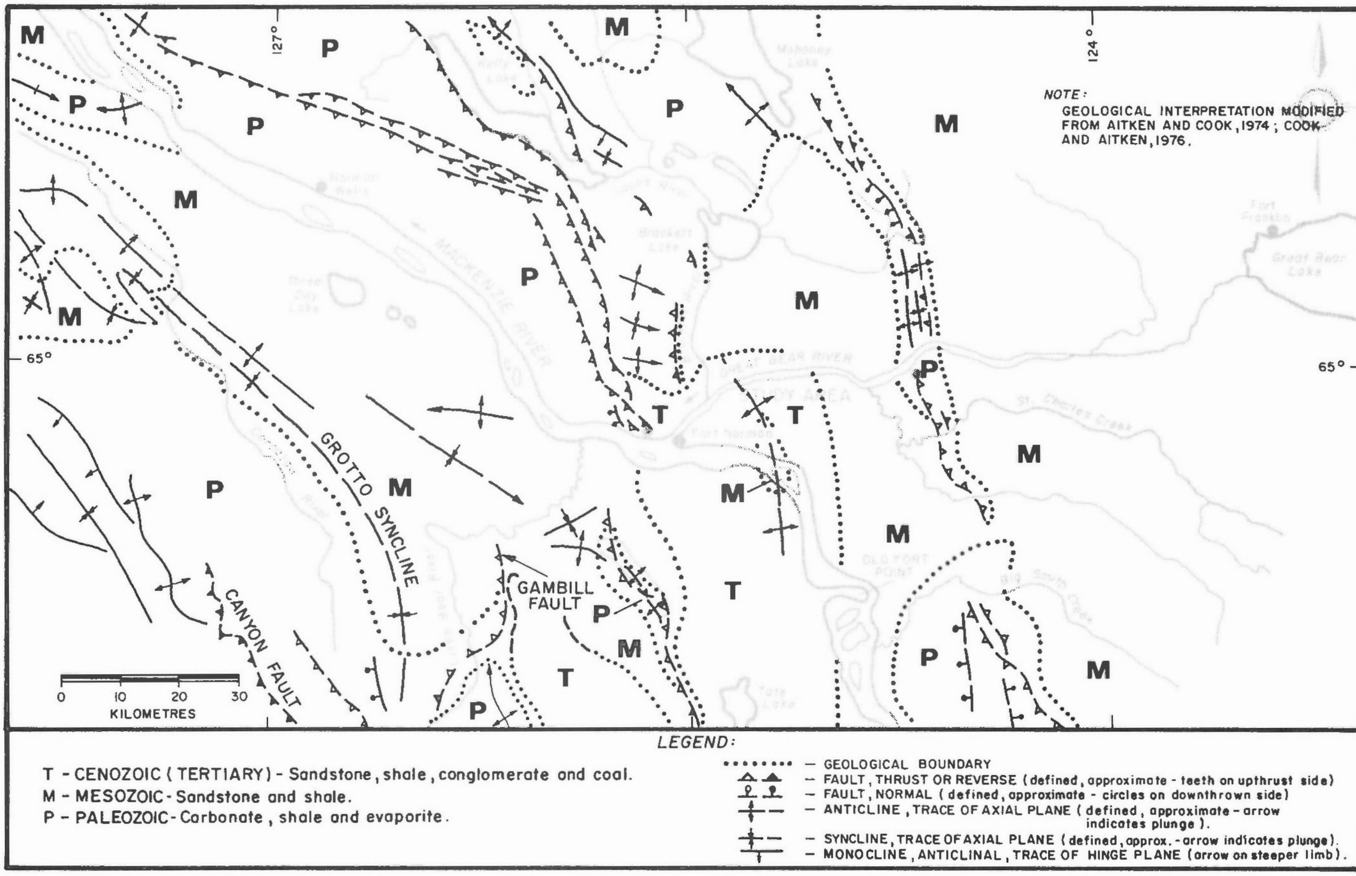


Figure 4. Generalized bedrock geology of the Great Bear River area.

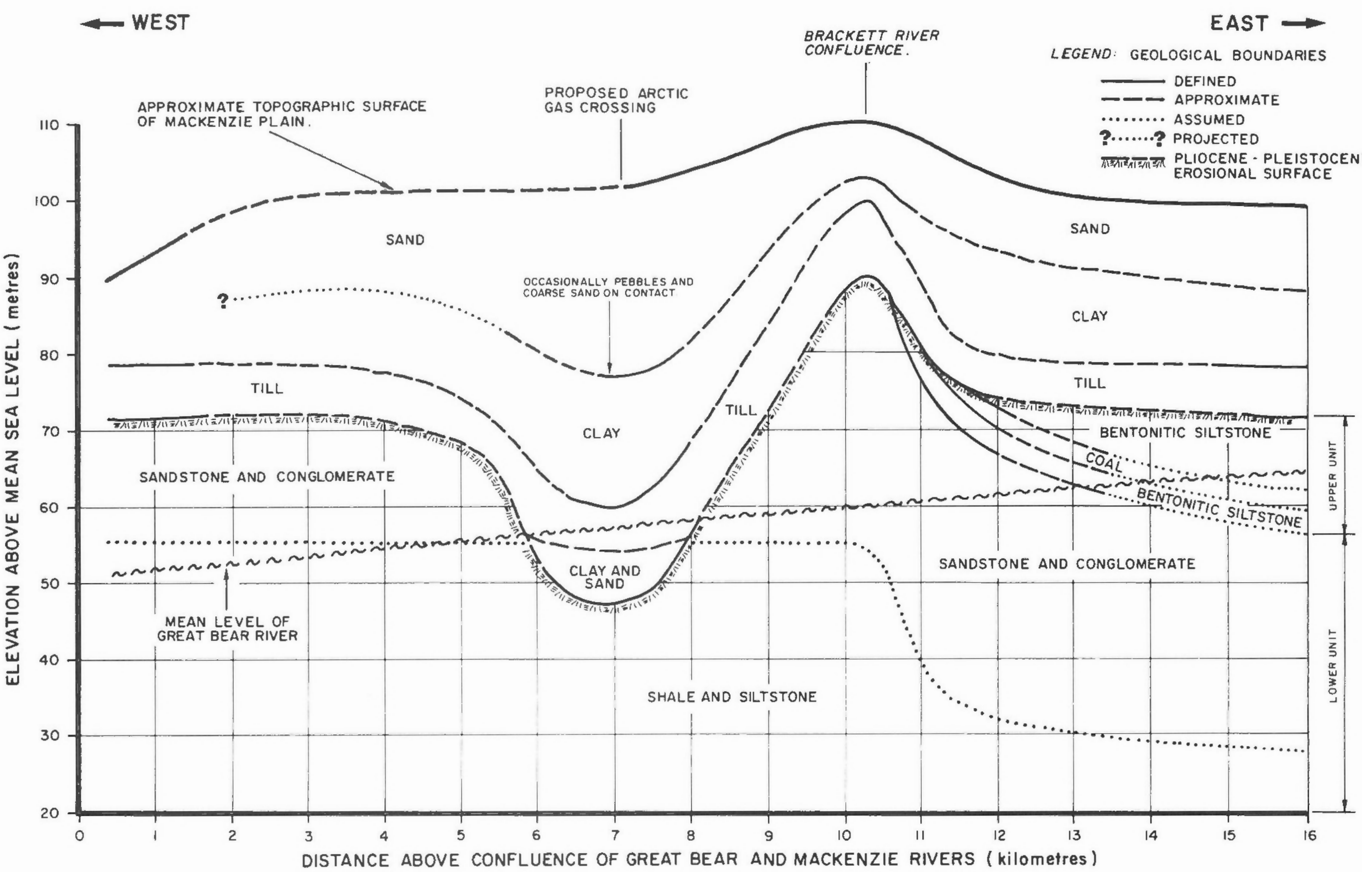


Figure 5. Cross-section of Tertiary and Quaternary stratigraphy between km 0 and km 16 of Great Bear River.

Sandstone is the most common rock exposed in the lower unit. It consists of medium to fine sand, of which 60 % is quartz and 40 % is argillite and chert. Exposures show well developed cross-stratification and few joints as illustrated in Figure 6. The degree of induration is low, and the material may be easily excavated with a shovel.

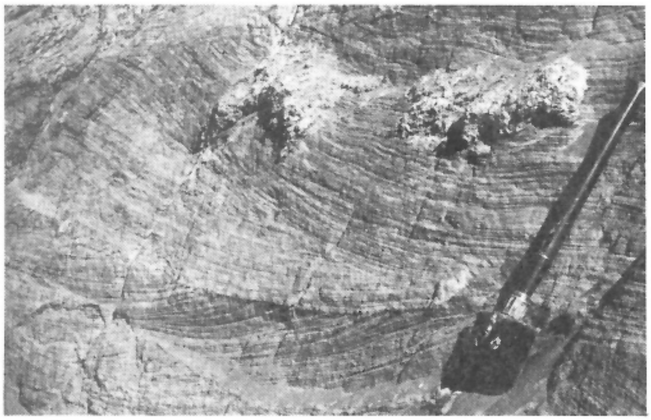


Figure 6. Crossbedded Tertiary sandstone exposed a short distance above river level at GB 32 (unit 9, Appendix 1; left bank of Great Bear River at km 10.3). 204698-1A

Figure 7. Tertiary strata consisting of sandstone overlying pebble conglomerate at GB 32(units 5 and 6, Appendix 1; left bank of Great Bear River at km 10.3). 204698-14A

The conglomerate is approximately 80 % gravel-sized clasts which consist mostly of quartzite and argillite with localized carbonaceous material (Fig. 7). Cross-stratification is extensive and commonly associated with deep scour into underlying sandstone. Joints in the sandstone also propagate through the conglomerate. The conglomerate is weakly indurated, and, like the sandstone, may be easily excavated with a shovel.

Upper unit

The upper unit consists of interbedded bentonitic siltstone and coal. The unit is exposed intermittently along Great Bear River from between 1 and 2 km above the confluence with the Brackett (Fig. 5) but is truncated by the Pleistocene erosional surface below the confluence. It reappears in the hanging wall of a normal fault in contact with the lower unit at Fort Norman (see GB40, Appendix 1).

Siltstone beds have a variable thickness and are separated by coal beds. The siltstone is generally highly plastic and is composed of up to 45 % montmorillonite, with an average of 20 %. In outcrop the material is highly fissured and consistently soft to finger pressure, indicating a low degree of induration.

Coal beds and laminae are common (Fig. 8). The coal is tentatively assigned a rank of lignite to sub-bituminous (A.S.T.M. coal groups). It breaks down easily into angular clasts, 10 to 20 mm long, and is characterized by the presence of plant fossils and small amber particles.

Cenozoic — Quaternary

The succession and basic lithology of Quaternary sediments in the environs of Great Bear River is given in Table 3. The regional surficial geology and geomorphology (modified from Hughes, 1970; Hanley and Hughes, 1973) are shown

Figure 8. Late Wisconsinan till unconformably overlying Tertiary lignite at GB 30 (units 2 and 3, Appendix 1; left bank of Great Bear River at km 11.5). 204698-15A

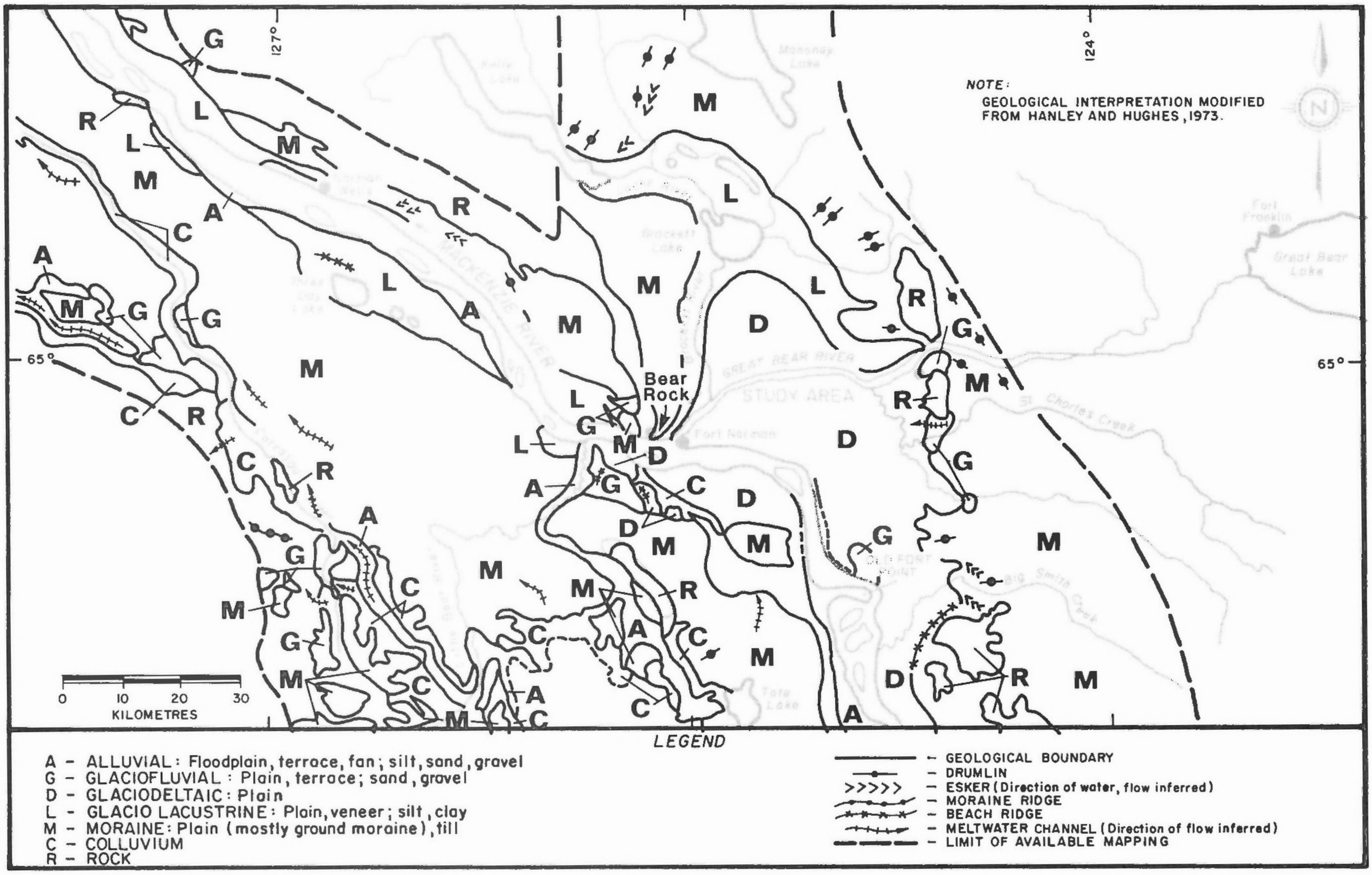


Figure 9. Generalized surficial geology of the Great Bear River area.

in Figure 9; a composite stratigraphic section of surficial deposits along Great Bear River from km 0 to km 75 is shown in Figure 10.

Surficial sediments[1] predating the last glaciation are present at two locations: sand and silty clay, which are considered alluvial, occupy a bedrock valley at km 7; deltaic silt, sand, and gravel lie immediately west of McConnell Range, between km 45 and 53.

Till which is assumed to have been deposited during Late Wisconsinan glaciation is the lowest widespread unit in the Quaternary section. This is present throughout Mackenzie Plain, and to varying elevations in McConnell and Norman ranges. Glaciolacustrine silty clay and overlying glaciodeltaic sand are widespread on Mackenzie Plain. These accumulated in the proglacial environment of Late Wisconsinan deglaciation.

Holocene sediments are common throughout the area. Organic soils, lacustrine clay, silt, and sand, and eolian sand are present on the surface of Mackenzie Plain. Alluvial silt, sand, and gravel are present on valley floors; clayey and sandy colluvium cover valley slopes. Holocene sediments are typically thin and of little significance in natural slopes along Great Bear River and are therefore not discussed further. For a detailed summary of these soils, the reader is referred to Tarnocai (1973).

[1]For the purposes of this report, "surficial sediments" refers to all sediments above the Tertiary bedrock surface.

Alluvial clay and sand — Pre-Late Wisconsinan alluvial clay and sand

Deposits of pre-Wisconsinan alluvial clay and sand were encountered only at the proposed Arctic Gas crossing (km 7.2, Fig. 5; Savigny and Morgenstern, 1986a). They consist of 6.7 m of silty clay and sand, and separate Late Wisconsinan till and Tertiary bedrock. The deposits occur at and below river level in a bedrock valley that is identified by following the bedrock surface in exposures upstream and downstream of the site. The trend of this valley away from the river is unknown, but it is likely north northwest parallel to bedrock structure (Fig. 4).

Blue-grey to brown, highly plastic silty clay (CH) and clayey silt (MH) make up most of this alluvial deposit (Fig. 11, 12). The beds are fissured and slickensided, and detrital coal is found throughout. Clay minerals present include montmorillonite (60 %), illite (30 %), and kaolinite (10 %). Very uniform (SP), uncemented, salt and pepper sand in beds, 200 to 300 mm thick, makes up approximately 10 % of the alluvial deposit. The grains are medium size, subangular, and consist of argillite (60 %) and quartz (40 %). The remainder of the deposit is made up of a bed, 300 mm thick, consisting mainly of detrital coal with thin clay laminae.

Segregated ground ice occurs where these strata lie within the permafrost zone. Thin films of ice coat most fissure surfaces, giving a pseudo-reticulate ground ice form. Stratified ice is also present with veins up to 40 mm thick

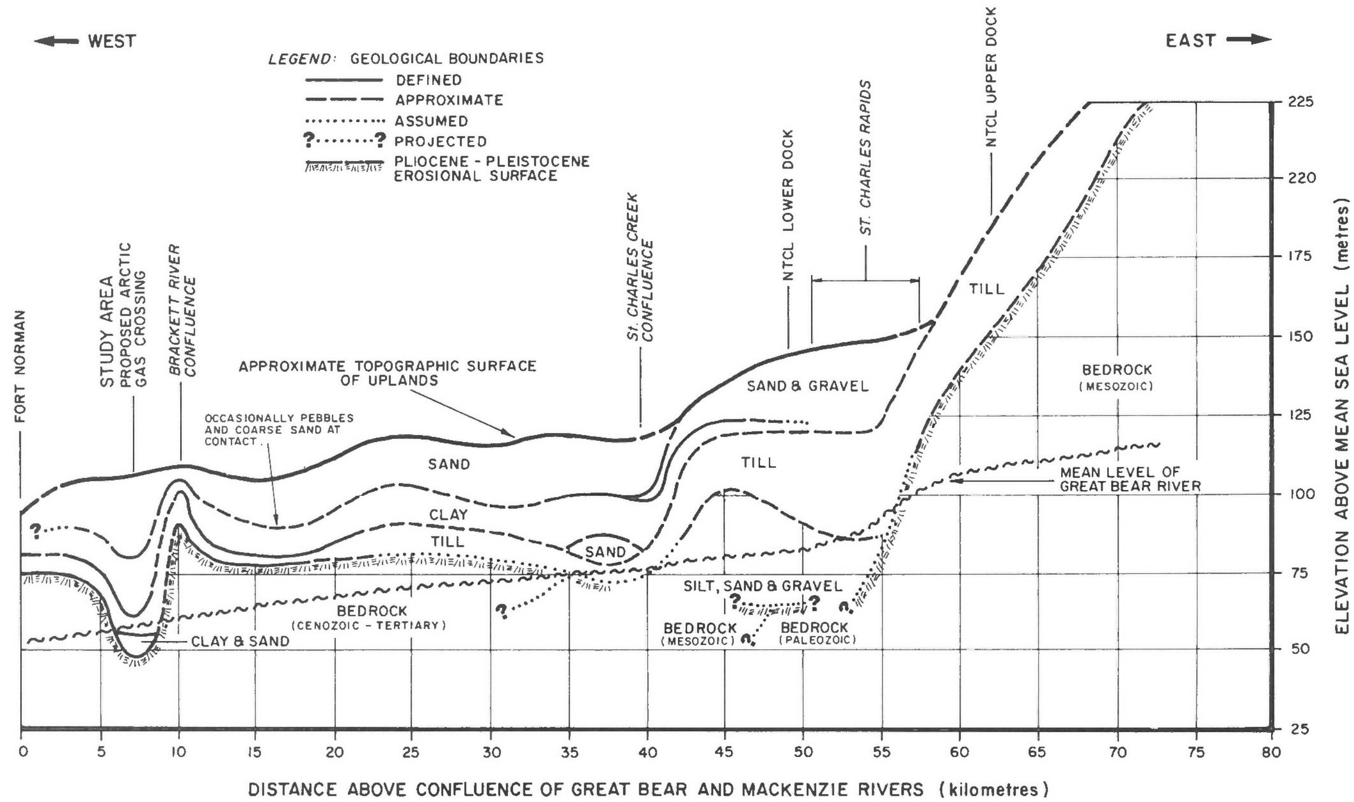


Figure 10. Cross-section of Quaternary stratigraphy between km 0 and km 75.

ERA	PERIOD	LITHOLOGY
CENOZOIC	Quaternary	Colluvium
		Lacustrine clay, silt and sand, organic deposits and marl, eolian sand, alluvium
		Glaciofluvial sand and gravel
		Glaciodeltaic silt, sand and gravel
		Glaciolacustrine silty clay
		Moraine (till), and locally sand and gravel
		Deltaic silt, sand and gravel
	?—?—? Tertiary (Pliocene)	Alluvial clay and sand

Table 3. Succession and lithology of Quaternary sediments in the Great Bear River area

occurring at some contacts of silty clay with sand or coal beds.

Deltaic silt, sand, and gravel

A sand and gravel complex underlies Late Wisconsinan till on the west side of McConnell Range. The deposit has a typical deltaic morphology in cross-section (Fig. 10), with a steep, west-facing delta front at approximately km 42. More than 20 m of silt, sand, and gravel belonging to this deposit outcrops at km 45.3 (GB9, Appendix 1). Sand and gravel beds dominate the exposure. Pebble-sized clasts represent up to 50 % by volume and consist primarily of crystalline and carbonate rocks. Cobbles and boulders are commonly less than 1 %, but locally as much as 5 % and as large as 0.9 m diameter. The sand is medium to coarse, angular and subangular, and mostly quartz (80 %) and feldspar (20 %). Silt seams, 150 to 250 mm thick, are common and make up 5 to 10 % of the exposure. Permafrost was not observed in the deposit.

Late Wisconsinan till

Till overlies Tertiary rocks, and locally pre-Wisconsinan alluvial deposits, in the Brackett River to Fort Norman area (Fig. 5, 10). To the east, across Mackenzie Plain, the contact is buried, but it is assumed to be with Tertiary rocks to approximately km 35, and then with Cretaceous rocks to St. Charles Creek. From this point to the east side of McConnell Range, the units rests on pre-Late Wisconsinan deltaic sediments. Over Mackenzie Plain, the till is covered by glaciolacustrine clay, and through valleys in McConnell Range, near Bennett Field, it is overlain by glaciofluvial outwash; elsewhere it comprises the surficial mineral soil. Thicknesses of from 3 to 10 m are common for till in Mackenzie Plain. The till is thin or lacking in the highlands of Franklin Mountains, but the presence of glacial erratics indicate Laurentide glaciers advanced over the region (Hughes, 1969).

The till is compact, with rare pockets and lenses of stratified material. The matrix is dark greyish brown (10YR4/2) to dark grey (10YR4/1), but becomes black near Tertiary lignite deposits (Fig. 8). The structure of outcrops is dominated by fissures, with peds ranging from 20 to 60 mm in size. Joints are present, but are indistinct.

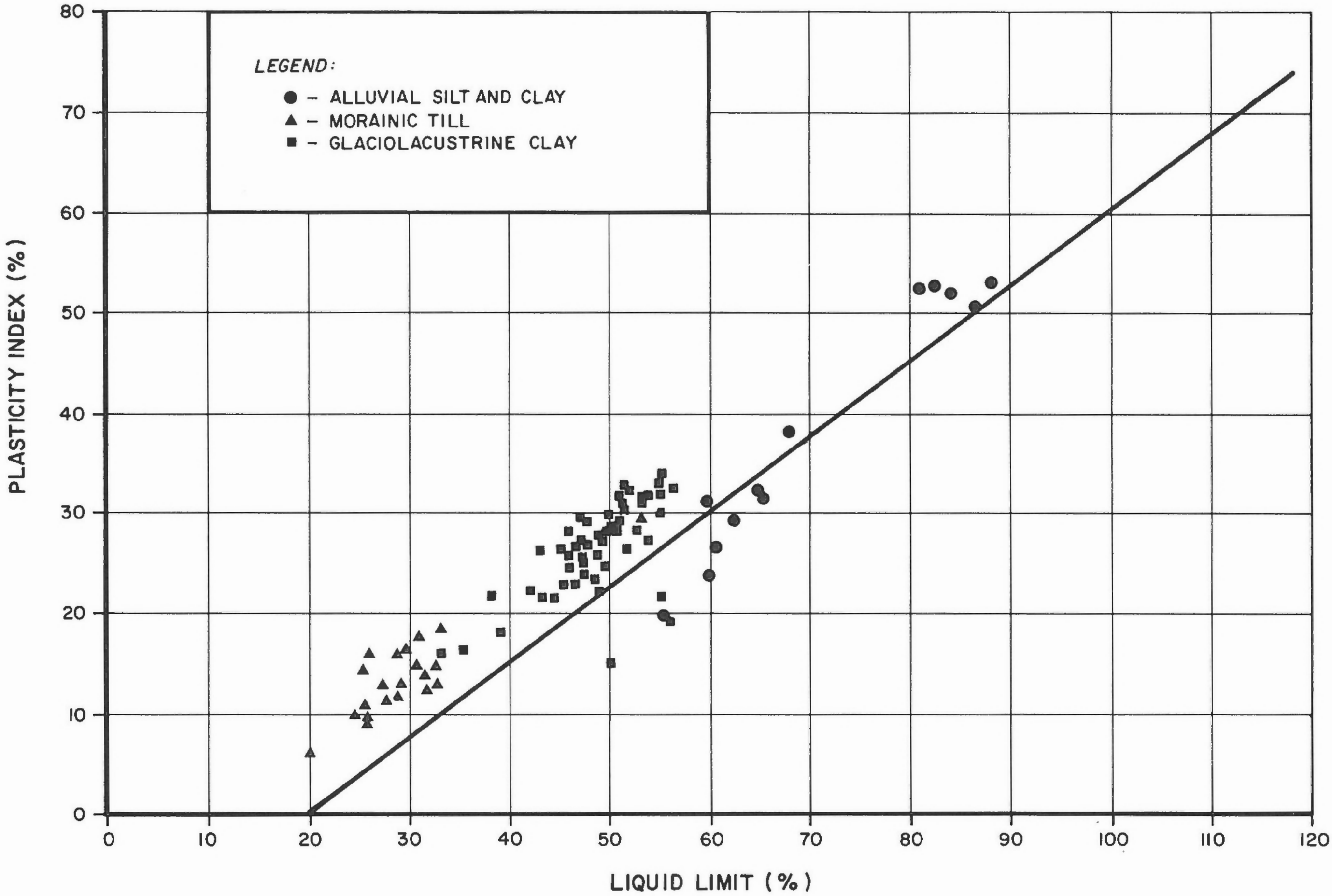


Figure 11. Plasticity chart for fine grained soils from the study area.

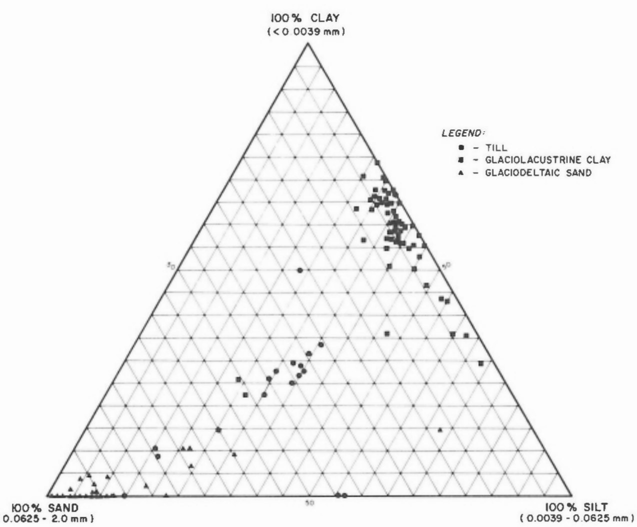


Figure 12. Textural clasification for the less than 2.0 mm size fraction of soils from the study area.

Clasts are all subrounded and consist mainly of granite (40 to 50 %) and carbonate (40 %) with random sandstone, quartzite, syenite, and local siltstone and shale. The average size is 10 mm, with cobbles and boulders making up less than 1 % of the total; the maximum size observed was 1 m in diameter. The long axes have a preferred east-west orientation, and many clasts are striated.

The matrix consists of a near-equal sand-silt-clay mixture, with local increases in sand content as shown in Figure 12. The plasticity characteristics summarized in Figure 11 give it a Unified Soil Classification of low to medium plastic clay (CL to CI), and liquidity indices between 0 and -1 indicate overconsolidation. The unit weight averages 22.1 kN/m^3, and the specific gravity of the soil particles is 2.74. Clay minerals identified are illite (60 to 75 %), kaolinite (20 to 25 %), montmorillonite (0 to 15 %), and chlorite (5 %).

The deposit is everywhere within the discontinuous permafrost zone, except in particularly deep sections in the valleys through McConnell Range. Ground temperatures at km 7.2 of Great Bear River range from −2.0 to −2.5°C (Savigny and Morgenstern, 1986a). Pore ice is the most common form of ground ice, but some segregated reticulate ice occurs near the upper and lower contacts. Veins of reticulate ice are usually widely separated, subhorizontal, and 20 to 50 mm thick.

Glaciolacustrine clay

Fine grained, glacial lake basin clay rests on till throughout its extent in Mackenzie Plain, except near km 37 where it overlies a small, coarse grained, ice contact deposit. Over most of Mackenzie Plain, it is overlain by glaciodeltaic sand (Fig. 10), but in the east, near the lower Northern Transportation Company (NTCL) dock, it is covered by glaciofluvial sand and gravel. It has extensive organic-soil cover where it is the surficial mineral soil.

The thickness of the deposit is directly related to the morphology of the underlying till surface. Accumulations typically range from 5 to 10 m, but over till highs this is reduced to 2 to 5 m, and in lows, such as the bedrock valleys at km 7, it is up to 18 m thick.

The maximum elevation of the deposit is associated with strandlines at approximately 150 m elevation near Big Smith Creek (Fig. 9), 50 km southeast of Fort Norman. North of Great Bear River, on the west side of McConnell Range, the sediments reach approximately the same level, and on the east side of Bear Rock, they reach 130 m elevation. The estimated isostatic recovery from these data is 0.35 m/km in both east and southeast directions.

Outcrops are common in the headscarp of bimodal flows, many of which are active and provide fresh exposure of the clay and its contact with overlying sand. However, the processes involved in these features commonly preclude exposure of the lower part of the clay and are responsible for a paucity of field data in the lower portion of the clay section. The lowest 1 m of glaciolacustrine sediments contains ice-rafted coarse sand and pebbles. The contact with the sand above is abrupt and locally marked by a thin lens of pebbles and coarse sand. No gradation was found in the clay near this contact. The clay is rhythmically laminated throughout the region, although only minor colour or textural differences exist between the "summer" and "winter" layers (Fig. 13). The former are greyish brown (10YR4/2), average 2 mm thick, and range from 0.2 mm to 2.0 m thick; the latter are dark greyish brown (10YR3/2), average 20 mm thick, and range from 0.5 to 100 mm thick. The bedding structure is highly contorted, and individual laminae show marked changes in thickness, both of which make lateral correlation of more than 1 m difficult. No diamicton deposits were found, and current-bedded silt laminae were only observed at GB14.

Preliminary grain-size analyses were planned to assess the textural difference between the "winter" and "summer" laminae. Because of the difficulty in sampling each layer, and because the maximum difference was consistently less than reasonable experimental accuracy, this objective was abandoned and further samples were taken indiscriminately.

The lack of strong textural contrast between the components of each couplet is at least partially a manifestation of bedrock conditions in Mackenzie River valley. Roggensack (1977) found that glaciolacustrine sediments from Fort Simpson and Norman Wells consisted of aggregates of clay minerals and proposed that these were derived intact from the local Cretaceous system, transported and deposited as silt-sized particles. His photomicrographs (Roggensack, 1977, p. 400) illustrate a predominance of this fabric.

The photomicrographs also show a degree of edge-to-face structure indicating flocculation. Fraser (1929) showed experimentally that this process could occur in solutions with salinity as low as 1/90 that of normal sea water. The availability of electrolytes in local Paleozoic rocks, together with evidence of solution cited earlier, suggests that adjacent glacial lakes contained a sufficient electrolyte concentration to effect the observed flocculation. In the Great Bear River area, these phenomena likely combined to produce silt-sized, clay-particle assemblages that settled from suspension at approximately the same rate as discrete silt grains. Therefore, clay sizes comprised a large percentage of the "summer" layers.

The results of 62 grain-size analyses, shown in Figure 12, indicate that the deposit is a silty clay. Plasticity characteristics illustrated in Figure 11 indicate a Unified Soil Classification of medium to highly plastic clay (CI-CH). Liquidity indices are consistently near zero, indicating slight overconsolidation, bulk unit weights have an average of 20 kN/m^3, and specific gravity of the soil particles is generally 2.75.

X-ray analyses of the less than 0.002 mm fraction show between 15 and 20% clay minerals, 55% quartz, 10% calcite, 10% dolomite, and less than 10% each of gypsum and feldspar. The average composition of the clay minerals is 60% illite, 20% kaolinite, and 10% chlorite. Montmorillonite varies from 5 to 25% with a mode of 10%.

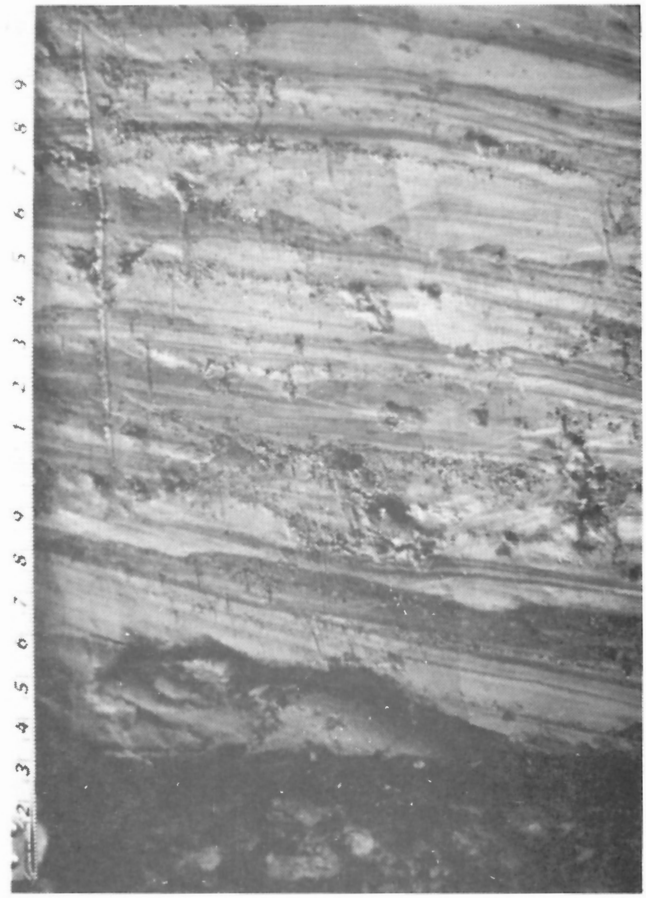


Figure 13. Gently dipping, rhythmically laminated glaciolacustrine sediments at GB14 (unit 5, Appendix 1; right bank of Great Bear River at km 37.1). 204698-16A

The deposits lie within the discontinuous permafrost zone throughout Mackenzie Plain. Segregated reticulate ice is the most common ground ice form. Veins of reticulate ice are up to 200 mm thick; a primary vertical and secondary horizontal ice structure commonly is evident, and the primary veins are almost always thicker. Random or nonoriented segregated ice is also common. In general, the ground ice to soil (volume) ratio is greater where the glaciolacustrine clay outcrops along valley sides than it is at depth beneath adjacent uplands. Because of the generally high ice content, the glaciolacustrine clay is thaw unstable where it is exposed to thawing conditions (Fig. 14).

Glaciodeltaic Sand

A thick blanket of glaciodeltaic sand covers Mackenzie Plain south of Great Bear River, southwest of Mackenzie River towards MacKay Range, and north of Great Bear River to 120 m elevation. It rests on glaciolacustrine clay throughout the region, locally separated from it by a lens or thin bed of pebbles and coarse sand. Where the sand is thin, its surface is covered by peatland and fenland containing up to 4 m of organic soil. Peat palsas and plateaus 1 to 3 m high, separated by shallow lakes and commonly showing active thermokarst activity, form distinctive topographic features. Where the sand is thick, organic soil is generally between 0.5 and 1.0 m thick, lakes are less common, and swampy bogland is much less widespread. East of Brackett River and southeast and east of Fort Norman, the monotony of the plain is broken in places by sand dunes.

Figure 14. Backwall of an active bimodal flow (cf. Fig. 16). The person is pointing at the approximate location of the contact between glaciodeltaic sand and underlying ice-rich glaciolacustrine silty clay. Sloughing conditions are a result of ablation which is locally accelerated by groudwater movement through the active layer at the interface between frozen and unfrozen soil (GB20 — units 2 and 3, Appendix 1; right bank of Great Bear River at km 24.1). 204698-18A

Sediment sources in the east and south are inferred from scattered paleocurrent data and general thickening of the sand facies in these directions. Incised glaciofluvial landforms, in gaps through McConnell Range (Fig. 9) and adjacent to Mackenzie River at the Redstone River confluence, are further evidence that the sediment source areas were to the east and south.

Exposures of the sand are common in the headscarp of active and stable bimodal flows along Great Bear River and its tributaries. The unit shows a general northwestward thinning except where it fills topographic depressions originating in the till surface and preserved through the glaciolacustrine clay. In the east, the deposit averages 20 m thick; at km 16.2, 10 m; and near Fort Norman, 5 m. A thickness of more than 20 m shown in Figure 15 successfully masks all evidence of the bedrock valley at km 7.2.

Bedding structures are highly variable. The dominant sand bedforms are massive, horizontally bedded and laminated, and cross-laminated. Draped lamination is common and generally made up of discrete silt- and sand-sized coal grains. Thin, horizontal lenses of cohesive material; tabular crossbeds of sand; and thin, horizontal, pea-sized gravel lenses occur in a few sections, but they represent an insignificant percentage of the overall sand facies.

The sand is varicoloured, ranging from yellow-brown, to brown, to black. Quartz is the primary mineral, making up between 70 and 90%, whereas coal, argillite, and feldspar are secondary. Wood fragments are common near the top of the sand section. Quartz grains are angular to subangular, whereas other lithologies vary from subangular to

Figure 15. Unusually thick section of glaciodeltaic sand on the left bank of Great Bear River at km 6.5 (GB34). This anomalous thickness occurs where a buried valley crosses Great Bear River at approximately km 7. An anomalously thick sequence of glaciolacustrine sediments underlies this sand. 204698-20A

subrounded. Moisture contents average 27 %, and bulk unit weights average 18.2 kN/m^3. The specific gravity of the soil grains is 2.68 and the void ratio ranges from 0.7 to 0.8. The textural breakdown of the less than 2 mm fraction gives a pure sand classification (Fig. 12). Gravelly lenses typically have up to 15 % gravel, with a maximum size of 60 mm and mode of less than 10 mm. Widely scattered, presumably ice-rafted clasts are as large as 0.6 m in diameter.

The sand is within the discontinuous permafrost zone; permafrost is generally present, except beneath deep lakes. The upper 3 to 10 m is within the zone of annual temperature fluctuation, and, depending upon the nature and thickness of organic soil cover, the active layer ranges from 0.3 to 5 m thick. Pore ice is the dominant ground ice form; vertical ice veins up to 20 mm thick are also present, but these are rare. The volume percentage of pore ice is sufficient to saturate the sand when it is thawed at its in situ void ratio, and any degree of shaking liberates abundant excess water. The sand is commonly thaw unstable. Natural slopes are generally 28° to 34°, but steeper slopes up to 38° occur along much of Great Bear River, especially on the left (north facing) valley wall.

Glaciofluvial sand and gravel

Glaciofluvial sediments were not examined in this study. The following brief discussion is based on data from Hughes (1970), Hanley and Hughes (1973), and on airphoto interpretation.

Glaciofluvial sand and gravel occupy lowland gaps which traverse McConnell Range adjacent to inflowing rivers such as the Great Bear, and St. Charles, and Big Smith creeks (Fig. 9). The kettled glaciofluvial plains and terraces are deeply incised by these rivers and coarse material that was eroded is typically redeposited a short distance downstream. Sections along Great Bear River show what is assumed to be the reworked material intercalated with glaciodeltaic sand. The deposits found along Great Bear River are composed of approximately equal quantities of sand and gravel and give a Unified Soil Classification of GW. The glaciofluvial deposits lie within the permafrost zone; the impoundment of small lakes in kettles and in abandoned channels suggests that ground ice is present and inhibits subsurface drainage.

GEOMORPHIC DEVELOPMENT

The earliest geomorphic record is the erosion and partial filling of a valley in Tertiary bedrock at km 7.2. Insufficient data are available to establish the local trend of this buried valley; on a regional scale, however, it is likely contiguous with the "Hare Indian — Mackenzie Trench" reported by Mackay and Mathews (1973). Attempts to date basal (alluvial) sediments lying in the valley on the basis of microflora are inconclusive. The presence of *Alnus* and c.f. *Ilex* indicates that the sediments are at least Tertiary, but the general lack of Tertiary taxa suggests a Pliocene-Pleistocene age[1].

Deltaic deposits underlying glacial till at km 45 testify to a lacustrine phase prior to Late Wisconsinan glaciation, and probably relate to deglaciation of an earlier glacial period. They were found to be barren of organic material and therefore could not be dated.

Flutings east of McConnell Range (Fig. 9) indicate that the Late Wisconsinan Laurentide Ice Sheet flowed from the southeast, but bifurcated east of McConnell Range (Hanley and Hughes, 1973). One lobe continued northwest in an arcuate pattern north of Mahony Lake. The second lobe crossed McConnell Range and flowed northwest along Mackenzie River valley as far as Beavertail Mountain where the two lobes merged again and continued in a northwest direction (Mackay and Mathews, 1973). The Late Wisconsinan advance reached its maximum against the mountain front approximately 14 000 years ago (Prest, 1970; Hughes, 1969).

Large ice-dammed glacial lakes, occupying consequent valleys along the eastern front of Mackenzie Mountains, coexisted with the glacial maximum (Hughes, 1969). Ice-marginal channels indicate that these glacial lakes stood at elevations greater than 300 m. During early retreat, the channels probably fed into a major meltwater system, which ultimately followed Mountain River into a glacial lake southwest of Fort Good Hope (Hughes, 1970; Mackay and Mathews, 1973); later the channels ended immediately north of MacKay Range, depositing coarse deltaic or outwash sediments east of Little Bear River. Retreat was accompanied by a steady decrease in lake level to an elevation of 150 m, where strandlines formed and below which glaciolacustrine sediments are widespread.

Lake-basin sediments near Sans Sault Rapids show a gradational change to an overlying deltaic facies (Mackay and Mathews, 1973). In the Great Bear River area, however, this contact is abrupt and may indicate that failure of an ice dam caused a sudden alteration to deltaic sedimentation. Subtle differences in the maximum elevation of glaciolacustrine sediments adjacent to Mackenzie River near the mouth of Little Bear River, and the presence of abandoned meltwater channels and strandlines near the mouth of Little Bear River (Fig. 9) suggest that the ice dam was coincident with the glaciofluvial sediments east of Little Bear River in Mackenzie Plain. After breaching occurred, glacial lakes above and below the barrier coalesced and a continuous body of water extended from the Ramparts-Ontaratue divide (Mackay and Mathews, 1973) to the area of the present Keele and Redstone River confluences with Mackenzie River.

Mackay and Mathews (1973) estimated that ice dams in the Fort Good Hope area had disappeared and that the relative stability of ice-marginal conditions had become established at elevation 95 m approximately 11 000 to 11 500 radiocarbon years ago. Assuming this is a reasonable estimate of when the ice dam near Little Bear River was breached, a minimum differential isostatic depression of 20

[1]W.S. Hopkins, Jr., personal communication, 1977: Identification of microflora revealed the following taxa: *Pleuricellaesporites*, *Lycopodium*, *Selaginella*, *Osmunda*, *Laevigatosporites*, *Verrocosisporites*, *Sphagnum*, Pinaceae, *Tsuga*, *Glyptostrobus-Taxodium*, *Sequoiapollenites*, *Liliacidites*, *Nuphar*, *Fibulapollis*, *Orbiculapollis*, *Aquilapollenites*, *Wodehouseia*, *Castanea*-Type, *Kurtzipites*, *Alnus*, *D.S. Ilex*.

to 25 m was requisite to have maintained deltaic conditions in the Great Bear River area; this is considered reasonable in relation to data from nearby regions (Craig, 1965).

At approximately the time when ice dams on Mackenzie Plain disappeared, the main ice front lay east of McConnell Range and meltwater discharged through gaps now occupied by Great Bear River, and St. Charles and Big Smith creeks (Prest, 1970; Hanley and Hughes, 1973). As the lake level fell, deltas adjacent to Mackenzie River near the mouths of Keele and Redstone rivers, and deltas and outwash plains in the valleys through McConnell Range became incised, and the new deltaic facies began to prograde as much as 30 m below the last. Systematic downcutting at the Fort Good Hope outlet, coupled with decelerating isostatic readjustment in the basin, facilitated northwestward progradation of the deltaic front. The shallow water environment, copious sediment supply, and abundance of uniform, fine to medium sand derived from Cretaceous sandstones combined to produce a fan-delta morphometry similar to the Hjulstrom model (Hjulstrom, 1952; Church and Gilbert, 1975).

As the ice front retreated east of McConnell Range, meltwater supply waned and became concentrated in Great Bear River. The river was established in its present course east of McConnell Range as early as 10 900 years ago (Craig, 1960; Prest, 1970), but wood fragments from tabular crossbeds in the sand section at GB34 (Appendix 1 and Fig. 15) indicate that deltaic sedimentation continued in the central Mackenzie Plain after 10 600 ± 260 BP (GSC-2328, Lowdon and Blake, 1979). It seems likely that terrestrial conditions were established at elevation 100 m in this area approximately 10 000 years ago, and further downcutting was in proportion to the outlet near Fort Good Hope as discussed by Mackay and Mathews (1973). A radiocarbon date reported by Roggensack (1977) indicates that the lake level had fallen to nearly 67 m by 3290 ±100 BP (GSC-2204, Lowdon and Blake, 1979); and wood fragments in colluvium, near the base of a stable refrozen bimodal flow at the proposed Arctic Gas Crossing site, indicate that Great Bear River was incised below approximately 68.5 m by 2670 ± 130 BP (GSC-2488).

Glaciodeltaic sand in the uplands over Mackenzie Plain was locally modified by wind action shortly after terrestrial conditions were established, and before extensive vegetation cover developed. More recent modifications to upland topography have resulted from repeated aggradation and degradation of permafrost.

ENGINEERING GEOLOGY

Whether development in the Great Bear River area is associated with its hydrocarbon or hydroelectric resources, or with pipelines, roads or railways servicing development at higher latitudes, designers and engineers will have to deal with complex soil and terrain conditions. Engineering geology considerations that emerge from this study provide valuable insight into these conditions. Specifically, knowledge of the stratigraphy and geomorphic development of surficial sediments beneath Mackenzie Plain, and of soil and rock units underlying slopes along Great Bear River, is important in connection with (1) the timing and nature of soil exploration programs, (2) slope stability, (3) borrow resources, and (4) hydrogeology.

Timing and nature of soil investigation programs

The widespread distribution of organic soil on Mackenzie Plain and the lack of road access to the area all but preclude the possibility of conducting a site investigation program outside of the winter period. Access is possible to most parts of the Mackenzie Plain via winter roads, or by grading snow from some of the many seismic lines that cross-cross the area.

Natural exposures facilitate quick evaluation of soil conditions along many of the large rivers and streams in the area. Where drilling and sampling are required, sampling is best carried out using CRREL barrels and dry augering techniques in the surficial sediments, and wire line core barrels with mud rotary drilling through the Cretaceous and Tertiary bedrock units. Commonly, wire line core barrels are also necessary in till deposits. A detailed site investigation program using these techniques is described by Savigny and Morgenstern (1986a).

Slope stability

Several types of slope instability have been observed in the Great Bear River area. These include skin flows, bimodal flows, multiple retrogressive flows and slides, and creep deformations (McRoberts and Morgenstern, 1974; Savigny and Morgenstern, 1986b).

Flows seated in ice-rich glaciolacustrine sediments, and, to a lesser extent, in till, are common along Great Bear River and its major tributaries. Bimodal flows, such as the one shown in Figure 16, are the most common form and are almost always seated in glaciolacustrine sediments. In areas where underlying till sediments are also ice rich, two prominent ablating headscarps have been observed, creating a multiple retrogressive flow. Skin flows are rare, but where present they appear to be the initial phase of development for bimodal or multiple retrogressive flows. Skin flows typically develop in areas of recent surface disturbance, such as the forest fire area on the north side of Great Bear River between km 15 and km 30. Flows may, however, develop anywhere that the surface organic mat is disturbed such that underlying ice-rich soils begin to thaw. Natural stabilization takes a considerable number of years and typically results

Figure 16. Typical form of an active bimodal flow (cf. Fig. 14) seated in ice-rich glaciolacustrine sediments (GB 20; right bank of Great Bear River at km 24.1). 204698-21A

from the accumulation of colluvium or blanketing by an insulating organic mat (Fig. 17). Because of the sensitivity of natural slopes to terrain disturbance, any development activity on them should be planned so as to minimize disturbance to the natural vegetative cover.

Multiple retrogressive slides occur in several areas along Great Bear River below the confluence with the Brackett. Slide surfaces appear to have developed in glaciolacustrine sediments and then propagated through overlying glaciodeltaic sands, but whether this occurred while the soils were perennially frozen cannot be established. It is clear, however, that pervasive shear planes are present and hence design must account for lower available short- and long-term strengths in the soil mass.

Creep deformation of in situ glaciolacustrine soils has been measured at a location on the left valley slope of Great Bear River (Savigny and Morgenstern, 1986b). The strain rates, although small, must be accounted for in the design of structures on or near the crest of valley slopes, where the stratigraphy beneath the slopes includes ice-rich glaciolacustrine clay (Fig. 18).

Borrow resources

Till and glaciolacustrine sediments are the only sources of fine grained borrow. These resources are covered by several metres of sand on Mackenzie Plain and would therefore have to be developed some distance from Great Bear River and likely on the flanks of Norman or McConnell ranges in order to be above the elevation to which overlying glaciodeltaic sands prograded during deglaciation. Their development would likely also have to be scheduled over a two to three year period during which time borrow areas would be stripped and allowed to thaw, and excess water from melting ground ice allowed to drain.

Glaciodeltaic sand is widespread on Mackenzie Plain and could be used as fine granular borrow. In most areas, it would require the scheduling of development over at least a one year period in order to allow the soils to thaw and drain.

Granular borrow is available in glaciofluvial deposits on the west flank of McConnell Range and on the west side of Mackenzie River south of the Little Bear River confluence. Although these soils have not been examined in detail, it is assumed that large volumes of sand and gravel are available, and that development scheduling over a one year period would allow for thawing of permafrost. Deltaic deposits exposed in bluffs a short distance below St. Charles Rapids also contain large quantities of granular borrow. These deposits, however, are covered by a considerable thickness of glacial sediments. Granular resources are also present in the Great Bear River floodplain between St. Charles Rapids and the mouth of St. Charles Creek; however, environmental restrictions would likely preclude removal of these soils.

Hydrogeology

Limited evidence of groundwater discharge has been observed along the valley slopes of Great Bear River and

Figure 17. Natural stabilization of bimodal flow along Great Bear River occurs when areas of ablation are blanketed by an insulating layer of organic material such as shown here, or an insulating layer of sand as shown in Figure 15. (GB21; left bank of Great Bear River at km 27.4). 204698-22A

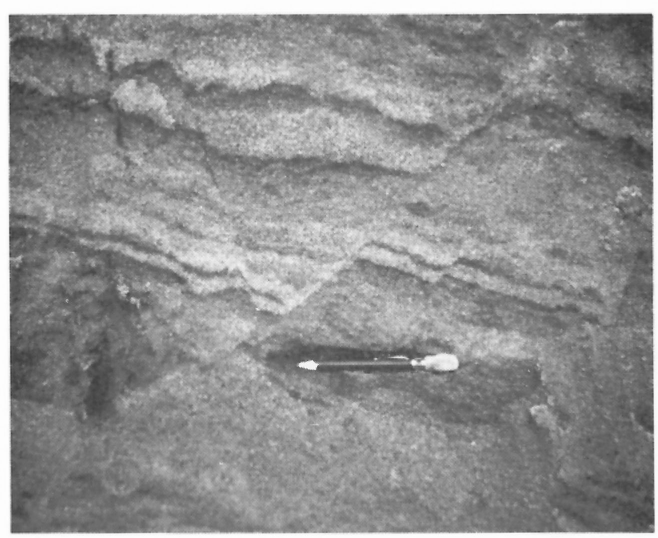


Figure 18. Small extension faults in glaciodeltaic sand are considered to be a result of creep deformations in underlying ice-rich glaciolacustrine silty clay. 204698-23A

in widely separated parts of Mackenzie Plain and Franklin Mountains (Hughes et al., 1973). Most discharge along the slopes of Great Bear River is attributed to discharge from the active layer. Aufeis commonly develops in these situations through the late fall, winter, and spring.

Groundwater may also be present below the permafrost table in Cretaceous and Tertiary bedrock units. These units outcrop at much higher elevations in Mackenzie Mountains, where recharge may be presently active or may have been active prior to aggradation of permafrost. Where these units are encountered beneath Mackenzie Plain, pore water may therefore be under considerable hydrostatic pressure. This condition would have to be carefully investigated in connection with exploration and development of lignite deposits in the area.

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Appendix 1

Geological field data from Great Bear River area

INTRODUCTION

Quaternary and limited Tertiary stratigraphy in the Great Bear River area was studied during the summer of 1973 as part of a larger mapping program supported by the Geological Survey of Canada. Data collected along Great Bear River were intended to supplement the mapping of surficial geology of the Mahony Lake (96F) map area (Mahony Lake) and supply baseline data for evaluation of several proposed dam sites along Great Bear River.

Geological studies were carried out in the following steps: 1) preliminary airphoto interpretation; 2) field reconnaissance via helicopter; 3) detailed field checking by boat traverse along Great Bear River; 4) final airphoto interpretation; and 5) compilation.

The work was supplemented by stratigraphic data obtained from testhole and test pit logs included in the following geotechnical reports:

1. G.E. Crippen and Associates Ltd., report to Northern Canada Power Commission on Great Bear River Power Development, October 1972.
2. Pemcan Services "72", report to Department of Indian Affairs and Northern Development on Granular Materials Inventory, Fort Norman, Northwest Territories, Community Study area, 1973.
3. R.M. Hardy and Associates Ltd., report to Department of Public Works on Geotechnical Investigations along Mackenzie Highway, Mile 544 to Mile 635, Volumes 1 to 7, April 1973.
4. R.M. Hardy and Associates Ltd., report to Northern Engineering Services Company Ltd. on 1974 Drilling and Sampling Program at the Proposed Arctic Gas Pipeline Great Bear River Crossing, 1974.

Survey data along Great Bear River were obtained from the Crippen report. Supplementary information was also gathered from later field checks carried out in association with other projects in the area.

Comments on field and laboratory technique follow in the next section. Sections measured at natural exposures along Great Bear River together with testhole and test pit logs, are summarized in the last section of this Appendix. In some cases the original lithological designation in testhole and test pit logs has been altered (i.e.GRAVELLY CLAY would be described as TILL, and the change clearly indicated as in GB61).

Field and Laboratory Technique

In the initial phase of field checking a helicopter reconnaissance was made over the Great Bear River area. Natural exposures along the river and for short distances upsteam along its major tributaries were located on aerial photographs and subsequently measured and described during a boat traverse along the river. Vertical distances were measured with a Brunton compass and referenced to approximate elevations along Great Bear River as given in the Crippen report.

Disturbed samples were taken and later analyzed to determine moisture content, Atterberg limits, specific gravity, and grain size distribution. All laboratory tests were carried out according to ASTM standards. Moisture content data are reported as a percentage of dry weight. Where high ice contents precluded the possibility of obtaining sufficiently large samples of representative moisture content determination, remote sensing techniques were used to obtain the values according to a procedure described by Savigny (1977).

SUMMARY OF MEASURED SECTIONS, TEST HOLES LOGS, AND TEST PIT LOGS FROM THE GREAT BEAR RIVER AREA

		Thickness (m)	Depth of base (m)
		March 20 - 23/75	
GB 1	Northern Engineering Services Ltd., testhole GB-1 (km 7.1, L)[1]		
	Collared at el. 101.5 m.		
PEAT (Pt.): 1	Dark brown to black	0.2	0.2
SAND (SP): 2	Pale Brown; well sorted; fine grained; horizontal beds and horizontal and subhorizontal laminae; pore ice and occasional segregated reticulate ice veins.	21.28	21.48
GRAVEL (GP): 3	Pebble size; subrounded; quarts (80%) and carbonate (20%)	0.16	21.64
CLAY (CI-CH): 4	Dark grey to dark greyish brown; medium to high plasticity; ground ice structures up to 0.25 m thick and ice veins 2 to 10 mm thick throughout	15.47	37.11
		March 31 - April 3/75	
GB 2	Northern Engineering Services Ltd., testhole GB-2 (km 7.1, L)		
	Collared at el. 80.2 m.		
CLAY (CI-CH): 1	Dark grey to dary greyish brown; medium to high plasticity; pseudo rhythmic lamination structure; randomly oriented segregated ground ice structures and reticulate ice veins throughout.	13.48	13.48
TILL (CL-CI): 2	Brown to very dark grey; low to medium plasticity; silty and locally very sandy; fissured; well bonded silty and permafrost with no excess ground ice.	11.20	24.68
SAND (SP): 3	Very dark grey; very well sorted; medium grained; well bonded permafrost with no excess ground ice.	0.40	25.08
CLAY (CH): 4	Grey to very dark grey; highly plastic; sandy, silty; detrital coal common; highly contorted bedding structures; fissured; thin ground ice veins on fissure surfaces, no excess water when thawed.	1.58	26.66
SAND (SP): 5	Dark grey; salt and pepper like; very well sorted; medium grained; well bonded permafrost with no excess ground ice.	0.67	27.33
CLAY (CH): 6	As above Unit 4; little sand, silty, organic fragments	1.96	29.29

1 Where the sections or testholes are near the banks of Great Bear River, the location is given by the kilometre location along the river followed by R or L signifying right or left bank, respectively, or "river course" if drilling took place in the channel. If the location is more than a few 100 m from the banks, it is given with latitude and longitude.

		Thickness (m)	Depth of base (m)
COAL: 7	Black; lignite to sub-bituminous rank (A.S.T.M. coal groups); stratified by clay laminae at base; coal appears to be detrital	0.21	29.50
CLAY (CH): 8	As above Unit 6.	1.92	31.42
SILTSTONE and SHALE 9	Pale brown to brown; very arenaceous; carbonaceous fragments common throughout.	3.94	35.36

		April 11 & 12/75	
GB 3	Northern Engineering Services Ltd., testhole GB-3 (km 7.1, L)		
	Collared at el. 70.4 m.		
PEAT (Pt): 1	Dark reddish brown; woody and mossy with numerous roots near top.	0.61	0.61
PEAT & CLAY (Pt & CI): 2	Peat as above Unit 1; with yellowish brown, medium plasticity, silty, sandy clay	0.48	1.09
CLAY & SAND (CI-CH & SP): 3	Dark greyish brown, medium to highly plastic, silty clay; pale brown, well sorted, medium grained sand; unit is assumed to be colluvium; recticulate ground ice throughout.	2.46	3.55
CLAY (CI-CH): 4	Dark greyish brown; medium to highly plastic; silty; ice veins present.	1.80	5.35
TILL (CL-CI): 5	Brown to dark brown; low plasticity; silty and locally sandy; lightly fissured; recticulate ground ice structures.	9.15	14.50
CLAY, SAND and COAL 6	Interbedded	6.50	21.00
SANDSTONE: 7		7.35	28.35

		March 26 & 27/75	
GB 4	Northern Engineering Services Ltd., testhole N74-303 (km 7.1, river course)		
ICE: 1	Estimated ice surface el. 56.7 m.	1.68	1.68
WATER: 2		1.07	2.75

		Thickness (m)	Depth of base (m)
CLAY and SAND: 3	Interbedded; grey, medium to high plasticity, sandy clay; and fine to medium grained, locally cemented, sand; unfrozen (originally described as SILTSTONE over SANDSTONE).	2.59	5.34
SILTSTONE and SHALE: 4	Dark grey; trace of fine sand throughout; hard; blocky except for occasional fissile lenses; varies from a silty clay with medium plasticity to a clay and silt with low plasticity; unfrozen (originally described as CLAY SHALE).	6.23	11.57

			March 23 - 25/74
GB 5	Northern Engineering Services Ltd., testhole N74-304 (km 7.1, rivercourse)		
ICE 1	Estimated ice surface el. 56.7 m.	1.37	1.37
WATER: 2		1.68	3.05
CLAY and SILT: 3	Grey; some fine to medium sand; low plasticity; unfrozen.	0.61	3.66
SILTSTONE and SHALE: 4	Dark grey; overall clay-silt classification; high plasticity components; fine sand throughout; carbonaceous; hard; laminated; unfrozen (originally described as CLAY SHALE).	0.15	3.81
SILTSTONE and SHALE: 5	Dark grey, finegrained silty clayey sand; laminated; some cementation, well cemented below 3.66 m; occasional thin layers of interbedded shale; variable plasticity (originally described as SANDSTONE).	9.39	13.20
SILTSTONE and SHALE: 6	Hard; sandy; interbeds of sandstone as above unit 4 (originally described as CLAY SHALE).	0.51	13.71

			April 3 & 4/74
GB 6	Northern Engineering Services Ltd., testhole N74-307 (km 7.1, L)		
	Collared at el. 87.5 m.		
PEAT (Pt): 1	Woody, coarse fibrous peat containing scattered wood; ground ice Vx with 70% excess.	0.27	0.27

		Thickness (m)	Depth of base (m)
SAND (SP): 2	Brown to grey; trace of silt; fine to medium grained; ground ice Vs & Vx with ice lenses to 1 cm thick and an excess of 50%.	0.95	1.22
PEAT (Pt): 3	Coarse fibres criss-crossing fine fibrous peat; ground ice Vs & Vx with an excess of 60%.	0.73	1.95
SAND (SM): 4	Brown with rust stains throughout; fine grained; calcareous; occasional small coal inclusion; ground ice Vs & Vx at top changing to Vx at bottom, excess decreases from 50% to 15% with depth, one 60 mm thick ice lens at 0.79 m.	2.47	4.42
SILT (ML): 5	Trace of fine sand; low plasticity; ground ice Vx with excess of 5%.	0.18	4.60
CLAY (CI-CH): 6	Grey; silty; calcareous; stiff when thawed; high unfrozen water content (based on deformability in frozen state); stratified below 1.19 m; medium plasticity; ground ice Vx, Vr, and Vs throughout with excess ranging from 10% to 30% and ice lenses up to .27 m thick.	4.54	9.14
7	Estimated distance from bottom of hole to local river level.	21.95	31.09

GB 7	Northern Engineering Services Ltd., test hole N74-308 (km 7.1, L)		Mar. 27/74 to Apr. 2/74
	Collared at 101.50 m.		
SAND (SM): 1	Medium brown; trace of silt; random fine gravel zones; generally fine grained, becoming medium to coarse in zones with fine gravel; calcareous; ground ice Nbn to 6.86 m (unfrozen between 0.61 and 1.22 m), Vx and Vr between 6.86 and 9.45 m, Nbn thereafter; excess varies from 10% to 40%, one ice lens at 11.43 m, 18 m thick.	17.68	17.68
CLAY and SILT (CL): 2	Brown; low plasticity; unfrozen to 0.31 m, ground ice Nbn thereafter; sloughing suggests other unfrozen areas.	1.52	19.20
SAND (SM): 3	As above unit 1; some silt and clay interbeds below 2.13 m.	3.20	22.40

		Thickness (m)	Depth of base (m)
CLAY (CI-CH): 4	Grey; silty, some silt partings; calcareous; medium plasticity; stiff when thawed; very deformable in frozen state suggesting high unfrozen water content; small ice partings and ice lenses up to 50% by volume outside of pure ice zones.	15.70	38.10
TILL (CL-CI): 5	Grey; silty, trace of fine sand, trace of medium gravel; medium to low plasticity.	1.86	39.96
6	Estimated distance from bottom of hole to local river level.	5.15	45.11

July 23/73

GB 8	This section is representative of the alluvial plains below St. Charles Rapids (km 46.3, R)		
COVERED: 1		1.16	1.16
SAND: 2	Greyish brown (10YR 5/2) fresh; silty 30% to 40%, increasing with height; plasticity and dry strength negligible; grain size ranges from silt size to coarse sand size, sand is angular, quartz and feldspar; overall structure is massive.	0.94	2.10
SAND and GRAVEL: 3	Sand 70%, as above unit 2; gravel 30%, up to 60 mm, mode 25 mm, subrounded to rounded, 90% granites and other crystalline rocks, 5% each of sandstones and carbonates.	0.1	2.2
SAND: 4	As above unit 2; gravel 5% to 10%, up to 100 mm, mode 50 mm, subrounded, predominantly crystalline rocks especially granites.	0.8	3.0
BEACH: 5	A loose boulder and cobble pavement; maximum size 0.8 m, mode 0.2 m to 0.4 m; matrix sand, medium to coarse as above unit 2.	3.16	6.16
RIVER LEVEL			

July 23/73

GB 9	First good exposure of glacial deposits below the St. Charles rapids. The section has a 45° slope and is unstable. The river is eroding the toe and debris is continually falling from the face. Small bimodal flows have developed in an ice-rich stratum overlying the till. Although largely covered, this unit appears to be a silty clay. All units dip slightly westward (km 45.4, L).		
COVERED: 1	Organic sand as Unit 2 below.	0.28	0.28

		Thickness (m)	Depth of base (m)
SAND: 2	Medium to coarse grained, mode coarse; angular; moderately sorted; quartz and feldspar; gravel 5% to 10%, maximum size 20 mm, mode 10 mm, subrounded to rounded, predominantly crystalline; lowest third stratified, beds average 50 mm thick and range from 10 to 130 mm, bedding control is between medium and coarse grained sorting. (AR-73-3 at 0.8 m)[1].	1.37	1.65
CLAY: 3	Very dark greyish brown (10YR 3/2), fresh; silty 40% to 50%; firm consistency undisturbed; medium dry strength; medium plasticity; massive; upper contact cryoturbated with overlying sand; very moist, high ground ice content is suspected (AR-73-2 at 0.25 m and WS-73-3a at 0.2 m).	0.35	2.0
COVERED: 4	Assumed similar to Unit 3 above. Together with Unit 3, this interval is the seat of bimodal flows. The lower boundary is defined at a break in slope.	5.8	7.8
COVERED: 5	Below the break in slope mentioned above (unit 4) the covered interval is assumed as unit 6 below.	2.48	10.28
TILL: 6	Dark greyish brown to very dark greyish brown (10YR 4/2 to 3/2), fresh, light grey (10YR 7/2), dry; moderately sandy, becoming very sandy with depth; hard undisturbed consistency; very low dry strength; low plasticity; inclusions 20% to 30%, maximum size 0.38 m mode 10 mm, boulders 1%, subrounded, predominantly crystalline; very rarely stratified by sand lenses, 10 mm to 70 mm thick, never greater than 1 m laterally; moderate fissuring throughout; no permafrost within 1 m of face and no evidence of this unit failing. (WS-73-4b at 2 m, WS-73-3c at 12 m).	14.12	24.40
SILT: 7	Very dark grey (10YR 3/1) fresh; clayey 20% to 30%; stiff consistency undisturbed; low dry strength; low to medium plasticity; massive; moderate fissuring.	2.0	26.40
SAND and GRAVEL: 8	Sand is medium grained; angular to subangular, well sorted; quartz 90%, feldspar 10%; 50% of total unit; well stratified and moderately crossbedded. Coarse sand and fine gravel beds up to 0.3 m thick make up 35% of total unit; gravel only pebble size. Silt beds up to 0.15 m thick; 15% of total unit, commonly fringed by a few millimetres of fine-grained, very well sorted sand.	4.45	30.85

1 Where samples were taken from a particular unit the sample number appears at the end of the description together with the sampling depth (when known) below the top of the unit.

		Thickness (m)	Depth of base (m)
SAND and GRAVEL: 9	Coarse grained; angular to sub angular, angular mode; well sorted; 70% quartz, 30% feldspar; gravel 10% to 40%, mode 15% to 20%, maximum size 0.9 m, mode 5 mm, boulders and cobbles 1%; stratified with minor crossbedding, bedding controlled by sorting of gravels.	7.74	38.59
SAND and SILT: 10	As Unit 9 above; interbedded with silt and fine sand, these beds are 0.15 m to 0.5 m thick and represent 50% of the unit; the beds are saturated, there is very slow seepage which evaporates from the face; no evidence of ground ice or permafrost within 1.5 m of face.	1.6	40.19
SAND and GRAVEL: 11	As Unit 9 above; maximum size of gravel 0.2 m, mode 40 mm, approximately 5% larger than pebble sizes.	5.85	46.04
RIVER LEVEL			

July 23/73

GB 10 — Major failure area, good exposure is limited to the top. The feature is a bimodal flow with its toe extending into the river. The backscarp angle is 21°. Permafrost is within 0.5 m of the backwall and is actively degrading (km 42.5, L).

COVERED: 1	Root strength is very high. In some cases the organic mat has folded 3 m over the face and has remained intact.	0.18	0.18
SILT or LOESS:	Dark brown (10YR 3/3) fresh, light grey (10YR 7/1) oxidized; stiff to hard consistency, undisturbed; negligible dry strength and plasticity; very well sorted; no structure.	0.46	0.64
SAND: 3	Coarse grained; angular; well sorted; quartz and feldspar; top 0.32 m oxidized; gravel up to 60 mm, mode 8 mm; stratified and crossbedded throughout; lignite common in lowest 1 m; permafrost at 0.48 m below the face.	6.88	7.52
CLAY: 4	Very dark greyish brown (10YR 3/2) fresh; silty (20% to 30%); firm consistency undisturbed; medium to low dry strength; fissured; upper contact cryoturbated with overlying sand. (WS-73-4a at 0.5 m)	2.6	10.12
COVERED: 5			
RIVER LEVEL			

July 23/73

GB 11 — This section is similar to GB 10 but is less well exposed. The failure is mildly active but the seat of melting is not visible. It is not affecting river hydraulics in any way. The backscarp angle is 27°. Permafrost is present at 1.2 m in the upper sand (km 41.05, L).

COVERED: 1	Organic sand as Unit 2 below.	0.67	0.67

		Thickness (m)	Depth of base (m)
SAND: 2	Dark greyish brown (10YR 4/2), fresh; silty, 10% to 30% except in last 20 mm where it is 50%; fine to medium grained, mode fine; angular to subangular; moderately to well sorted; predominantly quartz; stratified throughout, most beds 10 to 20 m thick, thickest bed is bottom 2 m of unit; zones of high silt content appear wet.	3.14	3.81
SAND: 3	Coarse grained; angular; moderately to well sorted; quartz 50%, feldspar 40%, dark minerals 10%; gravel 5% to 10% maximum size 40 mm, mode 10 mm, subrounded, predominately crystalline; gentle crossbedding; bedding controlled by sorting of gravel.	2.0	5.81
COVERED: 4	A break in slope at the lower boundary of this unit is assumed to be a sand clay contact.	4.0	9.81
COVERED: 5		22.6	32.41
RIVER LEVEL			

July 23/73

GB 12 — An alluvial plain section similar to GB 8. The high water mark is 3 m above the top of this section (km 40.0, about 75 m up St. Charles Creek on its left bank).

COVERED: 1	Organic cover immediately above exposure.	0.05	0.05
SILT: 2	Dark greyish brown (10YR 4/2) fresh; sandy 20% to 40%; hard consistency undisturbed; negligible dry strength and plasticity; sand, fine grained, angular, quartz and feldspar; occasional horizontal clay and silt lenses (10% of unit) up to 18 mm thick and up to 5 m long, mode 1.5 m long.	4.41	4.46
SAND & GRAVEL: 3	Oxidized; sand 50% to 60%, medium and coarse grained, angular, moderately sorted; gravel, maximum size 0.8 m, 10% to 15% boulders, 20% cobbles, mode 20 mm, predominantly crystalline rocks.	1.19	5.65
RIVER LEVEL			

July 24/73

GB 13 — An old bimodal flow now stable and vegetated. No permafrost found although it is suspected at between 2 and 5 m (km 39.55. R).

COVERED: 1	Organic cover immediately above exposure.	0.31	0.31

		Thickness (m)	Depth of base (m)
SAND: 2	Medium to coarse grained; angular; moderately to well sorted; quartz 70%, feldspar 20%, dark minerals 10%; gravel 10% to 15%, maximum size 20 mm, mode 3 to 4 mm; stratified; bedding controlled by different grain sizes of sand and by sorting of gravel; bedding horizontal.	17.48	17.79
GRAVEL: 3	Pebbles and small cobbles; maximum size 90 mm, mode 15 mm; rounded; predominantly crystalline.	0.15	17.94
CLAY: 4	Dark grey (10YR 4/1), fresh; silty 30%; firm consistency undisturbed; medium dry strength and plasticity; massive; moderately fissured (AR-73-4 at 3 m).	12.73	30.67
COVERED: 5		9.4	40.07
RIVER LEVEL			

July 24/73

GB 14 Steep section exposed on the river bank. It is being cut back by the river. Permafrost is not a factor in this exposure and was not observed; it is estimated at 3 to 5 m below the face. Several pits were dug above the top of the exposure in a slope leading up to the local plain. Based on these pits, the stratigraphy above the section is estimated. The high water mark at this location is 2.75 m above present river level (km 37.1, R).

COVERED: 1	Considered sand and silt based on random holes.	18.0	18.0
COVERED: 2	Considered to be clay based on random holes.	9.15	27.15
COVERED: 3	Organic cover immediately above exposure.	0.20	27.35
CLAY: 4	Light brownish grey (10YR 6/2), fresh; silty 20% to 30%; firm consistency, undisturbed; medium dry strength; medium plasticity; massive and fissured.	2.62	29.97
CLAY: 5	Mottled rhythmites; silty 30% to 40%; stiff to hard consistency, undisturbed; low dry strength; low plasticity; stratified by dark lenses of clay, commonly containing traces of fine to mediumgrained sand; bedding is consistently 10% off parallel with lower contact (dips 10° northeast). Approximately 20 rhythmites present.	0.41	30.38

		Thickness (m)	Depth of base (m)
SAND: 6	Fine, medium, and coarse grained; trace of silt; angular; very poorly sorted; quartz 80%, feldspar 15%, dark minerals 5%; gravel 10% to 20%, maximum size 0.42 m, mode 50 mm; boulders 1%; well stratified and crossbedded, mode of bedding thickness 0.1 to 0.25 m, bedding controlled by sorting.	10.48	40.86
COVERED: 7		2.0	42.86
RIVER LEVEL			

July 24/73

GB 15 — Section exposed in stream cut high on bank and well back from river. Stable, vegetated, with no permafrost observed but estimated between 2 and 5 m below the surface (km 35.1, L).

COVERED: 1		13.0	13.0
COVERED: 2	Organic cover immediately above exposure.	0.35	13.35
SAND: 3	Very pale brown (10YR 7/3) dry; silty 20% to 40%; angular; well sorted; quartz and feldspar; massive.	7.4	20.75
COVERED: 4		25.0	45.75
RIVER LEVEL			

July 24/73

GB 16 — Small, well exposed section almost at river level. No permafrost was observed but it is assumed between 1 and 4 m from the surface. The natural moisture content is high in both major units. The section is stable (km 34.8, R).

COVERED: 1	Organic cover immediately above exposure.	0.3	0.3
CLAY: 2	Very dark grey (10YR 3/1), fresh; silty 20%; firm consistency, undisturbed; medium dry strength; medium plasticity; massive; moderately fissured throughout (AR-73-6 at 0.6 m).	1.2	1.5
TILL: 3	Very dark greyish brown (10YR 3/2), fresh; sandy texture; hard consistency undisturbed; dry strength negligible; low to negligible plasticity; inclusions 20% to 30%, boulders and cobbles 1%, maximum size 0.28 m, mode 40 mm; moderately fissured (AR-73-5 at 0.75 m).	1.5	3.0
COVERED: 4		4.75	7.75

		Thickness (m)	Depth of base (m)
RIVER LEVEL			

July 24/73

GB 17 Small section almost at river level. No permafrost observed but assumed between 1 and 4 m from the surface. The natural moisture content is high. The section is stable (km 32.6, R).

		Thickness (m)	Depth of base (m)
COVERED: 1	Organic cover immedimately above exposure.	0.3	0.3
TILL: 2	Very dark greyish brown (10YR 3/2), fresh; sandy 10% to 15%; hard consistency, undisturbed; negligible; dry strength and plasticity; inclusions 15% to 20%, maximum size 1.52 m, boulders and cobbles 1%, mode 30 to 50 mm; moderately fissured.	1.0	1.3
COVERED: 3		5.48	6.78
RIVER LEVEL			

July 24/73

GB 18 Steep sand section forming backwall of bimodal flow. The angle of the backwall is 52ł, the flow angle of the bank is 28ł. The section appears stable, however, small streamlets emerging near the base and its bimodal character suggest degradation of ground ice in a unit below the exposed sand. No permafrost found but it is suspected at between 1 m and 3 m below the face (km 31.1, L)

		Thickness (m)	Depth of base (m)
COVERED: 1		6.52	6.52
COVERED: 2	Organic sand as Unit 3 below	0.48	7.00
SAND: 3	Fine and medium grained, fine mode; angular; well sorted; quartz 85%, feldspar 10%, dark minerals 5%; commonly interbedded with silt, silt beds range from 0.1 to 0.5 m thick.	10.0	17.0
COVERED: 4	Assumed same as Unit 3	4.38	21.38
COVERED: 5	There is a distinct break in slope at the top of this unit. Within several metres below this break, small streamlets come through the colluvium. This is assumed to be a sand-clay contact and the water is from degrading ground ice within the clay.	20.0	41.38
RIVER LEVEL			

July 24/73

GB 19 Small exposure in the backwall of a bimodal flow. The backwall angle is 55ł and the flow angle is 29ł. Permafrost ranges between 140 and 350 mm below the face at the top and bottom of the exposure, respectively (km 29.0, L).

		Thickness (m)	Depth of base (m)
COVERED: 1	Root strength is high. The organic mat folds up to 2.4 m over the face.	0.48	0.48
TILL: 2	Very dark grey (7.5YR 3/2), fresh; silty, sandy texture; hard consistency, undisturbed; low dry strength; low plasticity; inclusions 10% to 20%, maximum size 0.45 m, mode 10 mm, boulders 1%, subrounded to rounded, predominantly crystalline; reticulate ice, maximum thickness of ice veins 4 mm, mode 1 to 2 mm, 10% to 20% excess. (WS-73-12a)	2.0	2.48
COVERED: 3		12.52	15.00
RIVER LEVEL			

July 25/73

GB 20 Excellent exposure in the backwall of an active bimodal flow. The slope of the backwall is 59ł and from the base of the backwall to the river is 26ł. High ice content in the lower clay and groundwater movement along the permafrost table in the overlying sand contribute to the unusually high activity of this flow. The top of the plain is 3.0 m above the top of the exposure and has been recently burned (km 24.1,R).

COVERED: 1		0.16	0.16
SAND: 2	Silty with distinct silt bands; medium and fine grained, mode fine; well sorted; quartz 90%, feldspar 10%, dark minerals 1%; stratified, bedding controlled by silt bands and sorting of dark minerals; silt lenses up to 10 mm thick, mode 2 to 4 mm, 50% silt, 50% sand; commonly small extention faults showing downslope movement of exposure (toward river) in apparent frozen state; permafrost 0.1 to 0.75 mm below face; local ground water flow over permafrost table causes sand to slough off exposure (WS-73-14a at 1.0 m).	3.59	3.75
CLAY: 3	Dark grey (10YR 4/1), fresh; silty 20% to 30%; soft consistency undisturbed; high dry strength; highly plasticity; reticulate ice ranging from 10% excess at the top to 80% excess at the base of the exposure.	2.0	5.75
COVERED: 4	The sloughing material leading to the river is moist with numerous streamlets leading from the backwall. It is deeply gouged indicating recent large mass movement toward the river.	34.34	40.09
RIVER LEVEL			

July 25/73

GB 21 Several small active bimodal flows provide random exposures for approximately 45 m above the river. All of the contacts given are inferred except for the clay-sand contact. Limited permafrost was observed and is considered to be between 1 and 4 m below the surface (km 27.35, L).

		Thickness (m)	Depth of base (m)
COVERED: 1	Vegetation mat is quite strong; in several cases backwall ablation has ceased because of the insulating effect of overhanging organic cover.	0.3	0.3
SAND: 2	Locally silty; medium and fine grained, mode is medium; angular; well sorted; quartz 85%, feldspar 10%, dark minerals including lignite 5%; gravel 1%, maximum size 0.58 m (ice rafted); stratified and gently crossbedded; bedding control is grain size sorting; silty areas have high moisture content.	17.5	17.8
CLAY: 3	Silty 10%; soft consistency, undisturbed; high dry strength; high plasticity; moderately fissured; reticulate ice, up to 40% excess ice, mode 20% to 30%.	12.8	30.60
TILL: 4	Very dark greyish brown (10YR 3/2) fresh; sandy silty texture; hard consistency, undisturbed; low dry strength; low plasticity; inclusions 10% to 20%, maximum size 0.2 m, mode 30 mm; fissured throughout.	16.0	46.60

RIVER LEVEL

July 25/73

GB 22 — Small active bimodal flow. Permafrost at 0.8 m (km 25.6, L).

		Thickness (m)	Depth of base (m)
COVERED: 1	Thin organic soil mat partially covering top of exposure.	0.3	0.3
TILL: 2	Very dark greyish brown (10YR 3/2) fresh; silty; hard consistency, undisturbed; low dry strength; low plasticity; inclusions 10% to 15%, maximum size 0.38 m, mode 30 mm; 1% boulders; reticulate ice, 10% to 15% excess ice, ice lenses 1 to 2 mm thick.	1.3	1.3
COVERED: 3		5.2	6.8

RIVER LEVEL

July 25/73

GB 23 — Section is opposite large bimodal flow described in section GB 20. It is poorly exposed but till can be defined up to 17 m above the river (km 24.1, L).

		Thickness (m)	Depth of base (m)
COVERED: 1	Based on sections a short distance upstream, this is assumed to be clay (thickess given is not to the top of the bank).	10.0	10.0
TILL: 2	Dark grey (10YR 4/1), fresh; sandy and silty; hard consistency, undisturbed; very low dry strength; low plasticity; inclusions 10% to 20%, maximum size 0.26 m, mode 40 mm, subrounded, crystalline; fissured throughout.	17.0	27.0

		Thickness (m)	Depth of base (m)

RIVER LEVEL

July 25/73

GB 24 — Good exposure of sand. The sand appears to have been deposited in a channel eroded into underlying clay (km 21.1, L).

		Thickness (m)	Depth of base (m)
SAND: 1	Silty 10%; medium and fine grained, medium mode; angular; moderately to well sorted; quartz 30%, feldspar 15%, dark minerals and lignite 5%; stratified and gently crossbedded, bedding control is grain size sorting.	10.25	10.25
CLAY: 2	Silty 10% to 20%; firm consistency, undisturbed; medium dry strength; high plasticity; fissured throughout; reticulate ice, 20% to 30% excess ice, ice veins vary from 1 to 3 mm thick.	1.0	11.25
COVERED: 3	Assumed clay as Unit 2 above.	10.5	21.75
COVERED: 4	Assumed till as described in Sections GB 22 and GB 23.	10	31.75

RIVER LEVEL

July 25/73

GB 25 — Examined a number of poorly exposed bimodal flows. Based largely on observations of colluvium, the section is clay over till with a contact 13 m above the river (km 20.3, L).

July 25/73

GB 26 — Steep section with sand exposed from 41 m (the top of the section) to 27 m, then colluvium to river level. A trickle of water and a slight break in slope at 23 m may indicate the approximate position of a sand-over-clay contact (km 18.9, L).

July 25/73

GB 27 — Several small quasi-stationary bimodal flows. Exposure is poor but digging revealed several units. Clay is present at 11.6 m and rises at least 2 m above. No good evidence of the till was found, however pebbles and cobbles of crystalline rocks in colluvium at lower elevations in the flows suggest its presence (km 18.1, L).

July 25/73

GB 28 — Bedrock appears as bluffs rising sharply out of the river, capped by Pleistocene deposits which are exposed in small bimodal flows. Permafrost is present throughout the section. Reticulate ice was observed in the siltstone (km 16.2, L).

		Thickness (m)	Depth of base (m)
SAND: 1	This is a minimum thickness, thick bush and lack of time did not allow a thorough investigation of the extent of the sand. Silt 10%; medium and fine grained, mode is medium; angular; well sorted; quartz 85%, feldspar 10%, dark minerals including lignite 5%; several ice rafted cobbles observed, maximum size 0.34 m; stratified and gently cross-bedded, bedding control through grain size sorting; permafrost expected between 2 and 3 m below the face.	10	10

		Thickness (m)	Depth of base (m)
CLAY: 2	This contact was not located and is inferred with a possible error of 2 m. Silty 20% to 30%; soft consistency, undisturbed; high dry strength; medium to high plasticity; moderately fissured; reticulate ice, 20% to 30% excess ice.	10	20
TILL: 2	Silty; very dark greyish brown (10YR 3/2), fresh; stiff to hard consistency, undisturbed; very low dry strength; low plasticity; inclusions 5%, maximum size 0.17 m, mode 10 mm, crystalline 80%, shale and siltstone in various weathering states 20%; fissured throughout; reticulate ice, 10% to 15% excess ice, active layer 0.8 to 1.2 m thick (WS-73-22a at 6.5 m)	7	27
SILTSTONE: 4	Very dark greyish brown (10YR 3/1), fresh; loose; noncalcareous; heavily fissured rendering it unstable and crumbly; carbonaceous material common and in various stages of decomposition to lignite; massive except for a 0.2 m coal seam at 4.8 m; breaks down easily when wet, permafrost present, critical active layer thickness is 0.9 to 1.0 m before localized fall-type failures occur; reticulate ice, 10% to 15% excess ice (WS-73-22b at various levels in siltstone, WS-73-22c coal at 4.9 m above river level).	7.5	34.5
RIVER LEVEL			

July 26/73

GB 29 — Excellent exposure of Pleistocene sand over bedrock. The sand banks extend almost to river level but the unit itself seems perched on one or several units which are failing, causing the whole bank to regress. Tertiary bedrock dipping steeply southwest is exposed at river level. This attitude does not reflect regional trends rather it seems related to local instability (km 11.8, L).

COVERED: 1	Thin organic rich sand at top of exposure.	0.3	0.3
SAND: 2	Approximately 14 m of fresh exposure was examined at the top of the section). Medium and fine grained; mostly quartz; subangular to rounded, finer grains show greater roundness; subangular grains represent the medium fraction; lignite beds common, up to 30 mm thick, mode 3 mm; traces of undecomposed organics; bedding control is with lignite beds, limited cross-bedding; permafrost estimated between 2 and 3 m below the face (AR-73-7 at 8 m).	17.38	17.68
COVERED: 3	Assumed to be clay overlying till as described in Section GB 28.	18.08	35.76
COAL: 4	Fissured, peds up to 30 mm in diameter; sand and silt content up to 40%, mode 10% to 20%; commonly plant fossils are well preserved; amber crystals common up to 1 mm in diameter; no distinct bedding.	1.22	36.98

		Thickness (m)	Depth of base (m)
SILTSTONE: 5	Greyish brown (10YR 5/2), fresh; loose; noncalcareous; fissured throughout, maximum diameter of peds 30 mm, mode 20 mm; traces of plant fossils in various stages of decomposition to lignite; no distinct bedding; breaks down easily when wet.	2.30	39.28
RIVER LEVEL			

July 26/73

GB 30 — Exposure of Pleistocene deposits over bedrock in a west-facing stream cut approximately 700 m upstream from the confluence of Brackett River. Between this section and GB 29 the stratigraphy is obscured by cover whereas in a western direction through GB 31 and GB 32 the stratigraphy is well exposed (km 11.5, L).

		Thickness (m)	Depth of base (m)
CLAY: 1	Silty 40 to 50%; firm consistency, undisturbed; medium dry strength; medium plasticity; fissured; believed to contain ground ice, permafrost not observed within 0.75 m (thickness given is not to the top of the bank; WS-73-23 at 2.0 m).	3.8	3.8
TILL: 2	Silty 20%; sand 40%, very poorly sorted, quartz 50%, lignite 20%, other minerals 30%, subangular to subrounded;gravel 40%, very poorly sorted, maximum size 140 mm, mode 10 mm, subrounded, commonly coated with a finegrained, noncalcareous precipitate; unit is massive and dark in colour; it becomes very dusty (coal dust) when dried; coal grains are angular to subangular and rarely exceed 10 mm in diameter. The till described here is unlike any other exposure of till found along Great Bear River (WS-73-23b at various levels).	5.8	9.6
COAL: 3	Fissured; maximum diameter of peds 20 mm, mode 10 mm; sand and silt content up to 30%, mode 10% to 20%; abundant plant fossils; amber crystals common up to 1 mm in diameter; white siltstone bands common, up to 50 mm thick and extending 3 m laterally (WS-73-23c, at various levels).	2.89	12.49
SILTSTONE: 4	Very pale brown (10YR 8/4), weathered; sand 26% (74% passed #200 sieve); soft; noncalcareous; highly fissured, commonly breaks in egg-shaped peds; well oxidized along fissures; anastomosing bedding 60 to 230 mm thick (WS-73-23d at various levels). Laboratory analysis indicated high plasticity silt classification (MH) and high montmorillonite content (this clay mineral comprised almost 100% of material passing the #200 sieve).	4.1	16.59
COVERED: 5		8.84	25.43
RIVER LEVEL			

July 26/73

GB 31 — For the purpose of correlation with the same stratigraphic location as the top of Unit 4 Section GB 30, the difference in elevation to river level is now 15 m (km 11.2, L).

		Thickness (m)	Depth of base (m)	
GB 32	July 26/73 Excellent exposure of Pleistocene and Tertiary deposits opposite the Brackett River confluence. The upper part shows localized bimodal flow development. The lower portion is protected from large scale river erosion by the accumulation of colluvium in the river course. Permafrost is suspected at between 2 and 3 m below the face. Significant ground ice is likely only in the Pleistocene clay and till (km 10.3, L).			
COVERED: 1		3.0	3.0	
SAND: 2	Silty 10% to 20%; medium to fine grained, medium mode; subangular; moderately to well sorted; 80% quartz, 20% dark minerals and lignite, noticeably low in feldspar; no inclusions observed; minor crossbedding, otherwise bedding indistinct; lower contact is covered but is inferred with an accuracy of 1 m.		4.07	7.07
CLAY: 3	Silt 20% to 30%; firm consistency, undisturbed; medium dry strength; medium plasticity; fissured; substantial ground ice is suspected; many bimodal flow scars appear around the bluff.	3.0	10.07	
TILL: 4	Black (5Y 2.5/2), fresh; silt texture; hard consistency, undisturbed; low dry strength; low plasticity; inclusions 10% to 20%, maximum size 0.96 m, mode 8 mm, boulders and cobbles 1%; well developed fissures; (WS-73-25a at 5.0 m).	10.07	20.14	
SANDSTONE: 5	Very poorly indurated; easily broken down by sampling or rubbing between fingers; medium grained; subangular; very well sorted; quartz 50%, dark minerals 50%, no feldspar observed; stratified, beds range from 30 to 200 mm, bedding controlled by sorting of dark minerals; no permafrost observed; upper contact with till is undulatory (WS-73-25b at various levels).	1.3	21.44	
CONGLOMERATE: 6	Poorly indurated; easily broken down with a shovel and can be broken down by rubbing between fingers; maximum inclusion size 0.21 m, mode 10 to 20 mm, subrounded and subangular; predominantly dark siliceous igneous rocks; gravel 60% to 70%, sand 30% to 40%; stratified, bedding controlled by beds of sandstone (as above, Unit 5) up to 1.3 m thick (WS-73-25d at 11 m).	13.75	35.19	
SILTSTONE: 7	Light grey (10YR 7/1), weathered; slightly sandy 10%; loose; noncalcareous; fissured; breaks down very easily when wet; sand is 50% quartz, 50% dark minerals, subrounded; fissured structure; no permafrost observed (WS-73-25e at 4.0 m).	6.0	41.19	
CONGLOMERATE: 8	As above, Unit 6; very irregular thickness, never exceeding 0.6 m and in places pinching out completely.	0.6	41.79	

		Thickness (m)	Depth of base (m)
SANDSTONE: 9	Light olive brown (2.5Y 5/6), fresh and weathered; poorly indurated; easily broken down by sampling or rubbing between fingers; medium and fine grained; subangular to subrounded; very well sorted; quartz 50%, dark minerals 50%, no feldspar observed; massive but well crossbedded; vertical joints spaced at between 0.5 and 1.0 m throughout (WS-73-25f at various levels).	9.32	51.11
RIVER LEVEL			

July 26/73

GB 33	Observed coarse alluvial deposits overlying Tertiary sandstone. Contact approximately 6 m above river level (km 8.0, L).

July 26/73 and July 1/75

GB 34	Similar to GB 30. Pleistocene sand over tertiary bedrock. Failure of one or more units beneath the sand is hidden by colluvium. Tertiary bedrock is almost totally covered with colluvium but its top can be picked at a prominent break in slope with an estimated accuracy of 3 m (km 6.5, L).

COVERED: 1	Organic sand immediately above exposure.	0.3	0.3
SAND: 2	Clean; fine grained; subangular and angular; very well sorted; quartz 75%, lignite 10%, dark minerals and feldspar 5%; lignite commonly occurs in beds 20 to 30 mm thick; bedding control is by lignite beds, low angle crossbeds common; permafrost estimated at between 2 and 3 m below the face (AR-73-8 at various levels; C14 sample HH-WS-7527-1 sampled July 1, 1975 at 5.0 m).	20	20.30
COVERED: 3	The base of this covered interval is a prominent break-in-slope. This is assumed to be a contact of clay overlying till as described in GB 32.	18	38.30
COVERED: 4	This interval is assumed to be Tertiary bedrock, probably the basal sandstone mentioned in GB 32. This sandstone unit is observed across the river in GB 35.	7	45.30
RIVER LEVEL			

July 26/73

GB 35	Section on the north side of Great Bear River facing GB 34. Approximately 10 m of section is visible; 2 m of till overlying 6 m of sandstone and siltstone to a well developed boulder pavement which extends for a further 2 m to river level (km 6.6,R).

		Thickness (m)	Depth of base (m)

July 26/73

GB 36

A long exposure of Pleistocene deposits over Tertiary bedrock. The following observations were made from a boat in the river. One or more recessive units (probably sand over clay) occupy the top of the section and are largely hidden from view, their thickness is estimated at 13 m. Till is the first resistant unit. It underlies the recessive unit, and is estimated at 6 m thick. Bedrock is approximately 20 m thick and extends to river level. The recessive units show signs of recent bimodal flow activity (km 3.3, L).

July 26/73

GB 37

A Pleistocene and Tertiary section on the left bank of the Great Bear immediately off the west end of the Fort Norman air strip. The following observations were made from a boat in the river. The Pleistocene deposits consist of 6 m of sand over 7 m of till. Tertiary bedrock consists of 20 m of sandstone with beds of conglomerate. All units appear stable (km 0.4, L).

July 22/73

GB 38

This section is measured in Cretaceous bedrock on the north side of Great Bear River about mid-point in the St. Charles Rapids. A similar exposure on the opposite side of the river was inspected from a helicopter.

These rocks are placed in the Cretaceous Little Bear Formation. Upstream approximately two kilometres random exposures of a black very fissile shale, probably the Cretaceous East Fork Formation, were observed. No definite contact could be found between the East Fork and Little Bear formations. Downstream approximately 2 km there is evidence in stream cuts and along the river bank of still another shale. No good exposures of this shale were found.

The strata in the measured section dip 5ł to 73ł azimuth. At least two joint sets are visible. The averages of these joint sets give strikes of 122ł and 203ł, both with vertical dips. The range was as much as 20ł from these averages.

(Measuring down in the section)

The section can be divided into units of similar thickness. The top unit is a siltstone whereas the bottom unit is dominantly siltstone with interbeds of arenaceous shale (km 57.6, R.).

TOP UNIT

		Thickness (m)	Depth of base (m)
COVERED: 1	Mostly peat and organic material.	0.5	0.5
SILTSTONE: 2	Very pale brown (10YR 7/4), weathered, pale yellow (5Y 7/3), fresh; moderately well cemented, grains may be rubbed off with fingers, but the rock can only be broken with a hammer; noncalcareous; cement is often oxidized; fine sand represents about 30% of the rock; bedding resembles a thin brickwork, it is thinly bedded and broken; crossbedding is present and ripple marks common on bedding planes; the dominant mineral is quartz with feldspar and carbonaceous content 5%; iron-rich blotches on bedding planes are common.	12.1	12.6
SILTSTONE: 3	As above, Unit 2. Arenaceous, fissile shale interbeds up to 20 mm thick. Siltstone bedding planes show common but random iron stain.	1.0	13/6

		Thickness (m)	Depth of base (m)
SILTSTONE: 4	As above, Unit 2.	8.25	21.85

<u>BOTTOM UNIT</u>

SILTSTONE and SHALE: 5	Siltstone as above, Unit 2; fine sand content 10% to 20%; shale partings 1 mm thick run through siltstone beds; the shale is very arenaceous, fissile, and friable; beds vary in thickness from 10 to 20 mm; increasing near base to 30 to 50 mm thick; ironstone concretions are present in both the siltstone and shale beds; minor evidence of ripple marks on the siltstone bedding planes; minor burrowing in the siltstone; shale content increases with depth from 30% to 50%.	8.68	30.53
COVERED: 6		2.59	33.12
RIVER LEVEL	Estimated river surface el. 97.7 m.		

Aug. 30/72

GB 39 — G.E. Crippen & Associates Ltd. testhole B14 (65°01'N, 124°25'W)

Collared at el. 213.4 m.

TILL: 1	Grey; sandy 50%, fine to coarse sand with boulder chips (originally called CLAY).	15.55	15.55
TILL: 2	Sandy, fine to coarse, subangular; 25% rock chips; clay 10% (originally called SAND).	3.36	18.91
TILL: 3	Clay 25%; rock chips; boulders likely every 0.6 to 0.9 m where drill slowed down and vibrated [originally called CLAY (TILL)].	40.55	59.46

Oct. 7/75

GB 40 — Exposure of Pleistocene sediments over Tertiary bedrock. A normal fault present in bedrock. Orientation of fault plane is obscured by colluvium. Southwest side is down; bentonitic siltstone (see Unit 4, GB 30) in the hanging wall, against siltstone and sandstone (see Units 7 and 9, GB 32) in the footwall. This supports the correlation established in GB 30 and GB 31 above the Brackett River confluence (km 0, beach level along Mackenzie River at the northwest end of Fort Norman).

Sept. 5/71

GB 41 — G.E. Crippen & Associates Ltd. testhole number M20 (65°02'N, 124°38'W)

Collared at el. 135.3 m.

		Thickness (m)	Depth of base (m)	
TILL: 1	Encountered silt, sand, gravel, cobbles and boulders; boulders granitic, well rounded; silty material between 3.36 and 5.90 m; hole logged from wash water; began losing circulation at 30.50 m.	32.00	32.00	
2	Estimated distance from the bottom of this hole to river level.	7.30	39.30	
GB 42	G.E. Crippen & Associates Ltd. testhole M20 (65ł02'N, 124ł38'W)			Sept. 5/71
	Collared at el. 128.0 m.			
SAND: 1	Yellow-brown; very fine.	2.44	2.44	
GRAVEL: 2	Sandy; many boulders, rounded.	5.80	8.24	
TILL: 3	Grey; clayey, 50% passed the # 200 sieve. Estimated river level is at 29.46 m in this interval (36.59 m below collar).	34.45	42.69	
GRAVEL: 4	Sandy.	12.20	54.89	
GB 43	G.E. Crippen & Associates Ltd. testhole M2 (65ł03'N, 124ł50'W)			Sept. 6/71
	Collared at el. 147.8 m.			
SAND:	Gravelly; poorly sorted; few rounded boulders on surface, maximum size 0.6 m diameter.	4.88	4.88	
SAND: 2	Medium to coarse; some gravel and fines; sloughing in hole.	8.84	13.72	
GB 44	G.E. Crippen & Associates Ltd. testhole R2 (km 51.9, L)			Aug. 20/71
RIVER WATER: 1	Water surface at el. 84.80 m.	0.23	0.23	
BOULDERS: 2	Granitic composition.	0.45	0.68	
GRAVEL: 3	Few boulders; no finer material recovered.	4.27	4.95	
SAND: 4	Few granitic boulders; no fines, fines possibly washed away by drill water.	8.53	13.48	
SILT: 5	Grey; fine sand particles in drill water and a small amount in core barrel.	9.75	23.23	

		Thickness (m)	Depth of base (m)	
GB 45	Pemcan Services testhole 2, site number FN13 (64°57'N, 125°26'W)			Feb. 2/73
TOPSOIL: 1	Dark brown; little silt; fibrous; ground ice described as Vx, 10% to 50% by volume.	0.31	0.31	
SAND: 2	Grey; little silt; fine grained; poorly graded; ground ice described as Vx and Vs; bottom 0.61 m contains some gravel, ground ice described as Vx, 10% to 50% by volume.	3.66	3.97	
GRAVEL: 3	Brown; sandy; trace of silt; poorly graded; pebbles 25 to 40 mm, subangular to subrounded, few cobbles, mainly limestones and quartzites; ground ice described as Vx, 10% to 50% by volume.	1.52	5.49	
GB 46	Pemcan Services testhole 1, site number FN30C (64°15'N, 125°28'W)			Feb. 2/73
TOPSOIL: 1	Dark brown to black; little silt;organic and fibrous; ground ice as described as Vx, 10% to 50% by volume.	0.15	0.15	
SAND: 2	Grey; trace of silt; fine grained; poorly graded; silt pockets common below 3.20 m; ground ice throughout, described as Vx, 10% to 50% by volume.	5.34	5.49	
GB 47	Pemcan Services testhole 3, site number FN10 (km 5.9,L)			Jan. 30/73
SILT: 1	Dark brown; organic; ground ice described as Vx, 10% to 50% by volume.	0.46	0.46	
SILT: 2	Medium brown to grey; little sand; low plasticity; ground ice described as Vs, to 1.68 m greater than 50% by volume, below 1.68 m 10% to 50% by volume; change in ice content correlates with increase in sand content at 1.68 m.	2.59	3.05	
GRAVEL: 3	Medium brown; some sand; little silt; ground ice described as Vx, 10% to 50% by volume.	0.92	3.97	
SILT: 4	Blue-grey; little sand; ground ice described as Vs, 10% to 50% by volume.	0.92	4.89	
GB 48	R.M. Hardy & Associates Ltd. testhole 112 approximately mile 582, Mackenzie Highway (km 3.9, L).			December 12/72
PEAT: 1	Amorphous-granular peat containing woody, fine fibres; ground ice described as Nbn.	0.31	0.31	

		Thickness (m)	Depth of base (m)
SAND: 2	Brown; variable silt and clay content throughout (nonplastic); ground ice described as Nbn; w_n 13% to 35%.	6.70	7.32
CLAY: 3	Grey; high plasticity; ground ice described as Vx, 10% to 50% by volume; w_n 38%.	0.31	7.32
			Dec. 12/72
GB 49	R.M. Hardy & Associates Ltd. testhole 113 approximately mile 582, Mackenzie Highway (km 3.8, L)		
PEAT: 1	Amorphous-granular peat containing woody, fine fibres; ground ice described as Nbe.	0.15	0.15
SAND: 2	Brown; very silty, becoming less silty with depth; fine grained; nonplastic except between 1.37 and 3.20 m where low plasticity; ground ice described as Nbe to 1.18 m, Nbn thereafter; w_n 25% rising to 33% at base.	6.86	7.01
CLAY: 3	Grey; high plasticity; ground ice described as Vx, 10% to 50% by volume; w_n 24%.	0.31	7.32
			Dec. 12/72
GB 50	R.M. Hardy & Associates Ltd. testhole 107 approximately mile 581, Mackenzie Highway (64154'N, 125132'W)		
PEAT: 1	Amorphous-granular peat; ground ice described as Nbn.	0.31	0.31
SILT: 2	Sandy, organic; ground ice described as Nbn; w_n 66%.	0.31	0.62
SAND: 3	Brown; slightly silty; fine grained; nonplastic; ground ice described as Nbn; w_n near 80% at top levelling off quick- ly to 25%.	2.74	3.36
SILT: 4	Grey; clayey; medium plasticity; ground ice described as Nbn; w_n 25% (originally described as CLAY).	1.07	4.43
SILT: 5	Grey; clayey; medium plasticity; ground ice described as Vx, 30% by volume to 0.21 m, thereafter 5% by volume (sample RMH B3).	2.90	7.33
			Dec. 12/72
GB 51	R.M. Hardy & Associates Ltd. testhole 122 approximately mile 579, Mackenzie Highway (64154'N, 125129'W)		

		Thickness (m)	Depth of base (m)
SAND: 1	Brown; silty; fine grained, nonplastic; ground ice described as Nbn to 1.83 m, thereafter described as Vx, ice content rises with depth from 1% to 60% by volume; w_n increases with depth from 8% to 74%.	5.18	5.18
CLAY: 2	Grey; silty; high plasticity; ground ice described as Vx, excess by volume 15% to 20%; w_n 32% to 38%.	2.14	7.32

date not given

GB 52	Pemcan Services testhole C32, site number FN8 (drilled by R.M. Hardy & Associates Ltd; 64°53'N, 125°22'W)		
PEAT: 1	Ground ice described at Nbn.	0.62	0.62
SAND: 2	Brown; very silty; clayey through bottom 0.3 m; fine grained; low plasticity; ground ice described as Nbn.	1.52	2.14
CLAY: 3	Brown to grey, becoming grey; silty and sandy, becoming less with depth; medium plasticity becoming high plasticity at depth; ground ice described as Nbn.	2.74	4.98

Dec. 12/72

GB 53	R.M. Hardy & Associates Ltd. testhole 110 mile 582, Mackenzie Highway (km 3.1 L)		
PEAT: 1	Amorphous-granular peat; ground ice described as Nbn.	0.15	0.15
SAND: 2	Brown; trace of silt at top, increasing slightly downward; nonplastic; ground ice described as Nbn; w_n varies from 13% to 26%.	2.44	2.59
SILT: 3	Brown; sandy; low plasticity; ground ice described as Nbn; w_n 28%.	1.37	3.96
SAND: 4	Brown; silty; non-plastic; ground ice described as Nbn; w_n 28%.	0.46	4.42
SILT: 5	Brown; sandy; low plasticity; ground ice described as Nbn; w_n 24%.	0.76	5.18
CLAY: 6	Grey; medium plasticity; ground ice described as Nbn; w_n 26%.	0.31	5.49

		Thickness (m)	Depth of base (m)	
CLAY: 7	Grey; silty; medium plasticity; ground ice described as Nbn.	1.83	6.32	
GB 54	R.M. Hardy & Associates Ltd. testhole 111 mile 582, Mackenzie Highway (km 2.6, L)			Dec. 12/72
SAND: 1	Brown, becoming grey with depth; silty, becoming clayey with depth; ground ice described as Nbn; w_n 14% to 30%.	6.10	6.10	
CLAY: 2	Slightly silty; trace of sand; ground ice described as Nbn; w_n 25%.	2.22	8.32	
GB 55	R.M. Hardy & Associates Ltd. testhole 452 approximately mile 582, Mackenzie Highway (km 2.3, L)			Feb. 3/73
SILT: 1	Dark brown; sandy; organic with organic inclusions and peat inclusions below 0.61 m; ground ice described as Nbn; w_n 58% to 100%.	1.52	1.52	
SAND: 2	Light brown to grey; silty; fine grained; nonplastic; ground ice described as Nbn; w_n varies from 24% plus at the top to 29% with depth.	3.66	5.18	
CLAY: 3	Dark grey brown; slightly sandy; medium plasticity; ground ice 20% excess; w_n increases from 30% to 44% with depth.	0.92	6.10	
GB 56	Pemcan Services test pit TP1 site number FN-14. (All deposits in the test pits are assumed to be unfrozen (km 2.5, L).			date not given
TOPSOIL: 1	Black, organic, roots.	0.12	0.12	
SILT: 2	Light brown; some clay; moist.	0.12	0.24	
SAND: 3	Low in silt; fine grained; dry.	0.67	0.91	
GB 57	R.M. Hardy & Associates Ltd. testhole 465 approximately mile 538, Mackenzie Highway (km 1.2, R)			Feb. 5/73
SILT: 1	Organic.	0.31	0.31	
SILT: 2	Brown; slightly clayey; low plasticity; ground ice described as Nbn; w_n varies from 38% to 25% with depth (originally described as TILL).	1.22	1.53	

		Thickness (m)	Depth of base (m)
SAND: 3	Grey; slightly silty (silt and clay sizes 7%, sand sizes 93%); fine grained; low plasticity to nonplastic; ground ice described as Nbn; w_n 12% to 26% (originally described as TILL).	2.74	4.27
SILT: 4	Grey; sandy; pebbles to 6 mm; low plasticity; ground ice described as Nbn; w_n 12% to 26% (originally described as TILL).	1.22	5.49
SAND: 5	Grey; slightly silty (silt and clay sizes 11%, sand sizes 89%); fine grained; nonplastic; ground ice described as Nbn; w_n 20% to 25% (originally described as TILL).	0.61	6.10
			Feb. 5/73
GB 58	R.M. Hardy & Associates Ltd. testhole 461 approximately mile 583, Mackenzie Highway (km 1.4, R)		
PEAT: 1		0.15	0.15
SILT: 2	Brown; clayey; low to medium plasticity; ground ice described as Nbe to 0.31 m, unfrozen thereafter; w_n at top of unfrozen zone 28%.	0.76	0.91
TILL: 3	Brown; becoming silty at 0.92 m, then clayey at 2.42 m; pebbles up to 13 mm in the silty zone; generally nonplastic but exhibits low plasticity in clayey zone; unfrozen to top of silty zone, thereafter ground ice defined as Nbn; w_n 10% and 20%.	3.28	4.19
TILL: 4	Grey; sandy; pebbles to 8 mm; fine grained; nonplastic; rust specks below 2.74 m; ground ice described as Nbn; w_n 18% to 24%.	4.57	9.37
			Feb. 12 & 13/73
GB 59	R.M. Hardy & Associates Ltd. testhole 522 approximately mile 583, Mackenzie Highway (km 1.3, R)		
PEAT: 1	Predominantly amorphous-granular, containing fine woody fibres, held in a woody, coarse-fibrous framework; ground ice described as Vx with an excess of up to 65% in the top 0.31 m, and Vr with an excess of 5%; w_n 40% to 100% plus; the bulk unit weight is 7.43 kN/m^3 (47.3 pcf), the dry unit weight 1.81 kN/m^3 (11.5 pcf).	0.46	0.46
CLAY: 2	Dark brown; sandy; becoming slightly silty below 1.98 m; high plasticity; ground ice described as Vr to 1.07 m, Nbn thereafter; excess ice ranges from 49% to 55% in Vr zone; w_n drops from a high of 66% near the top to 10% at the bottom, overall it is variable; the bulk unit weight varies from 13.35 kN/m^3 (78.6 pcf) to 16.90 kN/m^3 (107.5 pcf), the dry unit weights vary from 8.16 kN/m^3 (51.9 pcf) to 12.21 kN/m^3 (77.7 pcf). Estimated river level 5.0 m.	5.50	5.96

		Thickness (m)	Depth of base (m)
TILL: 3	Brown; sandy (silt and clay sizes 9%, sand sizes 41%, gravel sizes 50%); nonplastic; ground ice described as Nf; w_n generally 8% increasing slightly near the bottom (originally described as GRAVEL).	2.42	8.38
CLAY SHALE: 4	Grey; arenaceous; rust specks; ground ice described as Nbn; w_n 22%.	5.64	14.02
SANDSTONE: 5	Grey; poorly indurated; nonplastic; trace of argillaceous material below 6.10 m (silt and clay sizes 27%, sand sizes 73%) low plasticity; ground ice described as Nbn; w_n 19% to 26%.	13.10	27.12
CLAY SHALE: 6	Grey; arenaceous; high plasticity;ground ice described as Nbn; w_n 23%.	0.61	27.73
SANDSTONE: 7	Grey; trace of argillaceous material; poorly indurated; low plasticity; ground ice described as Nbn; w_n decreases from 22% to 18% with depth.	1.22	28.95
GREY SHALE: 8	Grey; arenaceous; high plasticity; ground ice described as Nbn; w_n decreases from 18% to 15% with depth.	2.74	31.69

Sept. 12/71

GB 60 — G.E. Crippen & Associates Ltd. testhole M14, 4.88 km (16,000 feet) east northeast of the confluence of Porcupine River and Great Bear River (outside of map area)

Collared at el. 176 m.

		Thickness (m)	Depth of base (m)
TILL (CL): 1	Clayey; generally sand, gravel and boulders in a silty clay matrix; w_n 17% (sample GEC 43 @ 3.66 m, sample GEC @ 54.9 m).	62.5	62.5

Estimated river level at 25.9 m in this hole.

Aug. 31/71

GB 61 — G.E. Crippen & Associates Ltd. testhole M18, 3.05 km (10,000 feet) west northwest of the confluence of Rosalie Creek and Great Bear River (outside of map area)

Collared at el. 174.1 m.

		Thickness (m)	Depth of base (m)
TILL: 1	Contains about 25% brown clay; sand, medium, subangular (originally described as GRAVELLY CLAY).	3.35	3.35
SAND AND GRAVEL: 2	Pea gravel with medium to fine sand. Very few fines.	6.10	9.45

		Thickness (m)	Depth of base (m)
TILL: 3	Clay matrix; some sand; gravel,few boulders. River level is estimated at 3.08 m beneath the top of this unit (originally described as GRAVELLY CLAY).	24.07	33.52
SAND AND GRAVEL: 4	Few fines.	5.18	38.70
TILL:	Clay matrix; some sand and gravel (originally described as CLAY).	23.79	62.49

Aug. 29/71

GB 62 G.E. Crippen & Associates Ltd. testhole R11 (km 10.4, R, at Brackett River confluence)

	Collared at el. 61.1 m.		
BOULDERS: 1	Estimated river level at 1.20 m of this unit.	4.57	4.57
SILTSTONE and SHALE: 2	Salt and pepper colour; very fine grained; argillaceous matrix; commonly soft; generally oxidized; 8 mm thick laminations; core recovered in 25 mm to 75 mm lengths (originally described as SANDSTONE).	3.50	8.07
SILTSTONE and SHALE: 3	Brown; sandy; weathered; core recovered in 75 mm lengths (originally described as SILTSTONE).	0.15	8.22
SILTSTONE and SHALE: 4	Grey; argillaceous; 4 mm tabular coal lenses, 1% of total unit; rock generally weak; core recovery in 0.31 m lengths, machine breaks; no visible alteration (originally described as ARGILLACEOUS SILTSTONE).	2.14	10.36

Sept. 26/71

GB 63 G.E. Crippen & Associates Ltd. testhole R21 (km 10.6, R)

SAND: 1	Brown; medium to coarse; very little fine material; poorly graded.	4.57	4.57
CLAY: 2	Grey; silty; no sand or gravel; very firm; no ice observed in core; good core recovery.	1.52	6.09
TILL: 3	Sandy; subangular boulders, very few fines (originally described as GRAVEL).	4.57	10.66

		Thickness (m)	Depth of base (m)
SANDSTONE: 4	Grey; fine; no recovery except for return in wash water (originally described as SILTY SAND).	7.62	18.28
CONGLOMERATE: 5	Grey; sandy, approximately 4% is 13 mm well rounded gravel (originally described as GRAVELLY CLAY).	0.31	18.59
CONGLOMERATE: 6	Well rounded; igneous rocks (originally described as SANDY GRAVEL).	3.05	21.64
7	Estimated distance from bottom of hole to river level.	19.56	41.20

			Sept. 28/71
GB 64	G.E. Crippen & Associates Ltd. testhole R22 (km 12.25,R)		
	Collared at el. 102.4 m.		
SAND: 1	Grey; more than 50% passed #200 sieve; gravel, subangular (originally described as SILTY CLAYEY TILL).	4.27	4.27
CLAY: 2	Grey; till-like; more than 80% passed #200 sieve; clay becomes very firm after thawing and drying; ice lenses in core (originally described as CLAYEY SILT).	12.20	16.47
TILL: 3	Grey; cobbles up to 10 cm, angular to subangular; approximately 50% passed #200 sieve; average core recovery for hole 62%.	3.36	19.83
4	Estimated distance from bottom of the hole to river level.	21.07	40.90

			Sept. 24/71
GB 65	G.E. Crippen & Associates Ltd. testhole R20 (km 12.25,R)		
RIVER WATER: 1	Surface el. 59.89 m.	1.50	1.50
BOULDERS: 2	Sandy gravel mixed with boulders no recovery.;	4.40	5.90
SANDSTONE: 3	Grey; medium; (originally described as SAND).	7.90	13.80

		Thickness (m)	Depth of base (m)	
GB 66	G.E. Crippen & Associates Ltd. testhole R206 (km 5.5, R)			April 8/72
	Collared at el. 96.5 m			
SAND: 1	Brown; fine to coarse; frozen; wet.	3.05	3.05	
SILT: 2	Grey; frozen; wet.	13.72	16.77	
GRAVEL: 3		2.13	18.90	
TILL: 4	Grey; sandy, small percentage of gravel (originally described as SILT).	11.58	30.48	
SILTSTONE and SHALE: 5	Light grey; poorly indurated; breaks down when soaked; very sandy; indication of vertical jointing (Estimate local river level at 11.22 m).	17.68	48.16	
GB 67	G.E. Crippen & Associates Ltd. testhole R207 (km 5.5, R)			April 8/72
	Collared at el. 91.4 m.			
SAND: 1	Brown; fine to medium; frozen.	3.96	3.96	
GRAVEL: 2	Sandy; maximum gravel size 19 mm.	0.61	4.57	
SILT: 3	Frozen; wet when thawed.	7.01	11.58	
TILL: 4	Silt 50%, sand 25%, gravel 25%; maximum gravel size 0.25 m, angular; low moisture content (originally described as SILT).	17.37	28.95	
SHALE: 5	Soft; sandstone interbeds near bottom (estimated local river level at 6.65 m, 34.74 m below collar).	7.62	36.57	
GB 68	G.E. Crippen & Associates Ltd. testhole R208 (km 5.7, river course)			April 8/72
ICE: 1	Ice surface el. 58.6 m. Estimated water surface el. 58.3 m.	1.52	1.52	
WATER: 2		0.20	1.72	

		Thickness (m)	Depth of base (m)
SAND: 3	Silty, some gravel.	1.20	2.92
SILT: 4	Grey.	0.90	7.82
SILTSTONE and SHALE: 5	Light grey with some greenish grey layers up to 6 mm thick; latter are higher in clay content; a few 6 mm thick layers of silty sandstone orthogonal to core axis; cement breaks down when soaked in water (originally described as SILTSTONE).	6.10	13.92

April 9/72

GB 69	G.E. Crippen & Associates Ltd. testhole R209 (km 5.6 river course)		
ICE: 1	Ice surface el. 58.5 m. Estimated water surface el. 58.1 m.	1.52	1.52
WATER: 2		0.70	2.22
GRAVEL: 3	Few cobbles and boulders.	0.30	2.52
SILT: 4	Sandy; few boulders.	5.80	8.32
SILTSTONE and SHALE: 5	Dark with layers of light, soft, silty material (originally ally described as SHALE).	2.70	11.02
SILTSTONE and SHALE: 6	Light grey with some greenish grey layers up to 0.64 m thick; latter are higher in clay content; generally soft; may be broken down by hand; random siltstone interbeds; a 0.31 m thick bed of calcareous sandstone near bottom; all disintegrate when soaked in water except calcareous sandstone; some evidence of jointing; maximum core length 0.18 m with 30% less than 25 mm (originally described as SILTY SANDSTONE).	18.30	29.32

April 10/72

GB 70	G.E. Crippen & Associates Ltd. testhole R210 (km 5.2, R)		
	Collared at el. 91.4 m.		
SILT: 1	Grey; sandy; frozen.	1.84	1.84
SAND: 2	Fine to coarse; some subangular gravel; ice lenses.	4.30	6.14

		Thickness (m)	Depth of base (m)
CLAY: 3	Frozen; ice lenses (originally described as SILT).	9.10	15.24
TILL: 4	Occasional boulder; angular; loss of drill mud reported (originally described as SILT, SAND and GRAVEL)	7.60	22.84
SILTSTONE and SHALE: 5	Soft; coring impossible (estimated river level at 13.2 m (originally described as SHALE)	21.40	44.24
SILTSTONE and SHALE: 6	Dark grey; fine grained; very soft, may be broken by hand; disintegrates when soaked; core recovered in lengths to about 25; drill mud loss reported (originally described as SILTY SANDSTONE)	4.50	48.74

April 5/72

GB 71	G.E. Crippen & Associates Ltd. testhole R201 (km 10.5, river course)		
ICE: 1	Ice surface el. 62.6 m. Estimated water surface el. 62.3 m.	1.83	1.83
WATER: 2		2.76	4.59
GRAVEL: 3	Sandy; some silt and a few boulders.	2.14	6.73
SILTSTONE and SHALE: 4	Slightly arenaceous; stiff; core could not be recovered (originally described as SILT).	16.75	23.48
SILTSTONE and SHALE: 5	Light grey with some greenish grey layers up to 6 mm thick; latter are higher in clay content; silty; brittle but may be easily broken down by hand; disintegrates when soaked in water; longest piece of core recovered 0.15 m, 50% less than 50 mm (originally described as SILTY SHALE).	6.09	29.57

April 6/72

GB 72	G.E. Crippen & Associates Ltd. testhole R202 (km 10.2, river course)		
ICE: 1	Ice surface el. 62.2 m. Estimated water surface el. 61.9 m.	1.83	1.83
WATER: 2		2.30	4.13
GRAVEL: 3	Sandy with small percentage silt and boulder sizes.	2.70	6.83

		Thickness (m)	Depth of base (m)
SILTSTONE and SHALE: 4	Grey; slightly arenaceous; stiff, core could not be recovered (originally described as SILT).	14.60	21.43
SILTSTONE and SHALE: 5	Light grey with some greenish grey layers up to 6mm thick; latter are higher in clay content; soft and easily broken in hand; disintegrates when soaked in water; longest piece of core recovered 1.5 m; indications of vertical joints (originally described as SILTY SHALE).	26.60	48.03

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GB 73	G.E. Crippen & Associates Ltd. testhole R203 (km 10.6,R)		
	Collared at el. 108.6 m.		
SAND over CLAY (undif-ferentiated): 1	Stiff; low moisture content (originally described as SILT).	12.19	12.19
TILL: 2	Small percentage of sand and gravel, subangular (originally described as SILT).	7.62	28.95
SILTSTONE and SHALE: 3	Light grey with some carbonaceous seams; very soft and may be broken by hand; disintegrates when soaked in water; longest piece of core recovered 0.15 m, 90% longer than 25 mm.	7.62	28.95
4	Estimated distance from bottom of hole to river level.	20.05	49

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GB 74	G.E. Crippen & Associates Ltd. testhole R204 (km 10.6,R)		
	Collared at el. 111.3 m.		
SAND: 1	Brown; fine to medium grained; moist.	6.10	6.10
CLAY: 2	Clean; moist (originally described as SILT).	7.93	14.03
TILL: 3	Sandy; small percentage subangular gravel (originally described as SILT).	5.79	19.82
SILTSTONE and SHALE: 4	Drilling indications were that the rock was soft and became harder than depth (originally described as SHALE).	3.66	23.48

		Thickness (m)	Depth of base (m)
GB 75	G.E. Crippen & Associates Ltd. testhole R205 (km 9.9, R)		April 7/72
	Collared at el. 79.3 m.		
SILT: 1	Grey; sandy; frozen, wet when thawed; below 18.29 m drier and firmer; few ice lenses (Estimate river level at 19.82 m).	20.42	20.42
SILTSTONE and SHALE: 2	Greenish grey; contains few 6 mm carbonaceous seams and few sandy seams; very soft and easily broken by hand; disintegrates when soaked in water; core lengths all less than 50 mm (originally described as SILT).	32.92	53.34