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QUATERNARY GEOLOGY OF THE NORTHEASTERN PART OF THE CENTRAL MACKENZIE VALLEY CORRIDOR, DISTRICT OF MACKENZIE, NORTHWEST TERRITORIES

A. Duk-Rodkin and O.L. Hughes

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Cover description

Ice-rich glaciolacustrine silt and clay exposed in backwall of a retrogressive thaw flow slide within rolling moraine topography. Banding reflects variation in segregated ice content, which may exceed 60%. Bands are truncated at base of the active layer. Grand View hills. (Photo by O.L. Hughes, 1973. GSC 1995-076)

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Preface

This report presents the results of studies (1985-1987) which entailed detailed mapping of surficial deposits, terrain evaluation, and reconstructing the Late Quaternary history of the northwestern Interior Plains.

Background information was obtained from terrain evaluation studies for pipeline and road construction purposes during the Mackenzie Transportation project (1971-1973) headed by the late O.L. Hughes.

This bulletin not only provides insight into the processes and effects caused by the Late Wisconsian Laurentide Ice Sheet in the study area, but also addresses regional development concerns inherent in an area that is underlain by permafrost.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

Le bulletin présente les résultats d'études (1985-1987), notamment la cartographie détaillée des matériaux superficiels, l'évaluation du terrain et la reconstitution du Quaternaire supérieur, entreprises dans le nord-ouest des Plaines intérieures.

Les renseignements généraux ont été recueillis lors d'études de terrain entreprises en prévision de l'installation de pipelines et de la construction de routes, études effectuées dans le cadre du projet sur le transport dans la vallée du Mackenzie (1971-1973) dirigé par feu O.L. Hughes.

Le bulletin renseigne sur les processus et effets de l'Inlandsis laurentidien du Wisconsinien supérieur dans la région à l'étude et aborde la question des préoccupations liées au développement régional dans une zone pergélisolée.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada

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QUATERNARY GEOLOGY OF THE NORTHEASTERN PART OF THE CENTRAL MACKENZIE VALLEY CORRIDOR, DISTRICT OF MACKENZIE, NORTHWEST TERRITORIES

Abstract

During its maximum extent, the Late Wisconsinan Laurentide Ice Sheet buried the study area under approximately 600 m of ice. The Hyndman and Travaillant uplands were free of ice about 23 ka during Katherine Creek Phase. Series of glacial lakes were formed as the ice retreated southeastward. Glacial Lake Tenlen was the first glacial lake to form after deglaciation of uplands and was followed by glacial Lake Travaillant when ice retreated from the Tutsieta Lake Moraine about 13 ka (Tutsieta Lake Phase). The lake had a series of outlets that migrated from east to west. The last outlet of glacial Lake Travaillant was Mackenzie River. Further ice retreat resulted in the formation of glacial Lake Ontaratue which drained into a late stage of glacial Lake Travaillant and established a permanent channel for Mackenzie River (Ontaratue glacial Lake stage). Glacial Lake Mackenzie, with an outlet at Ramparts, was formed before final deglaciation of the region about 11.5 ka.

The surficial materials in the region are mainly deposits of the Late Wisconsinan Laurentide Ice Sheet. Most of the region is covered by morainic deposits of which a belt of hummocky moraines (Tutsieta Lake Moraine) is the most prominent feature. Moraine plains surfaces have flutings and drumlins indicating that the general direction of ice movement was southeast-northwest. Extensive glaciolacustrine sediments, deltaic deposits, and peat mark the location of former glacial lakes.

The study area is located mainly within the zone of discontinuous permafrost, with the northernmost part lying within the zone of continuous permafrost. Development in this region particularly in the southern areas is constrainted by permafrost conditions. Geomorphic processes take place naturally and continually in terrain affected by permafrost and may damage human-made structures, particularly where human activity exposes the permanently frozen soil to thawing.

Résumé

Lors de son extension maximale, l'Inlandsis laurentidien du Wisconsinien supérieur a enfoui la zone à l'étude sous quelque 600 m de glace. Les hautes terres de Hyndman et de Travaillant étaient libres de glace il y a environ 23 ka, pendant la Phase de Katherine Creek. Une série de lacs glaciaires se sont formés au fur et à mesure que la glace s'est retirée vers le sud-est. Le Lac glaciaire Tenlen s'est formé le premier après la déglaciation des hautes terres. Par la suite, le Lac glaciaire Travaillant été créé lorsque les glaces se sont retirées de la Moraine de Tutsieta Lake il y a quelque 13 ka (Phase de Tutsieta Lake). Le lac avait une série d'exutoires qui se sont déplacés d'est en ouest. Le dernier exutoire du Lac glaciaire Travaillant a été le fleuve Mackenzie. Le retrait plus poussé des glaces a produit le Lac glaciaire Ontaratue qui se déversait dans une phase tardive du Lac glaciaire Travaillant et qui a produit le lit permanent du Mackenzie (phase du Lac glaciaire Ontaratue). Le Lac glaciaire Mackenzie, dont l'exutoire était à Ramparts, s'est formé avant la déglaciation définitive de la région, il y a quelque 11,5 ka.

Les matériaux superficiels de la région sont principalement des dépôts laissés par l'Inlandsis laurentidien du Wisconsinien supérieur. La plus grande partie de la région est couverte de dépôts morainiques dont l'élément le plus proéminent est une ceinture de moraines bosselées (Moraine de Tutsieta Lake). La surface des plaines morainiques est parsemée de cannelures et de drumlins qui indiquent que la direction générale du mouvement des glaces était sud-estnord-est. De vastes étendues de sédiments glaciolacustres, de dépôts deltaïques et de tourbe marquent l'emplacement d'anciens lacs glaciaires.

La région à l'étude se situe principalement dans la zone de pergélisol discontinu, l'extrême nord de la région se trouvant dans la zone de pergélisol continu. La présence de pergélisol limite le développement de la région, particulièrement au sud. Des processus géomorphologiques se poursuivent en permanence dans les terrains pergélisolés et peuvent endommager les structures artificielles, notamment aux endroits où les activités humaines exposent le pergélisol au dégel.

SUMMARY

The study region includes mostly plains and local uplands between Arctic Red River to the southwest and Anderson River to the northeast. Except for landforms resulting from Holocene fluvial activity, all the major landforms of this region are the result of glaciation by the Laurentide Ice Sheet during the Late Wisconsinan. Little evidence of older glaciations was found in the study area, and the glacial deposits are assigned to Late Wisconsinan time; however the study area could have been overridden during pre-Late Wisconsinan glaciations, and evidence for this has been found to the north of the study area (Rampton, 1988).

This report deals with the Quaternary geology, general stratigraphy, and geotechnical and economic aspects of the Northern Interior Plains region of the Northwest Territories. It includes parts of the Peel Plain in the southwest and Anderson Plain in the northeast that are divided arbitrarily by Mackenzie River. The accompanying maps cover the northeastern central part of the Mackenzie Transportation Corridor: Arctic Red River (1746A), Travaillant Lake (1747A), Canot Lake (1748A), Fort Good Hope (1741A), and Ontaratue River (1742A).

The main surficial categories are:

a) Till deposits cover 80 per cent of the area; they consist of sediments with 5-20 per cent granule size and larger in a silty clay or clayey silt matrix. The till of rolling moraine may be coarser and include small areas of unmapped kame gravel. Higher relief forms typically consist of glacial till with 20-60 per cent granule size and larger, and includes small areas with much higher proportions of kame gravels.

b) Glaciolacustrine deposits cover 10 per cent of the area; they consist of 3-30 m thick, ice-rich silt, clay, and minor sand. Poor drainage results in the development of peatlands and fenlands with intermittent seepage along depressions.

c) Glaciofluvial, deltaic, and fluvial deposits cover 4 per cent of the area; glaciofluvial deposits consist mainly of sand and gravel, locally with a veneer of eolian silt or sand. Silt and/or peat can be present as filling in channels. The deltaic deposits consist mainly of fine sand and silt and commonly overlie glaciolacustrine silt and clay. The alluvial deposits along high energy streams consist of medium to coarse sand and gravel with a veneer of silty overbank sediments. Sediments along low energy streams such as Mackenzie River are mainly silt and fine grained sand up to 5 m thick.

d) Organic deposits cover 5 per cent of the area; organic deposits are most common on till, silt, and clay of glaciolacustrine plains of the Ontaratue lowland. Organic units of the area have been separated into

SOMMAIRE

La région à l'étude comprend principalement des plaines et des hautes terres locales entre la rivière Arctic Red au sud-ouest et la rivière Anderson au nord-est. À l'exception des reliefs résultant de l'activité fluviale à l'Holocène, tous les reliefs de cette région sont le produit de la glaciation par l'Inlandsis laurentidien au Wisconsinien supérieur. On a trouvé très peu de traces de glaciations antérieures, et tous les dépôts glaciaires sont attribués au Wisconsinien supérieur. Toutefois, la région a peut-être été touchée par des glaciations antérieures au Wisconsinien supérieur, comme on a pu le constater au nord de la région à l'étude (Rampton, 1988).

Le présent rapport porte sur la géologie et la stratigraphie générale du Quaternaire et les aspects géotechniques et économiques de la région des Plaines intérieures septentrionales des Territoires du Nord-Ouest. Cela comprend des parties de la plaine de Peel au sud-ouest et de la plaine d'Anderson au nord-est que divise arbitrairement le Mackenzie. Les cartes ci-jointes couvrent la partie nord-est centrale du couloir de circulation du Mackenzie : rivière Arctic Red (1746A), lac Travaillant (1747A), lac Canot (1748A), Fort Good Hope (1741A) et rivière Ontaratue (1742A).

Les principales catégories de dépôts superficiels sont les suivantes :

a) Les dépôts de till couvrent plus de 80 pour cent de la région; ils se composent principalement de 5 à 20 pour cent de matériaux de la taille des granules ou plus grand dans une matrice d'argile silteux ou de silt argileux. Le till des moraines ondulées peut être plus grossier et contenir de petites zones de graviers de kame non cartographié. Habituellement, les reliefs les plus élevés comportent du till glaciaire contenant entre 20 et 60 pour cent de matériaux de la taille des granules ou plus grand, avec de petites zones ayant des proportions beaucoup élevées de graviers de kame.

b) Les dépôts glaciolacustres couvrent 10 pour cent de la région; ils comportent du silt, de l'argile et un peu de sable riches en glace, dont l'épaisseur varie de 3 à 30 m. Du fait du mauvais écoulement, on y trouve des tourbières et des tourbières minérotrophes, avec des écoulements intermittents suivant les dépressions.

c) Les dépôts fluvioglaciaires, deltaïques et fluviatiles couvrent 4 pour cent de la région. Les dépôts fluvioglaciaires comportent principalement du sable et du gravier avec, localement, un placage de silt ou de sable éoliens. Du silt, de la tourbe ou les deux comblent parfois les chenaux. Les dépôts deltaïques sont surtout du sable fin et du silt qui recouvrent fréquemment du limon et de l'argile glaciolacustres. Les dépôts alluviaux le long de cours d'eau à haute énergie se composent de gravier et de sable moyen à grossier, avec un placage de sédiments silteux d'inondation. Le long des cours d'eau à faible énergie, comme le Mackenzie, il y a surtout du silt et du sable fin dont l'épaisseur atteint parfois 5 m.

d) Les dépôts organiques couvrent 5 pour cent de la région; ils sont particulièrement communs sur les tills, les silts et les argiles des plaines glaciolacustres des basses terres de l'Ontaratue. Les unités organiques de la région sont divisées

two types: 1) peatland (permanently frozen bog) and 2) fenland (wetlands). Peatland vegetation is typically lichen, sphagnum, and heathy shrubs with less than 20 per cent black spruce; fenlands consist mainly of moss, sedge, and heathy shrubs.

e) Slope deposits cover 1 per cent of the area; slope deposits are not widespread in the study area as a dominant unit, although they commonly are minor components of the surficial materials, particularly where they are associated with morainic deposits. These deposits are usually shown as a complex unit that may also include alluvial fans and landslide deposits too small to be mapped as a separate unit.

Mapping of the surficial deposits within and outside of the area has led to recognition of ice marginal positions that mark the limits of significant readvances of the Laurentide Ice Sheet during its retreat from its maximum position. Two successive readvances named the Katherine Creek Phase and the Tutsieta Phase can be recognized over much of the western District of Mackenzie. During deglaciation several extensive glacial lakes formed and were named after the main lakes that occupy the Tenlen, Travaillant, and Ontaratue lake basins.

The present lower course of Mackenzie River was established as a result of a pattern of deglaciation and formation of successive glacial lakes and interconnecting outlets between Grand View hills and Travailant and Iroquois uplands. Lower Mackenzie River was formed when the ice retreated from the uplands and the Tutsieta Lake Phase moraine belt that bordered them. Mackenzie River evolved as an outlet of glacial Lake Travaillant, followed by the formation of glacial lake Ontaratue and Mackenzie.

Paleosurfaces and drainage patterns show that the preglacial regional landscape was quite different from present drainage patterns. The latter are a complex of preglacial and interglacial drainage patterns modified significantly by meltwater channels and drainage established in the Holocene following deglaciation. Segments of valleys that reflect drainage south, in particular Mackenzie River, imply the possibility of subparallel drainages that followed the regional slope towards the east and northeast.

The study area is located mainly within the zone of discontinuous permafrost, with the northernmost part lying within the zone of continuous permafrost. In addition to the constraints imposed on development by terrain conditions in southern areas, significant additional constraints are imposed by permafrost conditions. Geomorphic processes prevalent in permafrost regions (slope failures, differential subsidence, and accelerated hydraulic erosion) can be severely damaging to man-made structures. These processes take place naturally

en deux catégories : 1) les tourbières (marais gelés en permanence) et 2) les tourbières minérotrophes (terres humides). La végétation des tourbières comporte des lichens, des sphaignes et des arbustes genre bruyère avec moins de 20 pour cent d'épinette noire; les tourbières minérotrophes renferment surtout des mousses, des carex et des arbustes genre bruyère.

e) Les dépôts de pente couvrent 1 pour cent de la région; ils constituent rarement une unité dominante dans la région à l'étude, mais ils peuvent être assez souvent un constituant mineur des matériaux superficiels, notamment lorsqu'ils sont associés à des dépôts morainiques. Ils sont habituellement représentés comme faisant partie d'une unité complexe qui peut aussi comprendre des cônes alluviaux et des dépôts de glissement trop petits pour être cartographiés séparément.

La cartographie des dépôts superficiels, dans la région et à l'extérieur, a conduit à reconnaître les positions du front glaciaire qui marquent les limites des réavancées importantes de l'Inlandsis laurentidien pendant son retrait. Dans une grande partie de l'ouest du District du Mackenzie, on peut reconnaître deux réavancées successives, la Phase de Katherine Creek et la Phase de Tutsieta. Pendant la déglaciation, plusieurs grands lacs glaciaires se sont formés, tirant leurs noms des lacs principaux qui occupent les bassins des lacs Tenlen, Travaillant et Ontaratue.

Le cours inférieur actuel du Mackenzie résulte de la déglaciation et de la formation de lacs glaciaires successifs et d'exutoires reliés entre les collines Grand View et les hautes terres de Travaillant et d'Iroquois. Le cours inférieur du Mackenzie s'est formé lorsque les glaces se sont retirées des hautes terres et de la ceinture de moraines de la Phase de Tutsieta Lake qui les bordait. Le Mackenzie a débuté comme exutoire du Lac glaciaire Travaillant, puis a évolué à partir des lacs glaciaires Ontaratue et Mackenzie.

Les paléosurfaces et le tracé du réseau hydrographique montrent que le paysage régional préglaciaire était très différent du paysage actuel. Le réseau hydrographique actuel est un complexe de réseaux hydrographiques préglaciaires et interglaciaires, largement modifiés par les chenaux d'eau de fonte et le réseau hydrographique établis à l'Holocène après la déglaciation. Des segments de vallée qui reflètent un écoulement vers le sud, en particulier le fleuve Mackenzie, semblent indiquer la possibilité de réseaux hydrographiques subparallèles qui longeaient la pente régionale vers l'est et le nord-est.

La région à l'étude se situe principalement dans la zone de pergélisol discontinu, l'extrême nord de la région se trouvant dans la zone de pergélisol continu. Aux contraintes que le terrain impose au développement dans le sud s'ajoutent les contraintes provenant du pergélisol. Les processus géomorphologiques qui prévalent dans les terrains pergélisolés (glissements de talus, subsidence différentielle et érosion hydraulique accélérée) peuvent endommager gravement les structures artificielles. Ces processus and continually, but the rate of the processes and resulting damage to structures can be greatly increased by human activity that exposes the permanently frozen soil to thawing.

Extensive areas of sand for fill occur in deltaic sediments and alluvial plains. Less extensive areas of sand and/or gravel are available in glaciofluvial plain and complexes. These areas also offer good construction sites except where the units grade into glaciolacustrine deposits; here the surface deposit is typically sand rather than gravel and may be underlain by ice-rich till.

sont naturels et constants, mais leur vitesse et les dommages qui en résultent peuvent être considérablement accrus par les activités humaines qui exposent le pergélisol au dégel.

Les sédiments deltaïques et les plaines alluviales renferment de vastes zones de sable utilisable comme remblais. Il y a aussi des dépôts plus restreints de sable et de gravier dans les plaines et complexes fluvioglaciaires. Ces endroits constituent de bonnes zones de construction, sauf lorsque les unités passent à des dépôts glaciolacustres; à ces endroits, les dépôts superficiels sont généralement du sable plutôt que du gravier, et au-dessous il peut y avoir du till riche en glace.

INTRODUCTION

Systematic mapping of the surficial geology of the area was begun in 1968 by R.J. Fulton as part of Operation Norman of Geological Survey of Canada (Fulton, 1970). Discovery of oil at Prudhoe Bay, Alaska in 1969 was followed quickly by proposals for both oil and gas pipelines that would be routed along the Beaufort Sea coast and up Mackenzie Valley, following what has since become known as the Mackenzie Transportation Corridor. The pipeline proposals, and a subsequent proposal for a Mackenzie Valley Highway, created an immediate need to map and characterize the terrain of the corridor as a basis for both engineering and environmental planning. Photo interpretative surficial geology maps with limited ground control, including the map areas of the present study, were prepared by Hughes and others during the period 1971-1973 (Hughes et al., 1972a, b; Hanley et al., 1975) and a terrain evaluation, including evaluation of engineering and environmental hazards and specific recommendations for pipeline routing were prepared by Hughes et al. (1973). Vegetation and soils of the area, and their relationship to the mapped surficial geology units, were studied by Zoltai and Pettapiece (1973) in conjunction with the mapping of the surficial geology.

Revision of the maps covering approximately 216 000 km^2 was begun by Duk-Rodkin in 1986, including 45 000 km^2 of previously unmapped terrain. This revision involved complete re-examination of the original photo interpretation, and the use of additional ground control and geotechnical data from proposed routes of oil and gas pipelines and the Mackenzie Valley Highway. The present report refers to the maps covering northeastern central part of the Mackenzie Transportation Corridor (Fig. 1) – Arctic Red River (1746A), Travaillant Lake (1747A), Canot Lake (1748A), Fort Good Hope (1741A), and Ontaratue River (1742A).

Access

From the beginning of the fur trade until the completion of Dempster Highway in 1972, the two communities of the area, Fort Good Hope in the southeast and Arctic Red River in the northwest, were served by traffic on Mackenzie River. Northern Transportation Company Limited continues to operate tugs and barges on the river, and truck lines that serve Inuvik also serve Arctic Red River. Both communities are served by light aircraft. The numerous lakes of the area also provide access by float-equipped aircraft. Both helicopters and fixed-wing aircraft can be chartered in Norman Wells and Inuvik.

Vegetation and soils

The most common mature plant community of the area is black spruce-lichen forest developed on imperfectly drained soils on moraine plains, drumlinoid till plains, glaciolacustrine plains, and rolling moraine (Table 1). White spruce-lichen woodland occurs on well drained sites and is found mainly on glaciofluvial deposits and some south- and southwest-facing scarps in bedrock. Open stands of white spruce occur on floodplains that receive increments of alluvial sediments during occasional floods. These stands, the largest of which occur on floodplains of Mackenzie River, are dependent on flooding for their survival. The accumulation of sediments and of sphagnum moss would otherwise restrict the thickness of the active layer and lead to death of the trees (Zoltai and Pettapiece, 1973). Fire disturbance is so prevalent in the area that most stands are at various stages of second growth and mature forests occupy only a small part of the remaining area.

Thin eutric brunisols occur in the best drained sites within the area (gravelly glaciofluvial deposits, hummocky moraine), but turbic cryosols are by far the most common soil type of the region. Earth hummocks, commonly 40-50 cm high (and exceptionally 80-100 m high) occur throughout the area on glacial, glaciolacustrine, and other deposits with a moderate to high silt content. The hummocks are formed by soil displacement through cryostatic pressure. The process is still active, as shown by leaning trees ("drunken forest") on hummocks (Zoltai and Pettapiece, 1973).

Climate

The study area is located in the boreal climatic region of Canada (Hare and Thomas, 1974) and is mostly covered by forest tundra. The climate is characterized by long, very cold winters and generally cool summers, although short periods with temperatures 25°C or higher occur most summers (Fletcher and Young, 1978). A combination of short summer storms and dry-hot days can cause forest fires.

Acknowledgments

During the course of revising Open File maps of the Mackenzie Corridor, valuable stratigraphic information was provided by R.J. Fulton, J.A. Pilon, D.A. Hodgson, and various oil companies that conducted exploration in this region. Valuable comments were given by R.W. Klassen and R.J. Fulton who critically reviewed this report. D.S. Lemmen deserves special mention for his help in editing this report. J. Bond's drawing abilities and understanding of ice movements are demonstrated in block diagrams and figures. T. Robertson provided capable assistance in computer generated figures.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The study area is in the Northern Interior Plains region and comprises parts of the Peel Plain in the southwest and Anderson Plain in the northeast that are divided arbitrarily by Mackenzie River. Several smaller physiographic features have been identified in the area and named after

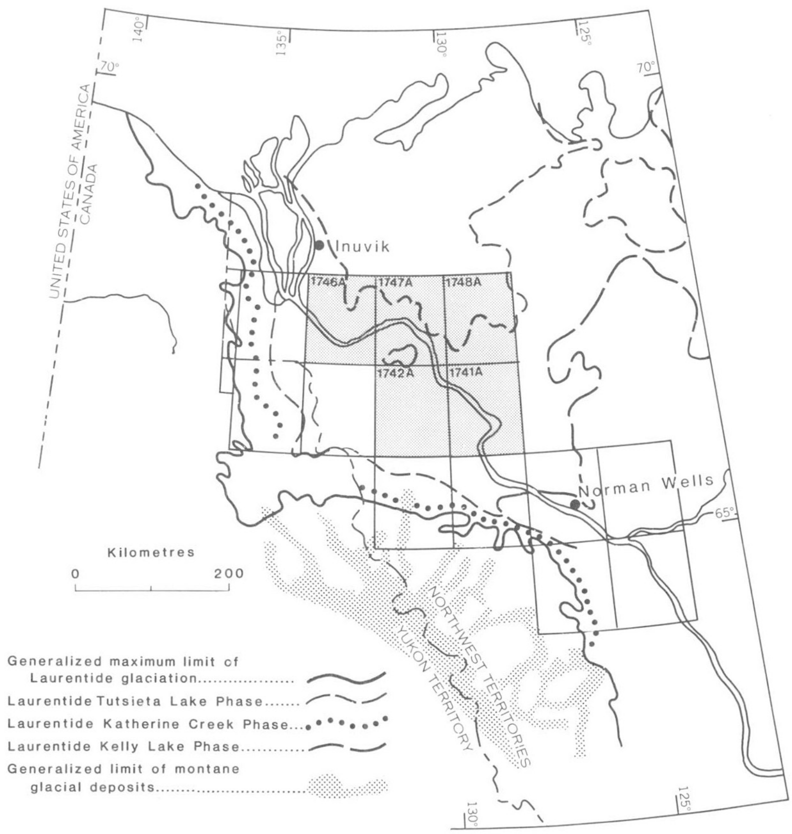


Figure 1.

Location map showing the study area in dark grey.

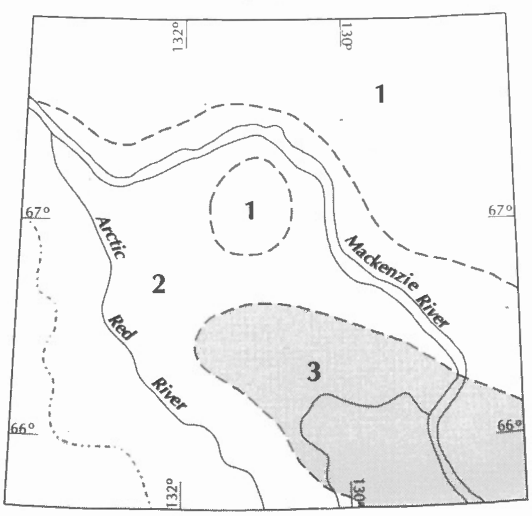
Table 1. Vegetation associated with surficial geology units (after Zoltai and Pettapiece, 1973).

Map Unit[1]	Land Zone[2]	Vegetation[4] Stable	Vegetation[4] After Fire	Occurrence[3]
O	0			
	1.1 m	Cx-Cott. or Cx-Bi-tL	Cx-Cott.	1
	2.2 m	Cx-Cott. or Cx-Bi-tL		2
	3	Cx-Cott. or Cx-Bi-tL		2
pO	0	Lichen-Sphagnum	Sphagnum-Er	1
	1.1 m	Lichen-bS	Sphagnum-Er	1
	2.2 m	Lichen-bS	Sphagnum	2
	3	Lichen-bS	Sphagnum-Er	2
Ag HES		Occasionally flooded	Frequently* flooded	
	0	Wi	Bare	1
	1.1 m	Wi-Al	Bare	1
	2.2 m	Wi-Al	Bare	1
	3	bPo-Al-Wi	Bare	1
Ap LES	0			1
	1	wS Cx-tL	Wi-Al Cx-Wi	1
	2.2 m	wS-bS Cx-tL	Wi-Al Cx-Wi	1
Ap-k	0			
	1	wS wS-bS-lichen Cx-Wi		2
	2	wS wS-bS-lichen Cx-Wi		1
	3	wS wS-bS Cx-tL	wB-bPo-wS bPo-Al Cx-Wi	1
At HES	0	Lichen-Er Cx-Wi Cx	Er Cx-Wi Cx	1
	1.1 m	wS wS-bS-Lichen Cx-Wi	wB-wS Al-Wi Wi-Cx	1
	2.2 m	wS-lichen bS-lichen Cx-Wi	wS-bPo bPo Wi-Al	1
	3	wS wS Cx-tL	wB wB-bS Cx-tL	1
At LES	1 m	bS-tCx tCx-bS	Bi-Wi tCx	1
	1	wS wS-bS-lichen Cx-Wi-bS	wB-wS Al-Wi Wi-Cx	1
	2	wS-bS Cx-tL	Wi-Al Cx-Wi	1
	3			1
Af	0	tCx-Bi tCx-Wi tCx		1
	1	wS wS-bS-lichen Cx-Wi	Wi-Al Wi-Al Cx-Wi	1
	1 m	wS-wB bS-lichen Wi	Wi-Al Wi-Al Wi	1
	2.2 m	bS-wB bS-tCx tCx-bS	wB-Al tCx tCx	1
Cx		South aspect	North aspect*	
	0			1
	1.1 m	Bare Grass=wB bS-lichen	Cx wS-lichen wS-bS-lichen	1
	2.2 m	Bare tA-wS-wB bS-lichen	Cx bS-lichen bS-lichen	1
	3	Grass tA-wB-wS bS-wS	Wi-Al bS-wS bS-lichen	1
Cv	0	Cx Cott.-tCx tCx-sphagnum		2
Lp	0	bS-tCx bS-Er-tCx	tCx tCx-Wi	1
	1 m	wS-bS-lichen tL-bS-Cx	wB-wS-Wi Cx-Wi-Al	1
	2.2 m	bS-lichen-tCx bS-tL-tCx	wS-wB-Wi tCx-Wi-tL	1
		bS-lichen tL-bS-Cx	bS-lichen tL-Wi-Cx	1
Lp-k				
	1	wS-bS-wB wS-bS-lichen bS-Cx	wS-wB bS-Wi-Al Cx-Wi	2
	1 m	bS-wB bS-tCx bS-tCx	wB-Al tCx tCx	2
	2.2 m	wS-wB-bS bS-lichen-tCx bS-tL-tCx	wS-wB wS-wB-Wi tCx-Wi tCx-Wi-tL	2
	3			
Lx	0			
	1			
	2	bS-lichen bS-tL-Cx	wS-wB-Wi Cx-Wi-tL	1
	3	bS-lichen tL-bS-Cx	bS-wB tL-Wi-Cx	1
Lx-k	0			
	1			
	2	wS-wB-bS bS-lichen bS-tL-Cx	wS-wB wS-wB-Wi Cx-Wi-tL	1
	3	wS-wB bS-lichen tL-bS-Cx	wS-wB wS-wB tL-Wi-Cx	1
Gp	0	Bi Bi-Wi tCx-sphagnum	Cx Wi tCx	1
	1	wS-lichen bS-lichen tL-Bi-Cx	wB-Wi-wS wB-bS-Wi Cx-Bi	1
	2	wS bS-wS-lichen bS-tL-Cx	wS-wB-grass wS-wB-bS Cx-tL	1
	3			
Gt	0			
	1		-	
	2	wS=wB bS-wS-lichen bS-tL-Cx	wS-wB-grass wS-wB-bS Cx-tL	1
	3			
Gh Gr	0	Lichen-Bi tCx	Bare tCx	1
	1	wS-wB bS-wS	wB-wS-grass wB-wS-bS	1
	2	wS bS-wS-lichen	wS-wB-grass wS-wB-bS	1
Mp Mv Mpv	0	Cott.-tCx tCx-sphagnum		1
	1	wS-lichen bS-wS-lichen tL-bS-Cx	wB-wS wB-wS-Wi Cx-Al-Wi	3
	2	bS-wS-wB bS-lichen tL-bS-Cx-Al	wS-wB-bS wS-wB-Wi Cx-Al	3
	3	wS-bS-bPo bS-lichen tL-bS-Cx	wB-wS-Al BS tL-Wi-Cx	2
Md	0	Cx tCx-sphagnum		1
	1	wS-lichen bS-wS-lichen tL-bS-Cx	wB-wS wB-wS-Wi Cx-Al-Wi	1
	2	bS-wS-wB bS-lichen bS-tL-Cx	wS-wB-bS wS-wB-Wi Cx-tL	1
	3	wS-wB-bPo bS-lichen tL-bS-Cx	wB-wS-Al bS tL-Wi-Cx	1
Mm	mmm0	Cott.-tCx tCx-sphagnum		1
	1	wS-lichen bS-wS-lichen tL-bS-Cx	wB-wS wB-wS wB-wS-Wi Cx-Al-Wi	2
	2	bS-wS-wB bS-lichen bS-tL-Cx	wS-wB-bS wS-wB-Wi Cx-tL	1
	3			
Mh Mr	0	Bi-Cx Cott.-tCx tCx-sphagnum		1
	1	wS-lichen bS-wS-lichen tL-bS-Cx	wB-wS wB-wS-Wi-Al Cx-Al-Wi	1
	2	wS-wB-bS bS-lichen bS-tL-Cx	wS-wB wS-wB-Wi Cx-tL	1
	3			

[1]See legend Map 1741A, 1742A, 1746A, 1747A, 1748A for description of geological units
[2]See Figure A
[3]Occurrence
1 = minor (less than 5% of zone)
2 = common (5% to 20% of zone)
3 = major (greater than 20% of zone)
[4]Vegetation (Data compiled by S.C. Zotial)
bS–black spruce (*Picea mariana*)
wS–white spruce (*Picea glauca*)
wB–white birch (Betula neoalaskana)
Bi–dwarf birch (*Betula glandulosa*)
tL–tamarack (*Larix laricina*)
Wi–willow (*Salix* sp.)
Al–alder (*Alnus* sp.)
tA–trembling aspen (*Populus tremuloides*)
bPo–balsam poplar (*Populus balsamifera*)
Cx–sedge (*Carex* sp.)
tCx–sedge tussock (*Carex* sp.)
Cott.–cotton grass (*Eriophorum* sp.)
Lichen–*Cladonia* sp., *Cetraria* sp.
Sphagnum–*Sphagnum* sp.
Er–Ericaceae *Ledum* sp., *Chamaedaphne*, *Kalmia* etc.)
HES–High Energy Streams
LES–Low Energy Streams

*Stable/After fire categories replaced by 'Occasionally flooded/Frequently flooded' for alluvial units, and by 'South aspect/North aspect' for colluvial units

FIGURE A



known geographic features, Iroquois upland, Travaillant upland, Hyndman upland, Grand View hills, and Ontaratue lowland (Fig. 2).

Anderson Plain is developed mainly on flat to gently dipping shale of the lower Devonian Hare Indian Formation and limestone of the Ramparts Formation, with local occurrences of Lower Cretaceous sandstone and shale (Cook and Aitken, 1969; Yorath and Cook, 1981; Fig. 3). The uplands bordering Anderson Plains to the south, including Iroquois upland, are capped by Lower Cretaceous sandstone, with larger valleys incised into the underlying Devonian formations. The northeast corner of the Anderson Plain is developed on grey shale of the Hare Indian Formation, bituminous black shale of the Canol Formation, and siltstone, shale, and sandstone of the Imperial Formation. The western part of Anderson Plain is developed on the Imperial Formation, locally capped by Cretaceous sandstone over the Hyndman and Travaillant uplands and over smaller upland remnants.

Within the study area, Peel Plain is developed entirely on Cretaceous rocks, except for a broad belt bordering Mackenzie River which is underlain by Hare Indian, Canol, and Imperial formations. Although *Grand View hills*[1] have a broad mesa-like form that suggests a resistant capping, the hills and Ontaratue lowland are both developed on the relatively weak concretionary mudstone and siltstone of the Arctic Red River Formation.

SURFICIAL GEOLOGY

The surficial materials in the region are mainly deposits of the Late Wisconsinan Laurentide Ice Sheet (Fig. 4, Maps 1841A, 1842A, 1846A, 1847A, 1848A). The main categories of surficial materials are: a) till deposits that cover 80 per cent of the surface area, b) glaciolacustrine deposits (10%), c) glaciofluvial and fluvial deposits (4%), d) organic deposits (5%), and e) slope deposits (1%). The surficial deposits can be divided into Late Wisconsinan and Holocene age groups.

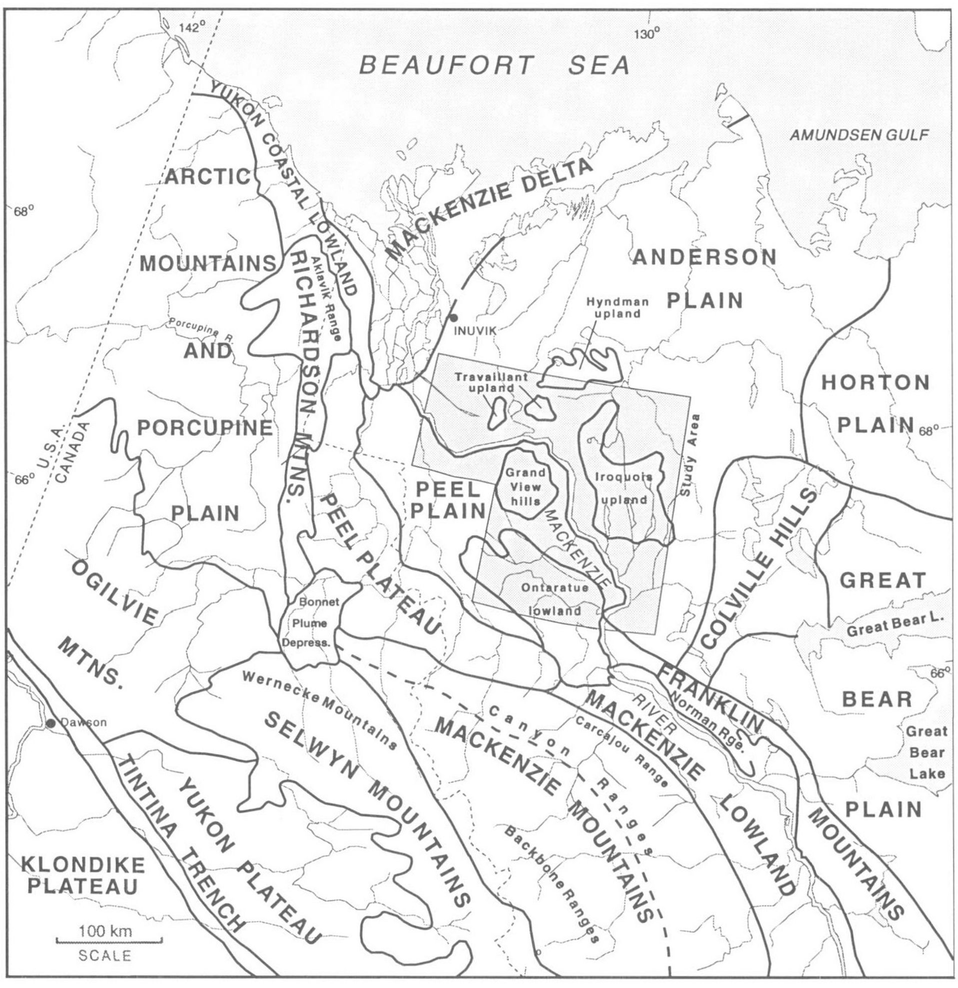


Figure 2. Physiographic map (after Bostock, 1967).

[1] Grand View hills is not an official name

In the accompanying maps, labelling of surficial deposits has been done using upper cases letters for the geological categories (for example, M moraine) and lower case letters for the geomorphic descriptors (for example, p plain, and Mp moraine plain). Combined geological units are used (for example, Mp/Af or MpAf) to indicate percentage of ground coverage per unit. Geological processes are shown (for example, g gullying; Mp-g gullyed moraine plain; Mp-c channelled moraine plain).

Moraine deposits

The glacial deposits, like all other major categories of deposits, except organic (O) and bedrock (R), are subdivided on the basis of landform (see accompanying maps). Landform types include flat to gently irregular till plains (Mp, Mpv), moraine blankets or veneers (Mb, Mv), and drumlinoid till plains (Md, Mvd). More irregular surfaces include rolling moraine (Mm) with intermediate relief to higher relief forms such as hummocky moraine, ridged moraine, and moraine complex (Mh, Mr, Mx).

The low relief forms typically consist of glacial till with 5 to 20 per cent granule size and larger in a silty clay or clayey silt matrix. The till of rolling moraine may be coarser and include small areas of unmapped kame gravel. The higher relief forms typically consist of glacial till with 20 to 60 per cent granule size and larger, and small areas with much higher proportions of kame gravels.

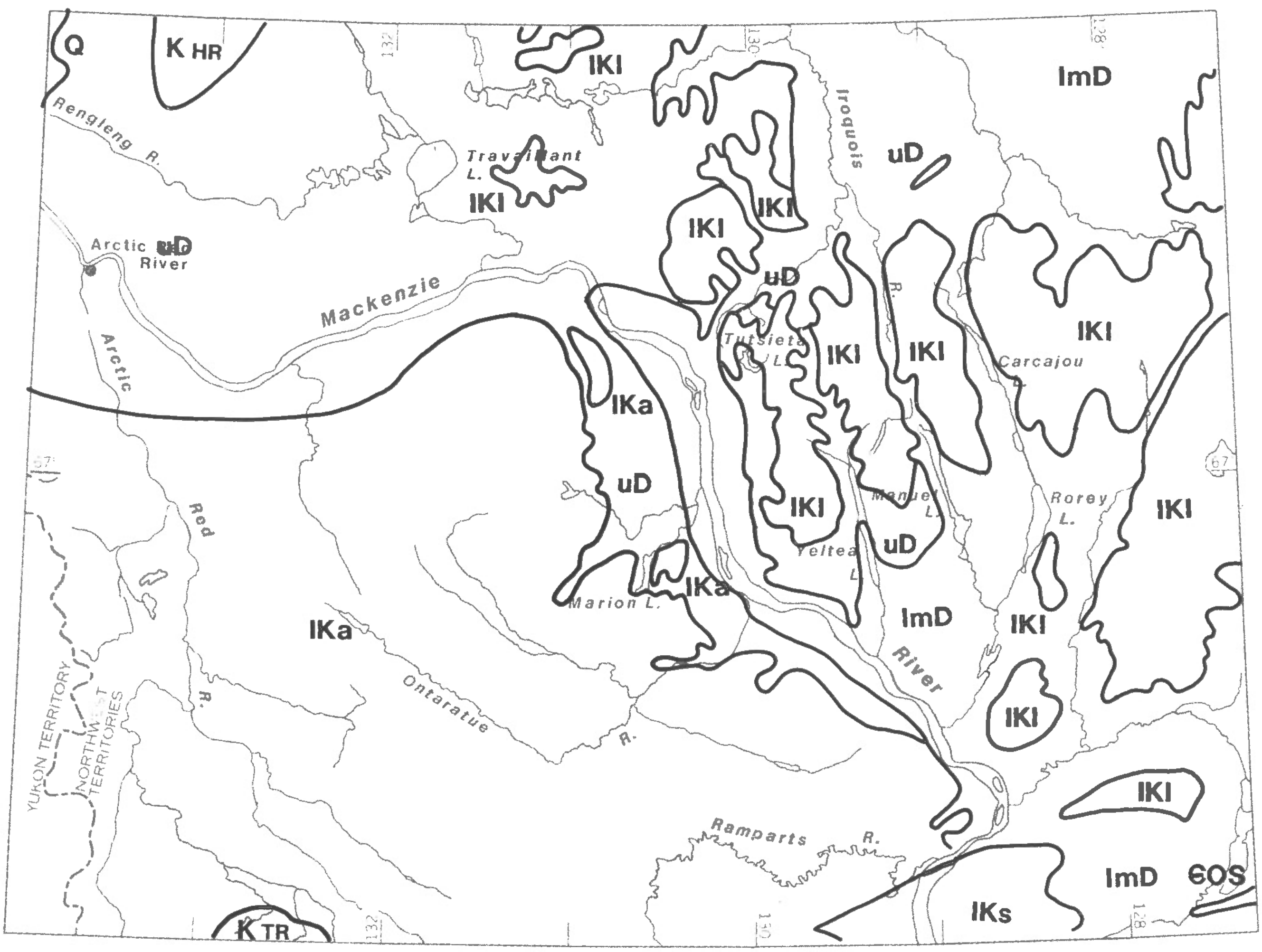


Figure 3. Schematic bedrock map (after Yorath and Cook, 1981). Cretaceous; Lower and Upper Cretaceous: Trevor Formation (sandstone) (KTR); Lower Cretaceous: Sans Sault Formation (sandstone) (lKs); Arctic Red River Formation (lKa); Horton River Formation (shale) (KHR); Langton Bay Formation (sandstone) (lKl). Devonian; Upper Devonian: Canol and Imperial formations (shale) (uD); Lower Devonian: Bear Rock, Hume, Hare Indian, and Ramparts formations (lmD); Mount Clark, Old Fort Island, Mount Cap, Daline River, Franklin Mountain, and Mount Kindle formations and Katherine groups (EOS).

Moraine plain (Mp) and till plain veneer (Mpv)

The moraine plains have flat to gently irregular surfaces that reflect the form and slope of the underlying shale and siltstone of the Devonian Imperial and Cretaceous Arctic Red River formations. Till plains are the most common unit in the area and cover some 4700 km^2. They extend from latitude 66°N to Iroquois upland on the eastern side of the Mackenzie River, and west of the river they form till plains along the north part of Ontaratue lowland that extends westward to Peel River and northward to Rengleng Moraine (Fig. 4). West of Ontaratue River the plains have abundant patches of fenlands and peatlands, with individual patches covering areas up to 380 km^2. The density of these organic patches increases towards Martin House and in the headwaters of Ontaratue lowland region are a dominant map unit. Typically the plains surfaces have abundant black spruce and lichens, but tamarack, alder, and sedge are common (Table 1).

The moraine plains may include individual drumlins or a few subparallel drumlins or flutings, as well as eskers too small to be mapped as glaciofluvial deposits. The otherwise

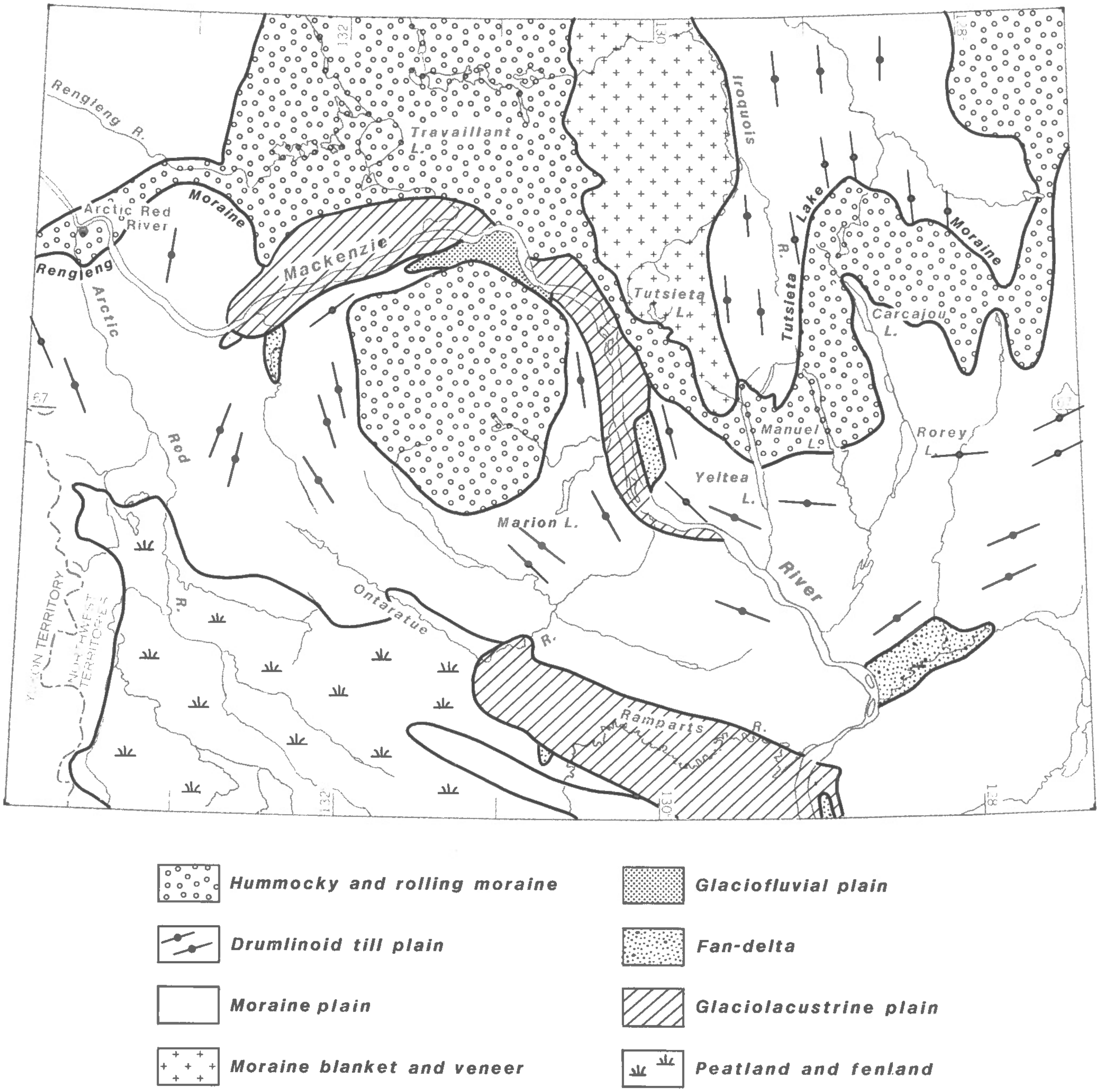


Figure 4. Generalized surficial geology map of the study area and bordering areas.

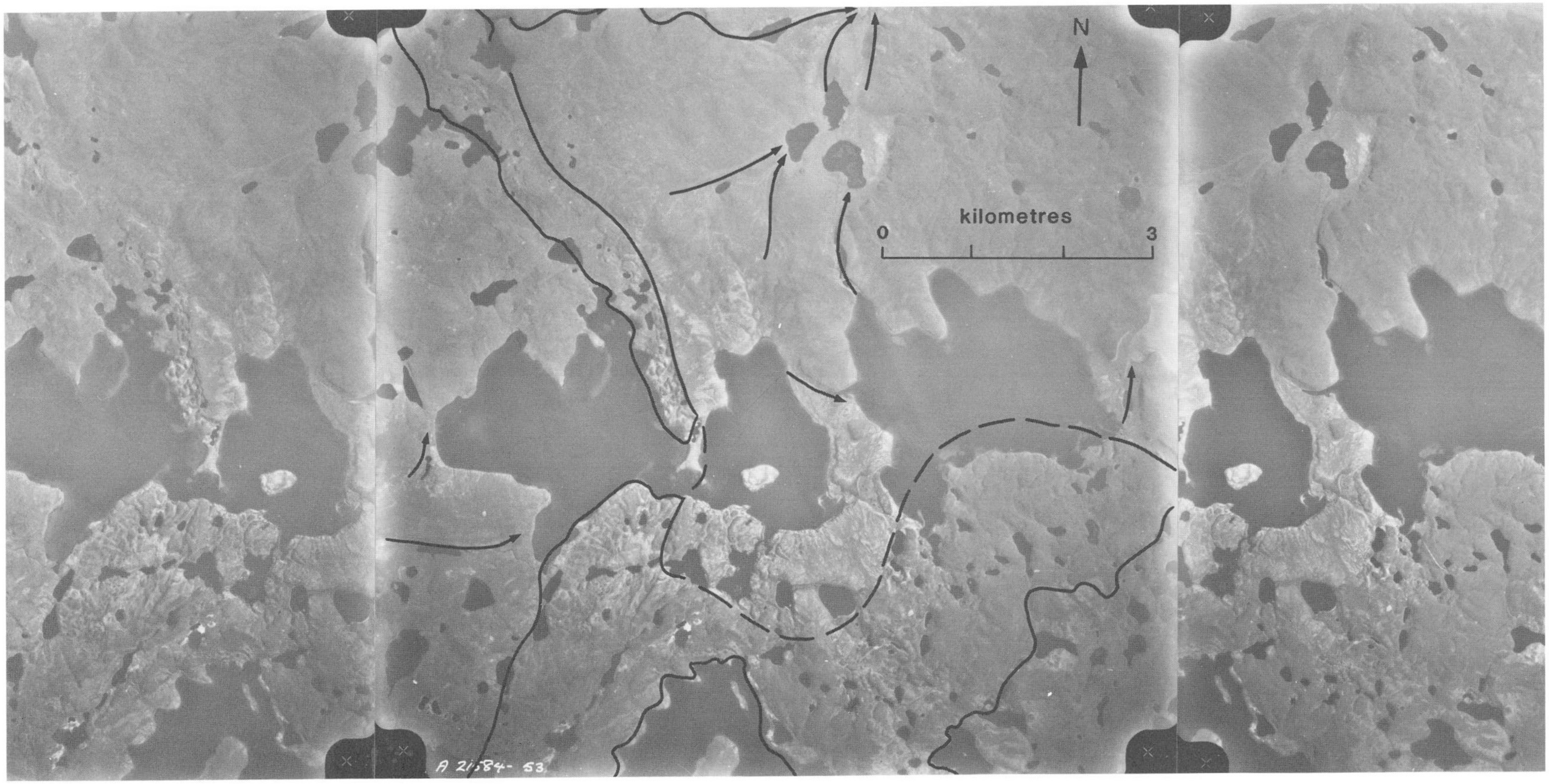


Figure 6a. Stereotriplet showing the ice frontal position for Tutsieta Lake Phase at Bathing, Deep, and Jiggle lakes.

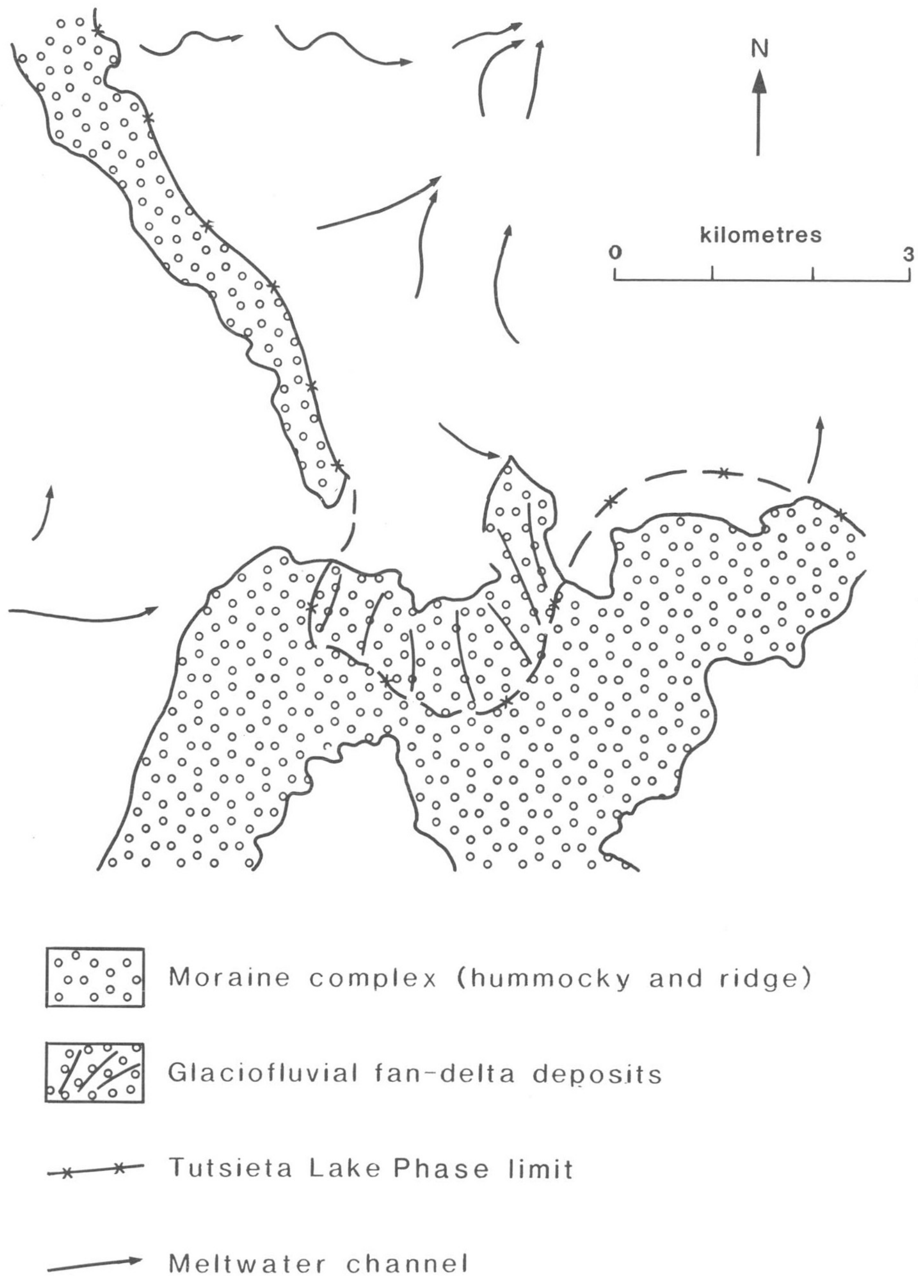


Figure 6b.

Tutsieta Lake Phase glacial limit and deposits.

featureless plains areas are crossed by major and minor meltwater channels with a general southeast-northwest orientation. The best example of moraine plain with drumlinoid patches lies northeast of the Mackenzie River and north of Hare Indian River.

The most extensive area of moraine plain veneer (Mpv) lies along the west side of the Mackenzie River between The Ramparts and Ontaratue River, where thin till (0-2 m) overlies Lower Cretaceous sandstone and shale and siltstone of Devonian Imperial Formation. Another large tract lies on the east side of the river north of Rengleng Moraine (Fig. 4), where the thin till overlies Imperial Formation.

Moraine blanket, veneer (Mb, Mv)

These units differ from moraine plains mainly in being deposited on moderately to steeply sloping bedrock-controlled surfaces rather than generally level plains. Thickness varies from 3-6 m for Mb and 0-2 m for Mv. Surface drainage is therefore better than on the plains and is reflected by the local dominance of white spruce over black spruce, particularly on steeper, south- to southwest-facing slopes.

Drumlinoid till plains (Md, Mvd)

The surface of drumlinoid till plains is characterized by drumlins, crag-and-tail forms, and glacial fluting. Limited data indicate that the till texture is similar to that of Mp and Mv units, except for some unusual hybrid forms found to the east of Rorey Lake. Because of difficult access, these have not been studied on the ground. Landform and vegetation cover, however, suggest that the proximal parts of these forms may be till and the distal parts sand and/or gravel. Common thicknesses for Md units vary from 3-30 m and for Mvd, 1-3 m. Local relief is from a few metres to tens of metres.

Rolling (Mm) and hummocky (Mh) moraines

These types of moraine have rolling (Mm) to hummocky (Mh) topography with up to 50 m of local relief. Rolling moraine topography has broad swales of 10 to 20 m width. Hummocky moraines usually have knolls less than 10 m in diameter. The thickness of drift in both types is up to 20 m. The tops of the hummocks are usually well drained permitting a good tree cover (black and white spruce, tamarack, lichen, and sedge; Table 1). The same can be said about drumlins, however hummocky moraines, which locally can have up to 60 per cent or more of granular material support a denser vegetation cover. Intervening depressions are poorly drained and commonly are occupied by fenlands. The hummocky and rolling moraines (generally in belts) are associated with ice marginal positions in the study region. They cover approximately 25 per cent of the study area, most of which form belts of moraine, 15 to 40 km wide and 125 km long, which mark ice frontal positions of the Laurentide Tutsieta Phase (Fig. 4; 5, in pocket). The belt has a sinuous form that follows the outline of the Iroquois upland, the south part of Travaillant upland, north of Travaillant Lake, south of Jiggle, Deep, and Bathing lakes (Fig. 6a, b), and west of Sandy Lake. North of the Tutsieta Lake moraine belt, hummocky and rolling moraines cover approximately 25 per cent of the area. They dominate areas around a chain of lakes including Tenlen Lake, but they are more subdued than the Tutsieta Lake moraines and were deposited during Katherine Creek Phase. Another moraine belt, about 15 km wide and 115 km long extends in an arc from Big Lake to the village of Arctic Red River (Fig. 4) and thence westward to Peel River. To the northeast of the village, the Mackenzie River forms an anomalous arc that seems to have been caused by the moraine belt. Grand View hills are surrounded and topped by rolling moraines of several deglaciation intervals. The most conspicuous interval is marked by the moraines of Tutsieta Lake Phase because they are accompanied by meltwater channel and segments of moraine ridges.

Moraine ridge (Mr)

Moraines of this type comprise individual or compound ridges (up to 7 km wide) associated with ice marginal positions. Mostly they are too small to form a geological unit at 1:250 000 scale, and therefore are represented in the maps with moraine ridge symbols. These ridges have relief up to 60 m. They have the same textural characteristics (gravelly sandy till) and the same vegetation cover as hummocky moraines. Commonly they constitute the outermost part of moraine complexes of the Tutsieta Lake Moraine. Such a ridge complex can be traced almost continuously for 110 km from north of Manuel Lake, continuing north of Yeltea Lake to Tutsieta Lake, crossing Iroquois River, and continuing north up to Thunder River. They are also common in the periphery of Grand View hills.

Glaciofluvial deposits

The glaciofluvial deposits of the study region can be separated on the basis of landform into glaciofluvial plains and terraces (Gp, Gt) and glaciofluvial kame and esker complexes (Gh, Gr). Vegetation is typically open forest of white and black spruce and tamarack, with ground cover of dwarf birch and lichens. Depressions within esker complexes or kames may be occupied by fenlands (Table 1).

Glaciofluvial plain (Gp)

These surfaces are flat to gently sloping (up to 2°). They range in size from 0.6 km^2 to 100 km^2 (north of Grand View hills). The sediment is sand and gravel, locally with a veneer of eolian silt or sand. Silt and/or peat can be present as channel fill. The thickness of deposits varies from 3-30 m. Small glaciofluvial plains are dispersed throughout the area, generally in association with meltwater channels. Glaciofluvial plains are most common north and east of Mackenzie River and in Grand View hills, where they mark the limit of the Tutsieta Lake Phase.

Typically the glaciofluvial plains are virtually unmodified since their formation, as some parts retain details of original channel patterns, however, a glaciofluvial plain between

Grand View hills and Mackenzie River, which consists mainly of sand, is extensively eroded by modern streams in a dendritic erosion pattern.

Glaciofluvial terrace (Gt)

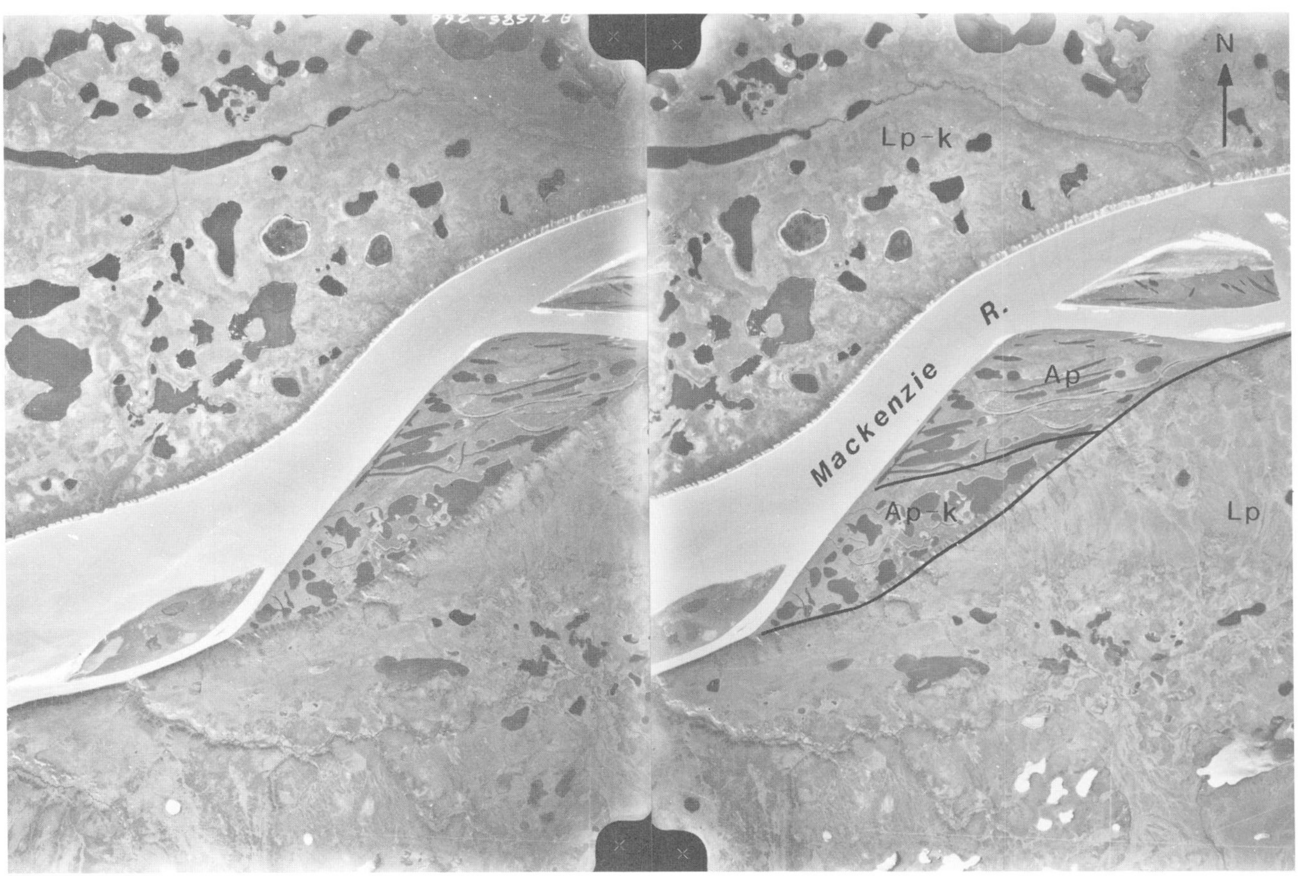
These terraces are associated with Carnwath, Iroquois, and Thunder river systems that were used as meltwater channels during deglaciation. The sediment in this type of glaciofluvial deposit is the same as in glaciofluvial plain areas. The terraces form flat surfaces that range from 0.1 km^2 to 80 km^2 in area. Thickness of deposits vary from 3-30 m. Iroquois River has the most extensive and continuously developed glaciofluvial terraces within a meltwater channel system that headed in the Tutsieta Lake Moraine belt. Like the glaciofluvial plains, the glaciofluvial terraces have undergone little postdepositional modification and some of the surfaces retain original shallow channel systems.

Glaciofluvial deposits-ridged (Gr), hummocky or kettled (Gh)

These deposits include individual esker ridges a few metres wide and up to 4.2 km long, and kame mounds a few square metres to 1.2 km^2. The sediment in this type of deposit is mainly gravel and less sand. Thickness of sediments in both deposits varies from 3-20 m. The main difference between them is topography; deposit characteristics are the same. Locally they form complex areas up to 30 km^2 of irregular topography that combines ridges, mounds, and small flat surfaces (Gx). Deposits of this type are ice-contact glaciofluvial, hence are mostly associated with the Tutsieta Lake Phase moraine belt (Fig. 6).

Glaciolacustrine deposits

The glaciolacustrine deposits comprise mainly glaciolacustrine plain (Lp), with a few patches of shoreline deposits (Ls) in southern Ontaratue map area (Map 1742A). The glaciolacustrine plains are typically flat to gently undulating, commonly with numerous shallow thermokarst lakes and ponds (Lp-k) (Fig. 7, 8). The 3-30 m thick material is ice-rich silt,



Mp	Glaciolacustrine plain	Lp-k	Thermokarst glaciolacustrine plain
Ap	Alluvial plain	Ap-k	Thermokarst alluvial plain

Figure 7. *Thermokarst glaciolacustrine and alluvial plain. Mackenzie River 10 km west of Trading Post.*

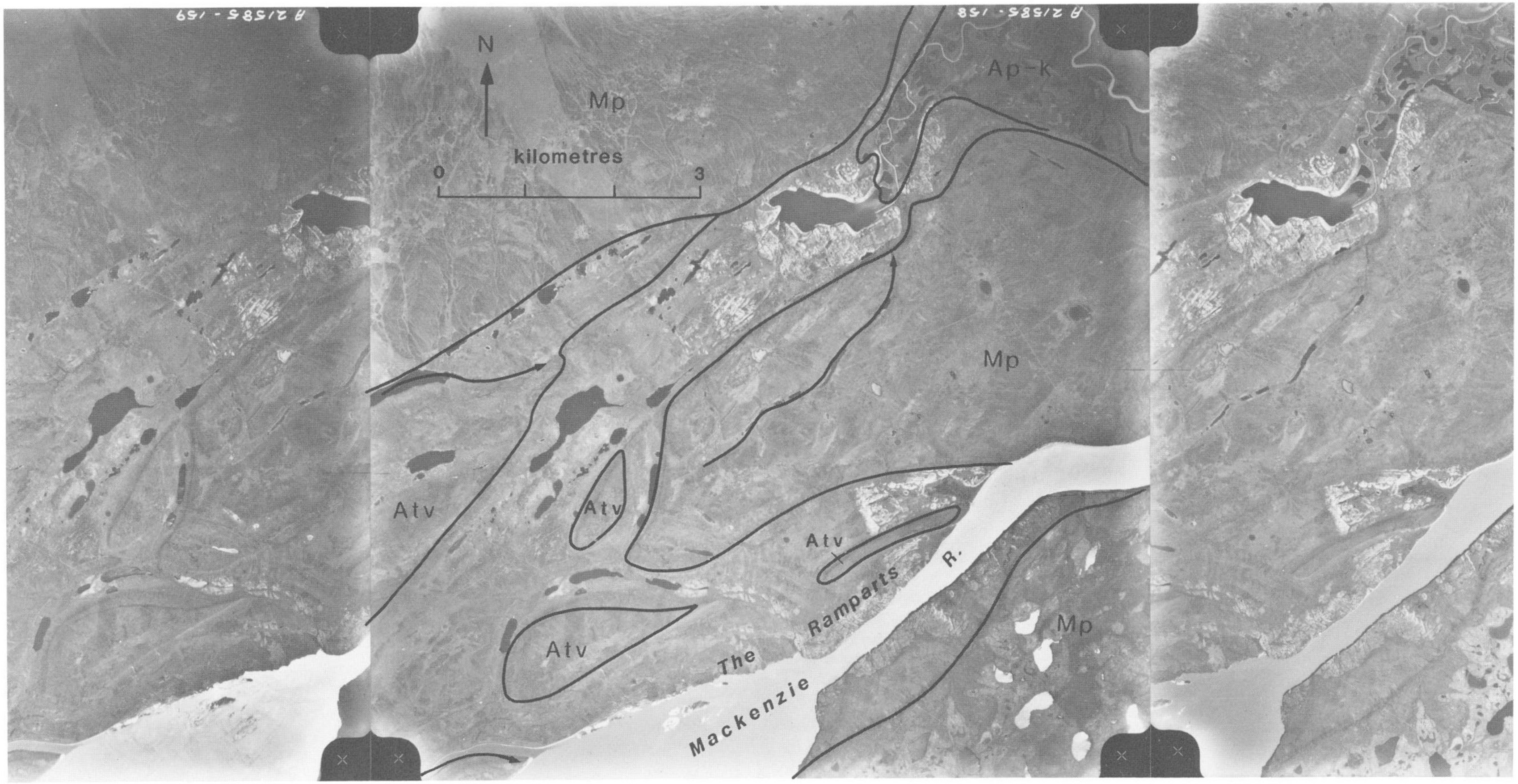


Figure 8a. *Stereotriplet showing outlets of glacial Lake Mackenzie at The Ramparts, Mackenzie River.*

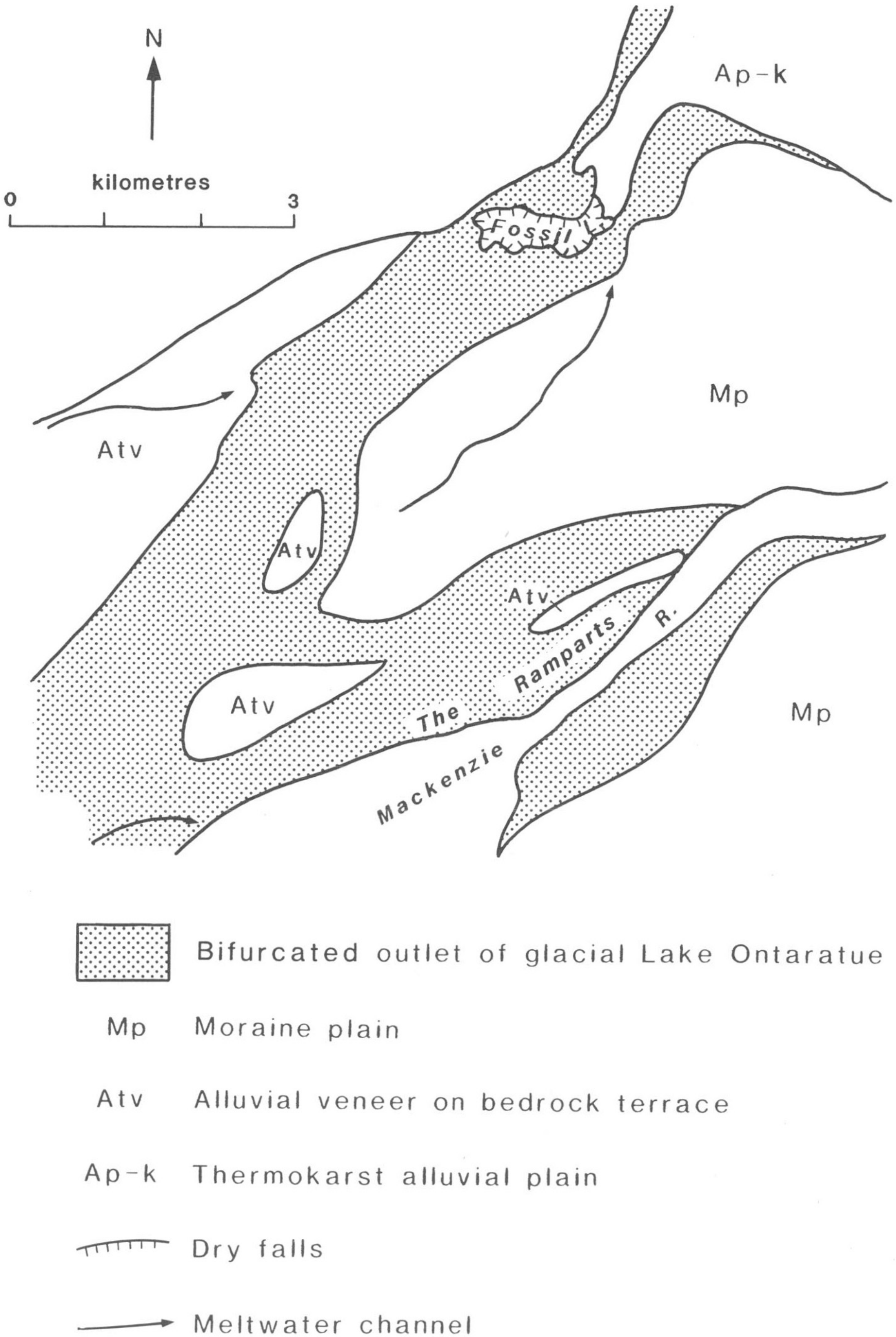


Figure 8b.

Interpretation of stereotriplet shown in Figure 8a.

clay, and minor sand. It is poorly drained terrain which results in the development of peatlands and intermittent seepage along depressions (fenlands). Peat surfaces can be several metres thick and they are best developed on flat glaciolacustrine surfaces with permafrost about 0.5 m below the surface. Fenlands are developed on unfrozen ground during the summer. Thermokarst topography generally occurs in association with discontinuous cover of peat. Thermokarst topography appears to be best developed in flat parts of glaciolacustrine plain which is underlain by thick glaciolacustrine silt and clay with no sand cover or with relatively thin sand cover less than 5 m. Typical vegetation cover is sparse forest of black and white spruce, white birch, and tamarack with ground cover of lichens and sedge (Table 1).

There are two main areas of glaciolacustrine plain in the region, corresponding to two glacial lakes: a) along the Mackenzie River (glacial Lake Travaillant), and b) the Ontaratue lowland (glacial Lake Ontaratue). The first has an approximate area of 1600 km^2 and the second, 2900 km^2.

Transitional glaciofluvial-glaciolacustrine deposits

These deposits (Lx) are transitional between glaciofluvial and glaciolacustrine deposits and form the distal parts of glaciofluvial fans-deltas that were built mainly into glacial lakes Ontaratue and Travaillant. The sediments are mostly fine sand and silt and commonly overlie glaciolacustrine silt and clay. The sand commonly was reworked by former southeasterly winds into stabilized parabolic dunes. The vegetation in these areas is sparse forest of spruce and tamarack with a ground cover of lichens, and minor sedge in depressions (Table 1).

Lacustrine complex deposits were built into the western part of glacial Lake Travaillant at a stage when the lake was no longer dammed by ice, and discharged along the present day Mackenzie River (Fig. 4). The lake level was controlled by a channel passing through the Rengleng Moraine (Fig. 4) at the village of Arctic Red River. At about the same time, another area of lacustrine complex was built into the southeastern extremity of the glacial lake, along the eastern side of Mackenzie River. Another lacustrine complex was deposited in glacial Lake Ontaratue during earlier stages of the glacial lake and late stages of glacial Lake Travaillant, west of Ramparts River (Fig. 4). Sediment was supplied by a system of meltwater channels that earlier had carried meltwater to Arctic Red River. A much larger lacustrine complex was deposited into glacial Lake Mackenzie during its early stages by Hare Indian and Mackenzie rivers. It drained northward into a remnant of glacial Lake Travaillant. The area forms the distal part of Mountain River fan-delta (the largest such complex anywhere in the Mackenzie River valley) and Hare Indian River fan-delta.

Alluvial deposits

The alluvial deposits of the region are flat to very gently sloping surfaces associated with rivers and streams. Four types of landforms are recognized: alluvial plain (Ap), alluvial terrace (At), alluvial terrace veneer (Atv), and alluvial fan (Af).

Alluvial plain (Ap)

The deposits along high energy streams consist of medium- to coarse-grained sand and gravel with a veneer of silty overbank sediments. Sediments along low energy streams such as Mackenzie River are mainly silt and fine grained sand up to 5 m or more thick. The fine grained sediments commonly contain a high proportion of segregated ice and the alluvial plains are marked with numerous thermokarst ponds and lakes (Ap-k) (Fig. 7). The most extensive alluvial plain, about 90 km^2 in area, borders the west side of the Mackenzie River, north of the mouth of Ontaratue River (Map 1747A). Parts of the alluvial plains with shifting channels have a cover of willow, poplar, and alder. The more stable parts are covered by forests of white and black spruce and tamarack (Table 1).

Alluvial terrace (At)

Alluvial terraces are present along scattered parts of the Mackenzie, Iroquois, Ontaratue, and Hume rivers. Smaller terraces have been lumped together with flood plains (Apt) along Hare Indian, and Tree rivers. Successions of terraces ranging from glaciofluvial to low alluvial terraces occur only along Iroquois River. Mackenzie River, despite its great size, has remarkably little development of alluvial terraces. This implies that the deep entrenchment of the river between Arctic Red River and The Ramparts took place rapidly, allowing little time for development of alluvial plains above modern river level that would be seen today as terraces. Indeed, there is very limited development of modern floodplains along this reach of the river, a clear indication of its youth. Well developed terraces can be found along lower Ontaratue River. They extend along the entrenched valley for 25 km and they cover an area of 15 km^2.

At The Ramparts, where Mackenzie River was maintained at successive levels above the modern gradient by the resistant Ramparts Formation, there is an extensive area (about 62 km^2) of terraces and channels. These surfaces, mapped as Atv, have a discontinuous veneer of up to 2 m of sand and silt that may be underlain by gravel (Fig. 8).

Typical vegetation cover of the alluvial terraces consists of white and black spruce, willow, sedge, and lichens (Table 1).

Alluvial fan (Af)

Alluvial fans are present in the study area at the foothills of Grand View hills, Travaillant and Iroquois uplands, along the tributaries of Iroquois River, and as a complex slope unit along the slopes of the Mackenzie River (Cx).

Alluvial fans consist of highly variable material, mainly silt, sand, and minor gravel. They have gently to moderate sloping surfaces (1-6°) marked by channels formed by shifting streams, subject to sudden floods with damaging effects.

Organic deposits

Organic deposits form a dominant unit over approximately 5 per cent of the study area, but they are secondary components within extensive parts of Mp, Mpv, Md, Lp, and Lp-k. Although found in the entire region, these deposits are most common on till and silt and clay of glaciolacustrine plains of the Ontaratue lowland. Organic units of the area have been differentiated into two types: peatland (pO) and fenland (fO) (Table 1). Peatland in the study area is a permanently frozen bog that raises above the level of surrounding wetland and receives only rain water. Fenland is wetlands located in the depressions allowing seepage water to drain downslope. Fenland is not frozen below the active layer in the study area.

Peatland (pO) and thermokarst peatland (pO-k)

Peatland of the area typically comprises sedge and woody sedge peat overlain by sphagnum peat, with a maximum aggregate thickness of 4 m. Three types of peat landforms were identified in the area: peat plateau, palsas, and peat polygon areas (Zoltai and Pettapiece, 1973). Peat is the dominant deposit within an area of about 1500 km^2, mainly in Ontaratue lowland, but discontinuous patches are widespread within other surficial geology units, particularly till plains and drumlinoid till plains as a secondary element (less than 50%). The vegetation of peatlands is typically lichen, sphagnum, and heathy shrubs with less than 20 per cent black spruce (Table 1). Much of the peatland of the area has numerous ponds and wet depressions (pO-k).

Fenland (fO)

Fenland occupies shallow depressions mainly within areas of till and glaciolacustrine plains (Fig. 9). They are flat to gently sloping, and drain by slow downslope seepage. Some areas of fenland within the study area have a reticulate network of low ridges up to 50 cm high formed by moss, sedge, and heathy shrubs (Table 1). Fenlands range in area from a few square metres to an area of 350 km^2 northwest of Ontaratue basin.

Slope deposits

Slope deposits are not widespread in the study area as a dominant unit, although they commonly are minor components of the surficial materials, particularly where they are associated with morainic deposits. These types of deposits are usually shown as a complex unit that may also include alluvial fans and landslide deposits (Cx) too small to be mapped as a separate unit (Cz).

Colluvial veneer (Cv) and blanket (Cb)

Colluvial veneer (Cv) and blanket (Cb) are derived from rock detritus and surficial deposits transported by gravity. The deposits reflect the bedrock topography and occur mainly at the base of the slopes, valley walls, and scarps. The thickness of deposits varies from veneers (less than 2 m) to blankets (>2 m). These units generally overlie impermeable bedrock and high ice content is therefore possible.

Figure 9.

Fenland with reticulate network of low ridges, Ontaratue map area. (ISPG 320-1)

Sheetwash deposit (Ca)

Sheetwash deposits of mostly silt and sand occur as a veneer or blanket on gently sloping surfaces usually developed on glaciolacustrine sediments or soft bedrock. They are commonly poorly drained and most likely they have high ice content because of their composition.

Landslide (Cz)

Landslides are common on glaciolacustrine sediments in the form of retrogressive thaw-flow slides and in shale as rotational slumps because of the high ice content and poor drainage associated with these deposits. Retrogressive thaw-flow slides are commonly less than 45 000 m^2 in area and they are abundant on glaciolacustrine plains bordering the Mackenzie River (Fig. 10).

Figure 10. *Retrogressive thaw-flow slides on glaciolacustrine sediments, north bank of Mackenzie River, 34 km east of Arctic Red River village. (ISPG 4090-1)*

QUATERNARY HISTORY

The study region covers mostly plains areas and local uplands between Arctic Red River to the southwest and Anderson River to the northeast. Except for landforms resulting from Holocene fluvial activity, all the major landforms of this region are the result of glaciation by the Laurentide Ice Sheet during the Late Wisconsinan. The study area was overridden during pre-Late Wisconsinan glaciations; evidence for this has been found to the north (Rampton, 1988) and west (Hughes et al., 1981) of the study area, however, little evidence of older glaciations was found in the study area, and the glacial deposits are assigned to Late Wisconsinan time.

Mapping of the surficial deposits within and outside of the area has led to recognition of ice marginal positions that mark the limits of significant readvances of the Laurentide Ice Sheet during its retreat from the Laurentide maximum position. Two successive readvances named the Katherine Creek Phase and the Tutsieta Lake Phase (Hughes, 1987; Duk-Rodkin and Hughes, 1991; Fig. 5 this report) can be recognized over much of the western District of Mackenzie. During deglaciation several extensive glacial lakes formed and were named after the main lakes that occupy the Tenlen, Travaillant, and Ontaratue lake basins.

Late Wisconsinan limit (maximum glaciation)

During Late Wisconsinan time, the Laurentide Ice Sheet occupied the region including the lower Mackenzie River valley, and adjacent parts of the Mackenzie and Richardson mountains. The ice stream that occupied this region was the Mackenzie Lobe (Dyke and Prest, 1987), with a sublobe extending into the Bonnet Plume Depression (Fig. 2). During this period (ca. 30 ka BP) the Laurentide ice reached its all-time limit (Fig. 5). The ice sheet diverted the drainage from Mackenzie Mountains, together with drainage from Ogilvie Mountains (Peel and Porcupine rivers) and the drainage of eastern Richardson Mountains, towards northwestern Yukon and into the Yukon River drainage basin. Deeply incised channels that carried diverted mountain waters from Thundercloud Range at latitude 62°10′ in southern Mackenzie Mountains have been traced for some 800 km to Bonnet Plume Depression. The diverted drainage flowed into a glacial lake herein referred to as Lake Hughes, that was formed when the Ice Sheet blocked the drainage of Peel River and drainage of southern Richardson Mountains and northern Wernecke Mountains to Bonnet Plume Depression (Fig. 11). Most of the drainage from Mackenzie-Wernecke mountains drained into south Bonnet Plume Depression subglacially as shown by well defined, short but deeply encised channels indicating that connecting channels drained supraglacially. Drainage from southern Richardson Mountains followed the edge of the ice draining through ice marginal channels and a western tributary of Doll Creek. An ice tongue of the Laurentide Ice Sheet occupied the Doll Creek tributary damming a small glacial lake with an outlet that follows modern Canyon Creek westward to Eagle River discharge channel (Fig. 5).

Glacial Lake Hughes had several different outlets that were formed as the ice advanced and retreat from Bonnet Plume Depression being Eagle River discharge channel the main outlet that exited drainage to Porcupine River basin. Most of the outlets were occupied for a short period of time considering the size of the secondary outlets in comparison to Eagle River discharge channel (Fig. 5).

Eastern drainage of Richardson Mountains was diverted westward across the continental divide, through Rock River, by way of McDougall Pass and several small channels. Paleo-Porcupine River drained across Richardson Mountains and into the Mackenzie Delta area (Hughes, 1972; Duk-Rodkin and Hughes, 1994). A tongue of Laurentide ice extended into McDougall Pass blocking eastward drainage of Porcupine River and diverting Porcupine River drainage westward (Fig. 5). Diverted drainage caused the inundation of Bell, Bluefish, and Old Crow basins and established a new channel at The Ramparts to Yukon River. Lake level in basins reached a maximum elevation of about 360 m forming glacial Lake Old Crow that covered approximately 13 000 km^2 and it was in contact with the ice at McDougall Pass for less than 2 km (Lemmen et al., 1994). After the ice retreat from McDougall Pass area the outlet at The Ramparts had cut below the postglacial level (315 m) and the diversion was permanent. Porcupine River is incised about 60 m below the general level of the former glacial Lake Old Crow.

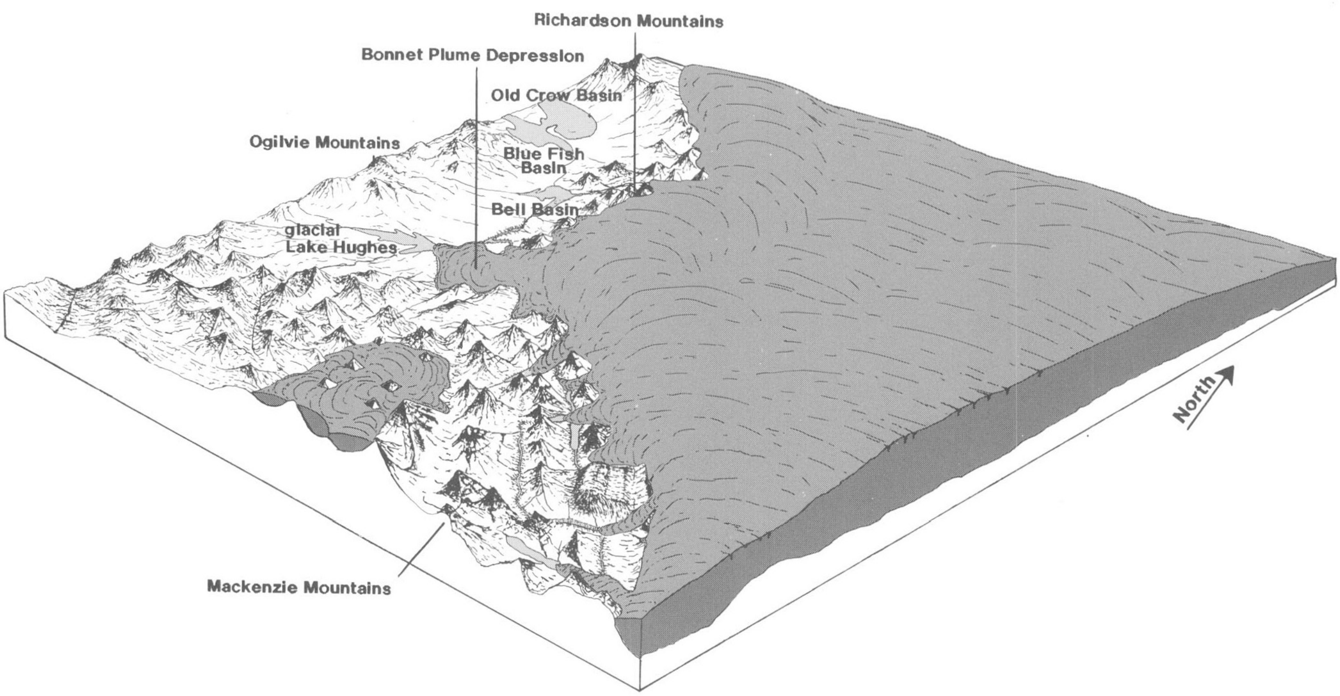


Figure 11. Block diagram depicting the Laurentide Ice Sheet maximum.

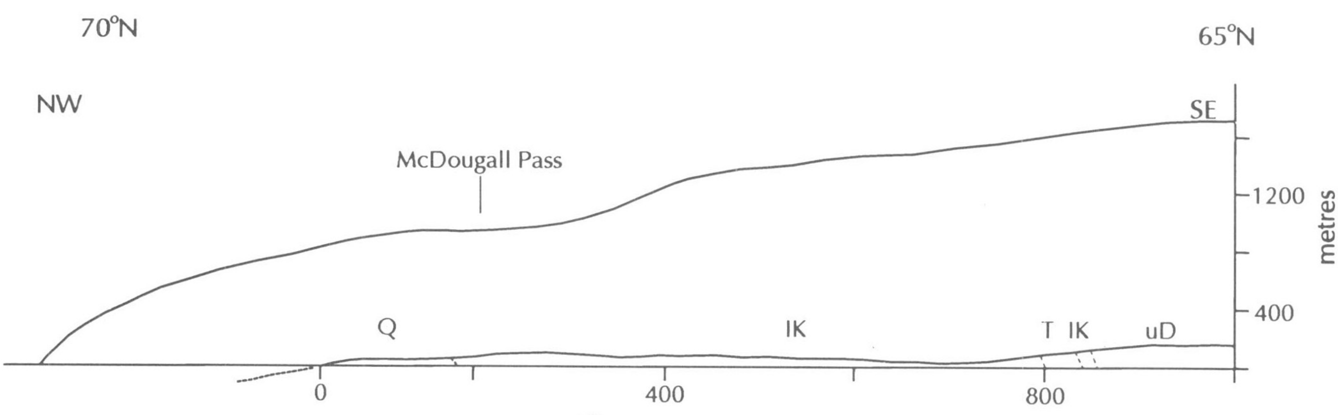


Figure 12. Longitudinal cross-section of the Laurentide Ice Sheet from 65° N (SE) to Herschel Island (NW).

During this stage, the Laurentide Ice Sheet covered Peel Plateau and Peel and Anderson plains. The ice surface was high enough (830 m) at McDougall Pass to have covered Anderson Plains to the coast (Fig. 12). The highest uplands in the study area, Hyndman upland and Grand View hills, both with highest elevations of 495 m, were submerged beneath several hundred metres of ice.

As the ice retreated from its maximum position along Richardson Mountains, local drainage together with meltwater drained along the retreating ice margin and incised meltwater channels along the eastern slopes of the mountains and adjacent Peel Plateau (Fig. 5). Two major retreatal positions, Katherine Creek Phase and Tutsieta Lake Phase (Fig. 5), are marked by meltwater channels and discontinuous moraine belts along the eastern slopes of Richardson Mountains. Ice marginal features that mark the maximum and the two readvances phases of the ice sheet where it impinged against Mackenzie and Richardson mountains, were used to reconstruct ice sheet profiles for the three different levels (Fig. 13). The smoothness of the respective glacial profiles obtained by plotting individual ice-marginal features validates the inferred ice frontal positions. The deflection on the Laurentide maximum profile (broken line, Fig. 13) corresponds to glacial features that were left by the ice where a lobe extended into Bonnet Plume Depression. During Katherine Creek Phase, the deflection indicated in the ice profile was less conspicuous because the lobe was less extensive. During Tutsieta Lake Phase the ice did not extend into Bonnet Plume Depression, so no deflection is seen on the profile of the ice. The Laurentide Ice Sheet had similar low profiles during Laurentide maximum and the Tutsieta Lake Phase but had a somewhat steeper profile during the Katherine Creek Phase (Fig. 13 and 14).

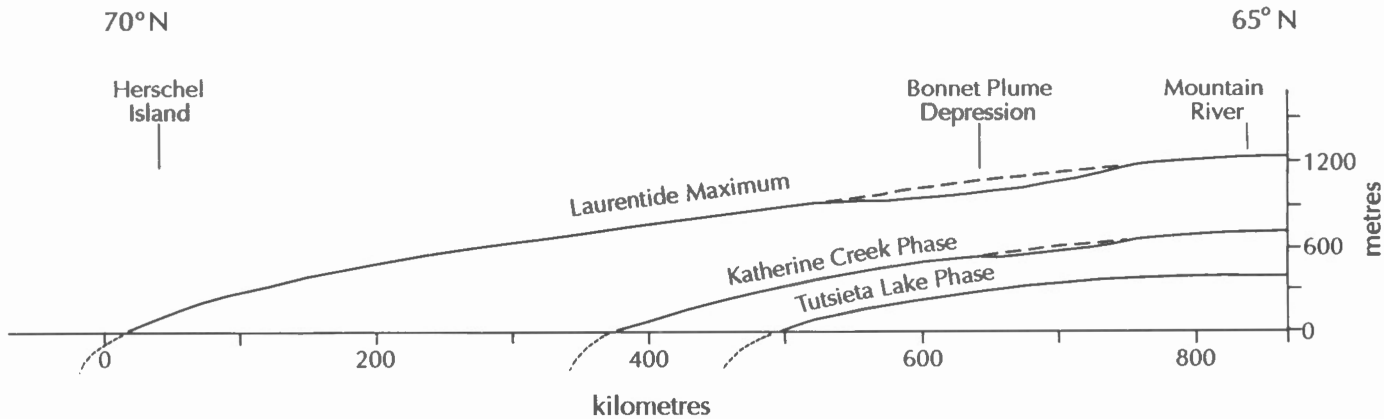


Figure 13. Reconstructed profiles of the Laurentide Ice Sheet for maximum, Katherine Creek, and Tutsieta Lake positions based on elevations of moraines, ice-marginal channels, and glacial erratics from the Canadian Shield.

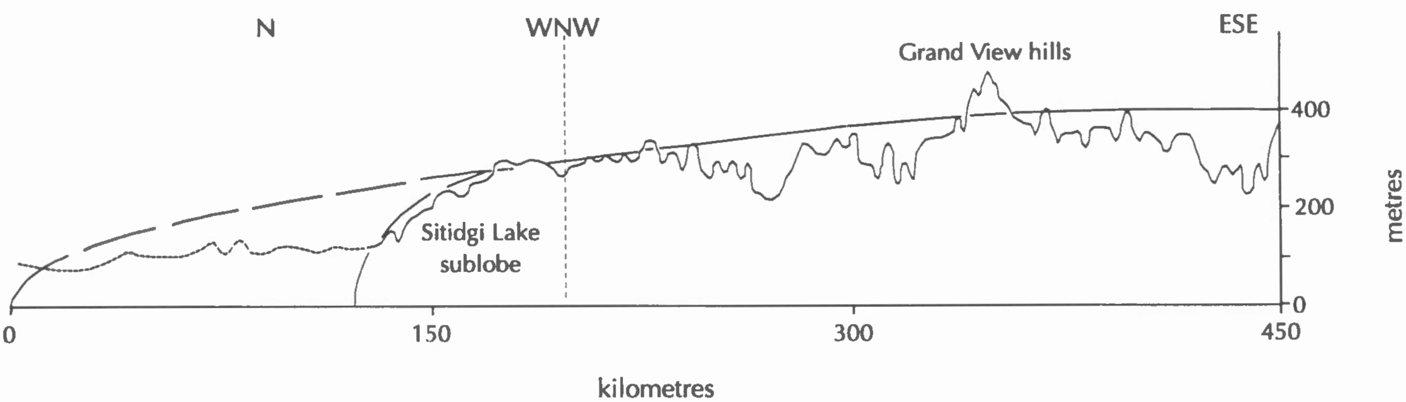


Figure 14. Reconstructed profile of the northeast side of the Mackenzie lobe of the Laurentide Ice Sheet during Tutsieta Lake Phase; based on elevations of moraines and ice-marginal channels; position of Sitidgi sublobe based on Rampton (1988).

Katherine Creek Phase

The limit of Katherine Creek Phase is marked by a system of moraines and meltwater channels that lie about 180 m below the maximum elevation reached by of the Laurentide Ice Sheet at Katherine Creek in the Canyon Ranges of the Mackenzie Mountains, 64°56′N, 127°34′W (Duk-Rodkin and Hughes, 1991). In Peel Plateau, bordering Richardson Mountains an ice marginal position marked by a major meltwater channel system that lies about 270 m below the Laurentide maximum is considered to be correlative with Katherine Creek Phase. The channel is presently occupied by parts of Vitrekwa River, Stony Creek River, and Rat River (Map 1745A, Duk-Rodkin and Hughes, 1992b). Part of this channel was recognized by Catto (1986) as the result of a still stand of the Laurentide Ice Sheet, however it extends some 70 km farther south than he proposed. This channel system can be traced as a continuous feature from Rat River (east of McDougall Pass) to Vetrekwa River for approximately 100 km. South of Vitrekwa River in the Richardson Mountains, Katherine Creek Phase is marked by moraine ridges and segments of Road, Trail, and Caribou rivers (Fig. 5). These segments are marked by conspicuous bends in the middle reaches of each river indicating deflection of drainage along the ice margin. Katherine Creek Phase has been recognized by Duk-Rodkin and Hughes (1991) as a regional readvance of the Laurentide Ice Sheet. Evidence of this readvance has been found at four localities within the Mackenzie Mountains and channels related to this phase can be traced as far south as North Nahani River, latitude 62°35′N. Katherine Creek Phase was synchronous with the maximum extention of the Late Wisconsinan montane glaciation in the Mackenzie Mountains, Gayna River Glaciation (Duk-Rodkin and Hughes, 1991, 1992a).

The projection of the Katherine Creek profile northward beyond McDougall Pass is continuous with the profile of ice marginal features of the Sabine Phase (Rampton, 1982).

During Katherine Creek Phase the entire study area was covered by Laurentide ice, except possibly the highest part of Hyndman upland (Fig. 5, 15a). Ice marginal features contouring the northwest side of the upland at 335 m, if correlative with Katherine Creek Phase, would indicate that a small area of the upland stood above the ice as a nunatak.

Retreat from Katherine Creek Maximum

Within the study area, the first retreatal feature to develop was Kugaluk meltwater channel. The channel extended southward as the reentrant between ice streams migrated southward due to parting of the Mackenzie Lobe (Dyke and Prest, 1987; Fig. 15a). Hyndman upland was deglaciated progressively as the northwesterly flowing ice stream retreated (Fig. 15b). At least four major channels carried meltwater across the upland, and elongate lakes occupy segments of the channels today. These channels are too small to shown in the diagrams but are visible in Figure 5.

With further retreat, a shallow glacial lake, glacial Lake Tenlen with an outlet to Kugaluk channel (Fig. 15b) was impounded in the depression between Hyndman, Iroquois, and Travaillant uplands. During deglaciation of Iroquois and Travaillant uplands, meltwater discharged into glacial Lake Tenlen along channels incised into the uplands (see Map 1747A for distribution of glacial lake sediments and fan-deltas). When the lower reaches of Iroquois River became ice-free, partial drainage of the eastern part of the depression was re-established along a tributary of Iroquois River, and the western part of the basin along a tributary of Kugaluk River. The remnants of glacial Lake Tenlen consist of a chain of interconnected lakes, including Tenlen Lake.

For certain meltwater channels, it is uncertain whether they were initiated during retreat from Katherine Creek maximum, and re-occupied during Tutsieta Lake Phase readvance or were formed during the maximum of Tutsieta Lake Phase. The largest of these channels begins north of Thunder River and drains northward to a tributary of Iroquois River (Fig. 5). The southernmost part of the channel formerly drained to Thunder River, but was captured by the northward drainage during downcutting of the channel (Fig. 5).

The most extensive drumlinoid till plain, in the northeastern part of the study area north of Iroquois Upland, records northerly and northwesterly ice flow during Katherine Creek Phase. The drumlinoid pattern is truncated to the south by a belt of rolling to hummocky moraine that was deposited during the Tutsieta Lake Phase (map 1748A).

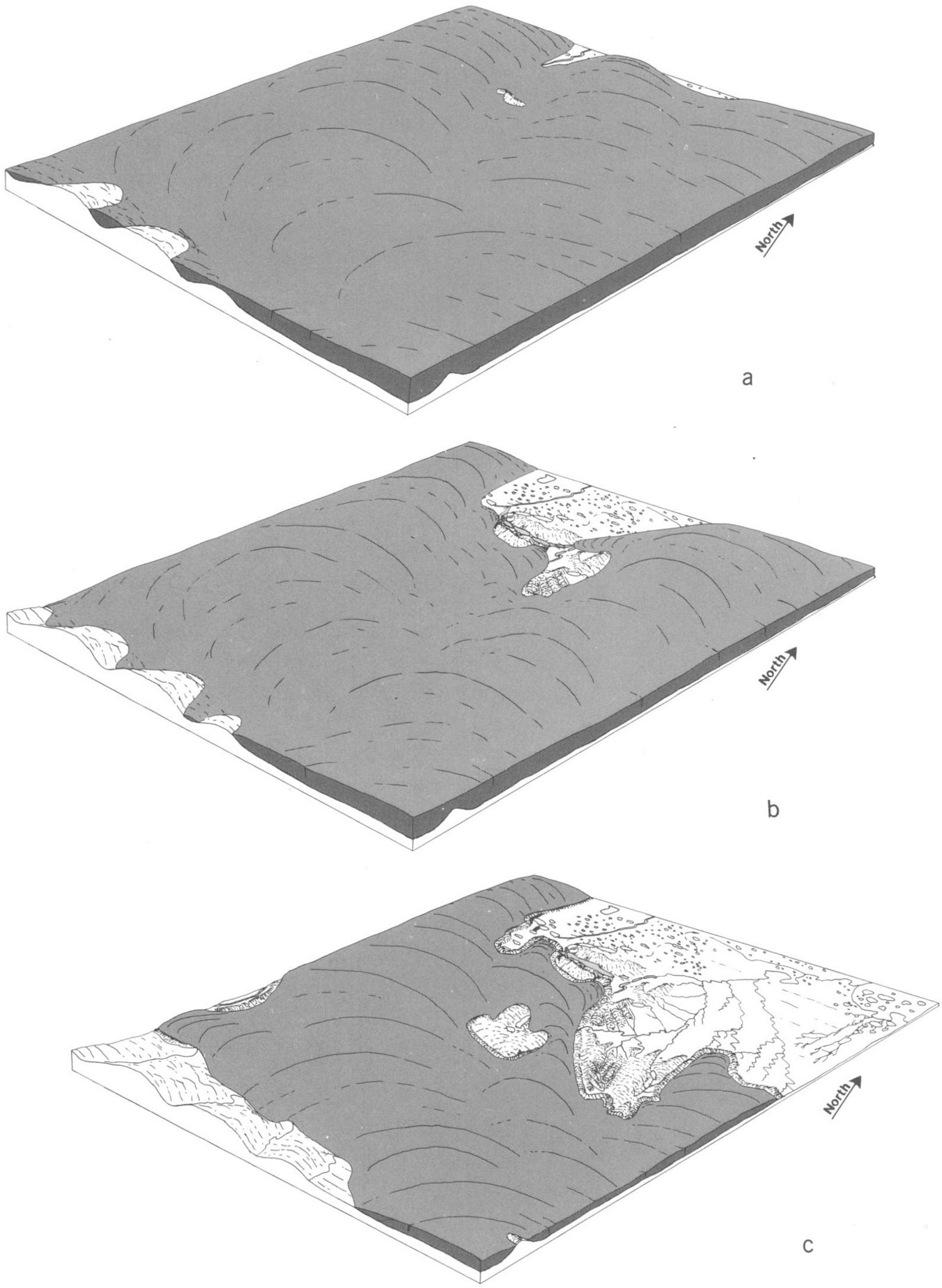
Tutsieta Lake Phase

A readvance of the Laurentide Ice Sheet following retreat of unknown magnitude from the Katherine Creek Phase was named the Tutsieta Lake Phase (Hughes, 1987). The eastern limit of readvance is marked by distinctive moraines and meltwater channels (Fig. 15c) east of Mackenzie River. The western limit along Peel Plateau is marked by a major meltwater channel, now occupied by Peel River north of Caribou River, and further south and by a moraine complex 2 to 8 km west of Peel River near the confluence with Snake River (Fig. 5, Map 1744A, Duk-Rodkin and Hughes, 1992d). The limit of Tutsieta Lake Phase where Peel Plateau extends eastward along the Mackenzie Mountain foothills is defined by discontinuous moraines, Snake River valley, and by major ice-marginal channels along which Arctic Red, Cranswick, Ramparts, and Hume rivers were diverted westward (Fig. 5).

Moraines of the Tutsieta Lake maximum within the study area form a broad moraine belt 15 km or more wide in the Carcajou Lake area and a single ridge west of Tutsieta Lake (Map 1747A). In the vicinity of Bathing and Deep lakes (Fig. 6, 16, Map 1746A), a complex of moraines and glacial fluvial deposits defines a re-entrant in the ice between a tongue of ice that moved northward across Travaillant Lake depression, and ice that splayed eastward from a sublobe that extended into Sitidgi lowland. The numerous large lakes are all impounded by moraines and/or glaciofluvial deposits.

In the eastern part of the study area, meltwater discharged northward along pre-existing channels that were mostly initiated during Katherine Creek Phase. A channel headed about 13 km northwest of Tutsieta Lake, and drained into a major

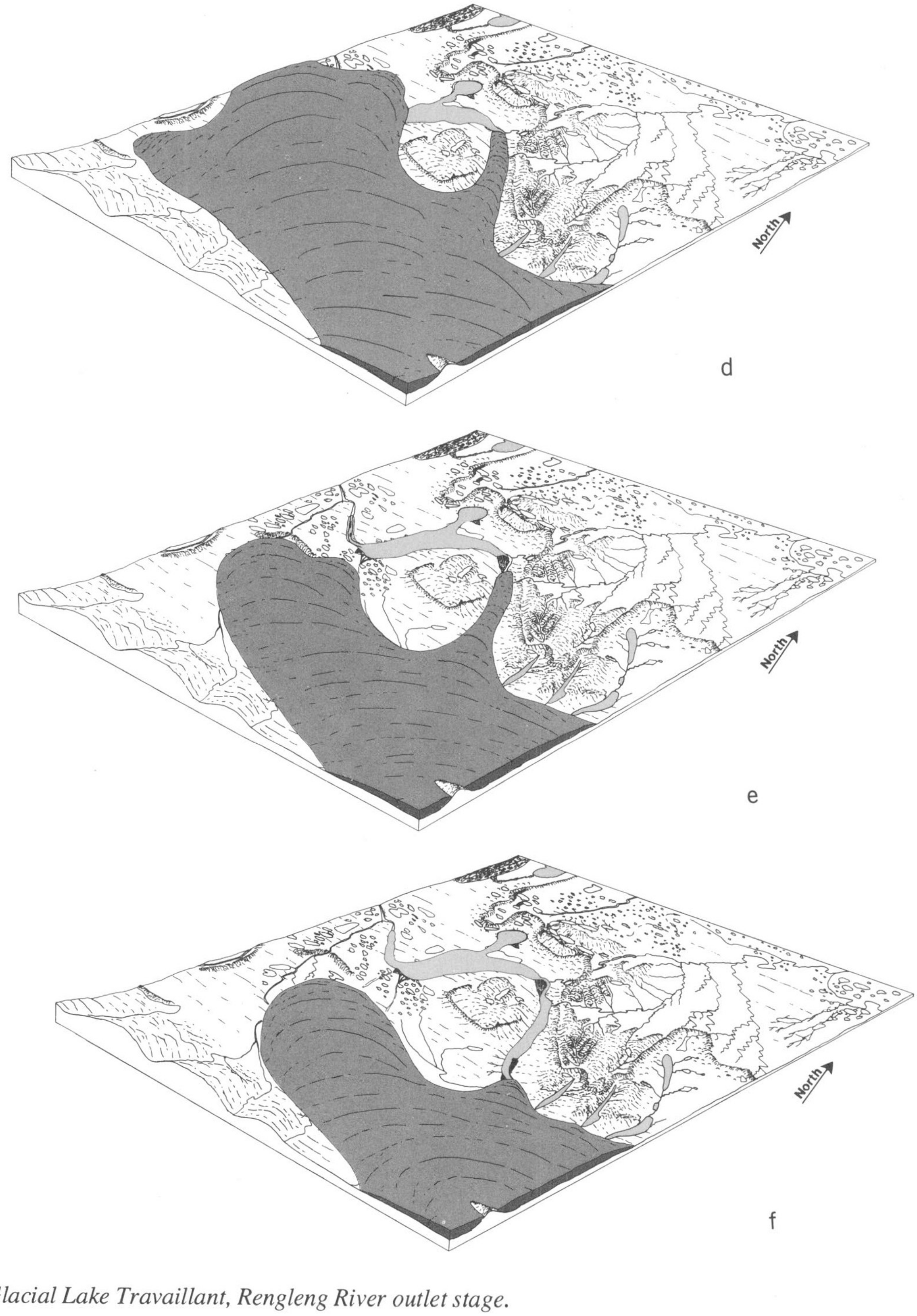
Figure 15. *Successive positions of the Laurentide ice margin during Late Wisconsinan time. (See Figure 2 for approximate location of study area).*



a) *Maximum of Katherine Creek Phase (ca. 23 ka).*

b) *Glacial Lake Tenlen stage.*

c) *Tutsieta Lake Phase maximum (ca. 13 ka).*

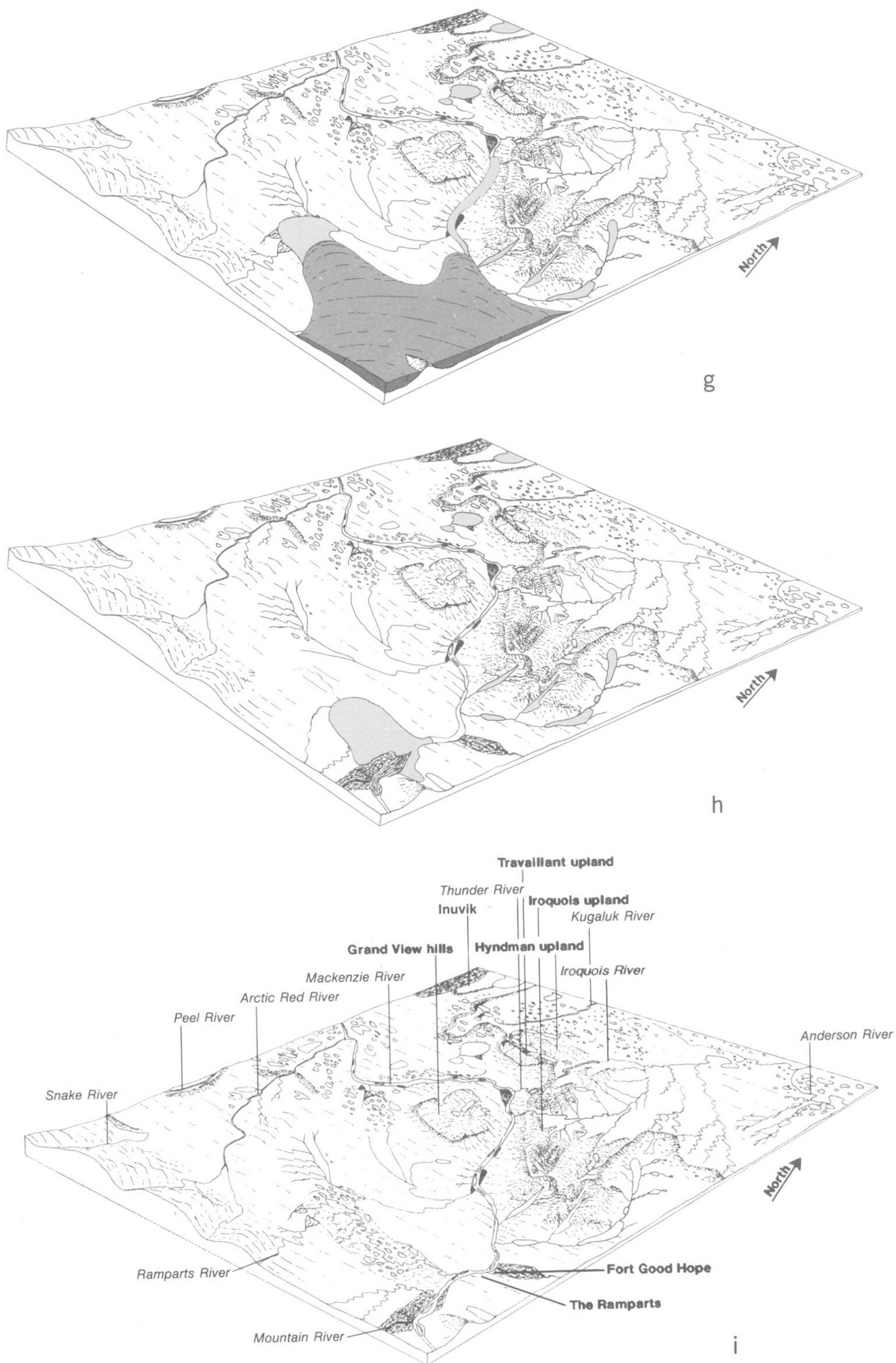


d) Glacial Lake Travaillant, Rengleng River outlet stage.

e) Glacial Lake Travaillant, Mackenzie River outlet stage. Arctic Red River ice marginal channel.

f) Migration of glacial Lake Travaillant and establishment of Arctic Red River as permanent drainage.

Figure 15. (cont.)



g) *Glacial Lake Ontaratue, Ontaratue River outlet stage; late stage of glacial Lake Travaillant.*

h) *Early stages of glacial Lake Mackenzie, Mackenzie River outlet stage (ca. 11.5 ka).*

i) *Modern landscape.*

tributary of Iroquois River. It carried a very large meltwater discharge (Fig. 5) that formed an outwash plain along the channel and along Iroquois River (Map 1747A and 1748A). It is the largest associated with any of the channels utilized at the Tutsieta Lake maximum. Several channels carried meltwater northward across the local divide between Iroquois and Travaillant uplands, and across the latter upland. Glaciofluvial fan-delta deposits associated with certain of the channels (Map 1747A) divided the depression formerly occupied by glacial Lake Tenlen into several parts that resulted in two outlets, one toward Kugaluk River, the other toward Iroquois River (Fig. 15c).

In the western part of the area, Kugaluk River channel carried most of the meltwater from the east, south, west, and northwest. The complexity of the drainage is shown by the channel network through Bathing, Deep, and Jiggle lakes and thence by a channel along the west side of Tregnatchiez Lake to Sandy Lake (Fig. 6a, b, Map 1746A). Sandy Lake drained northward for over 30 km via interconnected channels to Kugaluk River (Fig. 5).

Glacial Lake Travaillant

Following retreat of the ice from the Tutsieta Lake maximum, the ice impounded water at three different points: Travaillant depression (now occupied by Lake Travaillant) and against Travaillant and Iroquois uplands. Glacial Lake Travaillant spilled northward into Kugaluk River (170 m) (Fig. 15d) but at its earliest stages the outlets were at Thunder River (190 m) and at a channel northwest of Tutsieta Lake (190 m). With further ice retreat glacial Lake Travaillant expanded to occupy a segment of present day Mackenzie River. The glacial lake sediments along the Mackenzie River and surrounding areas of Lake Travaillant (Maps 1746A, 1747A and 1742A) were deposited at this time. The thickness of sediments, up to 30 m in the deepest part of the lake, along the main axis of the Mackenzie River, suggests the lake lasted for some time. In this case dates for the Tutsieta Lake Phase and the earlier stages of glacial Lake Mackenzie indicate that glacial Lake Travaillant lasted at least 1000 years.

The northern margin of Renglen Moraine (Fig. 4) is contured by an ice marginal channel now occupied by Rengleng River. Connecting channels to Rengleng River at 150 m and 90 m provided new lower outlets westward for glacial Lake Travaillant (Fig. 5, 15d, Map 1746A). Previously, all drainage had been northward via Kugaluk and Thunder rivers and a channel northwest of Tutsieta Lake. This stage established the first drainage westward from the area toward Mackenzie Delta. The drainage area that fed the lake at that time was limited because it collected the water that drained from the Tutsieta Lake Moraine to the ice margin.

There is no obvious eastward or westward continuation of the ice marginal position, although one of several retreatal ice marginal positions marked by moraines and meltwater channels on the flanks of Grand View hills may correlate with Rengleng Moraine; Rengleng Moraine possibly marks the limit of a surge that affected only that part of the ice margin.

Further retreat of the ice margin established drainage along Big Lake-Rat Lake channel, other alternative channels such as Pierre Creek and Big Woman Lake, and the present course of lower Mackenzie River (Fig. 5, 15e). The new course breached the Rengleng Moraine at 90 m a.s.l. at a conspicuous bend near the village of Arctic Red River. Thereafter, further lowering of glacial Lake Travaillant was accomplished by downcutting of the river channel, perhaps by upstream migration of a knickpoint. The Mackenzie River was established in the position that it is today as an outlet of glacial Lake Travaillant and as a postglacial feature.

At the maximum of Tutsieta Lake Phase, drainage from the northern Mackenzie Mountains and from upper Peel River was diverted around the ice margin and northward in a very large ice marginal channel on the slopes of Peel Plateau that became the modern course of Peel River (Fig. 16, 17). Also, drainage from the eastern Richardson Mountains became tributaries to the newly established river downcutting as much as 300 m. During further ice retreat, ice-marginal channels developed at lower elevations and joined an ice-marginal channel now occupied by Arctic Red River where it crosses Peel Plain (Fig. 5, 15f, Duk-Rodkin and Hughes, 1992b, c, d).

Figure 16.

View to north of moraine marking limit of Tutsieta Lake Phase, Bathing Lake, Arctic Red River map area. (ISPG 3817-4)

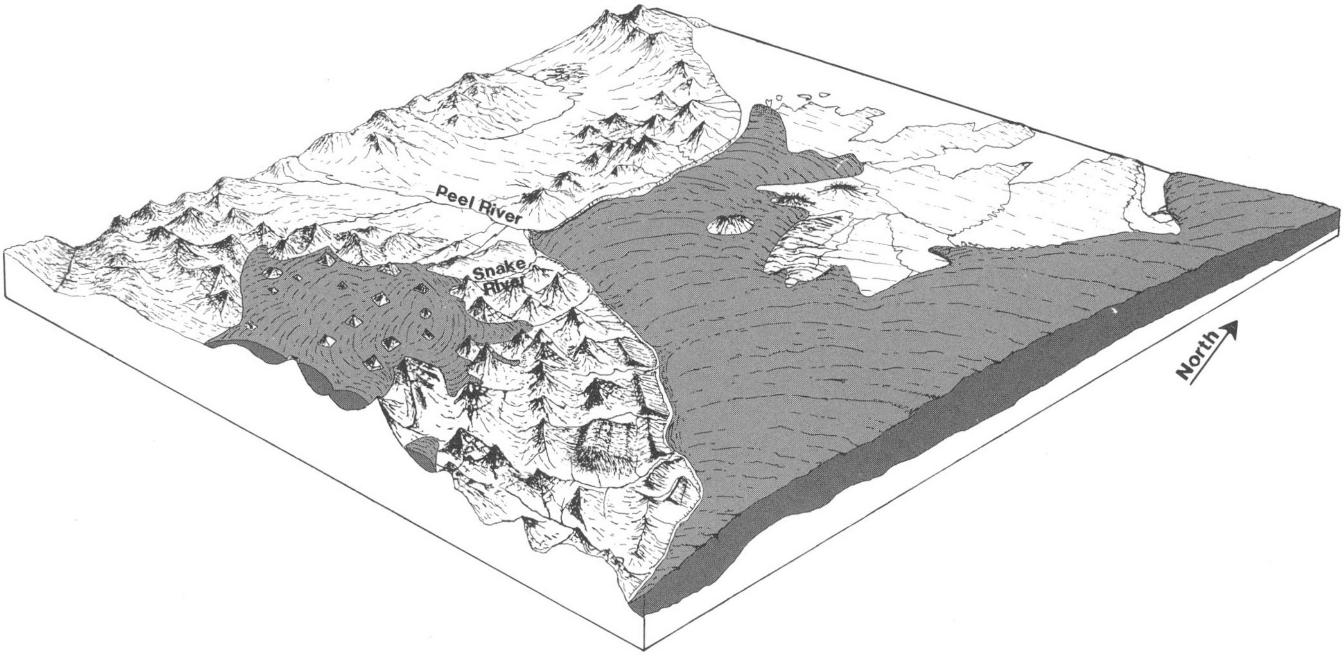


Figure 17. Block diagram depicting the Laurentide Ice Sheet during Tutsieta Lake Phase. (See Figure 2 for physiographic locations).

Figure 18. North oriented drumlins and flutings along the east side of Mackenzie River between Grand View hills and Iroquois upland. (ISPG 4132-1)

The deglaciation pattern south of Iroquois and Travaillant uplands record southwesterly flow that swung northerly down Mackenzie River (Fig. 18) and northwesterly along Ontaratue lowland after merging with ice moving northwesterly along Mackenzie lowland (Maps 1741A and 1742A). This flow pattern is reflected by drumlinoid and fluting topography.

Glacial Lake Ontaratue

An early stage of glacial Lake Ontaratue was initiated, with an outlet leading northwesterly to Arctic Red River which at this time became a major conduit for ice-marginal drainage. The lake expanded as the ice withdrew across a low divide between Arctic Red and Ontaratue river basins, until an alternative outlet opened and drained northeasterly to a remnant of glacial Lake Travaillant. The newly established outlet, now occupied by Ontaratue River, cut a 120 m deep channel across a bedrock divide that extends southeast of Grand View hills (Fig. 15g, 19). Deltaic sediments at the confluence of Ontaratue and Mackenzie rivers indicate lowest level of glacial Lake Travaillant was at 75 m elevation.

A fan-delta formed where Ramparts River entered glacial Lake Ontaratue (Fig. 15g, Map 1742A). Glacial lake sediments are wide spread in Ontaratue Basin where they generally are over 15 m thick, and locally up to 30 m thick

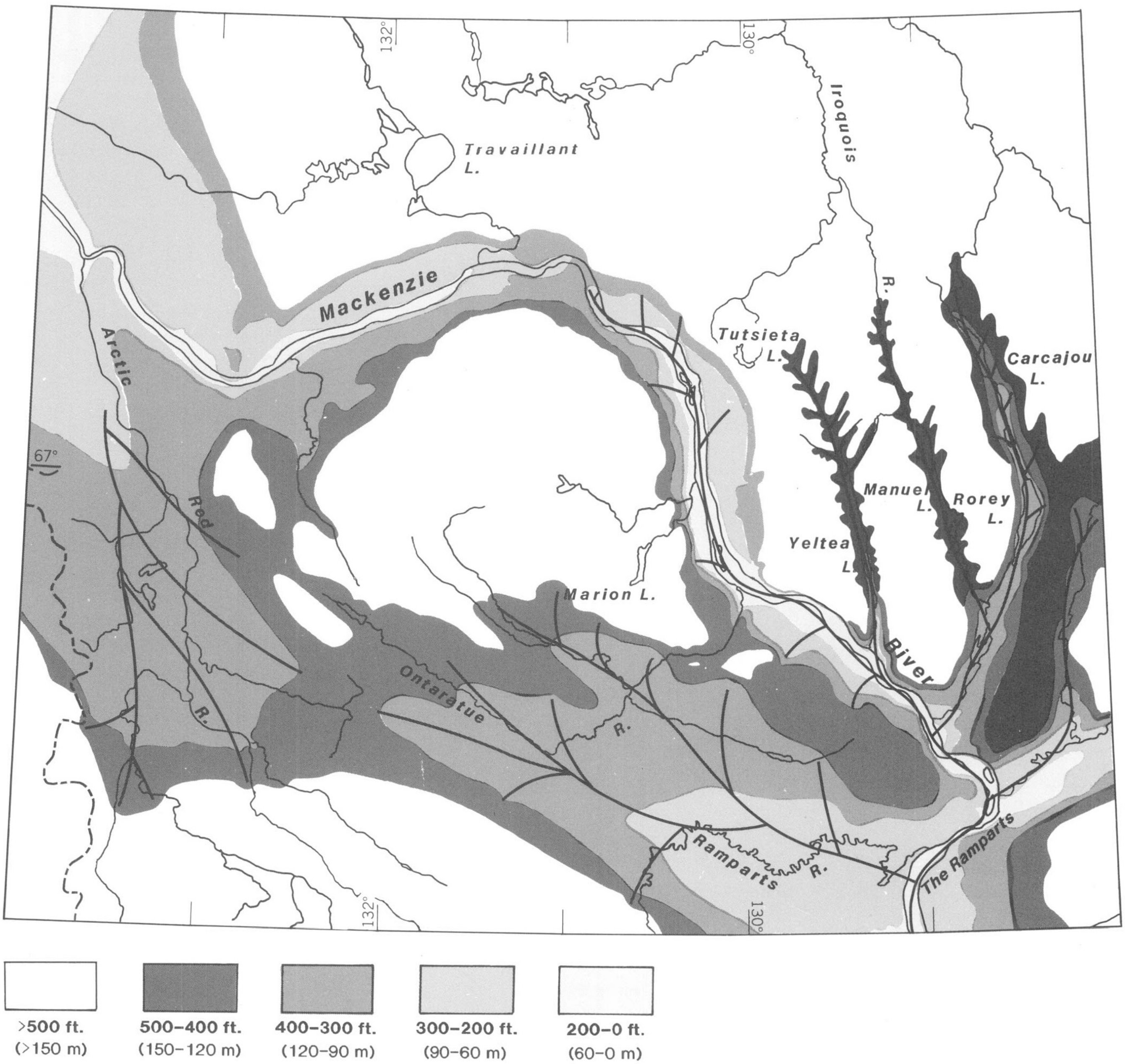


Figure 19. Reconstruction of paleodrainage based on paleosurfaces built from simplification of contour lines at 1:250 000 scale.

near the centre of the basin. Evidence of ice readvance is shown by a series of shallow channels reflected by fenlands through which the water of the lake spilled over to Arctic Red River. A section (Fig. 5, 20) where a diamicton is wedged between silty clay layers indicates ice readvance. Farther east, a series of channels marked by fenlands (Fig. 21, Map 1742A) indicates that drainage from the glacial lake spilled over towards Ontaratue outlet as a consequence of one or more readvances when most of the lake was in process of establishing the new outlet at The Ramparts. Channels at about 90 m a.s.l., the same elevation as the bluff at The Ramparts. This suggests that the water during the early stages of the glacial lake Mackenzie (Smith, 1992) would at times spill over the 90 m divide until the outlet was established at The Ramparts. A fan-delta was deposited during this stage in the lower reaches of Hare Indian River, and a much larger one in the lower reaches of Mountain River. This early stage of glacial Lake Mackenzie ended with further downcutting of the Mackenzie River, probably by knickpoint migration to just below The Ramparts (Fig. 15h).

An important consideration is the volume of water that drained into glacial Lake Ontaratue, and later into glacial Lake Mackenzie. At this stage of deglaciation the meltwater from the Mackenzie Mountains south of Arctic Red River drained through Ramparts River into glacial Lake Ontaratue, which at least tripled the volume of water that drained through the outlet of glacial Lake Travaillant. The water that fed glacial Lake Travaillant was collected from a restricted area on the south slopes of Iroquois and Travaillant uplands. The size of Renglen River can be used as a measure of the volume of water that drained through the Mackenzie River outlet before Ramparts River drained into glacial Lake Ontaratue. The large volume of water resulted in increased downcutting of the Mackenzie River at Renglen Moraine, near the confluence of Thunder River and at The Ramparts (Fig. 19, 22, 23).

Figure 20. Locality HH 71-54, Ontaratue River. Diamicton wedge within glaciolacustrine sediments. (ISPG 3817-5)

At The Ramparts, Mackenzie River is deeply incised through resistant massive limestone beds of Ramparts Formation, which dip gently southward, and into the subjacent siltstone and shale of Hare Indian Formation (Cook and Aitken, 1969). It seems likely that the gradient of Mackenzie River between Arctic Red River and The Ramparts was established by upstream migration of a knickpoint, which became the site of major falls, where it encountered the resistant Ramparts Formation. Upstream from the falls, a network of channels was gradually dominated by Fossil Lake channel and a channel occupied by the present day course of Mackenzie River (Mackay and Mathews, 1973; Fig. 8a, b). These channels became dual outlets of glacial Lake Mackenzie, which expanded south of the map area as ice receded from Peel Plain.

The falls associated with the respective channels migrated upstream. The one along present day Mackenzie River evidently migrated faster than the one along Fossil Lake channel and eventually all of the flow from the latter was captured, leaving "Dry Falls" and Fossil Lake, the plunge pool of the former falls. Because Ramparts Formation dips southward (upstream) the falls in the active Mackenzie channel became progressively lower as they migrated upstream and disappeared.

The present lower course of the Mackenzie River was established as a result of the pattern of deglaciation and formation of successive glacial lakes and interconnecting outlets between Grand View hills and Travaillant and Iroquois uplands (Fig. 24). The lower Mackenzie River was formed when the ice retreated from the uplands and the Tutsieta Lake Phase moraine belt that bordered them. The Mackenzie River evolved as an outlet of glacial Lake Travaillant, followed by the formation of glacial lake Ontaratue and Mackenzie. Preglacial drainage patterns different from present drainage are visible through glacial drift, even though the region was covered by 900 m of ice (Fig. 12).

Chronology

Radiocarbon dates from within the study area include eight "greater than" dates from wood of pre-Late Wisconsinan age. The dated samples may be of the same age as the enclosing sediments but recycling of some or all of the samples from older deposits is possible.

Radiocarbon dates that place the maximum extent of the Laurentide ice sheet within the Late Wisconsinan are as follow: 1) A 36 900 ± 300 BP (GSC-2422) date obtained from wood beneath Hungry Creek Till (Hughes et al., 1981;

Hughes, 1987); 2) a 34 220 ± 120 BP (TO-124) date of peat from underneath sands and clays of jökulhaup-type sediments located in a section in Rock River on the western slope of Richardson Mountains (Schweger and Matthews, 1992); 3) a 31 400 ± 660 BP (GSC-2739) (peat) and 32 400 ± 770 BP (GSC-952) (shell) date the glacial lake inundation of the Old Crow (Lowdon and Blake, 1979). New dates for the inundation of Old Crow Flats in northern Yukon Territory suggest that the maximum was attained as recently as 25 000 years ago (Morlan et al., 1990). The maximum extent of the Laurentide Ice Sheet was the only possible ice responsible for the inundation of northern Yukon Territory interior. The elevation of the former divide between Peel and Eagle rivers is 560 m. In order to breach the divide, an advancing Laurentide Ice Sheet must have impounded a glacial lake in Bonnet Plume Basin to that level. Consideration of topography of the eastern periphery of the basin suggests that for the ice sheet to have impounded a glacial lake at the 560 m level, it must have extended into the basin rather than merely approaching its eastern margin. This conclusion becomes important in attempts to correlate glacial events in Bonnet Plume Depression with glaciolacustrine events in northern Yukon Territory interior and evolution of westward drainage of the Porcupine basin via The Ramparts. On this basis it is possible to discount an early advance of the Laurentide Ice Sheet, as the agent that caused the

Figure 21. Shallow channels marked by fenlands between Ramparts and Ontaratue rivers. Channels (arrows) indicate former spillage northward of glacial Lake Ontaratue due to glacial readvance. (ISPG 4132-2)

establishment of the Eagle River discharge channel and the first westward discharge of Porcupine River through The Ramparts.

Although there are no dates that fix the time of Katherine Creek Phase at the type locality, it is known that the Laurentide Ice Sheet occupied the foothills of the Mackenzie Mountains at the same time as the montane glacier advance dated at about 23 ka (Klassen, 1987). During Katherine Creek Phase, the ice sheet occupied the eastern slopes of McDougall Pass at 230 m a.s.l. This elevation is 105 m below the Pass, thus the ice sheet could not have diverted drainage across the continental divide and into Old Crow Basin at this time. Dates of 21 300 ± 270 BP (GSC-3371) and 21 200 ± 24 BP (GSC-3813) on organic detritus (Catto, 1986) were obtained from glacial lake sediments which were deposited during Katherine Creek Phase when the ice occupied the lower reaches of Rat River. In Bonnet Plume Basin the ice sheet during Katherine Creek Phase reached an elevation of 250 m a.s.l. some 130 m below the level of Eagle River discharge channel of glacial Lake Hughes.

The Tutsieta Lake Phase advance (Sitidgi Stade of Rampton) appears to have culminated about 13 ka (Hughes, 1987; Rampton, 1988). The ice sheet had left the area between Fort Good Hope and Mountain River-Mackenzie River confluence by 11 530 ± 170 BP (I-3734, Mackay and Mathews, 1973). The Kelly Lake Phase reached its maximum after 11 530 but before 10.6 ka (10 600 ± 260 BP, GSC-2328). These dates indicate the ice sheet retreated at a rate of about 150 m/a, not unlike rates of 60 to 300 m/a proposed for the southern Canadian prairies (Klassen, 1989).

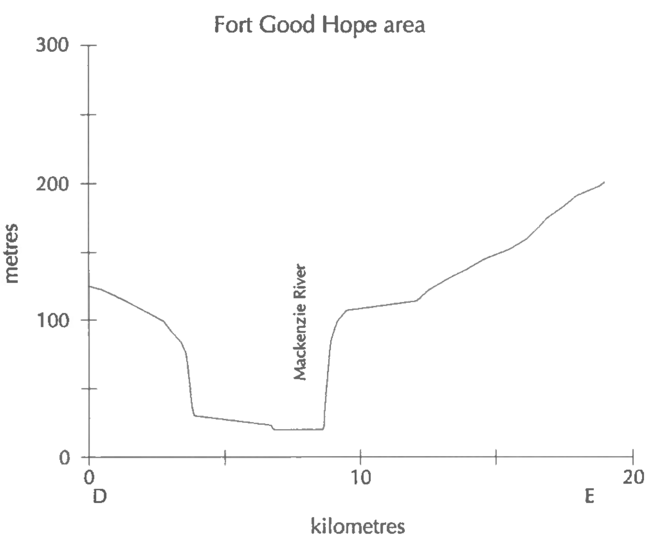


Figure 22. Profile across Mackenzie River at Fort Good Hope. The River is incised in limestone of Ramparts Formation. See Figure 5 for location of profile.

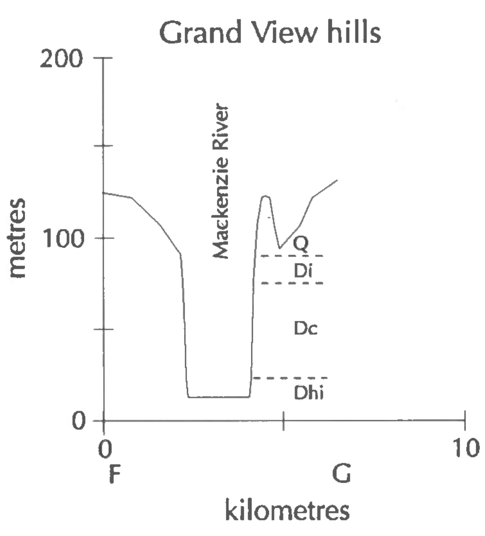


Figure 23. Profile across Mackenzie River south of Thunder River confluence. The river channel appears deeply incised in bedrock shale of Devonian Imperial (Di), Canol (Dc), and Hare Indian (Dhi) formations. See Figure 5 for location of profile.

Paleodrainage

Paleosurfaces and drainages in the study area show that the regional landscape was quite different during preglacial times. Segments of valleys that reflect drainage south, in particular the Mackenzie River imply the possibility of subparallel drainages that followed the regional slope towards the east and northeast.

The evolution of the main physiographic elements of the area, including the course of the Mackenzie River, is not readily deciphered. The southward gradient of Tieda, Loon, and Bluefish rivers indicates they formed as tributaries of a southward-flowing trunk stream rather than as tributaries of the northward-flowing Mackenzie River. A major channel, now partly buried beneath drift, can be traced northeastward from near Travaillant Lake, then eastward to the head of Anderson River (Fig. 5). Meander loops of the channel have radii of curvature of about 7 km, indicating that the channel was occupied by a major trunk stream, and implying a drainage direction very different from that of present.

The drainage pattern on Anderson Plain is notable in that the major streams head near the elevated southwestern margin of the area and drain northward to Amundsen Gulf. A topographic profile drawn from Canyon Ranges, an outer range of Mackenzie Mountains (Fig. 5, 25), northward across bordering Peel Plateau, then across Ontaratue lowland, through Grand View hills and continuing across Anderson Plain to Liverpool Bay, suggests the possibility that a paleosurface once sloped more or less uniformly from the mountain front to Liverpool Bay. Ontaratue lowland and the present course of Mackenzie River north of Grand View hills might be the product of glacial erosion that lowered those surfaces to below the inferred paleosurfaces.

The present drainage of the area is a complex of preglacial and interglacial drainage modified significantly by glacial meltwater channels and drainage established in the Holocene following deglaciation. Although certain meltwater channels may have been initiated during pre-Wisconsinan glaciation and re-excavated during retreat following the last glaciation, all meltwater channels are considered as related to glacial retreat following Katherine Creek Phase of Late Wisconsinan time.

Elements of the preglacial drainage remain recognizable despite significant modification by glaciation and by meltwater discharge. Carnwath and Iroquois rivers (Fig. 5), and a southwestern tributary of Iroquois River were dendritic streams tributary to a major sinuous channel, now mostly filled with glacial drift, which can be traced from near Travaillant Lake generally northeasterly to Anderson River. A regional divide separated this drainage from a southward draining system that comprised modern Tieda and Loon rivers (Fig. 19, 26). The middle reaches of these rivers have undergone extensive glacial erosion and overdeepening to produce elongate "finger" lakes such as Yeltea, Manuel, and Canot. Similar glacial erosion and overdeepening of relatively minor preglacial valleys occurred along the Mackenzie River between Grand View hills and Iroquois

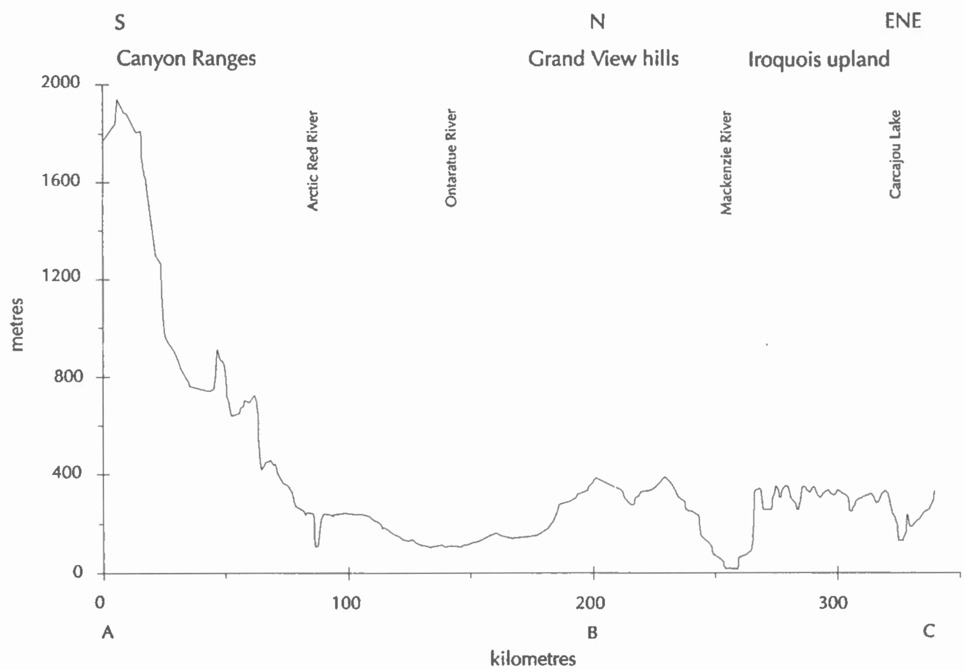


Figure 24. Topographic profile from the Canyon Ranges of the Mackenzie Mountains to Grand View hills to Iroquois upland. Note that Mackenzie River is incised between the uplands. See Figure 5 for location of profile.

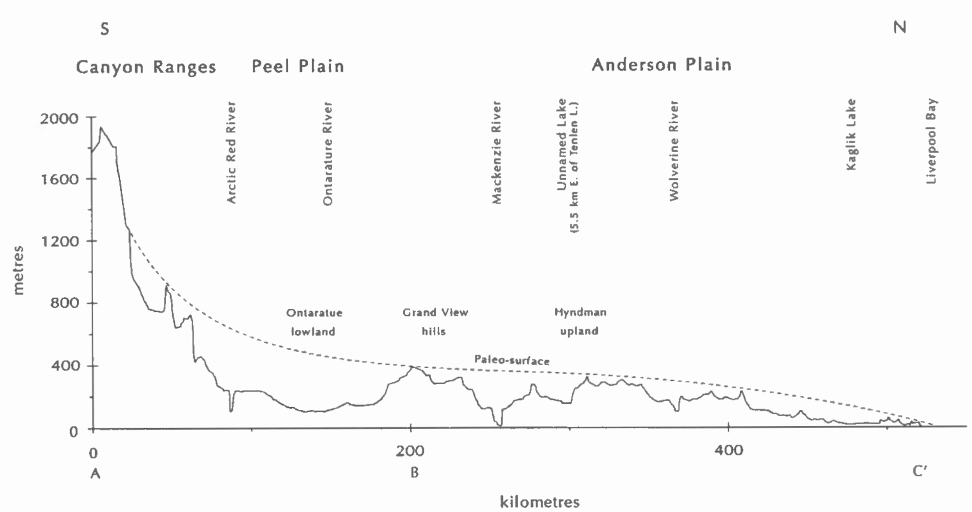


Figure 25. *Topographic profile from Canyon Ranges, across Anderson Plain, showing reconstructed paleosurface during preglacial time. See Figure 5 for location of profile.*

upland. Reconstruction of the paleosurface shows a southward dendritic drainage with the main divide between Grand View hills and Iroquois upland (Fig. 19). Reconstruction of the paleosurface was done by deletion of erosional surfaces using a topographic map at 1:250 000 scale. Figure 19 shows that the Mackenzie River occupied a drainage similar to Loon and Tieda rivers. Cross-sections at two locations along the Mackenzie River show the river today is incised in bedrock. This is particularly conspicuous at Thunder River site which is located at the reconstructed divide, where it cuts across bedrock shale of Devonian Imperial, Cannol, and Hare Indian formations (J.D. Aitken, unpub. field notes, 1968), (Fig. 23).

Other elements of the reconstructed paleodrainage are more subtle, in particular, the extension of the regional divide westward across the present course of Mackenzie River. The north flowing segment of modern Peel River follows an ice-marginal channel incised into Peel Plateau. The regional drainage trend suggests that preglacial Peel River, together with the preglacial Arctic Red River, were tributaries to the major sinuous channel described above (Fig. 5).

Kugaluk River is a rare example of a major stream initiated entirely as a meltwater channel. It was formed in an interlobate position (Fig. 15a), along the line of merger or suture between two major ice streams that prevailed during Katherine Creek Phase – one that moved northwesterly in Peel Plain, then northeasterly along Sitidgi lowland, and another that moved northerly through the headwaters of Carnwath River then northwesterly toward Kugaluk River, and finally northeasterly, parallel to the ice stream in Sitidgi lowland. Although these ice streams within the ice sheet are clearly defined by drumlins and glacial fluting, the upland between was covered by less active ice. During glacial retreat, a re-entrant persisted along the suture between the two ice streams, guiding meltwater flow along what became the modern Kugaluk River valley.

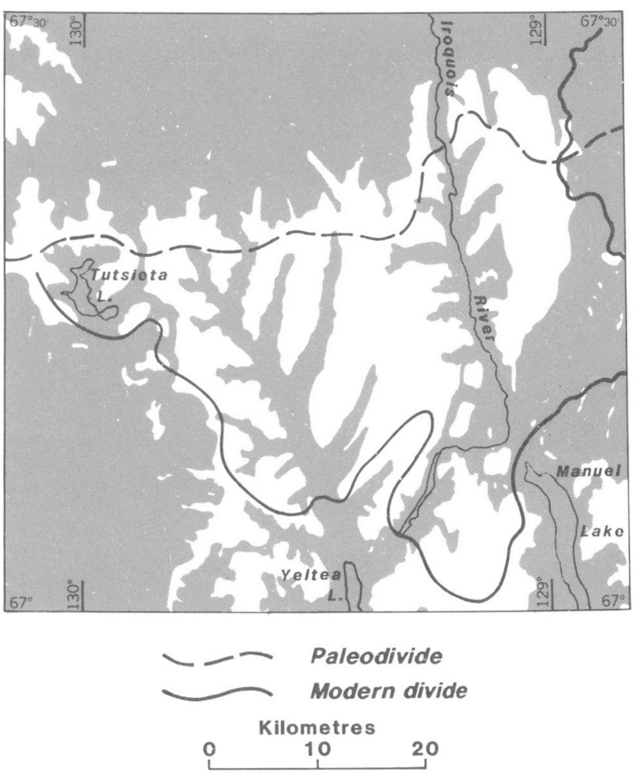


Figure 26. Iroquois upland showing difference in position between paleodivide and modern divide.

Modification of preglacial drainage by later meltwater flow is exemplified by the headwaters region of Iroquois River (Fig. 5, 26), where meltwater discharged northward after ice had retreated south of the regional divide. Large channels were cut across the divide, reducing the height of the divide between opposing streams by as much as 100 m. With downcutting of the north-flowing streams, local divides between north- and south-facing drainages were shifted southward as much as 30 km, with resultant capture of extensive drainage areas by the north-flowing streams.

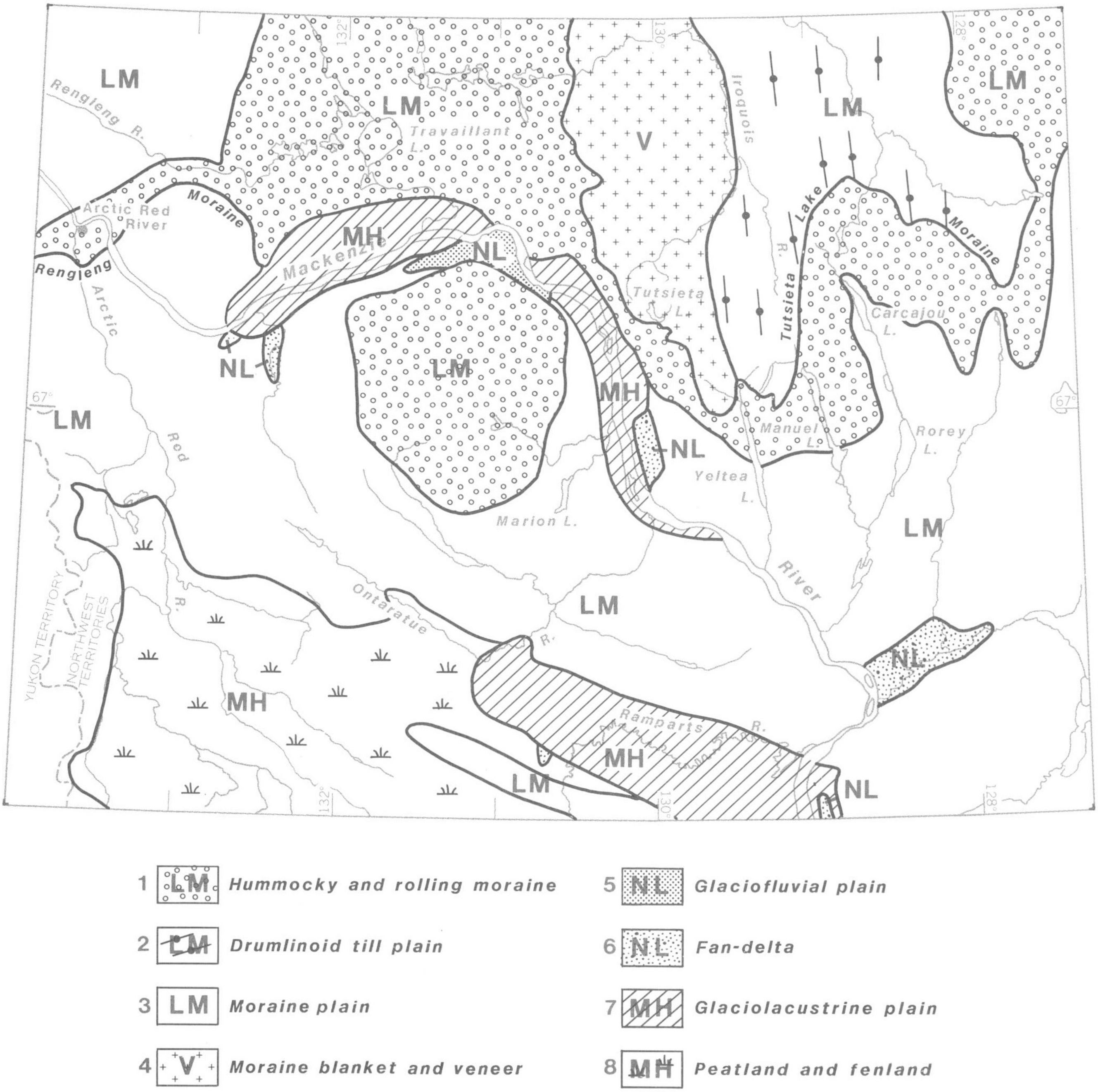
The major meandering preglacial channel reflects modification by glacial deposition. Much of the channel is completely filled by drift, with only a shallow depression over the former course. Several partly filled segments are occupied by Hyndman Lake and other, unnamed lakes. Headwaters of Kugaluk River occupy a small segment of the channel at the southwest end; the remainder is occupied by Wolverine River, which drains to Anderson River. The inferred connection between this channel and Peel and Arctic Red rivers is presumed to have been removed by glacial erosion. Evidence of preglacial drainage modified by glacial erosion can be found in other parts of the Mackenzie region southeast of the study area, for example, in the Norman Ranges (Duk-Rodkin and Hughes, 1994).

ECONOMIC AND GEOTECHNICAL ASPECTS

The study area is located mainly within the zone of discontinuous permafrost, with the northernmost part lying within the zone of continuous permafrost (Fig. 27). In addition to familiar constraints imposed on development by terrain conditions in southern areas, there are significant additional constraints imposed by permafrost conditions. Geomorphic processes peculiar to permafrost regions can be severely damaging to human-made structures. These processes take place naturally and continually, but the rate of the processes and resulting damage to human-made structures can be greatly increased by human activity that exposes the permanently frozen soil to thawing.

Geomorphic processes in permafrost

The geomorphic processes of greatest concern to development in permafrost areas are slope failures, differential subsidence, and accelerated hydraulic erosion. Two types of slope failures are recognized: active layer detachment slides and retrogressive thaw flow slides.



1) *Low to moderate ice content, as lenses and reticulate veins, higher ice content with depth.*

2) *Highly variable ice content where material frozen; crest of prominent ridges are generally free of ice.*

3) *Ice content low to moderate where material frozen as thin seams, reticulate veins, lenses, and wedges; massive ice may occur at depth.*

4) *Ice content as within hummocky and rolling moraine.*

5) *Nil to low ice content where material frozen, as thin seams.*

6) *Ice content as within glaciofluvial sediments.*

7) *Moderate to high ice content where material frozen, as thin seams, reticulate veins, and wedges; massive ice may occur at depth.*

8) *Peatland: Ice content as within glaciolacustrine sediments. Fenland: commonly free of ice in upper 2 metres.*

Figure 27. *Permafrost and ground conditions and associated surficial geology materials. Legend adapted from Heginbottom and Radburn (1987).*

Active-layer detachment slides involve downslope movement of the active layer, a metre or so thick, along with the overlying vegetation root mat and cover as a result of detachment from the subjacent permanently frozen material (Fig. 28). In some cases the entire surface layer moves more or less coherently as a unit but as a rule, the process begins with sliding of a restricted patch near the bottom of the slope. This is followed by a succession of slides moving progressively upslope, within a period of minutes, hours, or sometimes several days. The affected area is typically elongate upslope, although elongation across the slope also occurs.

Slides typically occur on slopes steeper than 10°. They are most common in freshly burned areas, where destruction of the insulating vegetation leads to increase in the thickness of the active layer. Thawing of the underlying ice-rich sediments produces unstable soil-water mixtures that result in slides. Detachment slides may also be initiated by extremely heavy rains. They are most common on slopes developed on shale or siltstone, but can also develop on other sediments with steep slopes and an active layer underlain by ice-rich materials.

Retrogressive thaw-flow slides occur as a result of thawing of soil-ice mixtures along nearly vertical slopes up to 14 m high. Typically, they develop in glaciolacustrine sediments by slow, backward melting (retrogression) of a nearly vertical backwall (Fig. 29a, b, 10). Backwalls over 30 m high occur but commonly they vary between 7 and 14 m. When thawed, the material slides from the melting backwall in periodic bursts. The surface slope of the outflow part of such slides in glaciolacustrine silts and clay is typically 2.5 to 4°, but may be up to 8° where sand overlies the silt and clay. The backwall migrates backwards (3 to 10 m or more per year) until the sloping floor meets ground surface, or until the backwall intersects soil that is stable when thawed. Most retrogressive thaw-flow slides are initiated when active layer detachment slides expose ice-rich sediments, but they can also be initiated by mechanical removal of vegetation from slopes.

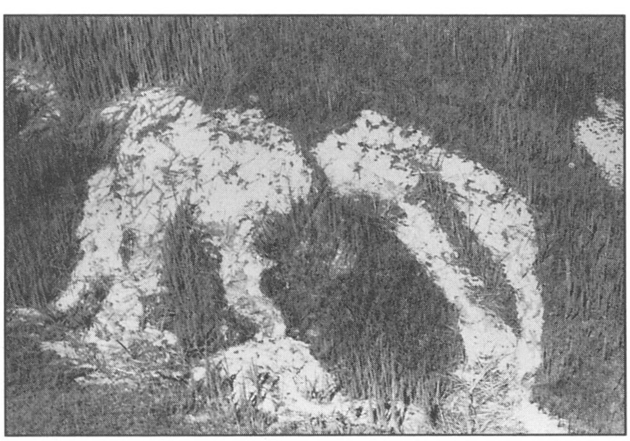


Figure 28. *Active layer detachment slides south of Tutsieta Lake. The slides were formed on colluviated morainic slopes. (ISPG 4090-2)*

Differential subsidence occurs as a result of the disturbance of the thermal regime in surficial deposits that have a relatively high content of segregated ground ice. Deposits such as glaciolacustrine silt and clay may have segregated ice distributed more or less uniformly through out the body of sediment. Differential subsidence occurs when the soil-ice mixture thaws and settles over a restricted area, leaving the remaining surface at its original level. In deposits such as hummocky moraine, bodies of segregated ice are distributed irregularly. When an area thaws, settlement takes place only over the former ice bodies.

The susceptibility of the respective surficial deposits to hydraulic erosion is a function of the texture of the constituent materials, and the amount and distribution of segregated ice. Casual observation suggests that frozen, fine grained soils are more susceptible to hydraulic erosion than their nonfrozen

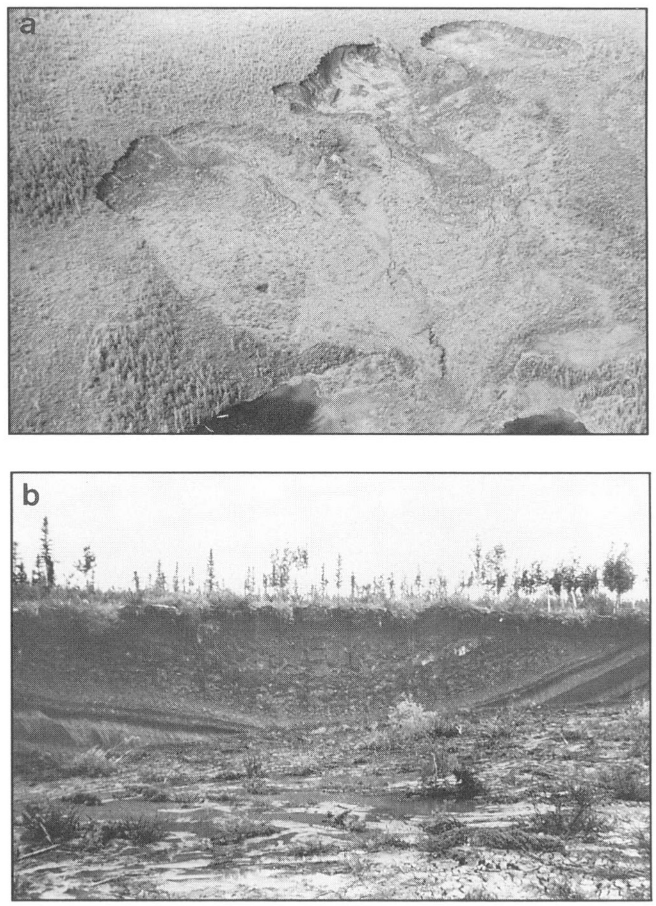


Figure 29. ***a)*** *Retrogressive thaw-flow slide, southern Grand View hills, Travaillant Lake map area. In June 1950, the slide comprised a small area near the lakeshore; by 1973 when this picture was taken, it had retrogressed and developed three distinct embayments; note steep backwalls of active embayments and gently sloping floor. (ISPG 320-10);* ***b)*** *Backwall of embayment at upper right in Figure 29a; clay with reticulate network of ice overlies layered ice with intercalated layers of silty ice containing up to 40% silt. (ISPG 320-6)*

counterparts. A possible explanation is that as each thin layer of soil is thawed by eroding water, it has zero cohesion, and less resistance to erosion than massive unfrozen sediment.

Engineering characteristics of surficial geology map units

Moraine plain (Mp)

Moraine plains typically have a moderate to high ground ice content immediately below the active layer, with the proportion of ground ice decreasing rapidly downward. Typically, the thickness of segregated ice is less than one metre; differential subsidence is thus restricted to less than one metre.

Gently sloping till plains commonly have subparallel "horsetail" drainage with shallow runnels (Fig. 30). Channelling of drainage from the runnels by highway or pipeline construction may lead to severe hydraulic erosion.

Rolling moraine (Mm)

Segregated ground ice occurs as irregularly shaped and scattered bodies in rolling moraine. Surfaces stripped of vegetation to provide common fill for construction of Dempster Highway in Rengleng Moraine west of Arctic Red River exhibit highly irregular differential subsidence up to 3 m and small-scale retrogressive thaw-flow slides are common in rolling moraine. They are probably localized over ice-rich pockets in the moraine.

There is virtually no evidence of slope failure or differential subsidence in high relief hummocky or ridged moraine. This reflects the generally low ice content of coarse granular materials in these units.

Glaciolacustrine deposits (Lp, Lp-k, Lb, Lv)

Glaciolacustrine sediments have by far the highest ice content of the surficial deposits of the area, and hence are highly susceptible to all of the geomorphic processes peculiar to permafrost regions.

The silty sediments contain pore ice, and segregated ice as tabular lenses to 1 m or more thick, as irregular veins, or as a reticulate network that encloses unfrozen, very stiffly plastic clay. Thickness, regularity of spacing, and proportion of ice forming the networks is highly variable. Clay masses range from a few centimetres to 1 m in thickness and the surrounding ice from a few millimetres to 20 cm. Over a single stratum, however, the thickness of surrounding ice tends to be rather uniform (Fig. 29b). In varved clays, segregated ice typically occurs as continuous uniform layers 1 to 5 cm thick intercalated between successive varves, together with widely spaced narrow vertical veins. The volume of the ice in the sediment is from 10 to 40 per cent or more of the total volume of ice and sediment.

Slopes developed in glaciolacustrine sediments are highly susceptible to active layer detachment slides and to consequent development of retrogressive thaw flow slides. The largest of such slides in the area occur within areas mapped as Lp, Lp-k, or Lb.

Thermokarst lakes, ponds, and wet depressions, typically closely spaced and highly irregular in shape, are features characteristic of the glaciolacustrine plains (Fig. 7). They are the result of differential subsidence of the ice-rich glaciolacustrine sediments. In most cases, the thermokarst topography is associated with a discontinuous cover of peat. Although there is much variation, the lakes, ponds, and depressions are typically bordered by steep slopes 1 to 2 m high and rarely 4 m high. Most slopes show evidence of recent or active collapse, such as drowned trees along lake or pond margins, tilted trees on the banks, or fresh exposures of actively thawing, ice-rich sediments. Recent or active collapse is usually localized at one or more sites along the

Figure 30.

Subparallel "horsetail" drainage on sloping till plain Canot Lake map area. (ISPG 320-9) periphery of the water body or depression. Lack of apparent control mechanisms suggests that the controls are very subtle, and that thermokarst glaciolacustrine areas are exceedingly sensitive to minor disturbances. Thermokarst topography appears to be best developed in flat parts of glaciolacustrine plains that are underlain by thick glaciolacustrine silt and clay with no sand cover or with relatively thin sand cover (5 m or less). It is generally lacking in areas of thick sand cover, on sloping surfaces, or where the glaciolacustrine sediments thin and wedge out of the margins of the plains.

The glaciolacustrine plains are in general highly unsuitable for any type of construction, particularly pipelines, because of: 1) high susceptibility to thermokarst processes, 2) high susceptibility to gullying by combined hydraulic and thermal erosion, and 3) high instability of slopes developed on glaciolacustrine sediments. Where glaciolacustrine plains cannot be avoided, very careful selection of routing, especially stream crossings, is required. Burial would appear to be particularly unsuitable for warm oil pipelines crossing such areas. Burial may be possible for chilled gas pipelines, particularly over flat surfaces with a substantial sand cover. It would be impossible to avoid all ponds and wet depressions in thermokarst glaciolacustrine plains. Heaving would present a potential problem as nonfrozen sediments beneath the ponds began to freeze around the chilled pipeline.

Glaciofluvial deposits (Gp, Gt, Gr, Gh)

Glaciofluvial gravel and sand in the form of plains, terraces, esker ridges, and kames are the most stable unconsolidated deposits of the region. They are a major source of aggregate where the material is gravel rather than sand. Over much of the area these deposits have a very thick active layer that in places may contain pore ice. Small patches of gravel randomly distributed on the moraine plains may display orthogonal or polygonal networks indicating present or pre-existent ice-wedge networks. Subsidence resulting from melting of the ice wedges, if present, is unlikely to cause major construction problems.

Most glaciofluvial units within areas of glaciolacustrine plain are underlain by ice-rich glaciolacustrine silt and clay. This poses two main problems for pipeline location: 1) locally the glaciofluvial sand and gravel may be so thin that pipelines buried to 2 or 3 m may be in or close to ice-rich silt and clay, with high potential for differential subsidence in the case of warm oil pipelines, and 2) streams crossing such glaciofluvial deposits are typically incised through the gravel and sand into underlying silt and clay, to produce potentially highly unstable slopes.

Exploitation of gravel deposits where underlying silt and clay are suspected, should be preceded by drilling well below the intended depth of exploitation.

Alluvial deposits (Ap, Ap-k, At, Af)

In addition to risks from flooding inherent to development on alluvial plains there is also potential for differential subsidence. Silty overbank sediments typically have a high segregated ice content where the silts are thick, as in the floodplains of Mackenzie River. The potential is highest in thermokarst alluvial plains (Ap-k). A polygonal network of ice wedges occurs immediately below the active layer in the thermokarst alluvial plain near the village of Arctic Red River, Fig. 31). Ice wedges are most likely to occur in the area wherever silty overbank sediments exceed 2 m. Melting out of ice wedges produces obvious problems with airstrips or roads.

Alluvial fan deposits with extensive fan-aprons occur along major scarps on the Mackenzie and Iroquois rivers. Sediments of the fan-aprons consist mainly of slopewash and minor gullying on the scarps. The sediments are highly variable ranging from silt to gravel although ice-rich, organic sandy silt is most common. The sloping fan-aprons are subject to accelerated fluvial erosion if the vegetation cover is

Figure 31.

Furrows developed by melting out of a polygonal network of ice wedges in an airstrip cleared on thermokarst alluvial plain near the village of Arctic Red River. The middle part of the strip was regraded after much of the initial subsidence had taken place. (ISPG 320-3) removed. Stream avulsion, common to the large fans of Franklin and Mackenzie mountains, is probably a minor concern within the study area.

Organic terrain: peatlands (pO, pO-k) and fenlands (fO)

Peatlands of Peel and Anderson plains have numerous lakes, ponds, wet depressions, and connecting channels inset below the peatland surface. Peatlands in Peel Plain have highly irregular and sinuous peat plateaus elevated above surrounding wetland.

The peat areas are invariably permanently frozen, with a thin active layer, whereas the areas beneath lakes, ponds, and wet depressions are thawed to at least 4 m depth. The vegetation, unless recently burned, is dominated by lichens of high albedo which may comprise up to 65 per cent of the ground cover.

Typically, the peat contains a high percentage of irregular segregations of ice a few centimetres across within its fibrous structure. Ice wedge polygons occur sporadically in peatland over moraine plains and are widespread in peatland within rolling moraines of Anderson Plain. Thick tabular ice bodies are uncommon in the peat itself, however ground ice commonly occurs in thin layers 1 cm to 1 m or more thick, constituting up to 50 per cent or more by volume of the upper 2 to 7 m of mineral substrate (most commonly till, often with overlying slope-wash silt). Aggregate ice thickness in the upper part of the substrate is, as a rule, equal to the relief between the peat surface and the bottoms of adjacent ponds or depressions, indicating the relief in the peatlands is almost entirely due to the distribution of ground ice.

Large diameter pipelines buried in peatland would mostly likely bottom in the ice reach substrate, with resulting high potential for subsidence, because peat thickness is typically 1.5 to 2 m. There would also be potential for frost heave if chilled gas pipelines were laid through ponds and wet depressions of thermokarst peatland.

Slope deposits (Cv, Cb, Ca, Cz)

Colluvial units generally are not suitable for construction because of the potential slope instability. Active transportation of material in the form of rock falls, soil creep, and slumping are common on slopes with a colluvial veneer or blanket (Cv, Cb). These slopes can be affected by active layer detachment slides that commonly follow forest fires. Active layer detachment slides can develop into debris flows and the debris-fans can be observed at the base of the slopes (Fig. 28). Retrogressive thaw-flow slides (Cz) can evolve in these slopes with the exposure of the active layer, in particular if the colluvium is developed on silty till and/or glaciolacustrine sediments (Fig. 10). Moderate to high ice content is common in sheetwash deposits. Landslides (Cz) commonly occur as rotational slumping on shale along the Mackenzie River because of lateral erosion by streams. These slumps are usually too small to be mapped as a unit and are included within the slope complex unit (Cx).

Engineering practice in permafrost areas

Construction practices within the area have been restricted mainly to passive techniques aimed at minimal disturbance of permafrost. They include techniques such as use of piles installed in permafrost, or construction of aggregate pads that are thick enough to insulate the subjacent permafrost below buildings or simply preserving whatever protective cover exists.

The design of Dempster Highway within the area involved construction of berms from ripped shale and siltstone of the Imperial Formation. Construction of highway across Rengleng Moraine west of the study area involved use of till for berm construction. Much of the till was discarded because of its high ice content, and the retained portion proved unstable on thawing. Slope stabilization measures were required on cuts in till. Locating Dempster Highway within the study area on a till plain veneer was highly advantageous, as it allowed optimal spacing of borrow pits and costs for removal of overburden to access the bedrock were minimal. The Dempster Highway experience shows the advantages of using certain bedrock types of material other than gravel in highway construction. Even where gravel is available, its use in areas of permafrost should probably be restricted to road surfacing and concrete.

The occurrence of ice wedge polygons at the site of the airstrip near Arctic Red River was not evident from study of airphotos or from observation on the ground. For example when the airstrip was constructed, ice wedges caused serious problem. Ice wedges should be anticipated in areas of Ap-k deposits, and passive construction used.

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1973: Studies of vegetation, landform and permafrost in the Mackenzie Valley: terrain, vegetation and permafrost in the northern part of Mackenzie Valley and northern Yukon; Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report No. 73-4, 105 p.

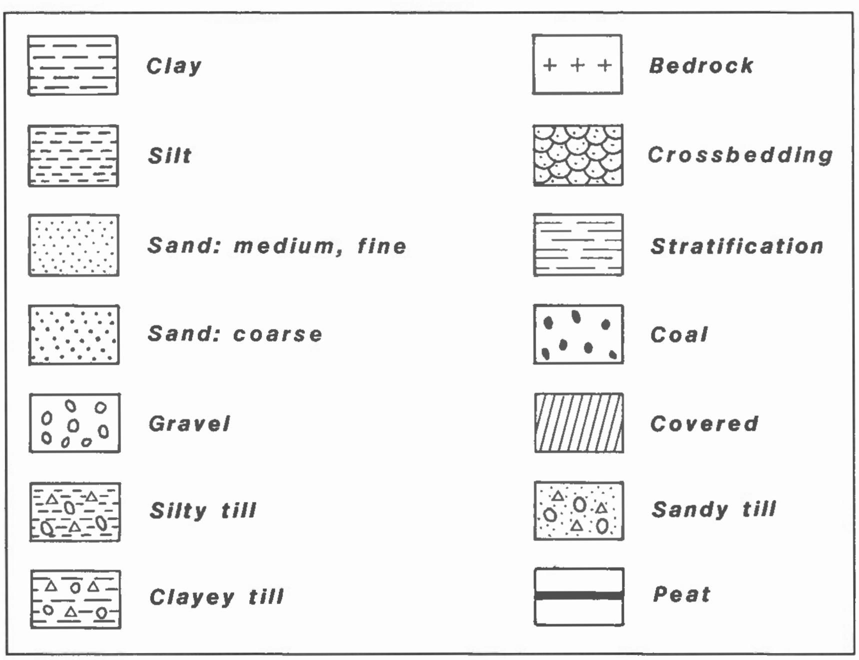
APPENDIX

Description of stratigraphic sections

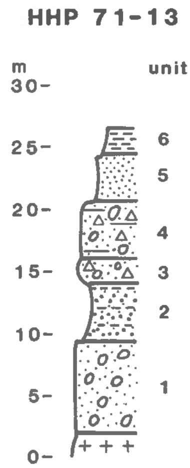
Stratigraphic sections were examined and described briefly by O.L. Hughes, J.A. Pilon, and D.A. Hodgson in 1971, 1972, and 1973 as part of a surficial geology mapping project in the central part of the Mackenzie Transportation Corridor. Stratigraphic descriptions were also made by R.J. Fulton in 1968 as part of GSC Operation Norman. Sections in Fort Good Hope area were studied in 1972 by J. Ross Mackay and in 1973 by W.H. Mathews.

The lack of good exposures and discontinuity of drift cover make it difficult to establish a comprehensive stratigraphic framework. Exposures are mainly developed in scarps along the Mackenzie River and its major tributaries. Within the study area, Mackenzie River drains mainly across thin glacial deposits and along most of its course within the area, it is deeply entrenched into bedrock. There are no stratigraphic sections showing multiple tills that could indicate more than one glaciation. No paleosols were found.

Descriptions of stratigraphic sections are arranged to follow the general pattern of retreat of the ice in order to explain the different surficial geology deposits and related glacial events (Fig. 15). Location of stratigraphic sections are in Figure 5. All sections are described from bottom to top.



HHP 71-13 (Tree River)



2 m of shale exposed above river level.

Unit 1: 7.5 m of gravel and medium to coarse sand.

Unit 2: 4.7 m of fine sand and silt with intercalated layers of coarser sand in some cases with fine gravel.

Unit 3: 2 m of sandy, matrix-supported till. Clasts subangular to subrounded.

Unit 4: 4.5 m of fine sandy, matrix-supported till. Some lenses of silt visible. A 40 cm silty layer provides a sharp contact with unit below.

Unit 5: 3.7 m of medium sand.

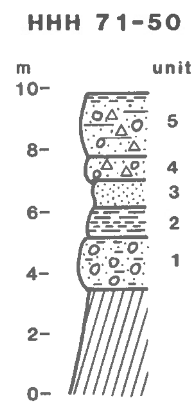
Unit 6: 1.8 m of silt.

Comments: Following retreat of the ice from the Tutsieta Lake Phase maximum, glacial Lake Travaillant was impounded to the north of the ice front. One of the western discharge channels from the front of the ice into the glacial lake was located at Tree River.

From the local setting it is apparent that sand (unit 5) that overlies the till is part of the fan-delta complex built into glacial Lake Travaillant. Unit 2 is probably part of a similar fan-delta complex built into a glacial lake impounded in front of the advancing ice.

A detrital wood fragment obtained from unit 2 was dated at >32 000 BP (GSC-1694). The wood is detrital, hence the date may not be relevant to the sediment.

HHH 71-50 (Tree River)



From river level to 3.5 m. is covered by colluvium.

Unit 1: 1.6 m of gravel, with a fine sand and silt matrix; about 70 per cent coarse clasts.

Unit 2: 1 m of intercalated layers of clay and silt (varves?).

Unit 3: 0.9 m of fine sand.

Unit 4: 0.9 m of sandy, matrix-supported till.

Unit 5: 2.2 m of stony diamicton; weakly expressed stratification due to changes from clayey to sandy to silty till, and lenses of fine laminated sand.

Comments: The gravel of unit 1 is probably glaciofluvial, but the matrix of fine sand and silt and the high percentage of coarse clasts also suggests a possible debris flow origin. Unit 2 is glaciolacustrine. The coarser sediment of unit 3 suggests the near approach of the Laurentide ice front, and unit 4 may be lodgement till deposited by that ice; unit 5 may be a basal meltout or ablation facies of the same till. Unit 4 and 5 may correlate with till units 3 and 4 of section HHP 71-13.

A sequence similar to the two previously described is located approximately 70 km up the Mackenzie River.

HHP 71-11 (south side of Mackenzie River)

From river level to 15 m is a colluviated slope.

Unit 1: 5 m of sand.

Unit 2: 9 m of gravel.

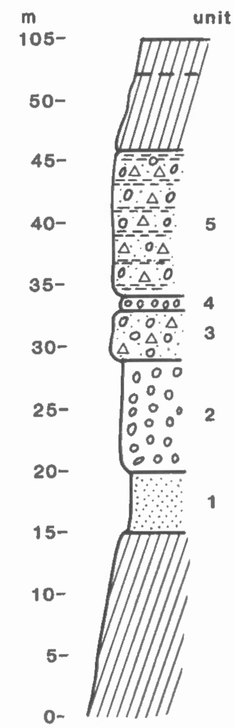
Unit 3: 4 m of sandy, matrix-supported till.

Unit 4: 1 m of gravel.

Unit 5: 12 m of diamicton with lenses of fine sand and silt.

Comments: Units 1 and 2 are considered to be glaciofluvial in origin, and unit 3 is lodgement till. Units 4 and 5 can be interpreted as basal meltout facies of the same till. A colluviated slope conceals 55 m of fine grained sediments above unit 5. These may be deltaic and glaciolacustrine sediments deposited in glacial Lake Travaillant; if so, it is the thickest occurrence of such sediments in the study area.

HHP 71-11



FI 68-84 (north side of Mackenzie River)

From river level to 11.5 m is covered by colluvium.

Unit 1: 6 m of rusty brown, fine- to medium-grained sand and silt, with local beds of coarse grained sand and pebbly sand including coal detritus throughout; mainly horizontal stratification with scattered channel fill structures.

Unit 2: 1.5 m of coarse gravel <20 cm diameter; no discernible fabric.

Unit 3: 1.5 m of reddish, medium grained, stratified sand.

Unit 4: 7.5 m of till; matrix-supported dark clayey, blocky and compact till; wood 1 m from the base was dated at >52 000 BP (GSC-1190).

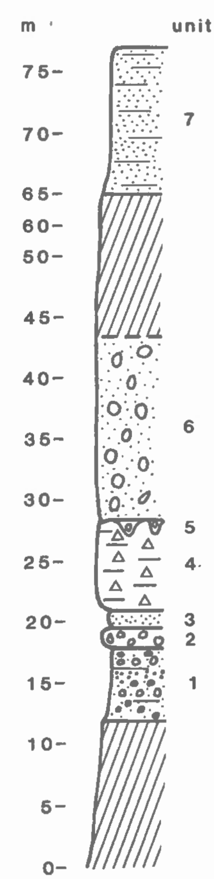
Unit 5: 1.5 m of small discontinuous pockets of rusty cemented sand and gravel.

Unit 6: 15 m of till followed by a 24 m covered interval with fine grained sand(?).

Unit 7: 12 m of fine grained sand, horizontally stratified; the lower 9 m is poorly exposed.

Comments: The surficial material at this site is mapped as a glaciofluvial plain. Glaciofluvial plains and complexes are distributed in patches along Thunder River meltwater channel (see Map 1747A).Units 1 to 3 may be part of a fan-delta sequence built into a glacial lake impounded before the advancing ice sheet, as suggested for locality HHP 71-13, discontinuous sand and gravel parting (unit 5) that separates till units 4 and 6 may be a basal meltout sediment within a single till, if so the combined units form the thickest till sequence recorded from the area. The sand of unit 7 is compatible with the interpretation of the surface as glaciofluvial plain, although it could also be transitional sediment of glaciofluvial and/or glaciolacustrine (Lx).The dated wood from unit 4 (>52 ka) has presumably been recycled from an undetermined source, hence the date is not relevant to the age of the unit.

FI 68-84



FI 68-83 (north side of Mackenzie River)

River level to 10 m covered by colluvium.

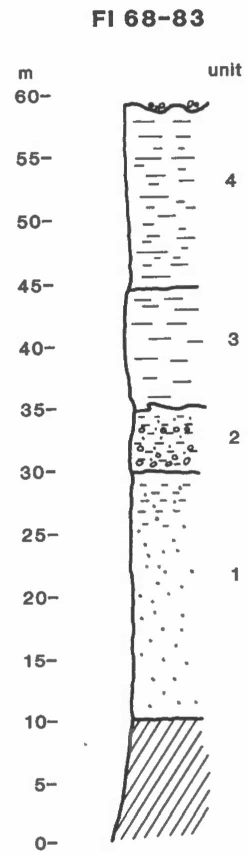
Unit 1 : 20 m of medium grained sand, well sorted; grains are angular to subrounded. The lower 2 m has small scale channel structures and planar stratification. The upper part lacks clearly defined stratification, but has silty lenses up to 40 cm thick.

Unit 2 : 5 m of silt and sand interstratified with poorly sorted gravel; the silt and sand beds are up to 75 cm and the gravels up to 1 m thick. The gravel has scattered boulders <30 cm; pebbles in the gravel generally are subangular.

Unit 3: 8 to 11.5 m of compact dark grey till with a poorly defined base, where the till appears to be interbedded with underlying material.

Unit 4: 15 m of poorly exposed silt and clay. Pebbles on exposure surface suggest that the unit contains pods of gravel or ice- rafted till.

Comments: This section is located approximately 23 km up Mackenzie River from the last site and is within a thermokarst glaciolacustrine plain, reflected by stratigraphic unit 4. Stratified silt and sand below the till may be of deltaic and/or lacustrine origin related to glacial lakes formed during advance and/or retreat of the last ice in the area.



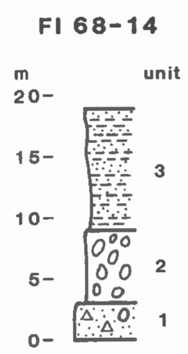
The following sections serve to characterize an extensive deltaic complex (Lx) that was deposited in the eastern reaches of glacial Lake Mackenzie during the Late Wisconsinan (15h). The sections are located in both sides of Hare Indian River some 15 to 25 km from the mouth of the river.

FI 68-14 (Hare Indian River)

Unit 1: 3 m of sandy till.

Unit 2: 6 m of poorly sorted gravel.

Unit 3: 10 m stratified silts and fine grained sand.

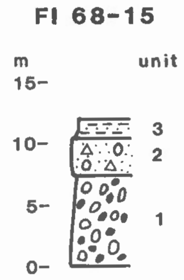


FI 68-15 (Hare Indian River)

Unit 1: greater than 7 m of well-sorted gravel with scattered detrital coal fragments.

Unit 2: 3 m of dark grey, sandy till.

Unit 3: 0.5 to 1.5 m of stratified silt and fine grained sand.

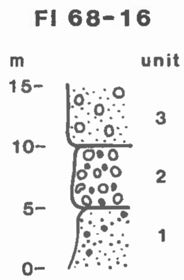


FI 68-16 (Hare Indian River)

Unit 1: 5 m of medium to coarse grained stratified sand exposed about 8 m above river level; contains many layers up to 5 cm thick of coal fragments.

Unit 2: 5 m of well sorted, stratified gravel, with well-rounded pebbles less than 10 cm in diameter; lenses of detrital coal and chert occur in the gravel.

Unit 3: greater than 5 m of sandy, dark grey till.



FI 68-17 (Hare Indian River)

15 m covered from river level.

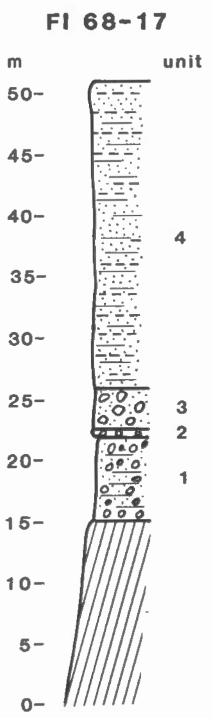
Unit 1: 7 m of stratified, dark grey sand with coal fragments and pebbles; beds less than 60 cm thick; a piece of spruce wood from this unit yielded a date of >38 000 BP (GSC-1285).

Unit 2: 0.5 m of boulder gravel.

Unit 3: 3 m of gravel and sandy gravel, moderately sorted.

Unit 4: 25 m of well stratified silt and fine grained sand.

Comments: Sections FI 68-16 and FI 68-17 are located on opposite sides of a meander in Hare Indian River. The wood from unit 1 is most likely detrital, as suggested by its association with coal detritus. If so, the date is not relevant to the enclosing sediment, which is interpreted as a fluvial channel deposit; till (unit 3) of FI 68-16 may have been eroded in the vicinity of FI 68-17.



FI 68-12 (Bluefish River)

Unit 1: 5 m of sandy till.

Unit 2: 3 m of coarse grained sand with some pebbles.

Unit 3: 10 m of stratified silt and fine grained sand; lower 7 m poorly exposed.

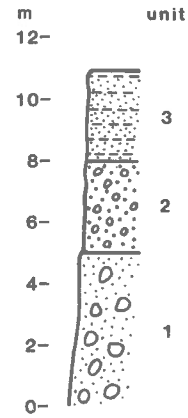
Comments: This section is located at the eastern reaches of the deltaic complex (Lx) in a tributary to Hare

Indian River. Unit 3 is part of the deltaic complex.

In sections FI 68-12 through 68-17, the uppermost unit of silt and sand characterizes of the map unit (Lx). The thickness of this unit increases towards the distal part from location FI 68-12 to FI 68-17 and reflects its origin as a delta.

That part of former glacial Lake Ontaratue that is now drained by the lower reaches of the meandering Ontaratue and Ramparts rivers is blanketed by thick glaciolacustrine sediments (Lp, Lp-k). The following section reflects the wedging out of those thick sediments towards the northwest part of the basin.

FI 68-12



HH 71-54 (Ontaratue River)

From river level 4.7 m of shale is covered by a lag concentrate of broken concretions, and granite, sandstone, and limestone boulders.

Unit 1: 0.6 m of shale.

Unit 2: 1.9 m of compact till.

Unit 3: 0.3 m of stony silt with sandy lenses, grading up into stone-free silt.

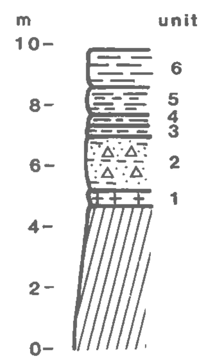
Unit 4: 0.3 m consists of a single varve with a wedge of diamicton (Fig. 20).

Unit 5: 1 m of varved silt and clay; bottom varve consists of 20 cm of silt and 2.0 cm of clay; varves thin upward to 1.3 cm of silt and 0.6 cm of clay.

Unit 6: 0.6 m of massive grey clay.

Comments: The diamicton in unit 5 is probably the edge of a debris flow wedge that came from the snout of the ice.

HH 71-54



HHH 71-36 (Ontaratue River)

From river level to 0.7 m: shale.

Unit 1: 0.7 m of fine sand with small pebbles.

Unit 2: 1.4 m of dark grey clay alternating with gravel and sand, beds have a thickness between 0.5 and 5 cm.

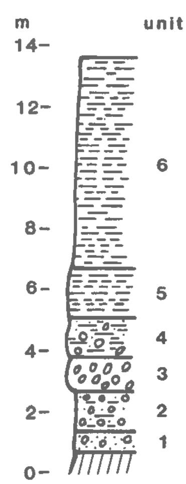
Unit 3: 1.2 m of openwork gravel with clasts up to 8 cm.

Unit 4: 1.3 m clayey silt with 50 per cent small pebble dropstones and coarse sand; poorly defined horizontal lamination.

Unit 5: 1.6 m clay and silt, with more distinct laminations and fewer dropstones than in unit 4 below.

Unit 6: 7 m of silty clay.

HHH 71-36



Comments: This section is located at the northeastern margin of glacial Lake Ontaratue and near the outlet of the lake, via lower Ontaratue River, to glacial Lake Travaillant. The glaciolacustrine sediments are thicker than at HH 71-54, but thicknesses increase towards the axis of the basin.

The abundance of dropstones in unit 4 indicates deposition near the ice margin. The reduction of dropstones in unit 5, and their absence in unit 7, likely reflects the retreat of the ice margin to the southeast.

HHH 71-8 (west side of Mackenzie River)

Unit 1: 45 m (from river level) of silty clay with sand lenses.

Unit 2: 9 m of stratified medium grained sand.

Unit 3: 2 m of crossbedded sand (foresets).

Unit 4: 0.1 m of gravel and cobbles.

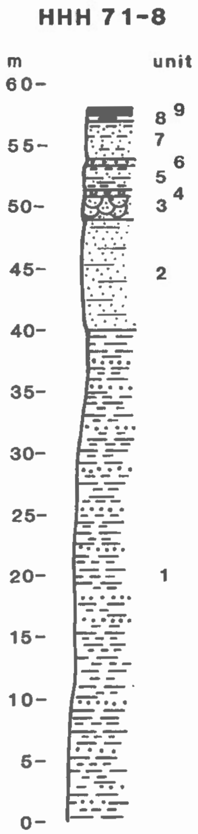
Unit 5: 2.2 m silty sand with clayey silty laminae.

Unit 6: 0.1 m of coarse sand.

Unit 7: 3 m of fine sand and silt.

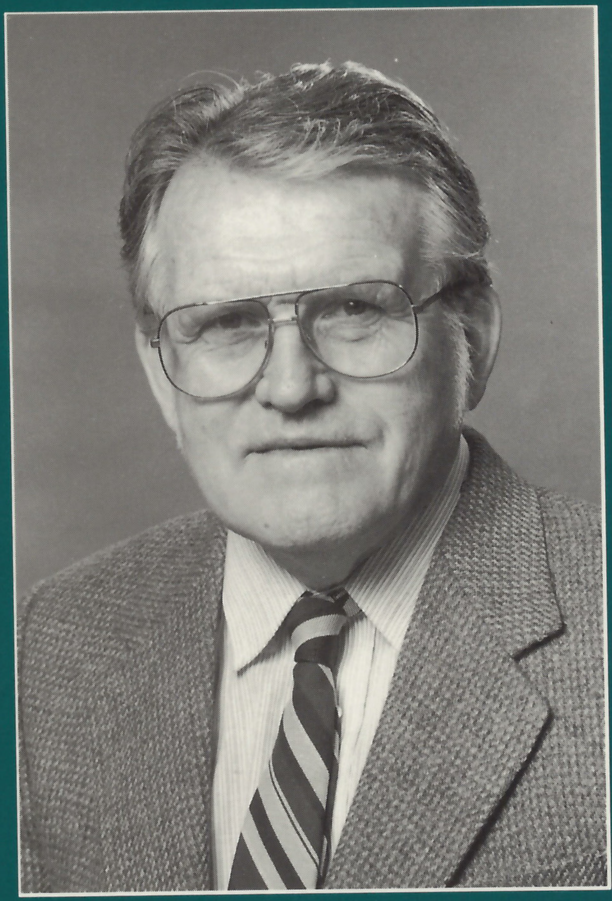
Unit 8: 0.2 m of light grey clay.

Unit 9: 0.2 m of black compacted peat.



Comments: This section is typical of the deltaic complex (Lx) that forms the distal part of Mountain River fan-delta complex. The sediments of the complex came from Mountain River that was a collecting channel for the mountain waters that were carried along the southwest side of the ice sheet and emptied into the northern end of glacial Lake Mackenzie.

A date of 11 200 ± 220 BP (GSC-1573) was obtained from a wood fragment in unit 2. The date gives an approximate age for the drainage of glacial Lake Mackenzie.



In Memoriam
O.L. HUGHES
1924-1992