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Memoir 419

SURFICIAL GEOLOGY OF NORTH-CENTRAL MANITOBA

R.W. Klassen

1986

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Preface

This report and accompanying map are the results of an inventory-type surficial geology mapping project mostly within the Precambrian Shield region of a relatively inaccessible part of north-central Manitoba. Maps were compiled on the basis of airphoto interpretation verified by selective field studies. Information given in this report concerning the nature and distribution of surficial materials and the glacial history of this region will be of value in resource development and related activities as well as those pursuits with a greater academic focus.

John Netterville, whose tragic death, as a result of a car accident in February 1977, prematurely ended a promising career, contributed much to this study. His Master of Science thesis provided the basis for the stratigraphic framework proposed in this report.

R.A. Price
Director General
Geological Survey of Canada

Préface

Le présent rapport et la carte qui l'accompagne résultent d'un projet de cartographie visant à faire le bilan de la géologie des formations en surface, surtout dans le Bouclier précambrien, d'une partie relativement inaccessible du centre-nord du Manitoba. Les cartes ont été dressées à partir d'interprétation de photos aériennes dont certaines données ont été vérifiées au sol. Les renseignements que fournit le rapport au sujet de la composition et de la répartition des dépôts de surface et de la glaciation de la région seront utiles pour la mise en valeur des ressources et d'autres travaux connexes tout en faisant progresser les travaux plus fondamentaux.

Nous devons beaucoup, pour cette étude, au regretté John Netterville, dont la mort tragique en février 1977 a prématurément mis fin à une carrière en plein essor, surtout sa thèse de maîtrise ès sciences qui a fourni la base du cadre stratigraphique mis de l'avant dans le rapport.

Le directeur général de la
Commission géologique du Canada
R.A. Price

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SURFICIAL GEOLOGY OF NORTH-CENTRAL MANITOBA

Abstract

The study area is largely within the Precambrian Shield but includes part of Hudson Bay Lowland and Manitoba Plain. Boreal forest masks and is interspersed with wetlands that cover most of the nearly flat, to gently hilly, drift veneered bedrock.

A record of glaciations is preserved in the thick drift of Hudson Bay Lowland. The oldest till (Amery Formation) underlies intertill sediments rich in pollen (Gods River sediments) that are correlated with the interglacial (Sangamonian?) Missinaibi Formation of the Moose River Basin, Ontario. Three tills and intertill sediments (Wigwam Creek Formation) overlying the Gods River sediments are considered to be deposits of Wisconsinan stades and interstades.

Final deglaciation began in the southwest part of the region about 9500 years ago and ended about 7500 years ago when the Tyrrell Sea covered the Lowland. Lake Agassiz inundated essentially all parts of the region during various phases of deglaciation and was finally drained when it breached the glacial ice dam shortly before the sea entered the northwestern part of Hudson Bay Lowland.

Glaciolacustrine clay and silt blanket much of the former main basin of Lake Agassiz. Patchy veneers of clay and silt on the till plains to the northeast and east of the main basin were also deposited in Lake Agassiz, although some lacustrine sediments are postglacial deposits. A prominent system of kame moraines (Burntwood-Etawney) formed between and along the Keewatin ice lobe over the western part of the region and the Hudson lobe over the eastern part. Bog and fen began developing over northern Manitoba about 6500 years ago.

Résumé

La région étudiée se trouve en grande partie dans le Bouclier précambrien, bien qu'une portion s'étende jusque dans les basses-terres de la baie d'Hudson et dans la plaine du Manitoba. La forêt boréale masque les terres inondables qui la clairsèment et qui recouvrent la plus grande partie de la surface plaquée de dépôts morainiques, dont le relief passe du plat presque uniforme à des collines arrondies.

L'épais matériel détritique qui couvre les basses-terres de la baie d'Hudson témoigne des diverses glaciations. La couche du till le plus ancien (formation d'Amery) repose sous des sédiments interglaciaires riches en pollens (sédiments de River Gods) qui ont été mis en corrélation avec l'interglaciaire de la formation de Missinaïbi (Sangamonien ?) du bassin de la rivière Moose, en Ontario. Trois couches de till et des sédiments interglaciaires (formation du ruisseau Wigwam) sus-jacents aux sédiments de River Gods seraient des dépôts stadiaires et interstadiaires du Wisconsinien.

La dernière déglaciation a débuté dans la partie sud-ouest, il y a environ 9 500 ans, et a pris fin quelque 2 000 ans plus tard, lorsque la mer de Tyrrell a envahi les basses-terres. Le lac Agassiz a submergé pratiquement toute la région à une phase ou à une autre de la déglaciation. Il s'est drainé lorsqu'il a percé le barrage de glaces peu avant l'intrusion de la mer dans la partie nord-ouest des basses-terres de la baie d'Hudson.

Des argiles et limons glaciolacustres recouvrent la plus grande partie de l'ancien grand bassin du lac Agassiz. Ils se sont aussi déposés, par endroits, sur les plaines de till au nord-est et à l'est du grand bassin, dans le lac, bien que certains sédiments lacustres datent en fait de la période postglaciaire. Une chaîne élevée de moraines à kames (Burntwood-Etawney) s'est formée parallèlement et transversalement au lobe glaciaire du Keewatin, dans l'ouest, et au lobe de l'Hudson, dans l'est. Des tourbières et des marais ont commencé à se former dans le nord du Manitoba, il y a environ 6 500 ans.

INTRODUCTION

This report completes a reconnaissance mapping program covering some 160 000 km^2 of terrain mostly within the Precambrian Shield of north-central Manitoba (Fig. 1, 2; Klassen and Netterville, 1979a-c, 1980a-i). Field work, begun in 1971 and completed in 1973, was conducted by a three man, helicopter supported mapping party. It entailed ground and aerial observations in selected localities within various map units delineated on the basis of airphoto interpretation.

Geological mapping in this region is hampered considerably by the nature of the vegetation and terrain. It is within the boreal forest zone that is characterized by closed to open stands of black spruce and jackpine on and between extensive wetlands. Most of the field data were obtained in the vicinity of landing sites on open fen adjacent to bogs or to well drained surfaces. Although ground checks were generally widely spaced (average one site per 260 km^2), locations were chosen primarily for the purpose of 'typing' map units and not on the basis of a grid. Thus, in areas of extensive map units, sites were more widely spaced than in areas of smaller but contrasting map units. Pits were dug by hand to determine the nature of the surficial sediments at sites where the permafrost or organic cover was thin or absent. Where sediments were blanketed by frozen peat, sampling of the underlying mineral sediments was done by means of a special type of hand auger. Ground control was at

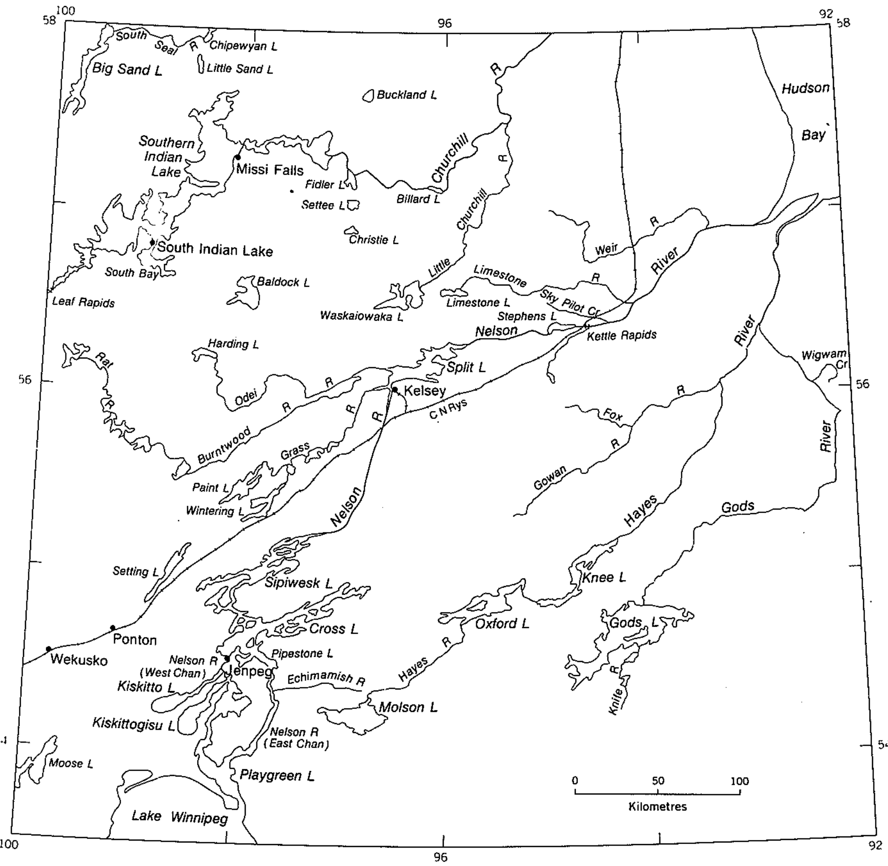

Figure 1

Location map.

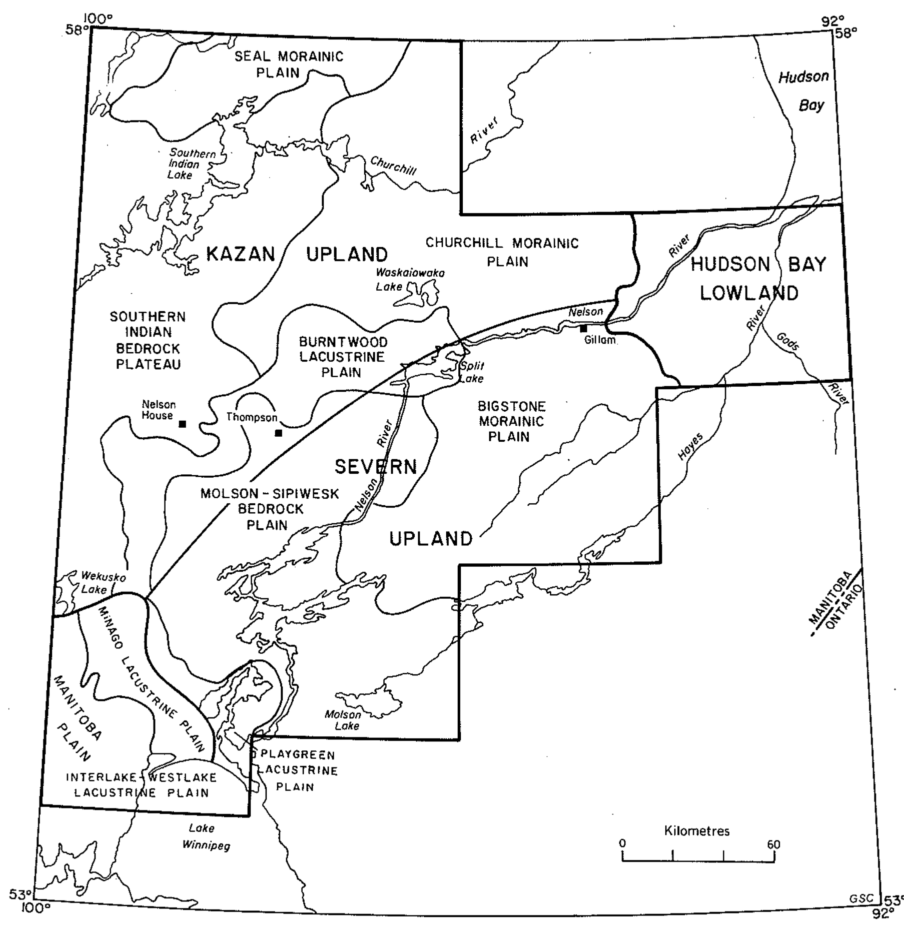

Figure 2

Physiographic regions of the study area (major units after Bostock, 1969).

best minimal and "characterization" of map units was extrapolated over considerable distances. Greater detail was obtained in some localities from exposures along stream banks, escarpments, roads and railway cuts, and a few borings in the vicinity of Thompson. Exposures in the thick drift along the lower reaches of Nelson and Hayes rivers provided the most significant stratigraphic information in this region.

Previous work

Notes on the geographical and geological aspects of this region are included in some of the earliest reports of exploration in this country. Hayes River, which crosses part of the study area, was the staging point for exploration of the interior and one of the great trade routes of the West until the completion of the trans-continental railway to Winnipeg in 1877. It naturally followed that Nelson and Churchill rivers and their tributaries were avenues for exploration and mapping of much of this region. Reports based on field studies by Bell (1880), Tyrrell (1897, 1916), McInnes (1913), Johnston (1918), and Alcock (1918, 1921a) include most of the information available up to the last decade on the general nature of the terrain and surficial deposits of this vast region. Bedrock maps with descriptive notes are published for more than half of the study area (Wright, 1948; Harrison, 1950; Quinn, 1955a, b, 1959, 1961; Mulligan, 1956; Kretz, 1959); the maps show glacial striae and some of the prominent glacial landforms and the notes include generalizations concerning the "drift" or "overburden".

Regional glacial maps of Wilson (1958) and Prest et al. (1967), compiled on the basis of airphoto interpretation, outline certain broad categories of glacial landforms and deposits in the study area. A soils report (Ehrlich et al., 1959) on a small part of the study area includes a figure map showing the distribution of surficial deposits between latitudes 53° and 58° and a brief discussion of the types of deposits. Studies of the late glacial chronology and ice retreat (Craig, 1969) and the Quaternary stratigraphy of the Hudson Bay Lowland (McDonald, 1969) were part of a geological reconnaissance of the Hudson Bay Lowland in 1967 known as "Operation Winisk".

Acknowledgments

The late John Netterville shared much of the responsibility for map preparation and fieldwork with the author. His Master of Science thesis on the Quaternary stratigraphy along Gods River was basic to the stratigraphic framework proposed in this report.

Personnel of Manitoba Hydro were helpful in making available relevant reports and data from damsite investigations and for allowing the use of their base camp facilities at minimal cost. Particular thanks are due E.K. Overgaard of the System Planning Division for his efforts regarding the former.

George Sabourin and Robert Sharon assisted in the field during 1972 and 1973, respectively.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

Regional setting

Most of north-central Manitoba is within the southern part of Kazan Upland and northern part of Severn Upland of the Canadian Shield (13 8000 km^2), although minor parts of the Manitoba Plain (7000 km^2) and Hudson Bay Lowland (15 000 km^2) in the southwest and northeast, respectively are also included (Fig. 2; Bostock, 1970).

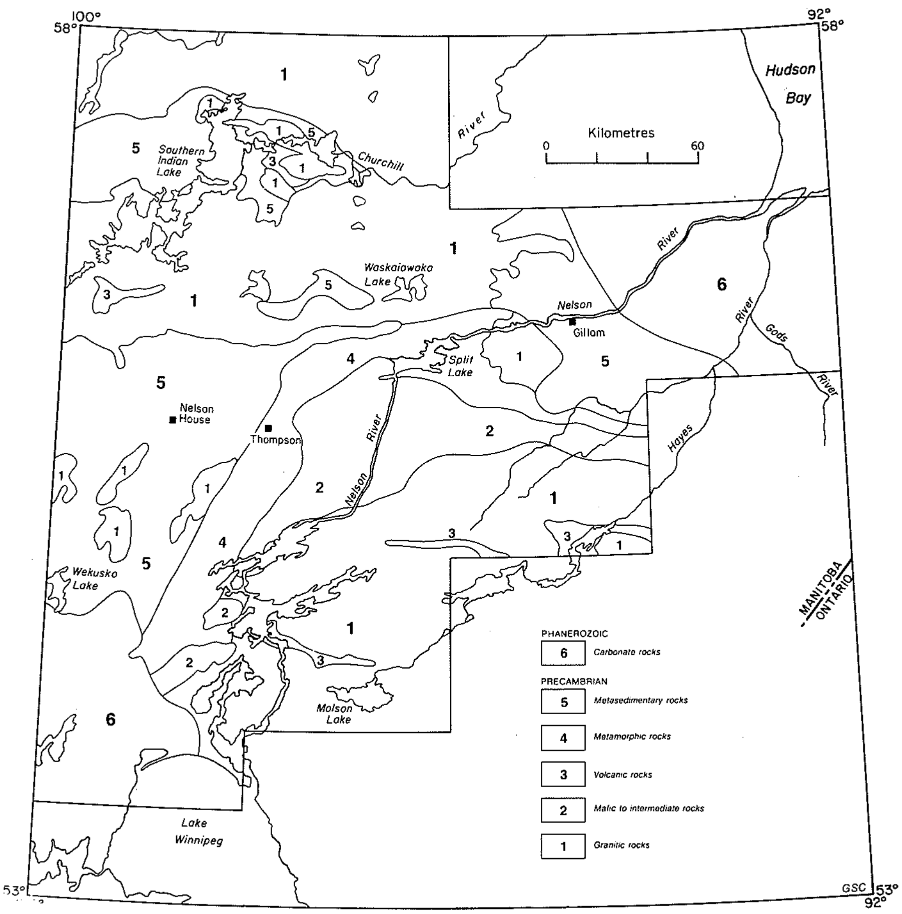

Figure 3

Bedrock geology of north-central Manitoba (modified after Manitoba Mineral Resources Division, 1979).

The Shield part is composed mainly of Precambrian granitic rocks interspersed with volcanic rocks and belts of gneisses and schists (Fig. 3). Manitoba Plain and Hudson Bay Lowland are underlain by nearly flat-lying Paleozoic carbonate rocks. Bostock (1970, p. 13, 16) described these uplands of the Shield as rather expressionless, rolling, lake spattered country where relief rarely exceeds 60 to 90 m. The physiographically similar Kazan and Severn uplands lie within the Kazan and James regions which make up the northern and southern parts, respectively, of the Canadian Shield. The regions in turn are the physiographic equivalents of geological structural provinces that have distinct structural trends and styles of folding (Stockwell et al., 1970). Structural trends of the Severn Upland are reflected by the alignment of large lakes roughly to the southwest, whereas on the Kazan Upland similar trends are not apparent.

Early reports on the bedrock geology of the western parts of the study area stated or implied that the surface topography generally reflects bedrock structure. Alcock (1918, p. 9D) commented on the close harmony of topography and bedrock structure in the Wekusko area and cited specific examples where lakes are aligned to the strike of formations cutting across the direction of glacial movement. He also observed a close relationship of topography and bedrock type where valleys are underlain by softer gneisses and schists, and where interstream areas are underlain by granite. Wright (1948, p. 2) made similar observations in the Uhlman Lake area where "Granitic rocks underlie rugged terrain and sedimentary rocks underlie either long narrow troughs. . . or larger, low lying areas".

Ambrose (1964) presented well documented evidence indicating that the topography of the Shield predates Paleozoic time and that it was modified relatively little by erosion and deposition since then. White (1972) challenged this interpretation and speculated that Shield areas were deeply eroded during Pleistocene glaciations. His view, however, appears incompatible with field evidence from the map area and that given by Ambrose (1964). Arguments against White's proposal were also presented by Gravenor (1975) and Sugden (1976).

Kazan and Severn uplands

Kazan Upland is herein further divided into physiographic units named the Southern Indian bedrock plateau, the Seal morainic plain, Churchill morainic plain, and the Burntwood lacustrine plain (Fig. 2). Severn Upland is divided into Molson-Sipiwesk bedrock plain, Bigstone morainic plain and Playgreen lacustrine plain (Fig. 2). The subdivisions were made mainly on the basis of Map 1603A which accompanies this report.

Southern Indian bedrock plateau

Southern Indian bedrock plateau covers about 35 000 km^2 of mostly hilly, drift veneered bedrock terrain, and intervening low areas of organic terrain in the western part of the area in the vicinity and south of Southern Indian Lake (Fig. 2). The surficial materials units are predominantly areas of bedrock outcrop, glaciolacustrine veneer over bedrock, and morainic veneer over bedrock. Most of the bedrock plateau is underlain by granitic rocks. Granitized gneisses and schists, sedimentary gneisses and schists, along with volcanic rocks, occur in the southern part (Fig. 3).

The surface, relative to the other physiographic subdivisions, is generally hilly although there is considerable variation in relief and topography. Elevations are generally 270 to 300 m except in the vicinity of Big Sand Lake where elevations of 335 to 365 m are common with the highest elevation being a bedrock hill about 90 m high and 425 m a.s.l. The hilliest parts are in the Uhlman Lake (64B) and the northwest part of Nelson House (63O) map areas where local relief commonly ranges from 23 to 75 m; elsewhere the surface is broadly irregular to rolling with 8 to 23 m relief, broken in places by clusters of bedrock hills.

A veneer of bouldery till and/or varved clay is common on the bedrock hills although extensive patches of bedrock outcrop on the tops and sides of the hills (Fig. 4, 5). Small basins and randomly oriented valleys between the bedrock hills and rises are typically bottomed by bog and fen underlain by glaciolacustrine clay. Bedrock surfaces are most extensive along the southwestern margin of this subdivision.

Seal and Churchill morainic plains

Seal and Churchill morainic plains in the northern and northeastern part of the study area (Fig. 2) consist of about 25 000 km^2 of nearly flat, gently irregular ground moraine

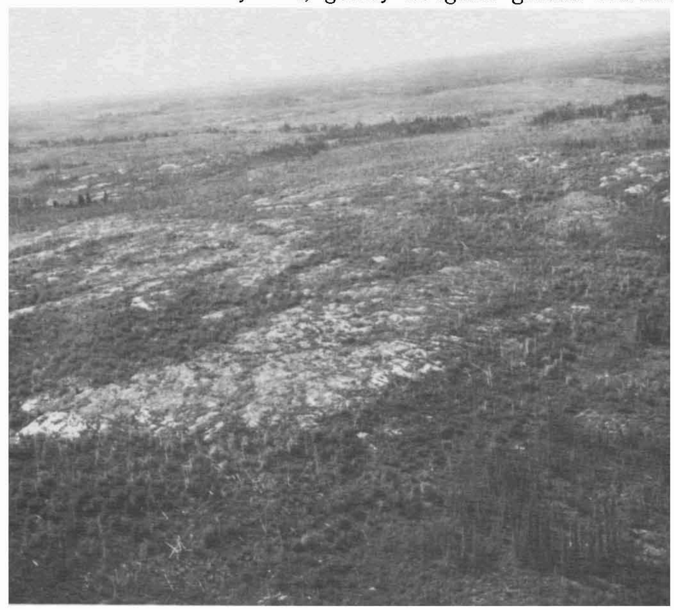

Figure 4. Aerial view of landscape typical of the Southern Indian bedrock plateau in the Uhlman Lake (64B) area. Light coloured patches are bedrock outcrops separated by scattered clusters of trees and bog. GSC 161422

Figure 5. Ground view of bedrock surface of the Southern Indian bedrock plateau in the northeast part of the Nelson House (63O) area. GSC 163389

with local relief generally less than 8 m. Elevations range from 120 m along the eastern boundary with Hudson Bay Lowland to 275 m along the western boundary with the Southern Indian bedrock plateau. Wetlands cover the numerous shallow local depressions between till and/or clay blanketed rises and sporadic bedrock outcrops. A few prominent morainic ridges and clusters of hills, mostly 15 to 35 m high that are parts of major moraine systems, cross parts of the plains.

Seal morainic plain, a belt covering some 5000 km^2, is blanketed by till of northern (Keewatin) provenance. Churchill morainic plain, bounded on the east by Hudson Bay Lowland and on the west and south by parts of the Burntwood-Etawney moraine system (Map 1603A), is blanketed by till of northeastern (Hudson) provenance.

Bigstone morainic plain

Bigstone morainic plain in the southeastern part of the study area (Fig. 2) consists of about 29 000 km^2 of gently irregular terrain with local relief generally from 1 to 8 m. Elevations in the western and southwestern parts are commonly 215 m and gradually decrease northeastward to 120 m along the boundary with Hudson Bay Lowland. The plain is a great expanse of ground moraine marked by drumlins and drumloids oriented west and southwest (Fig. 6).

Outcrops of granite and diorite are fairly common in the western and southern part, but in the northeastern part, where the drift thickens, the outcrops are generally restricted to stream channels or small lakes. The shorelines at these lakes are typically regular and contrast with the angular outlines of large lakes in aligned bedrock basins in the southwestern and in the extreme southeast corner where this subdivision is transitional to the Molson-Sipiwesk bedrock plain.

Molson-Sipiwesk bedrock plain

This subdivision covers about 31 000 km^2 in the south-central part of the study area. Much of central and southeast part is a gently irregular to rolling bedrock plain with 8 to 15 m relief that gives way to a broadly irregular to hilly belt with 15 to 40 m relief in the northwestern part. The extreme northeastern and southern parts bordering the lacustrine plains are nearly flat. Surface elevations are about 240 m in the southwestern part and gradually decrease northeastward to about 180 m along Nelson River.

The bedrock is predominantly granite and diorite except for a northeast trending belt of granitized gneiss and schist in the hilly northwestern part.

Lakes of various sizes are oriented along the southwesterly structural trend of bedrock. The large lakes in particular have angular shorelines reflecting bedrock topography and structure in an area where the drift cover is thin and patchy. Lake shorelines range from gentle slopes, such as one along Sipiwesk Lake, to steep bluffs up to 38 m high, such as those along parts of Wintering and Paint lakes. The channels of Nelson and Odei rivers in the northeast part near Split Lake are incised some 23 to 30 m below the surface of the nearly flat bedrock plain, but elsewhere these channels and the river channels between large lakes have bedrock banks mostly 8 to 15 m high.

Figure 6. Aerial view west across the Bigstone morainic plain in the northeast part of the Knee Lake (53M) map area. The drumlin in the centre is about 5 m high, 30 m wide, with a surface of loose, sandy till. GSC 161389

Burntwood lacustrine plain

This subdivision covers two main glaciolacustrine basins connected by two small ones covering about 12 000 km^2 in a southwest-trending belt from the centre of the study area. The surface is generally flat to gently irregular with local relief under 5 m and elevations from about 275 m in the southern part to 180 m in the northeast part (Fig. 7). Patches of hilly bedrock terrain occur in places and have substantially higher local relief. Bog and fen, underlain by glaciolacustrine silt and clay, are widespread.

Playgreen lacustrine plain

This subdivision covers about 2500 km^2 between the Minago lacustrine plain and the western boundary of Molson-Sipiwesk bedrock plain. The gently irregular to nearly flat surface is covered by extensive wetlands over glaciolacustrine silt and clay. A granitized gneiss and schist bedrock complex underlies the northwest part and predominantly granitic and dioritic bedrock the southeast part. Much of the plain is covered by Kiskitto, Kiskittogisu, and Playgreen lakes with markedly rounded, gently sloping shorelines of silt and fine sand washed from glaciolacustrine deposits (Fig. 8).

Figure 7. Aerial view west across Rock Lake on the Burntwood lacustrine plain in the southwest part of the Split Lake (64A) area. Scattered bedrock outcrops (foreground) have a darker colour, reflecting mixed tree cover that contrasts with adjacent bogs and black spruce cover. GSC 161391

Figure 8. Aerial view northwest across the southern part of the Playgreen lacustrine plain. Excavations are for deepening the 'eight mile channel' between Playgreen Lake (foreground) and Kiskittiguso Lake. This is part of the water regulating system of the Nelson River hydroelectric development. GSC 163312

Manitoba Plain

Manitoba Plain covers about 7500 km² of the southwestern part of the study area (Fig. 2) which is underlain by Paleozoic carbonate bedrock (Fig. 3). The northeastern part of the plain consists of about 2500 km² of extensive wetlands over lacustrine clay and is herein named the Minago lacustrine plain. The name Interlake-Westlake lacustrine plain (Weir, 1960, p. 7) is retained for the area to the southwest where carbonate bedrock is at or near the surface.

Minago lacustrine plain

The eastern boundary of this subdivision coincides with the Precambrian-Paleozoic bedrock contact (Fig. 2, 3). The western boundary with the Interlake-Westlake lacustrine plain is marked by a line of east-facing carbonate bedrock bluffs with local relief increasing from about 3 m in the north to 30 m in the south. The bluffs mark a gradual thickening of the carbonate bedrock that dips gently southwest beneath the Interior Plains.

The wetland cover over this flat plain is broken in places by a south trending line of abandoned beaches of carbonate rock rubble and/or sand. These features are in part developed along the crests of low bedrock scarps similar to the distinctive ones that mark the western boundary. Elevations drop gradually to the east and southeast from about 275 m to 215 m along the boundary with Playgreen lacustrine plain.

Interlake-Westlake lacustrine plain

This subdivision consists of nearly flat or broadly rolling carbonate bedrock terrain. Local relief is generally less than 8 m, although it may reach some 30 m between broad, southwest trending ridges in the southwestern part.

Lacustrine clay and till, or carbonate bedrock rubble occur as a discontinuous veneer over carbonate bedrock. Drumlins, minor glacial grooves, and segments of abandoned beaches occur here and there.

Hudson Bay Lowland

The part of Hudson Bay Lowland within the study area covers about 15 000 km². The boundary between Hudson Bay Lowland and Kazan Upland is a till scarp about 14 m high with an abandoned marine beach along the crest; the boundary with Severn Upland is marked by a string of low, discontinuous abandoned beaches.

The Lowland is a flat plain consisting of wetlands over a veneer of mostly marine sediments, separated from the underlying Paleozoic carbonate bedrock by thick till. Tyrrell (1913, p. 12) aptly referred to it as the "Archudsonian Swamp". The only distinctive landforms, other than the organic ones, are low abandoned marine beach ridges that are scattered here and there, and the channels of Nelson, Hayes, and Gods rivers incised 15 to 60 m below the level of the plain.

Drainage systems

Two major river systems of Western Canada – the Nelson and Churchill – cross the study area and much of the Hayes River drainage basin is in the southeastern part. The headwaters of South Seal and Knife rivers of the Seal-Caribou drainage basin are just inside the northern boundary. The main rivers and their tributaries across the Shield typically consist of rock-bound channels, less than 1 km wide, marked by rapids and waterfalls joining lakes ranging in size from somewhat greater than channel width to water bodies tens of kilometres long and several kilometres wide. Southern Indian Lake along the Churchill drainage system is the largest lake, with a length of nearly 160 km and a width of about 24 km at its widest parts. The average gradient of these systems of lakes and rivers across the Shield is about 0.3 m per km with gradients of 0.5 to 1 m per km along connecting channels between lakes and the deeply incised channels across the drift of Hudson Bay Lowland.

Nelson River

The Nelson River system lies entirely within the study area. The upper reaches include two narrow lakes and connecting channel systems referred to as the East and West Channels. These originate in a single channel draining the northeast end of Lake Winnipeg and continue as separate channels for about 100 km to Cross Lake. Below Cross Lake the system continues north and northeastward for about 300 km across the Shield as a series of lakes and interconnecting channels.

A straight stretch of channel, oriented north-northeast for some 100 km between Sipiwesk and Split lakes, is atypical of most river channels in this part of the Shield. It is a structurally controlled feature with a width of about 600 m and bank heights of 15 to 23 m. Bell (1880, p. 24c) noted that the west bank of the channel is mainly in bedrock and the east bank mainly in till which led him to propose that this segment was in a preglacial valley that was excavated, along the course of a great dyke, thus invoking structural and lithological control. Newbury (1968, p. 43) cited somewhat more detailed evidence for the relationship of this feature to the structure and lithology of the bedrock.

Dams at Kelsey, just above Split Lake, and at Kettle Rapids, about 80 km below Split Lake, have resulted in expansion of pre-existing lakes as far upstream as

Sipiwesk Lake. Stephens Lake is the area of most extensive flooding and includes the forebay of Kettle Rapids dam which joins the considerably expanded former Moose Lake.

Nelson River across Hudson Bay Lowland below Kettle Rapids, occupies a fairly straight, steep sided trench between 1 and 2 km wide and 30 to 60 m deep with an average gradient of 0.8 m per km. A series of rapids in carbonate bedrock marks the drop from the Shield to the Lowland along the upper 40 km reach. The channel is cut mostly in till and bottoms in carbonate bedrock. Most stretches of the bottom are covered from bank to bank by fast water.

Grass and Burntwood rivers drain the west-central part of the study area and join the Nelson near or via Split Lake. Rat River, which forms part of the headwaters of Burntwood River, occupies a channel used for diverting water from the Churchill drainage into the Nelson drainage by means of a weir constructed at the outlet of Southern Indian Lake that raises the lake level by about 3 m.

Churchill River

The Churchill drainage system in the study area consists mainly of a string of lakes joined by short connecting channels. A 56 km stretch of channel between Fidler and Billard lakes is the longest part in the study area. The channel width is variable with parts up to 1 km wide. Banks are typically 6 to 9 m high although they are up to 20 m high where the river crosses the moraine east of Fidler Lake.

Little Churchill River is the principal tributary of Churchill River in the map area. It flows from Waskaiowaka Lake and joins Churchill River outside the map area.

Hayes River

Hayes River flows from Molson Lake in the southeast corner of the study area across about 300 km of the Shield, then continues another 130 km across Hudson Bay Lowland and flows into the sea. Oxford and Knee lakes, along with numerous smaller lakes, are part of two segments of this drainage system outside the map area. The average gradient of this system across the Shield is 0.3 m per km, whereas across the Lowland it is nearly 1 m per km. Steep banks some 23 to 30 m high, mainly in silt and clay, are typical of the lower part.

Gods and Fox rivers in the area are the principal tributaries of Hayes River. The lower 50 km part of Gods River across Hudson Bay Lowland has a gradient of 0.5 m per km. The 15 to 23 m-high banks are cut in till and the underlying carbonate bedrock is commonly exposed along upstream parts. Fox River drains the Shield between Hayes and Nelson rivers; the stretch near the confluence with Gowan River is incised through till, 15 to 30 m thick, into the underlying bedrock.

SURFICIAL DEPOSITS AND LANDFORMS

Map 1603A shows a generalized distribution of surficial materials at 1:500 000 scale. This map was compiled from 1:250 000 scale surficial geology maps of the study area (Klassen and Netterville, 1979 a-c, 1980 a-i) but does not include organic units; the reader is referred to the larger scale maps for a more detailed portrayal of the surficial geology.

The surficial deposits most common in the study area are ground moraine, ice contact, sand and gravel in the form of kame moraines, and silt and clay of glaciolacustrine and marine origin. The distribution and geomorphology of the deposits were determined by means of airphoto interpretation. Additional information concerning the composition and thickness of the surficial materials is included in the section on *Quaternary Stratigraphy.*

Morainal deposits

Ground moraine (M, Mv)[1]

Ground moraine is widespread over the Seal, Churchill, and Bigstone morainic plains that together make up an area of nearly 55 000 km^2. The surface is nearly flat or gently irregular with local relief typically less than 8 m. Bogs covered with black spruce and patches of open fen occur over flat areas or between drumloids or rises.

Unmodified ground moraine occurs within the Seal morainic plain and the northern part of the Churchill morainic plain. Scattered drumlins are oriented to the south and southwest in the northwest part of the Churchill morainic plain and to the southeast in the Seal morainic plain. Although the ground moraine forms a fairly continuous blanket over bedrock, its general thickness is less than 3 m, except locally in bedrock depressions or valleys transverse to the direction of ice flow where thicknesses probably range from 6 to more than 15 m. The surface till in the western part is somewhat sandier and has a lower carbonate content than the surface till in the eastern part (Tables 1, 2).

Bigstone morainic plain is a vast area of ground moraine marked by drumlins and drumloids oriented west and southwest (Fig. 6). The till is generally thinner than it is over the plains to the north and scattered outcrops of bedrock occur locally. The tops and sides of drumlins expose a silty till somewhat eroded by lakewater. The average carbonate content of the till is slightly higher than the surface till of Churchill morainic plain (Tables 1, 2).

Hummocky moraine (Mh)

Hummocky moraine has a limited distribution in the map area (Map 1603A). Clusters of till knolls and depressions with local relief of 8 to 25 m are here designated as hummocky moraine, although it lacks the distinctive dead-ice features that characterize this type of moraine on the prairie uplands.

The largest patch of hummocky moraine forms part of the northern terminus of a kame moraine (Settee moraine) between Christie and Settee lakes; till hummocks and closed depressions are part of this regional kame moraine complex that here is up to about 24 km wide. Another occurrence of hummocky moraine trends to the southeast about 30 km east of the Christie Lake locality. Numerous, small patches of till hummocks occur within the ground moraine in the eastern part of the Churchill morainic plain and the north-central part of the Seal morainic plain.

Glaciofluvial deposits

Ice contact deposits (G)

Kame moraines (Ih)[2]

Kame moraines, the most prominent landforms in the region, are markedly continuous systems of broad ridges, 15 to 90 m high and several kilometres wide, composed mainly of sand and some gravel. Surfaces are commonly pitted and boulders occur here and there.

The main system of ridges crosses the map area from north to south and is joined by several other segments trending southeast and west imparting a broadly dendritic aspect to it (Map 1603A). Although parts of this system were outlined on bedrock maps (Kretz, 1959; Mulligan, 1956) it was first shown on a regional map by Wilson (1958) and was later referred to as the Burntwood-Etawney moraine system by Elson (1961, p. 62). The name is retained in this report but each segment is here described and named separately.

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[1] Unit designators on Map 1603A.

[2] This map unit designator is used in Klassen and Netterville (1979 a-c; 1980 a-i). On Map 1603A all ice contact deposits have been combined into a single unit.

Table 1. Physical properties of till stratigraphic units of the Hudson Bay Lowland, Bigstone River and Churchill morainic plains

Unit	Grain Size (%) gravel	sand	silt/clay	Carbonate (% silt)	Thickness (m)	Colour	Location	Sample	Section (Appendix 1)	Physiographic Unit
Upper Till	2	53	45	28	1.8	dark greyish brown (10YR 4/2)	56°10'N, 92°32'W	116-72	1	
	13	45	62	27	2.1	dark greyish brown (10YR 4/2)	56°07'N, 92°27'W	106-72	2	
Member,	5	34	61	26	3	dark greyish brown (10YR 4/2)	56°17'N, 92°47'W	124-72	4	
Wigwam	5	47	48	30	2.1	dark greyish brown (10YR 4/2)	56°03'N, 92°24'W	68-72	9	
Creek Fm.	2	50	48	34	1.5	dark greyish brown (10YR 4/2)	56°05'N, 92°25'W	91-72	5	
	6	32	62	26	1.5	dark greyish brown (10YR 4/2)	56°03'N, 92°23'W	54-72	6	Hudson Bay
	8	40	52	25	12.8	brown (10YR 5/2)	56°01'N, 92°20'W	65-72	7	
	6	36	58	24		dark greyish brown (10YR 4/2)	56°01'N, 92°20'W	51-72	7	Lowland
	3	40	57	27	6.7	dark greyish brown (2.5Y 4/2)	56°03'N, 93°17'W	126-72	11	
	2	29	59	29	3.6	dark greyish brown (10YR 4/2)	56°16'N, 92°46'W	121-72	None	
	24	31	45	23	3.4	dark greyish brown (2.5Y 4/2)	56°44'N, 93°36'W	21-72	18	
	9	24	67	33	3.1	dark greyish brown (2.5Y 4/2)	56°37'N, 93°38'W	22-72	19	
	16	43	41	28	0.3	greyish brown (2.5Y 5/2)	56°39'N, 93°49'W	20-72	21	
	6	35	59	22	1.2	pale brown (10YR 6/2)	55°50'N, 94°13'W	176-72	24	Bigstone morainic plain
	23	42	35	19	1.2	pale olive (5Y 6/3)	56°36'N, 94°16'W	17-72	25	Churchill
	7	40	53	19	10.5	greyish brown (2.5Y 5/2)	56°45'N, 94°23'W	196-72	26	morainic plain
	4	34	62	23		brown	56°13'N, 96°42'W	180-72	27	
Average	*9*	*39*	*53*	*26*	*3.6*					
Middle Till	11	44	45	28	1.8	olive grey (2.5Y 4/2)	56°01'N, 92°20'W	64-72	6	
	3	43	54	38	6.1	dark grey (5Y 4/1)	56°10'N, 92°32'W	115-72	1	
Member,	4	55	41	34	12.2	very dark greyish brown (10YR 3/2)	56°03'N, 92°23'W	53-72	6	
Wigwam	2	34	64	28	3	brown (10YR 4/3)	56°17'N, 92°47'W	123-72	4	Hudson Bay
Creek Fm.	2	45	53	30	7	dark greyish brown (2.5Y 4/2)	56°03'N, 92°24'W	67-72	9	
	35	33	32	25	0.6	dark greyish brown (10YR 4/2)	56°05'N, 92°25'W	90-72	5	Lowland
	8	27	65	24	9.1	olive grey (5Y 4/2)	56°45'N, 93°36'W	9-72	17	
	6	28	66	22	3.1	dark grey (5Y 4/2)	56°59'N, 93°49'W	19-72	21	
	3	26	71	25		yellowish brown (10YR 5/4)	55°50'N, 94°13'W	175-72	27	Bigstone morainic plain
	8	34	58	26		light olive brown (2.5Y 5/4)	56°36'N, 94°16'W	16-72	28	Churchill
	4	28	68	28	10.6	yellowish brown (10YR 5/4)	56°45'N, 94°23'W	197-72	29	morainic plain
Average	*8*	*36*	*56*	*28*	*6*					
Lower Till	3	59	38	30	3.0	dark olive grey (5Y 3/2)	56°10'N, 92°32'W	114-72	1	
	11	33	56	28	6.1	dark greyish brown (10YR 4/2)	56°07'N, 97°27'W	105-72	2	
Member,	6	32	62	27		dark greyish brown (10YR 4/2)	56°07'N, 97°27'W	104-72	2	
Wigwam	11	26	63	27		dark greyish brown (10YR 4/2)	56°07'N, 97°27'W	103-72	2	
Creek Fm.	9	29	62	24		dark greyish brown (10YR 4/2)	56°07'N, 97°27'W	102-72	2	Hudson Bay
	6	29	65	28		dark greyish brown (10YR 4/2)	56°07'N, 97°27'W	101-72	2	
	10	43	47	29		dark greyish brown (10YR 4/2)	56°07'N, 97°27'W	108-72	2	Lowland
	2	35	63	32	6.1	dark greyish brown (10YR 4/2)	56°17'N, 92°47'W	122-72	4	
	7	29	64	25	4.6	dark greyish brown (10YR 4/2)	56°05'N, 92°25'W	88-72	5	
	11	44	45	28	1.8	olive grey (2.5Y 4/2)	56°01'N, 92°20'W	64-72	7	
	3	28	69	30	9.1	olive (5Y 4/3)	56°45'N, 93°36'W	10-72	17	
Average	*7*	*35*	*58*	*29*	*5*					
Amery Fm.	2	48	50	28	6.1	olive grey (5Y 5/2)	56°10'N, 92°32'W	110-72	1	
	1	40	59	28		olive grey (5Y 5/2)	56°10'N, 92°32'W	119-72	1	
	1	35	64	24		olive grey (5Y 5/2)	56°10'N, 92°32'W	109-72	1	
	6	35	59	25	5.5	dark greyish brown (2.5Y 4/2)	56°07'N, 92°27'W	98-72	2	Hudson Bay
	7	31	62	27	7.6	olive grey (5Y 5/2)	56°07'N, 92°27'W	95-72	none	
	2	45	53	36	6	dark greyish brown (2.5Y 4/2)	56°04'N, 92°25'W	69-72	none	Lowland
	10	28	62	33	9.1	olive grey (5Y 4/2)	56°45'N, 93°36'W	11-72	17	
				30	10.3	olive grey (5Y 4/2)	56°32'N, 94°09'W	4-72	22	
Average	*4*	*38*	*58*	*29*	*8*					

Table 2. Physical properties of surface tills in north-central Manitoba

Physiographic Unit	Grain Size (%) gravel	sand	silt/clay	Carbonate (% silt)	Colour	Location
	2	53	45	28	dark greyish brown (10YR 4/2)	56°10'N, 92°32'W
	3	45	62	27	dark greyish brown (10YR 4/2)	56°07'N, 92°27'W
	5	34	61	26	dark greyish brown (10YR 4/2)	56°17'N, 92°47'W
Hudson Bay	2	50	48	34	dark greyish brown (10YR 4/2)	56°05'N, 92°25'W
	8	40	52	25	brown (10YR 5/2)	56°01'N, 92°20'W
Lowland	11	41	48	22	pale yellow (5Y 7/3)	56°03'N, 92°14'W
	24	31	45	23	dark greyish brown (2.5Y 4/2)	56°44'N, 93°36'W
	9	24	67	33	dark greyish brown (2.5Y 4/2)	56°37'N, 93°38'W
	16	43	41	28	greyish brown (2.5Y 5/2)	56°39'N, 93°49'W
Average	*10*	*39*	*51*	*27*		
	6	35	59	22	pale brown (10YR 6/2)	55°59'N, 94°13'W
	8	40	52	21	olive grey	55°56'N, 95°32'W
	8	48	44	21	pale olive (5Y 6/3)	55°54'N, 94°38'W
	12	35	53	26	light olive brown (2.5Y 5/4)	55°49'N, 94°10'W
Bigstone	7	34	59	19	pale brown (10YR 6/3)	55°53'N, 95°39'W
	9	34	57	23	light brownish grey (10YR 6/2)	55°24'N, 95°49'W
morainic plain	8	37	55	16		55°53'N, 95°48'W
	8	45	47	9	olive grey	55°06'N, 95°27'W
	5	50	45	26	pale olive (5Y 6/3)	55°15'N, 94°35'W
	2	24	74	24	greyish brown (10YR 5/2)	54°54'N, 97°18'W
	24	35	41	14	light brownish grey (2.5Y 6/2)	55°50'N, 97°50'W
	10	41	49	17	light brownish grey (2.5Y 6/2)	54°37'N, 96°23'W
Average	*9*	*38*	*53*	*20*		
	23	42	35	19	pale olive (5Y 6/3)	56°36'N, 94°16'W
	7	40	53	19	greyish brown (2.5Y 5/2)	56°45'N, 94°23'W
	11	30	59	21	pale brown (10YR 6/3)	56°58'N, 94°24'W
	6	54	40	18	pale brown (10YR 6/3)	56°49'N, 94°20'W
	22	37	41	20	pale brown (10YR 6/3)	56°49'N, 94°20'W
	8	40	52	24	light olive brown (2.5Y 5/4)	56°45'N, 96°46'W
	21	33	46	18	pale brown	56°29'N, 96°09'W
Churchill	1	77	22	11	pale olive (10YR 6/3)	56°53'N, 96°10'W
	7	21	72	14	light olive brown (2.5Y 5/4)	57°38'N, 96°06'W
morainic plain	17	27	56	18	yellowish brown (10YR 5/4)	57°07'N, 96°02'W
	7	30	63	22	brown	57°08'N, 96°18'W
	5	29	66	21	brown	57°09'N, 96°35'W
	4	34	62	23	brown	57°13'N, 96°42'W
	5	29	66	20	light olive brown (2.5Y 5/4)	57°10'N, 97°10'W
	5	23	72	23	light olive brown (2.5Y 5/4)	57°57'N, 96°38'W
	21	46	33	14	yellowish brown (10YR 5/4)	57°52'N, 97°04'W
	10	41	49	19	light olive brown (2.5Y 5/4)	57°12'N, 97°30'W
Average	*11*	*37*	*52*	*19*		
	2	47	51	4	light olive brown (2.5Y 5/4)	57°41'N, 97°07'W
	16	55	29	10	light yellow brown (2.5Y 6/4)	57°19'N, 98°08'W
	7	42	51	12	light olive brown (2.5Y 5/4)	57°32'N, 98°48'W
Seal morainic	12	43	45	11	brown (10YR 5/3)	57°41'N, 98°24'W
	4	53	43	5	light olive brown (2.5Y 5/4)	57°54'N, 98°45'W
plain	11	50	39	5	yellowish brown (10YR 5/6)	57°54'N, 97°04'W
	4	74	22	1	yellowish brown (10YR 5/4)	57°56'N, 96°36'W
	8	52	40	23	yellowish brown (10YR 5/4)	57°57'N, 96°44'W
	1	37	62	3	greyish brown (10YR 5/2)	57°56'N, 97°01'W
	6	40	54	3	yellowish brown (10YR 5/4)	57°54'N, 97°04'W
Average	*7*	*50*	*44*	*8*		
	6	68	26	2	yellowish brown (10YR 5/4)	57°07'N, 99°57'W
Southern Indian	12	49	39	22	olive brown (2.5Y 4/4)	57°45'N, 99°40'W
bedrock plateau	6	53	41	25	yellowish brown (10YR 5/4)	56°34'N, 97°47'W
	21	47	32	4	light yellow brown (10YR 6/4)	57°32'N, 97°37'W
Average	*11*	*54*	*35*	*13*		
	15	74	11	15	greyish brown (10YR 5/2)	55°50'N, 97°50'W
	25	49	26	15	light olive grey (5Y 6/2)	55°47'N, 96°40'W
Molson-Sipiwesk	3	73	24	12	grey (10YR 6/1)	55°49'N, 97°48'W
	17	35	48	13	pale brown	55°11'N, 97°52'W
bedrock plain	7	25	68	18	greyish brown (10YR 5/2)	54°43'N, 98°22'W
	15	46	39	11	pale brown (10YR 6/2)	54°32'N, 98°02'W
	15	48	38	12	light greyish brown (2.5Y 6/2)	54°32'N, 98°02'W
Average	*14*	*50*	*36*	*12*		
Interlake lacustrine plain	19	31	50	35	greyish brown (2.5Y 5/2)	54°28'N, 99°50'W

Burntwood moraine. The southernmost part of the Burntwood-Etawney moraine system is here named the Burntwood moraine. It consists of discontinuous narrow ridges and kame hills, trending southwest to the north of Burntwood River. The southwestern part of the Burntwood moraine consists of several narrower segments up to 60 m high. The surface here is also sandy and abandoned beaches or wave-cut scarps are evident on some of the highest parts. The lower surfaces are strongly reworked by lakewater (Klassen, 1976, p. 17) and marked by scattered boulders (Fig. 9). A series of prominent kame hills and ridges parallel to Burntwood River east of Thompson form the northeast part of the Burntwood moraine. Pits and roadcuts in the moraine expose mostly gravel and sand with a wide range of sizes and degree of sorting, although bouldery ablation till commonly forms the surface (Fig. 10-12).

Limestone moraine. The west trending segment of the Burntwood-Etawney moraine system is named the Limestone moraine after Limestone Lake situated roughly midway along the length of the moraine. It is a single ridge or complex of

Figure 9. Bouldery, water-eroded surface of the Burntwood moraine in the northeast part of the Nelson House (63O) area (55°56'N, 98°36'W). GSC 163362

Figure 11. Bouldery gravel and sand overlain by ablation till in the gravel pit shown in Figure 10. GSC 163329

Figure 10. Aerial view of a gravel pit in the Burntwood moraine near Thompson (55°47'N, 97°53'W). Material is mainly gravel and sand veneered by ablation till. GSC 161357

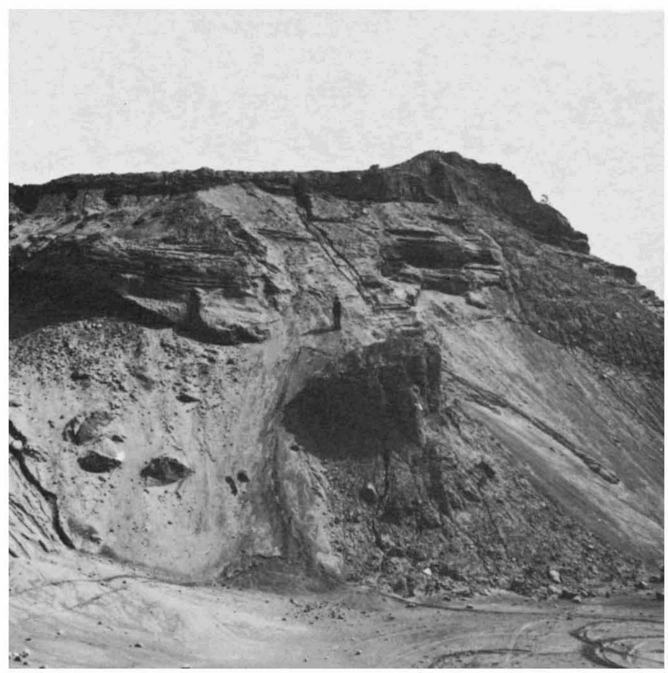

Figure 12. Excavation in the Burntwood moraine about 13 km northeast of Thompson (55°51'N, 97°48'W) exposes bedded sand and gravel some 24 m thick, overlain by ablation till up to 6 m thick. GSC 161428

ridges and kettled surfaces that can be traced for about 200 km from Baldock Lake nearly to the Hudson Bay Lowland escarpment. West of Limestone Lake it is a complex up to 8 km wide consisting of sand ridges and deeply pitted sandy surfaces generally some 30 to 60 m higher than the adjacent ground moraine to the north and lacustrine plain to the south. Some ridges near Limestone Lake are about 90 m high. East of Limestone Lake, where it separates Churchill and Bigstone morainic plains, it resembles an esker that terminates in a meltwater channel near the boundary with Hudson Bay Lowland.

The internal composition of the Limestone moraine appears to be mainly fine sand as the surface is sandy with the odd boulder or clusters of boulders. Sections along Little Limestone Lake in the eastern part and Waskaiowaka Lake in the central part expose some 12 to 24 m of mostly fine grained, bedded sand. Beds of clay and silt up to 1.5 m thick overlie 12 m of sand along Waskaiowaka Lake (Fig. 13). The direction of current flow was not determined from bedding, but the meltwater channels that continue east from the end of the moraine and drop across the escarpment bordering Hudson Bay Lowland indicate that the water that deposited this part flowed to the east; it is unlikely however, that meltwater flowed in this direction during deposition of the entire moraine and most of the western part was probably formed by west-flowing water.

Settee lake moraine. A south-southwest trending moraine, about 175 km long, between Settee Lake and the Burntwood moraine is here named the Settee moraine. In the vicinity of Settee Lake, it is a complex of ridges and hummocky moraine up to 24 km wide with local relief of 30 m.

To the south it narrows abruptly and is a pitted, sandy ridge about 1.5 km wide and 30 m high that widens to about 6 km and has a height of more than 60 m in the vicinity of Baldock Lake. The southern part is a low sandy ridge up to 10 km wide marked in places by kettle lakes and minor ridge segments. Abandoned beaches occur along the eastern slopes of the moraine. Sandy surfaces with scattered boulders are commonly seen and in places up to 9 m of sand and coarse gravel are exposed in banks. A 12 m-high bank in the moraine along the east side of Baldock Lake exposed fine to medium sand with current bedding to the southwest.

Northern Indian moraine. This moraine, named after Northern Indian Lake along its central part, is a nearly continuous, esker-like, southeast trending ridge about 80 km long that joins the Settee moraine in the vicinity of Settee Lake. This moraine forms the boundary between the Churchill morainic plain to the east and the Southern Indian bedrock plateau to the west and is within the east-west transition zone from a high carbonate (upper till member of Wigwam Creek Formation) to a low carbonate surface till. The ridge is generally about 1 km wide and 30 m high. Its surface is typically sand, although in places it is till.

Etawney moraine. This moraine, named after Etawney Lake, is the most northerly segment of the Burntwood-Etawney moraine system. From the northern boundary of the study area it trends south for 100 km where it is separated from the Settee moraine by a 6 km-wide gap in part occupied by Churchill River (Fig. 14).

Its outline, slightly convex to the west, is similar to the Northern Indian moraine, but its margin is much more irregular and the ridge is considerably wider (up to 10 km) and higher (more than 60 m) along most of its length. Where it is widest in the southern part, the surface is sandy and deeply pitted. The north bank of Churchill River exposes some 20 m of silt and fine sand where it crosses the moraine, but the northern, somewhat narrower part commonly has till knolls associated with it and only the highest parts of the ridges are sandy. A prominent till ridge trends northeast from the main ridge south of Buckland Lake and several clusters of till knolls continue this trend to the east-central margin of the map area where a meltwater channel segment is aligned with this trend.

Figure 13. Wave-cut bank exposes 12 m of silty sand capped by 1.5 m of clay and silt in the Limestone moraine along Waskaiowaka Lake (56°31'N, 96°13'W), near the eastern boundary of the Split Lake (64A) area. GSC 161432

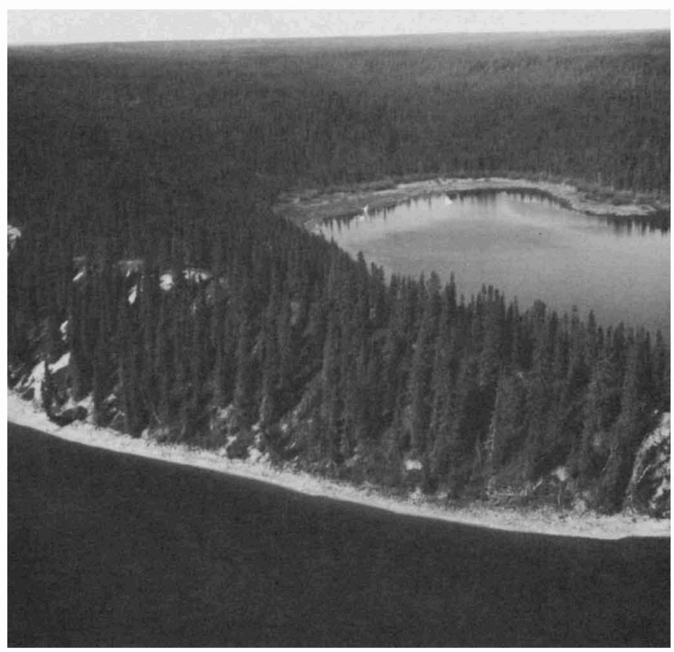

Figure 14. Aerial view to the north of the southern part of the Etawney moraine where cut by Churchill River (57°13'N, 96°44'W). Banks expose some 21 m of sand and fine gravel. GSC 163275

Other moraines. Several other kame moraine-esker complexes, less extensive than the Burntwood-Etawney system, occur in the study area.

The South Seal moraine, named after the river, is an extensive complex of hummocky moraine, isolated hills of till or stratified deposits, and esker-like ridges in the northern part. It continues to the southwest and south as a series of discontinuous ridge segments arranged en echelon to form a 130 km-long regional morainal system broadly convex to the northwest. The northern part of the moraine between Little Sand Lake, Chipewyan Lake, and South Seal River was described by Alcock (1921b, p. 15c) as follows: "The country is covered with superficial deposits of boulders, gravel, sand and clay. These deposits are in the form of sand plains, sand ridges, and hills, and irregularly scattered material. The relief is nowhere great. A few hills and ridges stand out prominently, but aneroid readings for elevations in all the higher ones showed that none rises more than 200 or at most 225 ft above the level of the river and the majority have an elevation considerably less than this." He also described a distinct esker-like ridge across the north end of Little Sand Lake as somewhat serpentine in outline, with steep sides near the angle of repose of sand, a narrow crest, and composed of unsorted clay, sand, gravel and boulders.

Part of the South Seal moraine consists of clusters of boulder-mantled hills that towards the south give way to irregular sandy surfaces and distinct sand ridges marked by wind deflation hollows along the crest. A stream bank along the edge of the southern part of this broad complex (57°59'N, 99°04'W) exposes some 18 m of sand. The ridge segments south of the broad northern part are typically 1 to 1.5 km wide and about 30 m high. Abandoned beaches occur on the segments east of Big Sand Lake. A bank along a lakeshore across the end of the southernmost ridge exposes 8 m of medium sand overlain by 30 cm of varved clay. Minor moraine ridges northwest of Big Sand Lake appear to be part of this moraine complex.

A number of low, discontinuous, sandy ridges within the south-central part of the study area are named the Sipiwesk moraine (Nielsen et al., 1981). These ridges, although rather widely separated, are aligned to the southeast and southwest and at two localities they join nearly at right angles, suggesting that they formed, at least in part, parallel to the glacier margin. The most northerly segment is about 23 km long, 1.5 km wide, and up to 23 m high. Roadcuts along this ridge expose mostly sand along with clay, silt, gravel, and till; it has a subdued appearance that probably reflects lakewater erosion. Elsewhere the ridges have similar characteristics, although bouldery surfaces were seen in places. The most westerly segment is a distinct esker-like ridge aligned to the southwest.

Eskers (Ir)[1] *and kames (In)*[1]

Eskers occur as nearly straight or sinuous ridges mostly aligned to the west, southwest, or south over most of the Shield part of the map area. Typical features are less than 23 m high, up to 100 m wide, and 3 to 24 km long. They occur on ground moraine, bedrock plains, or between bedrock hills. Shallow meltwater channels in places are continuous with eskers.

The esker surfaces are generally sandy (Fig. 15) and appear to be composed mostly of sand along with some gravel. The material in an esker ridge followed by the highway along the western margin of the Uhlman Lake (64B) map area was exposed in several pits. Near Leaf Rapids (sec. 36, tp. 86, rge. 16) where the ridge is about 12 m high, 6 m of sand and silt was exposed; farther south (sec. 18, tp. 83, rge. 16) where it is about 15 m high, a 3 m cut exposed fine gravel. A small esker, typical of many seen in this region, was a local source of fine sand for the Manitoba Hydro, Missi Falls project; a few remaining segments of the former ridge consisted of 2 m of crossbedded sand overlain by less than 1 m of varved clay (Fig. 16).

Kames occur as isolated hills and knolls or as parts of esker complexes. A cluster of kames in the vicinity of the Kettle Rapids hydroelectric dam on Nelson River provided much of the material for the construction of the dam. Gravel, sand, silt, and clay are exposed in the walls of borrow pits and boulders are scattered over the bottoms. One pit with banks 9 m high exposed bedded silty sand and gravel

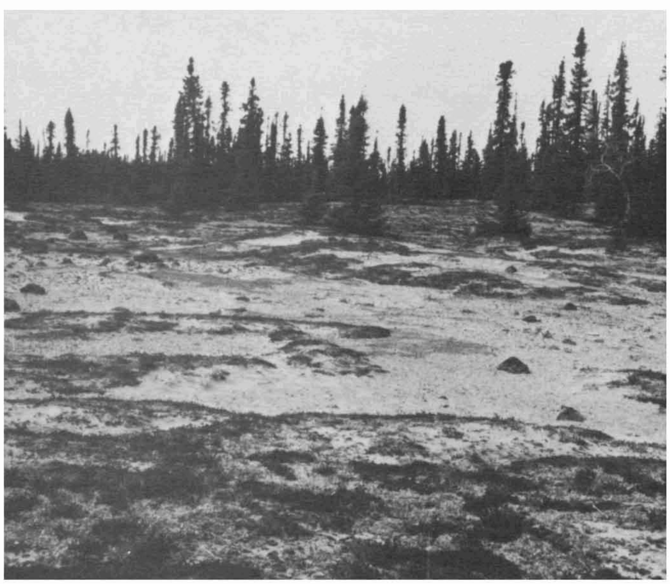

Figure 15. Deflation hollows on the sandy surface of an esker in the northwest part of the Northern Indian Lake (64H) area (58°57'N, 97°37'W); note the scattered boulders. GSC 163280

Figure 16. Fine sand gradational upwards into varved clay, exposed along the side of a small esker near the Missi Falls construction site on Churchill River where it flows out of Southern Indian Lake. GSC 163259

[1] This map unit designator is used in Klassen and Netterville (1979 a-c; 1980 a-i). On Map 1603A all ice contact deposits have been combined into a single unit.

overlain by 2 m of varved clay and crossbedded sand (Fig. 17). The sand was deposited by water flowing to the southwest. Pits in the southern periphery of this complex exposed some 8 m of sand (Fig. 18) or silt and clay.

Johnston (1918, p. 31) described this complex as an end moraine and named it the "Kettle Rapids moraine". Although a minor feature relative to the regional kame moraine systems, it is significant in that it marks a position of the ice front bordered by Lake Agassiz.

An isolated kame about 600 m wide and 23 m high occurs 10 km south of Missi Falls (57°17'N, 98°07'W). Several large pits exposed fine, crossbedded sand more than 9 m thick. Pockets of hard till, up to 1.5 m thick and 15 m long, were in places enclosed in the sand (Fig. 19). Numerous boulders embedded in the sandy surface and the somewhat streamlined aspect of this feature suggest that ice was active after the kame formed.

Figure 17. Poorly sorted gravel and sand overlain by a veneer of varved clay exposed in a borrow pit in the proximal side of a kame complex near Gillam (56°22'N, 94°37'W). GSC 161325

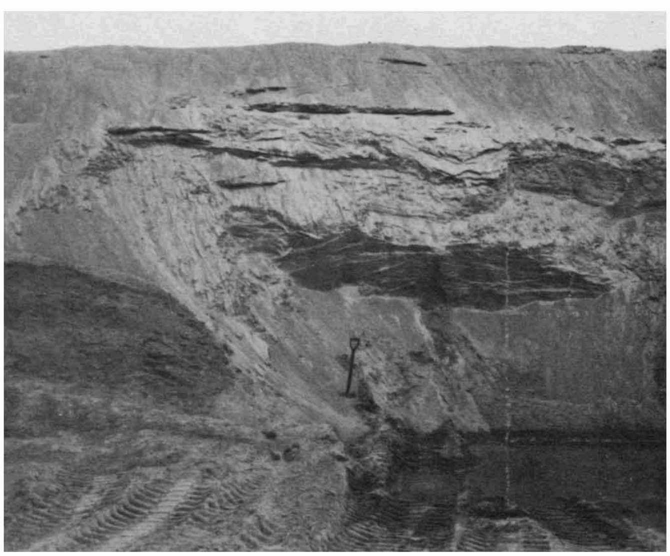

Figure 18. Bedded sand exposed in a borrow pit in the distal side of a kame complex near Gillam (56°21'N, 94°41'W). GSC 161322

Glaciofluvial channel deposits and landforms (Gt)

Most outwash deposits in the region are mapped as part of the kame moraine systems described above. Proglacial outwash gravel, sand, and silt were mapped separately within and adjacent to several large meltwater channels, occupied entirely or in part by Limestone and Weir rivers and Pilot Creek in the Kettle Rapids area. Here outwash forms pitted terraces on gently irregular surfaces underlain by gravel, sand, and silt, near or within the channels. Pitted terraces are distinctive features along the middle reaches of Limestone River and in an abandoned valley continuous with the east end of the Limestone moraine and now in part occupied by Weir River. Outwash also occurs as local patches of thin sand and gravel associated with a meltwater channel south of the Kettle Rapids moraine.

Glaciolacustrine deposits and landforms (L)

Glaciolacustrine clay, silt, sand, and gravel form the surface drift in much of the map area. Clay is the most widespread material and forms an almost unbroken cover in the lacustrine plains subdivisions and occurs in local basins or as a discontinuous veneer over most of the study area outside Hudson Bay Lowland (Map 1603A).

The widespread occurrence of glaciolacustrine sediments in this region is documented in numerous earlier geological reports and maps that make reference to surficial clay and silt and/or make inferences regarding their origin in glacial Lake Agassiz (Bell, 1880; McInnes, 1913; Tyrrell, 1916; Johnston, 1918; Bruce, 1920; Alcock, 1921a; Antevs, 1931; Wright, 1948; Elson, 1961, 1967). The most detailed account of varved clay exposures in the area was by Antevs (1931, p. 51-70) who measured thicknesses and counted varves in numerous cuts along the Hudson Bay Railway and banks of Nelson River in the Molson-Sipiwesk

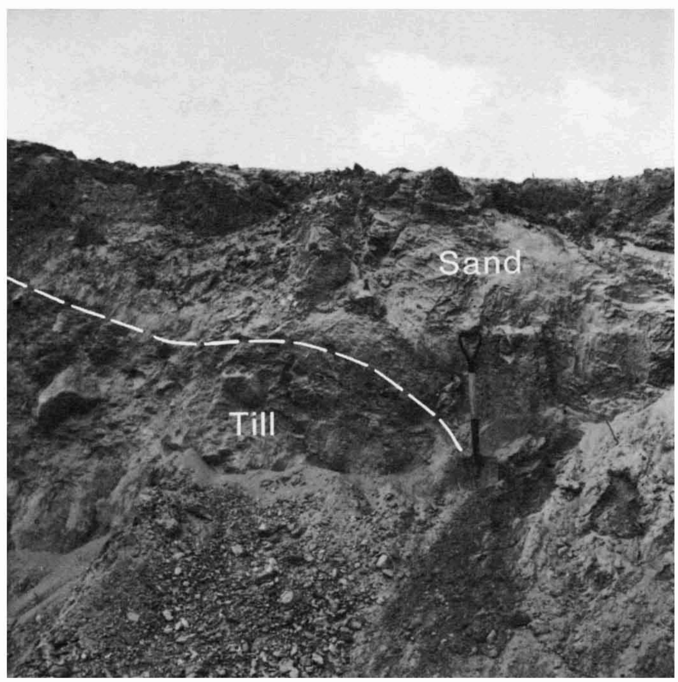

Figure 19. Bouldery till overlain by sand exposed in borrow pit in a kame 10 km south of Missi Falls (57°17'N, 98°07'W). GSC 163267

bedrock plain. He reported that varved clay occurs in an almost continuous sheet from the south end of Setting Lake, northeast to Nelson River. Elson (1961, p. 61) included this area in a map outlining a region of "extensive lake deposits (clay)" that he later (1967, p. 59) referred to as the 'Grass River basin'. This basin included most of the Southern Indian bedrock plateau, and the Burntwood lacustrine plain, as well as the Molson-Sipiwesk bedrock plain. The southern boundary of Elson's (1961, p. 61) Grass River basin is placed somewhat north of Lake Winnipeg, whereas this report considers the area immediately north of the lake as part of the lacustrine plain.

Basin deposits (L, L_M, L_R)

The thickest deposits of glaciolacustrine clay and silt occur in a broad belt that extends about 300 km north of Lake Winnipeg and is 120 to 160 km wide (Map 1603A). It includes all the lacustrine plains subdivisions, Molson-Sipiwesk bedrock plain, and the eastern part of Southern Indian bedrock plateau. The western limits of these deposits are at roughly 270 m a.s.l. in the southern part marked by the highest abandoned beaches west of Lake Winnipeg and at roughly 330 m at the north end of Southern Indian Lake; the eastern limits are at about 240 m in the south, 180 m along Nelson River, and about 200 m along the Limestone moraine.

Typical thicknesses of varved clay and silt seen in natural and man-made exposures range from 1 to 3 m (Fig. 20). In areas of hilly bedrock local thicknesses vary considerably. Banks along Harding Lake and South Bay in the Southern Indian bedrock plateau expose 2 to 3 m of varved clay overlying about 6 m of bedded sand and silt with minor clay. Railway cuts across the hilly bedrock between Thompson and the northeast end of Wintering Lake in the Molson-Sipiwesk bedrock plain, expose clay up to 5 m thick overlying sand, till, or bedrock (Fig. 21). The clay is thickest in bedrock depressions and bare bedrock forms the surface of most steep slopes. Roadcuts and natural banks in the Burntwood lacustrine plain expose 2 to 3 m of varved clay separated from bedrock by thin deposits of sand and/or till. Varved and massive silt and clay form a nearly continuous cover over the Minago and Playgreen lacustrine plains (Fig. 22), but to the east over the Molson-Sipiwesk bedrock plain it is discontinuous and bedrock outcrops are common.

Figure 20. Varved clay overlying striated and grooved bedrock surface exposed in a road ditch near the northern boundary of the Burntwood lacustrine plain in the north-central part of the Nelson House (63O) area (55°30'N, 98°51'W). GSC 163380

Figure 21. Depression in granitic bedrock filled with till (bouldery surface) and sand (light colour), capped by varved clay. Railway cut near the Grass River trestle (55°34'N, 97°37'W) in the west-central part of the Sipiwesk (63P) area. GSC 161348

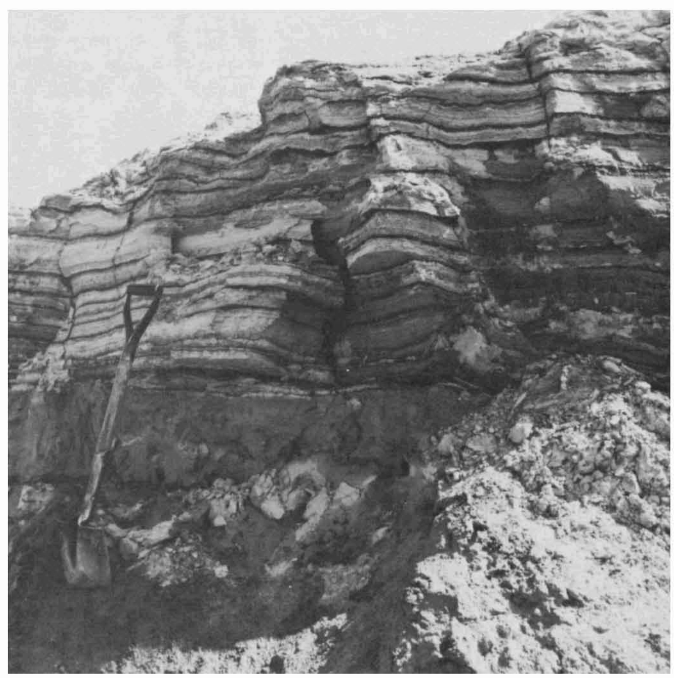

Figure 22. Massive fine sand overlain by varved silt and clay (dark beds) along channel excavation (54°09'N, 98°18'W) shown in Figure 8. GSC 163310

Bell (1978, p. 59) reported an average clay thickness of 18 m (maximum 45 m) in borings within the Minago plain. Within the Bigstone morainic plain, varved clays up to 1 m thick occur mainly within a belt bordering Nelson River. Varved clay also occurs within the western part of Hudson Bay Lowland to the vicinity of the confluence of Nelson and Limestone rivers. Elsewhere over the morainic plains the clay veneer is typically massive, although at most sites identification was made on the basis of small cores recovered in a sampler, and varves, if present, may not have been recognized.

Throughout the region the clay typically is greyish where it is varved and brownish in the upper zone (up to 1 m thick) where it is massive. Within areas of hilly bedrock, the massive clay appears to be a secondary deposit derived from higher slopes by mass wasting or slopewash. The massive clay within parts of the morainic plains, however, may also reflect deposition in postglacial lakes. The glaciolacustrine sediment of Hudson Bay Lowland is mainly sand, silt, and clay up to 5 m thick including varved beds less than 1 m thick, overlain by marine sediments (Fig. 23).

Shore deposits and landforms (Lr)

Abandoned beaches occur mainly as scattered low ridges of gravel, sand and bedrock rubble along the western margin of the southern part of the map area (Map 1603A). Nearly continuous flights of beaches occur along the carbonate bedrock bluffs in the southwest and along the crests and east-facing slopes of the Settee moraine. Segments of weakly developed beaches or lag deposits occur on the sides of bedrock hills in the extreme western and northwestern part and along the sides of moraines or low rises elsewhere in the area.

The highest flight of beaches includes the Grand Rapids beach (Johnston, 1946, p. 5). It is part of a complex of ridges across the face of an escarpment between 225 and 245 m

Figure 23. Massive sand and silt (1) overlain by thinly bedded, repetitive stringers of varved clay and stony silt (2 to 8) and covered by massive clay (9) of probable marine origin. Exposure is a borrow pit about 19 km east of Gillam in the Hudson Bay Lowland (56°22'N, 94°23'W) (see Appendix 1, section 26 for details). GSC 161329

elevation (from 25 foot contours on 1:500 000 topographic maps) near Grand Rapids and between 265 and 275 m elevation at a locality some 50 km to the north. The elevation differences indicate differential uplift of the order of 0.5 m per km. This figure is substantially higher than the 0.2 m per km uplift given for this beach by Johnston (1946, Fig. 2), who apparently mistook a lower beach (Ponton) for the northern terminus of the Grand Rapids beach.

Bell (1978, p. 59-60) named the lowest, continuous flight of abandoned beaches in the area the Ponton beaches. He traced them north of Lake Winnipeg for some 120 km and suggested that they formed shortly before final drainage of Lake Agassiz from the region.

The elevation of the Ponton beaches at their southern terminus near the northwest end of Lake Winnipeg is between 220 and 225 m elevation. The elevation increases to between 240 and 250 m near Ponton and to between 275 and 300 m along the southern part of the Settee moraine. Differential uplift over a distance of some 350 km ranges from 0.2 m per km along the southern part to 0.3 m per km along the northern part.

A discontinuous abandoned beach, trending northwest at about 250 m elevation for some 8 km between Northern Indian moraine and Fidler Lake (Klassen and Netterville, 1980f), is herein named the Fidler beach. Several beach segments at about 265 m elevation, some 50 km to the north, may be correlative with it. If so, the differential uplift is 0.3 m per km or about the same as calculated for the northern part of the Ponton beach.

Marine deposits and landforms (W, Wr)

Marine deposits consisting of clay, silt, sand, and fine gravel, generally less than 3 m thick, cover most of the till plain of Hudson Bay Lowland in the study area. The western boundary of these deposits is marked by the highest marine beaches at about 120 m along the escarpment separating the Lowland from the morainic plains to the west. Although parts of the morainic plains at higher elevations may have been covered by marine waters, no evidence of marine deposition was noted along the banks of Hayes and Nelson rivers where they cross the morainic plains.

The extensive wetlands over the Lowland restrict exposures to the beach ridges that stand above the organic terrain and to the banks of Nelson and Hayes rivers and their tributaries. Marine sediments are recognized on the basis of surface morphology (beach ridges) or the marine fossils that they contain. The sediments exposed in abandoned beaches are sand and fine gravel, mostly devoid of fossils. Fossiliferous sand and silt commonly veneers nonfossiliferous silt, sand, and gravel in the zones between beaches. Whether the underlying sediments are marine or nonmarine could not be determined but it was assumed that laminated sediments were glaciolacustrine. Marine clay occurs with silt and sand in places but generally the clay is not as widespread.

Alluvial deposits and landforms (A)

Alluvial gravel, sand, and silt were mapped mostly as terraces and valley bottom deposits along the lower stretches of Nelson and Hayes rivers and their principal tributaries. These postglacial deposits are separated from glaciofluvial deposits within valleys on the basis of the pitted surfaces evident on the latter, by the absence of a marine sand on the postglacial terraces, or simply on the basis of their position within the modern valley. A test pit in an alluvial terrace about 20 m above the valley bottom on the south side of Nelson River valley (56°41'N, 95°45'W) exposed some 6 m of coarse bouldery gravel overlain by 0.6 m of thinly bedded silt and sand. Freshwater fossils were identified in the upper bed

(Appendix 1, section 33). Alluvial gravel and sand cover the bottoms of Nelson, Gods, and Hayes rivers and their larger tributaries.

Peatlands

Peatlands that range in extent from nearly continuous blankets over vast tracts of flat terrain to patches in local flats in hilly terrain are the most widespread surface material in the study area. This material is not shown on Map 1603A because of map scale limitations, but the main areas of these deposits are shown in Klassen and Netterville (1979a-c, 1980a-i). The considerable variations in the physical characteristics of, and plant communities associated with, peatlands have resulted in a number of approaches taken in classifying and mapping this type of terrain. A brief review of previous studies regarding the latter in the Hudson Bay region is given to provide the reader with some background on the problem of classifying organic deposits.

Field studies to date, though focused on relatively few sites in this region, have resulted in detailed descriptions and a classification system that accommodates most aspects of peatland (Tarnocai, 1970; Zoltai et al., 1975). With the exception of a few unpublished biophysical maps and published soils or vegetation maps of small areas (Ritchie, 1958; Ehrlich et al., 1959), however, the peatlands over most of this region have not been mapped.

Sjörs' (1959, 1963) studies of the peatlands of the Hudson Bay Lowland in Ontario are directly applicable to similar terrain in the map area. He recognized two main types of peatlands: bogs-having a highly specialized type of vegetation reflecting a water source mainly from precipitation- and fens-having more abundant and varied vegetation types because of an additional water source from seepage (Sjörs, 1959, p. 3). He also used the term 'ombrotrophic peatlands' for fens, because of their high mineral ion content (Sjörs, 1959, p. 3). Sjörs (1963) described and documented in considerable detail the vegetative, chemical, and physiographic characteristics of bogs and fens, as well as the probable peatland successions.

Ritchie's studies of the vegetation in northern Manitoba (1956, 1958, 1960) deal with some regional and local aspects of peatlands within a somewhat different and more general classification. Peatlands of the Canadian Shield are placed within two broad categories designated as muskeg-tree-covered peatland- and peat bog-mostly open peatland (Ritchie, 1956, p. 547; 1958, p. 39). Peatlands of the Hudson Bay Lowland, however, are classified on the basis of a more complex system (Ritchie, 1960, p. 221-227).

Tarnocai (1970) and Zoltai and Tarnocai (1971) give detailed descriptions of peat landforms in northern Manitoba and outline a system of classification that has been included in a system of wetland classification proposed by Zoltai et al. (1975). The latter is a hierarchical system that, at the first level, includes five main categories of wetlands consisting of bogs, fens, swamps, marshes, and shallow open waters. These categories are based on the external morphology and general aspects of the plant community that can be recognized using airphotos and limited ground control.

The two broad categories of mappable peatland units recognized in this study are peat and fen; however much of the tree-covered peatland was not mapped because it could not be recognized on airphotos. In places individual features were studied and bogs were cored by hand auger to the underlying mineral sediments in order to obtain information on thickness and general physical properties. Basal peat and organic pond sediments were sampled and radiocarbon dated.

Peatland investigations reported here were restricted mainly to observations of the general surface morphology and nature of the organic deposits. A detailed description of the physical properties of a peatland site was given in Klassen (1976, p. 20).

Peatlands were identified as either bog or fen, or combinations of both (Klassen and Netterville (1979a-c, 1980a-i). Peat-covered areas with an open to closed tree cover were identified as bogs, and peat-covered flats with few trees and visible surface waters as fens. Most landing sites in the region were on fen near the margin of tree-covered bogs or other features; the spongy, watery surface of the fen provided the only access by helicopter to adjacent tree-covered areas.

A typical bog surface is gently irregular with up to 1 m of local relief, and stands from 1 to 2.5 m above the adjacent fen (Fig. 24). Low areas may have small pools of standing water and higher parts have a dense cluster of black spruce and a cover of moss and dry peat about 0.3 m thick over permanently frozen peat. The irregularity of the bog surface appears to reflect the distribution of ground ice in underlying, permanently frozen peat. Total thicknesses of peat and ice typically range from 1 to 2 m, although local thicknesses may reach 2.5 m or more in Hudson Bay Lowland and in bogs in the southern part of the study area; the thickness of peat increases somewhat from north to south.

The oldest radiocarbon date obtained on a sample from a bog bottom is 6490 ± 170 BP (GSC-1738). The sample was taken by hand auger beneath 1.8 m of frozen peat in a bog about 90 km northwest of Gillam (56°52'N, 95°47'W). The dated material was organic detritus within a lacustrine deposit containing plankton and ostracods (M. Kuc, unpublished GSC Bryological Report No. 184) and indicates that bog development began in a pond or along a lake margin during a fen to bog transition.

Figure 24. Collapsed bog margin resulting from the melting of permafrost. The bog surface is about 2 m above the fen in the foreground. Locality (56°28'N, 95°16'W) is typical of peatlands within the northern part of the Bigstone morainic plain in the Kettle Rapids (54D) area. GSC 177141

Information regarding fens is limited to casual observations of their surfaces as they could not be sampled with the equipment available. Beneath the surface, a typical fen consists of a loose mat of peaty material and water that offers little resistance to penetration by a hand auger. Samples were not recoverable from the fluid mass that was unfrozen to the maximum depth (about 1.5 m) probed. Most fen surfaces are flat, watery expanses with spongy fibrous vegetation mats, separated from bogs by a narrow stretch of open water. The vegetation mats are difficult to traverse on foot as one may sink in to the knees and even farther in the watery stretches along the bog-fen margin.

QUATERNARY STRATIGRAPHY

The discontinuity of the drift and lack of good exposures preclude the establishing of a comprehensive stratigraphic framework for most of this vast region. Thin drift overlying bedrock seen in exposures along rivers, roadcuts, and excavations over most of the map area is a deposit of the last glaciation. Older drift is preserved here and there beneath the surface drift in bedrock depressions or on the lee side of bedrock knolls but occurrences are too widespread to make tenable correlations. Over Hudson Bay Lowland and a narrow belt of the Shield adjacent to the Lowland, however, the drift blanket is fairly thick and continuous, and multiple tills and intertill sediments beneath a surface till are exposed along river banks and in local bluffs. Tyrrell (1913, p. 201; 1916, p. 12-15) described the drift exposed along Nelson, Hayes, Fox, and Gods (Shamattawa) rivers. Along Gods River he recognized a stratigraphic sequence that included two tills separated by fossiliferous interglacial sediments. Later studies along the Hayes and Gods rivers by McDonald (1969, p. 94) expanded on the earlier studies and added new information to the regional stratigraphic framework.

Most of the stratigraphy proposed in this report is based on units studied in exposures along the Gods, Hayes, and Nelson rivers across Hudson Bay Lowland (Appendix 1). Sections along a 50 km stretch of Gods River provided the material for an unpublished Master of Science thesis (Netterville, 1974), a part of which is given in Appendix 2. Units described along other rivers across the eastern parts of Bigstone and Seal-Churchill morainic plains adjacent to the Lowland are tentatively correlated with part of the stratigraphic succession of Hudson Bay Lowland.

The few multiple tills seen in exposures in the western part of Bigstone and Seal-Churchill morainic plains and other parts of the study area cannot be correlated, except for the uppermost till units which are correlated mainly on the basis of their stratigraphic positions.

Amery Formation

The oldest till of regional distribution overlies the Paleozoic carbonate bedrock exposed in places along Nelson and Gods rivers across Hudson Bay Lowland. It is here named the Amery Formation after the railway siding of Amery about 3 km north of the type section (Fig. 25; Appendix 1, section 20) along Nelson River (in NE¼ sec. 8, tp. 87, rge. 22; 56°32'N, 94°05'W). This till was referred to as 'Till A' by Netterville (1974, p. 11-14) who studied a number of exposures along Gods River.

Nielsen and Dredge (1982) described a till (lower grey till) that underlies the Amery Formation in an exposure along the north bank of Nelson River about 2 km downstream from the type section. The tills are here separated by a paleosol containing charcoal and pollen.

Figure 25. View of the lower part of the stratigraphic succession described in Appendix 1, section 20, along the north side of Nelson River about 3 km below the mouth of Limestone River (56°32'N, 94°05'W), showing dolomite bedrock (1), Amery Formation (2), and silt and sand of Lake Agassiz sediments (3). GSC 161332

Physical properties. The till of the Amery Formation is typically olive grey (5Y 5/2[1] or 5Y 4/2) and its overall colour is somewhat greyer than other tills in the study area. Grain size analyses (Table 1) indicate that, on average, this till is slightly sandier and less stony than most of the younger tills, yet the variability of the grain size distribution within the till may, in places, be as great as between tills. The average carbonate content of this till (29%) is similar to that of the younger tills (29, 28, 26%, Table 1). Shell fragments are present in places. The till ranges in thickness from 5.5 m along Hayes River to 10 m along Nelson River. Till pebble fabrics measured at four sites along Gods River suggest that it was deposited by a glacier that flowed to the southwest (Netterville, 1974, p. 14). Along Nelson River, however, till fabric measurements and striae on the underlying bedrock surface suggest that ice flow here was to the northwest (Nielsen and Dredge, 1982).

Distribution and stratigraphic relations. The Amery Formation appears to be restricted to Hudson Bay Lowland. Where it is exposed along the upper part of Nelson River, the overlying units are tills of the Wigwam Creek Formation (Appendix 1, sections 16, 20). Ordovician limestone of the Bad Cache Rapids Group underlies the exposures along Nelson River (Appendix 1, section 20). Along Gods River, it overlies Ordovician limestone of the Churchill River Group and underlies the Gods River sediments (Appendix 1, sections 1, 2). Although not exposed along Hayes River, the Amery Formation probably underlies the stratified sediments of the Wigwam Creek Formation that form the riverbank.

Age and origin. The stratigraphic position of the Amery Formation beneath Gods River sediments of probable Sangamonian age (Netterville, 1974, p. 48) suggests that the till is Illinoian or older. The paleontological and

[1] Munsell colour, taken from moist faces.

sedimentological evidence presented for the Sangamonian age of the Missinaibi beds (Skinner, 1973), which are correlated with the Gods River sediments (Netterville, 1974), supports this interpretation. Whether or not the till and paleosol underlying the Amery Formation till (Nielsen and Dredge, 1982) are also of Illinoian age is uncertain. Three named tills and intertill sediments underlying the Missinaibi Formation (Skinner, 1973, p. 50), in the area southeast of James Bay, may be in part correlative with the Amery Formation. Skinner (1973, p. 8, 50) indicated that the tills may be deposits of an Illinoian glaciation that is represented by one till unit in the eastern part of that area.

Gods River sediments

An intertill unit of peat, organic silt, sand, and gravel overlying the Amery Formation along Gods River was informally referred to as the "Gods River sediments" by Netterville (1974, p. 8). The name is herein formally adopted for these sediments exposed along Gods River in the map area.

The main exposures of these intertill sediments along Gods River (Appendix 1, sections 1, 2, 5) were reported by Netterville (1974) who gave a detailed description and paleoenvironmental interpretation of the sediments based mainly on palynology. This part of his thesis is included as Appendix 2. A brief summary of Netterville's study of the Gods River sediments and related studies follows.

Physical properties. The Gods River sediments consist of peat, organic-rich silt, silt, sand, and gravel. The lower units are predominantly silt, sand, and gravel that are overlain by organic-rich, massive silt and peat along a 120 m stretch of river bank (Appendix 1, section 1). Current bedding is common in the stratified sediments that are up to 12 m thick in places where the organic beds are absent (section 5). Elsewhere these beds contain seeds, beetle fragments, and freshwater mollusc shells (section 2); where the beds of intertill peat or organic-rich silt are thickest (4 m), the stratified sediments are thin (section 1) or absent.

Figure 26. View of part of the stratigraphic succession described in Appendix 1, section 1, exposed along Gods River (56°10'N, 92°32'W) showing Gods River sediments (1), lower till (2), middle till (3), upper till (4), and Tyrrell Sea sediments (5). GSC 161411

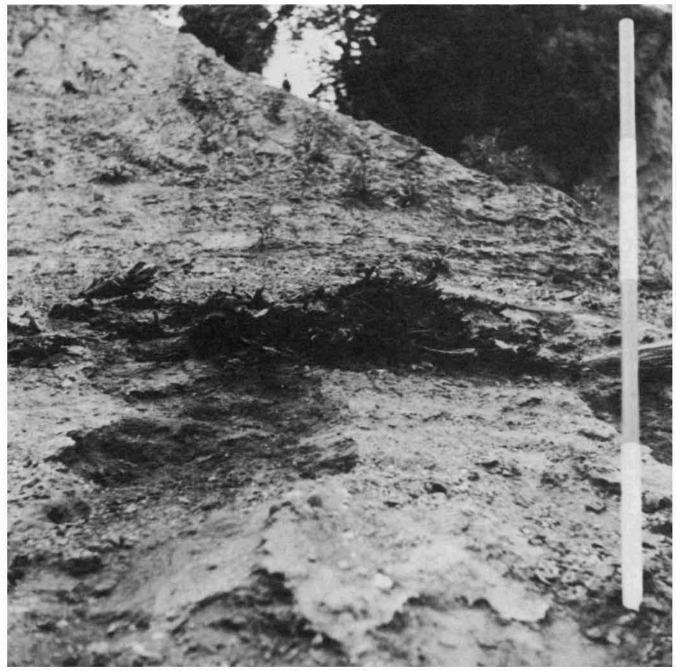

Figure 27. Gods River sediments, including a lens of branch fragments beneath silty peat; wood used for radiocarbon dating (GSC-1736, >41 000 BP) was taken from this zone. (see Appendix 1, section 1). GSC 163421

Distribution and stratigraphic relations. The Gods River sediments along Gods River in the map area are commonly seen between the Amery Formation and the overlying lower till member of the Wigwam Creek Formation. The massive organic beds were seen only along a 120 m stretch of riverbank (Fig. 26). Nielsen and Dredge (1982) reported the occurrence of numerous exposures of organic silt and clay along Nelson River that they considered stratigraphically equivalent to the Gods River sediments.

Age and origin. A radiocarbon date from wood in this unit (Fig. 27) was indeterminate (>41 000 BP, GSC-1736, Lowdon et al., 1977; Appendix 1, section 1). Netterville (1974) noted the similarity of his pollen diagrams (Appendix 2) from the peat beds in the Gods River area to ones from several modern tundra sites in this region and concluded that the mean summer temperatures were not unlike those of today and that the sediments were therefore of interglacial rank.

Pollen analyses and amino acid ratios on wood from the Gods River sediments along Nelson River led Nielsen and Dredge (1982) to the same conclusion. The beetle fauna, however, indicate a climate somewhat cooler than that at present, possibly an interstadial.

The stratified beds of the Gods River sediments are primarily of fluvial origin as indicated by fossils and bedding structures. The peat and organic silts most likely formed under conditions similar to those found around local ponds and bogs today.

Wigwam Creek Formation

A succession of up to three tills, including the surface till and intertill sediments stratigraphically higher than the Gods River sediments and lower than the Lake Agassiz sediments in the part of the area south and east of Seal morainic plain and Southern Indian bedrock plateau, is here formally named the Wigwam Creek Formation. The name is taken from Wigwam Creek, a tributary to Gods River in the southeast corner of the map area where the formation is exposed (Appendix 1, section 7); however, the type section is about 45 km downstream near the mouth of an unnamed stream (section 1). Netterville (1974, p. 35-39), who described the units of this formation along Gods River (sections 1-9), referred to the tills as Till B, Till C, and Till D, and to the sediments between them as Twin Creeks and unnamed sediments, respectively. Other exposures of this formation were identified along river banks and bluffs elsewhere in the Hudson Bay Lowland and the morainic plains to the west (sections 10, 11, 15, 17-19, 21-25, 27-30).

The tills are here referred to as the lower, middle, and upper till members of the Wigwam Creek Formation. The stratified sediments that in places separate the tills, are referred to as intertill sediments. The names Twin Creeks sediments and unnamed sediments applied by Netterville (1974, p. 36, 37) to the intertill sediments are not used in this report.

Physical properties. To a considerable degree the properties of the tills reflect the nature of the underlying or nearby source materials. Physical properties used to identify the tills of the Wigwam Creek Formation showed the greatest vertical differences and horizontal similarities over the Lowland and the eastern parts of the morainic plains to the west. As the distance from the thick drift and carbonate bedrock of the Lowland increased, the west- and southwest-flowing glaciers derived ever greater proportions of material from the Precambrian granitic bedrock.

On the Lowland and eastern parts of the morainic plains the tills are typically dark greyish brown (10YR 4/2 or 2.5Y 4/2) although the lower and middle members in places are olive grey or yellowish brown (Table 1) and the upper till commonly appears slightly darker than the older tills when seen from a distance. The lower and middle tills are commonly hard and marked by joints stained by oxidation, whereas the upper till is loose and not as distinctly jointed. Grain size distribution differs little among the till members (average 8% gravel, 36% sand, and 56% silt and clay), although the upper till is slightly coarser than the others (Table 1). The average carbonate content decreases slightly from 29% in the lowest till to 26% in the upper till (Table 1). Nielsen and Dredge (1982) reported that exposures of these till members along Nelson River are up to 12 m thick but the average thicknesses for the lower, middle, and upper tills are 8, 6, and 4 m, respectively.

The most westerly occurrences of the Wigwam Creek Formation tills are over the Molson-Sipiwesk bedrock plain; more than one till was rarely seen exposed on this plain where bedrock is commonly at or near the surface. The upper till over the Molson-Sipiwesk bedrock plain is coarser and has a significantly lower carbonate content (average 8% less) than the upper till over the Bigstone morainic plain (Table 1), even though both apparently were deposited by the same ice lobe.

Till pebble fabrics of the three tills were measured at several localities along Gods River (Netterville, 1974, Fig. 3, p. 79). Two directions of preferred orientation that are nearly at right angles occur in each till. The inferred direction of glacier flow is due south for the lower till about S15°W for the middle till and approximately to the southwest for the upper till. Fabric measurements of the lower till along Nelson River (Nielsen and Dredge, 1982) indicate mainly a northwest-southeast flow although a due south component was dominant at several sites; the upper till fabric along Nelson River suggests flow nearly due west and corresponds to the orientation of surface ice flow marks along Nelson River west of the Lowland.

Identification of the lower, middle, and upper tills was based mainly on stratigraphic position, particularly on the morainic plains west of the Lowland. However, the most apparent differences in the field are the somewhat darker colour and less compact aspect of the upper till in contrast to the other tills. These differences are most evident where the three tills are exposed along Gods River (Appendix 1, sections 1, 4, 5). Differences between the lower and middle tills are generally not of sufficient contrast to distinguish one from the other where only one is present. An exception was noted at one locality (section 2) along Gods River where the lower till contains wood fragments from the Gods River sediments. Exposures of only one or two tills elsewhere on the Lowland and the morainic plains were identified as upper till or as upper and middle till members (sections 15, 17-19, 22, 24 27-30) where the previously mentioned characteristics of the upper till were evident. The formation name only was used where a surface or near-surface till within the Lowland or eastern morainic plains was not adequately described and sampled or lacked the characteristics of the upper till (sections 10, 11, 21, 23, 24).

Distribution and stratigraphic relations. The lower till member was recognized only in Hudson Bay Lowland, along with the middle and upper tills (Appendix 1, sections 1, 4, 5) which also occur over the eastern part of the morainic plains bordering the Lowland. The upper till forms the surface or underlies stratified drift and/or peatland elsewhere over Bigstone morainic plain, Churchill morainic plain, and Molson-Sipiwesk bedrock plain.

The lower till overlies the Gods River sediments or the Amery Formation and underlies the middle till or thin intertill units of silt, sand, and gravel along Gods River. The upper till overlies the middle till or a thin intertill unit of sand and gravel. Along Gods and Hayes rivers across the Lowland, the upper till is overlain by Tyrrell Sea sediments; however, along the upper part of Nelson River across the Lowland and over extensive tracts elsewhere in the study area, it is overlain by Lake Agassiz sediments.

Age and origin. Datable material was not obtained from the Wigwam Creek Formation along Gods River. Along Nelson River, however, Nielsen and Dredge (1982) reported that aspartic acid ratios on shell fragments in the tills indicate that the lower till is much younger than the till of the Amery Formation, but that the ratios obtained from upper till shell fragments were not consistent with the stratigraphy. Inferences concerning the age of the Wigwam Creek Formation are relative and are limited to its stratigraphic position above the Gods River sediments and the fact that the upper till was deposited during the last glaciation of this region. The lower, middle and upper tills are thought to represent three Wisconsinan stades and the barren sediments that in places separate them are probably interstadial deposits.

The till fabrics measured along Gods River suggest that ice flow was to the south during deposition of the lower till. A shift of flow in a direction somewhat west of south followed. Finally, during deposition of the upper till, flow was generally to the southwest and west as indicated by the orientation of drumlins over the morainic plains.

In the Gillam area, the typical fabrics suggest a northwesterly ice flow during deposition of the lower till and a westerly flow for the upper till (Nielsen and Dredge, 1982).

Intertill sediments. Beds of silt, sand, and fine gravel, mostly less than 30 cm thick, separate the Wigwam Formation tills in places along Gods River. Netterville (1974, p. 36-37) referred to them as the Twin Creeks and unnamed sediments from oldest to youngest, respectively; because of their limited distribution and apparent lack of distinctive physical properties, fossils, or organic detritus, they are not assigned names here. Netterville (1974, p. 36) stated that the sand and gravel are oxidized to a reddish hue in all exposures, implying that a hiatus of interstadial rank is recorded by the sediments. Although this type of oxidation may simply reflect effects of iron oxide precipitation from groundwater along the banks, these beds do serve to mark the contact between tills. The units do not appear to be stratigraphically significant entities, except that they mark intervals in the deposition of the enclosing tills and are evidence for the deposition of each till member during a separate glacier advance.

Unnamed tills

The regional ice flow patterns suggest that the surface till of the southern part of the Southern Indian bedrock plateau and the entire Interlake lacustrine plain was deposited by a glacier that flowed to the southwest from the Hudson Bay region. The till thus correlates with the upper till member of the Wigwam Creek Formation. The surface till of the Seal morainic plain and the northern part of the Southern Indian bedrock plateau, however, was deposited by a south-flowing Keewatin ice lobe and is a different rock stratigraphic unit.

The surface till of the Southern Indian bedrock plateau and Seal morainic plain commonly has a markedly higher percentage of Precambrian rock than the upper till member of the Wigwam Creek Formation over the plains to the east.

Figure 28. Stratigraphic succession described in Appendix 1, section 32 in a damsite spillway excavation, showing bedrock (1), sand (2), till (3, 4), and varved clay (5). GSC 163316

The surface till is sandier and the carbonate content is significantly lower (Table 2; Fig. 28). The carbonate content of some surface till samples near the western margin of the Southern Indian bedrock plateau, however, is as high as that of the surface till of the morainic plains to the east (Table 2). The anomalously high carbonate content suggests a possible local source from unmapped outliers of Paleozoic carbonate rather than from the carbonates of Hudson Bay Lowland.

The lower carbonate content of the surface till of the Seal morainic plain (average 8%, Table 2) compared to that of the Churchill morainic plain (average 19%) clearly reflects the southerly ice flow direction (Keewatin source) over the former in contrast to the southwesterly flow direction (Hudson Bay Lowland source) over the latter. The abrupt drop in carbonate content of most surface till samples just west of the north end of Etawney moraine indicates that these differences are not entirely the result of dilution due to increasing distance from the carbonate source.

The high carbonate content (35%) and silty texture of the till veneer over the Interlake lacustrine plain directly reflects the local carbonate bedrock source. Although analysis was limited to one sample (Table 2), a high carbonate pebble content and compact silty matrix are evident on casual inspection of till exposures in roadcuts and natural banks.

Lake Agassiz sediments

Sediments of glaciolacustrine, glaciofluvial, and deltaic origin that were deposited in or along the margin of glacial Lake Agassiz or large remnants of it during final retreat of the last glacier from this region are here formally named Lake Agassiz sediments. Most aspects of physical properties and distribution discussed previously in the section on *Glaciolacustrine deposits and landforms* are briefly summarized here.

Physical properties. Lake Agassiz sediments consist of varved clay and silt, sand, and gravel. Thicknesses are variable and range from less than 1 m, where they form a veneer over drift or bedrock, to some 45 m locally.

Distribution and stratigraphic relations. These sediments form a broad, north-trending belt in the western part of the map area. The belt includes a nearly unbroken blanket of silt and clay over the Playgreen and Burntwood lacustrine plains and a discontinuous blanket commonly broken by bald bedrock knolls over the Molson-Sipiwesk bedrock plain (Fig. 3; Map 1603A). Wedges of thick clay and silt between bald or clay-veneered bedrock hills reflect the occurrence of Lake Agassiz over the Southern Indian bedrock plateau.

Lake Agassiz sediments commonly overlie bedrock or till of the Wigwam Creek Formation or its correlative in the western part of the study area. The sediments cover the surface or underlie organic deposits over most of the area, except in part of Hudson Bay Lowland, where they are separated from a nearly unbroken blanket of surface organic deposits by Tyrrell Sea sediments.

Age and origin. These sediments were deposited in Lake Agassiz during final deglaciation of this region between about 9500 and 7500 years ago (see *Deglaciation* section). The varved clay and silt accumulated in quiet water along and beyond the ice margin. Thick wedges of silt and sand accumulated near the glacier margin where the meltwater associated with kame moraines entered the lake.

Teller (1976, p. 34) and Langford (1977, p. 1288) suggested that most of the clay in the southern and western part of the Lake Agassiz basin was brought in by the drainage across the Cretaceous shales to the west. Saskatchewan and Churchill rivers flowed into Lake Agassiz during deglaciation and may have brought in much of the thick blanket of clay in the basin. The bulk of the coarser sediments, however, particularly the thick silt in places interbedded with clay (Fig. 22), had a glacial origin as most likely did the clay veneer outside the main basin of deposition. Study of the mineralogy of the clays (Teller, 1976, p. 34; Langford, 1977, p. 1288) should be a means of determining their probable source areas.

Tyrrell Sea sediments

The name Tyrrell Sea sediments was used informally by McDonald (1969, p. 94) and by Netterville (1974, p. 40) for marine sediments over the Hudson Bay Lowland part of the study area. They are named after the Tyrrell Sea (Lee, 1960) which inundated Hudson Bay Lowland following final deglaciation.

Physical properties. The Tyrrell Sea sediments consist of clay, silt, sand, and gravel, commonly fossiliferous and between 1.2 and 3 m thick (Appendix 1, sections 2, 3, 6-8, 10-14, 16-26). Hayes River below the confluence with Fox River has incised through mostly Tyrrell Sea sediments up to 30 m thick (sections 12, 13). The primary criterion for recognizing marine sediments is fossil content. Nonfossiliferous sediments are included as marine sediments but the designation has its basis in geomorphology (beaches) or stratigraphic position (Fig. 23); those based on the latter must be considered as tentative. The thickest marine sediments appear to be restricted to Hayes River valley.

A fossiliferous diamicton exposed near the confluence of Hayes and Gods rivers (Appendix 1, section 14) may be of marine or glacial origin. A marine origin is considered most likely because of its apparent local occurrence. Similar till-like sediments were not seen in other exposures in the Lowland. Furthermore, the underlying silt and clay are similar to nearby fossiliferous marine sediments.

Distribution and stratigraphic relations. Tyrrell Sea sediments blanket Hudson Bay Lowland where they commonly overlie tills of the Wigwam Creek Formation. Along the upper stretch of Nelson River, however, they are separated from the underlying tills by thick wedges of Lake Agassiz sediments, in places including varved clay (Appendix 1, sections 20, 22). The abandoned beaches at about 122 m a.s.l. mark the western limit of Hudson Bay Lowland and the highest known elevation of the Tyrrell Sea sediments in the area.

Age and origin. The Tyrrell Sea sediments in the study area range in age from at least 7000 years to the present, as Hudson Bay is its modern equivalent (Lee, 1960, p. 1610). A radiocarbon date of 7030 ± 170 BP (GSC-2294; Table 3) was obtained from shells at about 90 m a.s.l. (Appendix 1, section 23) 8 km east of the beaches that mark the western limit of these sediments within a former embayment occupied by Nelson River. Another date of 6610 ± 100 BP (GSC-1955; Table 3) was obtained from shells less than 3.4 m below the surface at 76 m a.s.l. along Gods River (section 3), and a date of 4890 ± 140 B.P. (GSC-1745; Table 3) was obtained from a wood fragment at about 8 m a.s.l. along lower Hayes River (section 12). The 7000 year-old shell date is a minimal age as the oldest dates from Tyrrell Sea sediments elsewhere on Hudson Bay Lowland range from 7300 to 7900 years (Craig, 1969, p. 70).

The sediments over the Lowland originated as shoreline or shallow marine deposits. The thick wedges of marine sediments restricted to the vicinity of Hayes River appear to have been deposited as a succession of small deltas or in estuaries along the sea coast as it shifted northeastward to its present position.

Recent sediments

Sediments deposited subsequent to the draining of Lake Agassiz or the retreat of the sea from Hudson Bay Lowland are referred to as Recent sediments. The bulk of these sediments are the extensive organic deposits that blanket much of this region. Also included are local deposits of clay, silt, sand, and gravel along modern streams as well as reworked drift deposits, particularly clay and silt of Lake Agassiz. Typical reworked deposits are clay and silt that were eroded from the slopes of bedrock hills or knolls by sheet wash or mass movement and deposited in adjacent low areas.

Regional correlations - Hudson Bay Lowland

The stratigraphic succession in that part of the study area within the Lowland is remarkably similar to ones described in other parts of the Lowland. Numerous riverbank sites between Churchill in the north and Moosonee in the south expose multiple tills and intertill sediments (Terasmae and Hughes, 1960; McDonald, 1969, Skinner, 1973; L.A. Dredge, personal communication, 1980). The regional distribution of a fossiliferous, intertill unit (Missinaibi Formation) provides a stratigraphic marker over the Lowland south of the study area and is the main basis of the proposed correlation of Quaternary deposits (Fig. 29).

The Gods River sediments were studied in considerable detail by Netterville (1974, p. 49-52, see Appendix 2) who proposed a correlation (Fig. 29) with units described by Skinner (1973). Additional evidence for these correlations is the similar stratigraphic position of the multiple tills and intertill sediments in various parts of the Lowland. The similarity of the stratigraphic succession over such a vast area suggests that it is a substantially complete record of late Pleistocene climatic events in this region and that glacial erosion was minimal.

A Sangamonian age for the fossiliferous intertill Missinaibi Formation and its equivalents as proposed by Skinner (1973, p. 50) and Netterville (1974, p. 19-34; Appendix 2) appears likely, as does the Illinoian age they suggested for the underlying tills and the Wisconsinan age for the overlying tills. The nonglacial sediments between the Wisconsinan tills are evidence that the glaciers retreated at least to these latitudes during two interstades. The barren nature of these sediments, however, in a region where the record is so remarkably well preserved, suggests proglacial and glacial conditions prevailed over Hudson Bay Lowland during the Wisconsinan.

Andrews et al. (1980) obtained ages from a suite of amino acid ratios on shells at the base of the Missinaibi Formation and shell fragments from two or more post-Missinaibi tills in the lowlands of southern Hudson Bay and James Bay. They concluded that at least two marine incursions of Hudson Bay and three advances of Wisconsinan glaciers occurred in the region since about 108 000 years BP.

PLEISTOCENE HISTORY

Pre-Late Wisconsinan events

The Pleistocene stratigraphy of Hudson Bay Lowland records five advances of glaciers within the study area. The occurrence of a paleosol between the Amery Formation and an underlying till (Nielsen and Dredge, 1982), and the Gods River sediments between the Amery Formation and Wigwam Creek Formation is evidence for two intervals of regional

Table 3. Radiocarbon dates from surface materials

^{14}C Age Years BP	Laboratory No.	Dated Material	Location	Reference	Comments
8530 ± 220	GSC-896	marine shell	56°18'N, 90°24'W	Lowdon and Blake, 1970	'Old beach' Creek, marine shell fragments in beach sand at 125 m a.s.l. and 11 m below marine limit
8310 ± 180	GSC-1679	freshwater shell	54°10'N, 98°50'W	Lowdon et al., 1977	Minago River, freshwater shell from Ponton beach ridge, ∼245 m a.s.l.
7970 ± 150	GSC-1825	organic silt	54°45'N, 101°41'W	Lowdon and Blake, 1975	Flin Flon, bottom sediment from small lake, ∼305 m a.s.l.
7030 ± 170	GSC-2294	marine shell	56°31'N, 94°05'W	Teller, 1980	lower Nelson River, surficial marine clay, ∼90 m a.s.l.
6920 ± 150	GSC-1818	organic debris and wood fragments	56°21'N, 97°58'W	Lowdon and Blake, 1975	Settee moraine, basal organic layer in Kettle Lake, ∼305 m a.s.l.
6610 ± 100	GSC-1955	marine shell	56°15'N, 92°45'W	Lowdon et al., 1977	lower Gods River, surficial marine sand, ∼75 m a.s.l.
6520 ± 130	WIS-72	organic detritus	56°50'N, 101°03'W	Teller, 1980	Lynn Lake, bottom zone of bog, 1.5 m thick
6490 ± 170	GSC-1738	peat	56°52'N, 95°47'W	Lowdon et al., 1977	Recluse Lake, bottom zone of bog 1.8 m thick, ∼185 m a.s.l.
6280 ± 80	GSC-2760	peat	56°40'N, 94°05'W	Teller, 1980	Charlebois, bottom zone of bog 2.4 m thick above marine sand, ∼122 m a.s.l.
5990 ± 80	GSC-2759	peat	59°28'N, 101°13'W	Lowdon and Blake, 1979	Moorby Lake, bottom zone of bog, 2.5 m thick
4890 ± 140	GSC-1745	wood	56°45'N, 92°42'W	Lowdon et al., 1977	lower Hayes River, wood was 8.2 m below surface of deltaic sand

deglaciation between three glaciations. Evidence for multiple glaciation over the Shield part of the study area is limited as only one till is seen over much of the bedrock terrain, although the three glaciations recorded over the Lowland were most likely of continental magnitude and extended well beyond the study area.

Tyrrell (1913, p. 196-207) proposed that the last 'Labradorean glacier' advance to the west and southwest was preceded by a 'Patrician glacier' that advanced northward and westward from a centre between Hudson Bay and Lake Superior. The earliest was a 'Keewatin glacier' advance to the south and southeast from a centre west of Hudson Bay and north of Churchill River. This interpretation was based on the multiple till stratigraphy he recognized along the rivers across the Lowland and on striae on bedrock exposures, although it appears that his conclusions concerning earlier glaciations were based largely on the differences in direction of glacial striae.

Fabric measurements of the tills exposed along Gods River (Netterville, 1974) and fabrics and erratic stones studied along Nelson River (Nielsen and Dredge, 1982) suggest a considerable divergence in ice flow directions during deposition of till units. A similar though lesser degree of divergence of ice flow directions is reflected in the surface features and striae in the study area, although these flow marks are thought to reflect ice flow directions during final deglaciation rather than during maximum glaciation.

The oldest till recognized in the study area by Nielsen and Dredge (1982) has a fabric and contains pebble erratics that reflect a northwesterly direction of ice flow. The overlying Amery Formation in the vicinity of Nelson River also has a pebble fabric suggesting ice flow to the northwest (Nielsen and Dredge, 1982), whereas in the vicinity of Gods River the pebble fabric has a preferred orientation to the southwest. The lower member of the Wigwam Creek Formation has a fabric predominantly to the northwest in the vicinity of Nelson River (Nielsen and Dredge, 1982) and towards the south in the vicinity of Gods River. Fabrics of the middle and upper tills of the Wigwam Creek Formation indicate ice flow to the southwest in the vicinity of Gods River, and the upper till fabric in the vicinity of Nelson River suggests a westerly ice flow direction in the vicinity of Nelson River as indicated by the surface features.

The rather limited evidence available suggests that the centres of ice accumulation and outflow of earlier glaciations were in roughly the same locations as the centres that controlled ice flow across the map area during the last glaciation. Earlier flow across the map area may well have been centred in the Hudson Bay and Keewatin regions.

TIME-STRATIGRAPHIC UNITS		STRATIGRAPHIC ROCK UNITS: Hayes - Gods - Nelson rivers (this Report)		Nelson River (Nielsen and Dredge, 1982)	Gods River (Netterville, 1974)	Moose River Basin (Skinner, 1973)	Hudson Bay Lowland (McDonald, 1969)	Missinaibi River (Terasmae and Hughes, 1960)		Churchill River (Dredge, unpublished)
WISCONSINAN	LATE	Tyrrell Sea sediments		Tyrrell Sea sediments	Tyrrell Sea sediments	marine unit	Tyrrell Sea sediments	fluvial and marine deposits		
		Lake Agassiz sediments		Lake Agassiz sediments		glaciolacustrine unit	Proglacial lake sediments			lacustrine silt
		Wigwam Creek Formation	upper till	sandy diamicton	Till D	Kipling till	till	Upper drift	till	till
			intertill sediments	brown clay till	unnamed sediments				silt and clay (varved ?)	silt and sand
			middle till		Till C				clay with till ? lenses	till
	MIDDLE		intertill sediments	upper grey till	Twin Creeks sediments	Friday Creek sediments	sand and gravel			sand and till
	EARLY		lower till		Till B	Adam till	till			till
SANGAMONIAN		Gods River sediments		Missinaibi Formation	Gods River sediments	Missinaibi Formation	peat marine sand	Missinaibi beds		sand, slightly fossiliferous
ILLINOIAN		Amery Formation		middle grey till	Till A	Till III	till	Middle drift	till	till
PRE-ILLINOIAN				paleosol		intertill sediments-II-III			silt and sand	
				lower grey till		Till II			till	
						intertill sediments- I- II			clay, sand and gravel	
						Till I		Lower drift	till	

GSC

Figure 29. Regional correlation of stratigraphic sections on the Hudson Bay Lowland.

Late Wisconsinan Glaciation

The surficial materials, landforms, and ice flow markings that provide the basis for reconstructing events related to the last glaciation and deglaciation of the map area reflect mostly events related to final deglaciation. Interpretations concerning the direction of ice movement and the nature of glacial deposition and erosion during the maximum extent of the last glaciation are necessarily rather speculative. Streamlined landforms in particular reflect ice flow directions along the ice margin during final deglaciation and not necessarily the direction during a glacial maximum.

Tyrrell's proposal (1913, p. 197) that centres of ice dispersal were located in a region to the southeast (Patrician), the east (Labradorean), and northwest (Keewatin) of the Hudson Bay basin was based largely on directions of glacial striae in the region bordering the basin. He suggested that each centre dominated a particular period of glaciation, although this concept of ice flow directions also has relevance to ice dispersal during the final stages of the last glaciation. Flint (1943, p. 333) proposed that the principal centre during the last glacial maximum was the main basin of Hudson Bay. This proposal has been recently challenged by Shilts et al. (1979) who cited field evidence concerning regional dispersal patterns of erratics that supports Tyrrell's original concept, at least for Labradorean and Keewatin ice centres. Shilts et al. concluded that these centres persisted throughout Wisconsinan time.

Dyke et al. (1982) have proposed a version of Late Wisconsinan ice centres that is close to Tyrrell's original concept. This proposal suggests an ice centre developed over Hudson Bay (Hudson Dome) somewhat farther north than Tyrell's proposed Patrician ice centre. Evidence cited by Dyke et al., along with evidence from the study area (interlobate moraines, surface till composition, and ice flow features) suggests that the eastern part of the study area was covered by a 'Hudson lobe' and the western part by a 'Keewatin lobe'

Deglaciation

Previous studies

The broad aspects of deglaciation, particularly with reference to glacial Lake Agassiz have been documented in a number of publications based on field studies and references to previously published data. Among these are reports and maps by McInnes (1913, p. 118-127), Antevs (1931), Elson (1967, p. 37-95), Prest (1969), and Craig (1969).

McInnes (1913, p. 118-127) made no attempt to chronicle deglaciation but concluded on the basis of striae that the last major advance across the region was "a little west of south" and was followed by a westerly advance that terminated just within the western boundary of the map area in the north and covered the entire extreme southern part of the map area. He also showed the approximate limits of the northern end of Lake Agassiz, based on the distribution of lacustrine clays (McInnes, 1913, p. 124); the lake boundary shown is a fairly good approximation of the distribution of the thickest, most continuous cover of lacustrine clay in the study area.

Some aspects of final deglaciation in northern Manitoba are discussed in considerable detail by Antevs (1931, p. 42-50), although he delineated only two highly generalized ice front positions in the map area (Antevs, 1931, p. 16). These are correlated with glacial lake stages in eastern Canada. Although he calculated local rates of ice retreat, the discussion lacks the continuity required to infer an absolute chronology of ice retreat in the area.

A particularly relevant part of Antevs' report is his proposal that deglaciation of the map area was dominated by the retreat of two separate ice lobes (Antevs, 1931, p. 43). He suggested that deglaciation was initiated along a line of weakness that developed where the "Patrician sheet" from the east had coalesced with the "Keewatin sheet" from the northwest. The sheets separated along a line through Lake Winnipeg and the Nelson lowland, and the final stage of deglaciation in the area included the drainage of Lake Agassiz along this line in the vicinity of Little Churchill and Churchill rivers in the northeast corner of the map area (Antevs, 1931, p. 46). The north-trending margin of the Patrician ice at this time was placed "somewhat east of the north-south reach of the Nelson River" and the west-trending Keewatin ice margin stood along the Indian Lakes and Churchill River.

Elson's (1967) report on the history of Lake Agassiz includes diagrams and discussion of a sequence of stands of Lake Agassiz and the positions of retaining ice margins in western Ontario, northern Manitoba, and a small part of eastern Saskatchewan. He depicted ice margins and the extent of Lake Agassiz during four speculative phases of final deglaciation that began about 9000 years ago in the southwestern part and ended about 7500 years ago in the northeastern part of the study area when the lake drained into Hudson Bay via Nelson River valley. The regional scale of the maps is such that ice frontal positions and lake margins cannot be directly related to moraine systems and abandoned beaches.

Speculative ice margins across the map area shown on Prest's (1969) map are assigned dates beginning at about 10 500 years ago in the southwestern to 8500 years in the northeast. Although highly generalized, the ice margin positions are related to the major moraine systems in the map area to the extent that re-entrants are drawn where the largest moraines occur.

Deglaciation of the eastern part of the map area within and bordering Hudson Bay Lowland is included by Craig (1969) in a general discussion of final deglaciation of the entire Hudson Bay region. He postulated a general northward and northwestward shrinkage of the continental glacier over Hudson Bay that finally formed a remnant glacier on the west side of Hudson Bay over the "Keewatin ice divide" north of the map area. At one stage during retreat, a re-entrant occupied by Lake Agassiz developed in the Nelson-Hayes River area. Gradual enlargement of the re-entrant was followed by marine inundation from the southeast that had begun about 8000 years ago when the sea entered the eastern and southern part of the Hudson Bay region through Hudson Strait. This marine inundation extended over the Churchill area (about 150 km north of the map area) some 7300 years ago. Craig's proposed chronology of marine inundation is based mainly on 15 radiocarbon dates of marine shells from the highest marine sediments around the periphery of Hudson Bay.

Present study

The stages of deglaciation outlined in this report are a somewhat modified version within the broad chronological framework of regional events proposed by Elson (1967) and Craig (1969). Interpretation of the positions of the retreating glacier margins and the margins of Lake Agassiz and its remnants in the area are based on (1) the distribution and origin of kame moraine systems, (2) the distribution and origin of glaciolacustrine sediments and landforms, (3) the distribution of till sheets and associated ice flow features, (4) radiocarbon dates, and (5) the average rate of ice retreat.

Kame moraines

The significance of kame moraines in reconstructing a sequence of events during deglaciation of the map area must be considered in the light of the following observations and their implications:

1. These features are major regional landforms, continuous for tens of kilometres, and are arranged in a roughly lobate pattern formed of distinctive south trending segments (Settee), west and southwest trending segments (Burntwood and Limestone moraines), and south to southeast trending segments (Northern Indian and Etawney moraines).
2. Along individual segments the morphology changes gradationally or abruptly from narrow esker-like ridges to broad, deeply pitted surfaces up to several kilometres wide.
3. The surface and internal composition of these features is typically sand of glaciofluvial and/or glaciolacustrine origin. Bouldery surfaces are not common and till surfaces are rare.
4. In places these features form the boundaries between map units (Limestone and Burntwood moraines) or mark the transition from till of eastern provenance to till of northern provenance (Etawney and Northern Indian moraines).
5. Distinctive flights of abandoned beaches occur on the east slopes and parts of the crests of the Settee and Burntwood moraines to about 335 m elevation whereas they are absent on the Limestone moraine to the west and Etawney and Northern Indian moraines to the north which are at lower elevations.

These features are within the broad category of stratified ice contact deposits. The regional lobate patterns formed by numerous ridge segments suggest that these features formed in successive increments, in part between and along the margins of retreating, regionally deployed ice lobes. The considerable depth of Lake Agassiz along the retreating ice margin resulted in the subaqueous deposition of much of the sediment at and beyond the ice front. Parts of the morainic ridges, deposited along subglacial or superglacial streams, are eskers.

Similar features in Finland (Aario, 1977a, p. 70) form a regional pattern much like the kame moraines in the map area. Aario (1977b, p. 98) classified such moraines as an "interlobe complex" and suggested that they reflected extensive ice stagnation. He also (1972, p. 7) described an "esker delta" in central Finland which he suggested formed along the ice margin in water at a depth of some 100 m. The sediments and bed forms described by Aario are not unlike those seen in parts of the kame moraine system of north-central Manitoba. Ice contact ridges in the Ottawa area, described by Rust and Romanelli (1975) and Cheel (1979) as "subaqueous outwash", appear to have formed in a similar manner. Rust and Romanelli (1975, p. 177) suggested that these features formed at about the same depth as Aario's esker delta. In fact, Cheel (1979, p. 23) believed the term "esker delta" to be a misnomer because of the subaqueous origin and suggested the term "subaqueous outwash" be used. The concept of a subaqueous origin for ice contact features in glacial lake basins is clearly not a new one. For example, Antevs' (1925, p. 9-10) illustrations indicate that he inferred such an origin for esker ridges in the Lake Barlow-Ojibway basin in Ontario.

The kame moraine system is interpreted as evidence of the essentially synchronous deployment of two major ice lobes in northern Manitoba during the initial stages of deglaciation, which proceeded by ice margin retreat as well as by stagnation of parts of the lobes. The morphology and composition of these features suggest that deglaciation occurred rather rapidly and continued uninterrupted by readvances or significant stillstands of the ice lobes. Water depths were likely in excess of 100 m. The deep water along the ice front probably accelerated "ice margin type" retreat in this zone (Aario, 1977a, p. 69). Downmelting and stagnation, however, were likely major factors in providing the vast amounts of meltwater that deposited sediments in tunnels, ice-walled channels, and in Lake Agassiz beyond the ice front. A glaciofluvial-lacustrine system of this nature would assure the virtual absence of classicial-type end moraines in the main glacial lake basin. Minor end moraines, transverse to the trend of eskers and ice flow indicators, occur in areas north and northwest of the main glacial lake basin.

Glaciolacustrine deposits and landforms

The distribution of glaciolacustrine sediments and abandoned beaches is evidence that Lake Agassiz covered the area following deglaciation. Stratigraphic relationships of basin and shoreline deposits reflect falling water levels and an absence of transgressive stages of Lake Agassiz in this region.

Lake Agassiz remained over the southern part of the study area for a much longer time than over northern and eastern parts, as indicated by the thick wedge of sediments in the south. The patchy distribution of sediments outside the main basin, however, probably reflects other factors as well as time. Sediment sources and current directions are also factors that influence the distribution and thickness of lacustrine sediments. The main basin is just beyond mouths of two major river systems (Saskatchewan and Churchill) that carried in clay from Cretaceous shales to the west. Furthermore, the positions of the major kame moraines indicate that most meltwater flow was directed into the main basin to the southwest.

The Grand Rapids and Ponton beaches (Fig. 30) reflect two intervals of stable lake levels during the gradual lowering of Lake Agassiz as it encroached on deglaciated terrain to the north and east. The Fidler beach (Fig. 30) marks a stable lake level shortly before final drainage.

The differential uplift rates for the northern part of the Lake Agassiz basin in Manitoba (0.2 to 0.5 m per km) are somewhat lower than rates of 0.4 to 0.7 m per km obtained by Hughes (1965, p. 561) and 0.5 to 1.2 m per km obtained by Vincent and Hardy (1979, p. 1) in the Lake Barlow-Ojibway basin in Ontario. The Manitoba figures, however, are close to the average rate of 0.5 m per km calculated from Walcott's (1972, p. 869) theoretical model.

Downwarping of the surface beyond the ice margin, suggested by theoretical considerations (Walcott, 1972, p. 869) and reflected by deformed strandlines, indicates that maximum water depths occurred along the ice front. The differential rates of uplift calculated from abandoned strandlines and applied to the distance from a particular point along an abandoned beach to a postulated postion of the contemporaneous ice margin provide a rough estimate of maximum water depths (Fig. 31). The maximum depth suggested for various phases ranges between 150 and 180 m over the Shield to some 250 m over Hudson Bay Lowland.

Till plains and ice flow features

The difference in the texture and composition of tills and the orientations of ice flow features within the various physiographic divisions reflect the deployment of two major ice lobes in north-central Manitoba. A lobe of eastern provenance (Hudson) flowed mainly in a southwesterly direction across the eastern part of the area and was confluent with a lobe of northern provenance (Keewatin) that flowed mainly in a southerly direction. These flow patterns reflect ice movements during final deglaciation. The ice flow directions reflected by superimposed bedrock striae are in the zone of confluence between the two lobes and suggest either minor fluctuations of the lobes during retreat or earlier ice movements in the area. Ice of the Hudson lobe was the last to cover the transitional zone.

Radiocarbon dates

Radiocarbon dates on marine and freshwater shells, peat, and organic detritus from northern Manitoba range from about 8000 BP in the south to 6000 BP near the Northwest Territories boundary (Table 3). They are minimal dates for the time of disappearance of glacial ice or deep water from this area.

Average rate of ice retreat

Surface radiocarbon dates and varve counts have provided a means of determining an average rate of deglaciation in northern Manitoba. It is unlikely that ice margins or shorelines retreated uniformly across this region, in part because of the stagnation of broad belts of ice and rapidly falling lake levels which resulted in contemporaneous exposure of large areas. The average rate calculated, however, compares well with published figures from the Prairies and eastern Canada, and the rate appears to be valid.

The 2000 year difference between surface dates from the southernmost and northernmost parts of the map area, which are some 500 km apart, suggest that ice retreated at an average rate of 250 m per year. Antevs' (1931, p. 47-70) varve counts across the southern part of the main basin indicate ice retreat of the order of 300 m per year. Similar rates of 200 to 300 m (Ritchie, 1976, p. 1809) and 275 m per year (Christiansen, 1979, p. 934) are proposed for the Prairies to the southwest. Hughes (1965, p. 561) obtained rates between 227 and 280 m per year based on varve counts in the glacial Lake Barlow-Ojibway basin in Ontario. Thus 300 m per year appears to be a realistic average rate of ice retreat across northern Manitoba; this rate was applied in determining the distance between the successive ice front positions shown in Figure 31.

Phases of deglaciation

Figures 32-37, depicting phases of deglaciation, include adjacent parts of Manitoba north of Lake Winnipeg because the major moraine system in north-central Manitoba provides control for events over the entire northern region. Ice front positions and the extent of Lake Agassiz outside the map area are depicted on the basis of data shown on a surficial geological map of Manitoba (Manitoba Mineral Resources Division, 1981) and in Dredge (1983). The latter information was particularly relevant in determining the northernmost extent of Lake Agassiz. Publications by Johnston (1946), Elson (1967, 1971), Craig (1969), and Prest (1970) provided additional information for the broad aspects of regional deglaciation.

A chronology of events is discussed with reference to six, somewhat arbitrarily defined, phases (Figs. 32-37). Each phase is referred to by a number (1 to 6) and related to a particular Lake Agassiz beach that formed at some time during the phase.

Phase 1.

Phase 1 depicts the extent of Lake Agassiz and deglaciation about 9500 years ago (Fig. 32). The Ojata beach at about 290 m elevation along the Manitoba escarpment southwest of the map area (Fig. 30) marks the southwest shoreline of Lake Agassiz during part of this phase and indicates a drop of about 75 m from the 10 000 year-old Campbell level (Prest, 1970, Fig. 16-o). Water depths along the ice margin some 270 km north of the Ojata beach were about 275 m. Lake Agassiz drained into the Lake Superior basin via Lake Nipigon (Prest, 1970, Fig. 16-p; Teller and Thorleifson, 1983). The former ice margin position is marked by the Hargrave and Hudwin moraines (Fig. 30), which are highly subdued features reflecting a subaqueous origin. The Hargrave moraine, for example, is mapped as part of a glaciolacustrine clay unit (Klassen and Netterville, 1980g, i). The ice margin position shown west of the Hargrave moraine is a speculative one, and may have trended along a northwesterly line rather than to the west as shown.

Phase 2.

Phase 2 depicts the extent of Lake Agassiz and deglaciation about 9000 years ago (Fig. 33). The Pas beaches, which occur at an elevation of 274 m along the front of The Pas moraine, formed during this phase (Fig. 30). Moraines related to this phase include the Highrock, Burntwood, Sipiwesk, and Cantin (Fig. 30). Water depths along the ice margin were about 200 m. Drainage continued to be eastward into the Lake Superior basin (Prest, 1970, Fig. 16-q).

Phase 3.

Phase 3 depicts the extent of Lake Agassiz and deglaciation about 8700 years ago (Fig. 34). The Grand Rapids beaches at about 250 m elevation near Grand Rapids just north of The Pas moraine (Fig. 30) formed during this phase and indicate a drop of some 50 m from the level of The Pas beaches in this vicinity. The moraines associated with this phase include the Burntwood and southern segment of the Settee. Water depths along the ice margin were in the range of 150 to 200 m. Drainage continued to be eastward into the Lake Superior basin (Prest, 1970, Fig. 16-r).

During the latter part of this phase, stagnation of a broad zone of the Hudson lobe occurred over the Bigstone morainic plain. Stagnation was likely initiated and accelerated by the incursion of the Tyrrell Sea (Lee, 1960) into the southern part of Hudson Bay Lowland. Meltwater activity was accelerated in this zone and many of the ice contact features on this plain were forming at this time.

Phase 4.

Phase 4 depicts the extent of Lake Agassiz and deglaciation about 8000 years ago (Fig. 35). The Ponton beach (Bell, 1978, p. 59) formed when the water level fell about 80 m from the Grand Rapids level (Fig. 30). Lake Agassiz was probably at its maximum extent in northern Manitoba. Shells from this beach yielded a radiocarbon age of 8310 ± 180 BP (GSC-1679) which is the only post-Campbell date obtained from Lake Agassiz beaches in this region.

The moraines associated with this phase include the South Knife, Northern Indian, Limestone, and Sachigo (Fig. 30). The eastern terminus of the Limestone moraine formed within a subglacial channel carrying water into the Tyrrell Sea. Water depths along the ice margin remained at some 150 m. Drainage of Lake Agassiz was accelerated because of further thinning and stagnation of the Hudson lobe. This allowed drainage channels to form beneath the glacier and carry meltwaters into the Tyrrell Sea that by this time had inundated much of Hudson Bay Lowland in Ontario (Craig, 1969, p. 71; Prest, 1970, Fig. 16-u). Saskatchewan River drainage entered Lake Agassiz via a series of lakes and a valley presently occupied by Minago River.

Phase 5.

Phase 5 depicts the extent of Lake Agassiz and deglaciation about 7700 years ago (Fig. 36). The Fidler beach at about 250 m elevation along the north side of Northern Indian moraine (Fig. 30) formed during this phase when the level of Lake Agassiz fell about 80 m from the Ponton level in this vicinity. West of Hudson Bay Lowland the lake was shallow and had an archipelago-like aspect to it. Along the ice margin across the Lowland, however, water depths were of the order of 300 m. Lake Agassiz continued to drain into the Tyrrell Sea via channels beneath and around the now stagnant Hudson lobe. The Tyrrell Sea was rapidly encroaching northward and was near the Manitoba part of the Lowland (Prest, 1970, Fig. 16-v). The lower segments of Saskatchewan and Churchill rivers drained into Lake Agassiz via channels presently occupied by Minago and Rat-Burntwood rivers, respectively (Fig. 1).

Phase 6.

The final drainage of Lake Agassiz and the inundation of Hudson Bay Lowland by the Tyrrell Sea occurred during the beginning of this phase about 7500 years ago (Fig. 37). The Hudson lobe had disappeared but the Keewatin lobe was in the vicinity of the 60th parallel.

Most of the present drainage pattern, except for the modern Nelson River, was likely established in Manitoba by this time. Lake Winnipeg may have drained via the Echimamish channel into the Hayes River system. Saskatchewan River may also have entered this system via the Minago channel and through Cross and Pipestone lakes. Drainage was later diverted along the present Nelson River channel, probably as a result of shifting of the drainage divide that accompanied isostatic rebound.

ECONOMIC AND GEOTECHNICAL ASPECTS OF SURFICIAL DEPOSITS

A primary purpose of this study was to provide background data for construction projects, land use studies, and mineral exploration in this region.

Permafrost

The widespread distribution of permafrost in the map area makes it an important factor to consider during all phases of development.

Previous studies

The increase in construction and mineral exploration activities in northern regions of Canada since the 1950s has resulted in a proliferation of technical and scientific reports concerning many aspects of permafrost. Some general and specific aspects particular to this region are considered here.

The study area is within the 'discontinuous permafrost zone' that includes a belt of 'widespread permafrost' and the 'southern fringe of permafrost' separated by a boundary that trends roughly west-northwest through Split Lake (Brown, 1967).

Much information concerning the nature and distribution of permafrost across the area, as well as its effect on construction and maintenance of rail beds and bridges, was gathered during construction of the Hudson Bay Railway. The most complete compilation and discussion of the general information obtained and expertise developed is given by Charles (1959); included is a map showing the approximate southern limit of permafrost in Canada.

Charles (1959) stated that permafrost occurs "in scattered patches or islands" as far south as 54°50'N from 56°30'N where the entire subsurface was permanently frozen. Permafrost is about 4 m thick along the southern limit and increases to about 8 m at the southern boundary of the belt where it is widespread in the vicinity of Kettle Rapids. From Kettle Rapids northward the thickness increases to more than 70 m at Churchill. The typical thickness of the active layer over peat bogs is about 45 cm, whereas over well drained, bare sites it reaches 2 m, and beneath open water it is 3 m or more. Ground ice to 15 cm thick occurs in lenses in both peat and drift.

Detailed investigations of permafrost at the Thompson townsite were reported by Johnston et al. (1963); permafrost was found to be unpredictably distributed within clay as patches 6 to 100 m across to a depth from 1 to 9 m. It was concluded that construction problems, which resulted mainly from the unpredictable distribution of permafrost, the occurrence of ice lenses, and the general 'near thawing' condition of the permafrost, could be resolved only by thorough site investigations.

Permafrost studies at Kelsey damsite (Johnston, 1965) dealt mainly with monitoring the effects of construction on permafrost degradation. General conditions were also described and were similar to those at Thompson although the maximum depth of permafrost was found to be somewhat greater (10 m) and average ground temperatures were slightly lower.

Piteau (1972) and Peters and McKeown (1976) discuss specific aspects of damsite construction in permafrost at the Kettle Rapids site and several proposed damsites farther downstream. The latter report deals mainly with engineering aspects of permafrost in till and general conclusions concerning distribution and depth confirm the results of earlier reports. These reports state that in the vicinity of Kettle and Long Spruce rapids permafrost occurrences are commonly marked by dwarfed spruce; permafrost commonly extends from the active layer to 4.5 to 9 m below the ground surface and terminates in the lacustrine deposits or in till, and in places in bedrock.

Present study

Information concerning the distribution and depth of permafrost in the study area was obtained by studying riverbanks, by hand augering peat bogs to 3 m depth, and from ten testholes drilled to 9 m depth along the Thompson - Lynn Lake highway (Klassen, 1976). The results obtained support the conclusions drawn from earlier studies particularly those by Charles (1959). Charles (1959, p. 125) cited the following factors as contributing to the general and local permafrost condition:

"1. Altitude and average air temperature.
2. Surface covering and its insulating properties.
3. Type and conductivity of the sub-soil.
4. Topography and natural drainage, both surface and sub-surface.
5. Location in relation to rays from the sun,
6. Precipitation".

The element of unpredictability of occurrence mentioned by Johnston et al. (1963) appears to relate to factors 3 and 4, which require detailed subsurface information.

The peat bogs within the study area invariably harbour permafrost and ground ice. Over typical surfaces the active layer consists of 30 to 60 cm of dry moss and wet peat covering the permanently frozen zone that extends to about 3 m near the southern fringe of the study area and to below the 9 m-deep testholes drilled in the vicinity of 56°N. The active layer is commonly thinnest where clusters of black spruce occur and deepest beneath treeless parts. South of 57°N, evidence of degrading permafrost was noted around the margins of some bogs, and trees were tilted and peat banks were freshly collapsed (Fig. 24).

Beneath fen and open water that border many peat bogs, permafrost is either absent or below the depth probed by hand auger (3 m). Details of the distribution of permafrost in a typical bog found in the southern part of the study area are given by Zoltai and Tarnocai (1971).

Elsewhere in the map area, the local occurrence of permafrost depends upon various combinations of the factors cited by Charles (1959). Elsewhere, the permafrost generally becomes more widespread going from south to north within low lying, poorly drained areas, devoid of standing water. These areas typically have permafrost within 0.5 to 2 m of the surface depending on the density of surface vegetation and thickness of the organic mat. Higher surfaces mantled with lacustrine clay or till commonly are permanently frozen at similar depths beneath heavily wooded, northwest facing slopes. Permafrost is predictably absent beneath the well drained parts of landforms composed of silt, sand, and gravel (kame moraines, kames, eskers, beach ridges) over most of the study area. It may, however, occur below 2 m depth in the larger, heavily wooded features, particularly in the north and northeast part of the map area.

Construction in permafrost

Development of this region has, to date, included major construction projects that were begun in the first decade of this century and have continued at fluctuating levels of activity to the present day. This type of activity will undoubtedly increase markedly in the future when the economic potential of this region is more fully realized.

These projects had significant pioneering components in the area of construction technology applicable to the zone of discontinuous permafrost. The building of the Hudson Bay Railway, begun in 1910 and completed in 1929, was followed by the beginning and completion of a major townsite at Thompson, damsites at Kelsey, Grand Rapids, and Kettle Rapids along with related facilities such as roads, railway spurs, and transmission lines. Much of the documentation of the technology developed is scattered through technical journals, symposia papers, and scientific journals, although information regarding a variety of technical and theoretical aspects of permafrost terrain is documented in publications by the staff of the National Research Council.

A list of general and specific recommendations for construction and maintenance of railway beds in areas of permafrost given by Charles (1959, p. 135) has wide implications for general construction and is quoted as follows:

"1) Before ground surveys are commenced to establish a proposed railway, air photos should be analyzed and interpreted to indicate where permafrost may occur and to what extent and to locate possible deposits of granular materials.

2) Air photographs and photogrammetry should also be used to aid in selection of the best route. Careful consideration of drainage features is particularly important.

3) In territory where permafrost occurs in comparatively small isolated areas - "Islands" - such areas should be avoided to the extent practicable in relation to distance and ruling gradients, etc.

4) Permafrost on a side-hill slope can become very troublesome.

5) Where it is not practicable to avoid excavating in permafrost for construction of a railway roadway, excavations should be extended to a depth of 3 feet to 5 feet below sub-grade, then backfilled <u>immediately</u> with comparatively dry materials, preferably granular, if available within reasonable hauling distance.

6) Sides of cuts in permafrost should be excavated to very flat slopes, as a precaution against material sliding and obstructing drainage ditches.

7) Drainage is always important, this especially so in areas of permafrost. Off-take ditches should be excavated and well maintained to prevent accumulation of water against side-slopes of embankments, particularly where they are built on permafrost, as water in contact with it will cause thawing.

8) Special care is necessary in selecting sites for bridges and culverts and type of structure with respect to site conditions. Whereas first class foundations are essential for rigid type structures, such as steel bridges on concrete structures, it is not so serious if some distortion occurs in a timber trestle or a cedar box culvert; they will remain functional.

9) Cross section area of culverts should be comparatively large to facilitate cleaning in event of an accumulation of ice.

10) In areas where permafrost is general and there are no great changes in topography, such as the tundras, design the location to obtain a roadway to be entirely embankment, if practicable to do so.

11) Relative telegraph and telephone lines should be erected on tripods of cedar poles, set on the surface.

Excavations should be restricted to off-take ditches and minor levelling on the railway right-of-way just sufficient to permit track to be laid. Then the track should be lifted by trainfill, to build up embankments on undisturbed permafrost.

Finally, when constructing where permafrost is general, preserve this condition, build on it, do not excavate into it, except for essential drainage to prevent accumulation of water and relative thawing."

Observations made at various construction projects underway in the study area during field studies indicate that these recommendations have become standards for good construction practices. Where permafrost-related problems developed, they usually could be related to avoidance of some aspect of these basic recommendations; some examples are given by Klassen (1976). The most generally applicable recommendations made is to preserve and build on the natural permafrost condition (Fig. 38).

Granular materials

Construction projects generally require materials in the sand and gravel size. Materials in this size range are most abundant in ice contact and glaciofluvial units, although significant quantities of well sorted grades can be recovered from minor features such as deltas, terraces, and beaches within deposits of marine, lacustrine, and alluvial origin. Some of the looser 'Shield' till may be used as a source for granular material requirements where sand and gravel are not available (Fig. 39).

A problem particular to this region is the preponderance of sand sizes within the major and minor ice contact features (Map 1603A). The surfaces of these features and the few natural and man-made cuts seen typically expose fine sand suggesting it constitutes the bulk of these extensive deposits. In places, however, the features are composed predominantly of coarse material as indicated by excavations and shallow surface exposures. Few criteria

Figure 38. Sand pad built over permanently frozen clay and till at Missi Falls construction site (57°21'N, 98°07'W). GSC 163288

Figure 39. Till exposed in a borrow pit near the Missi Falls construction site (57°21'N, 98°07'W). GSC 163265

were formulated for predicting the occurrence of the coarser materials using airphotos, although large isolated kames, along or near major kame moraines, appear to be mostly coarse material. Bouldery surfaces seen along parts of these features also suggest that material at depth is coarser than where the surface is entirely fine sand.

Mineral prospecting

Knowledge of the nature and distribution of surficial deposits has practical applications for mineral prospecting in glaciated terrain. The general approach entails the location of a mineral source by identifying a dispersal pattern resulting from glaciation and by detecting 'dispersal halos' in the drift blanketing mineral deposits, or of a combination of both of these approaches.

The prospecting techniques developed have ranged from simple boulder tracing to sophisticated mineral tracing and other types of geochemical sampling (Lee, 1963, 1965, 1968; Jones, 1975; Shilts, 1976; Kujansuu, 1976). Boulder tracing was shown to be an effective prospecting tool as early as 1842 before the glacial origin of 'drift' was recognized (Holmes, 1966, p. 431). The discovery of the Lynn Lake nickel deposit in 1941 has been attributed to boulder tracing by the propsector Austin McVeigh (T. Oliver, University of Calgary, personal communication, 1979), although an official report of the discovery makes no mention of the use of this prospecting technique (Brown, 1955).

This discussion offers some general guidelines for mineral prospecting specific to the study area and is directed towards locating economic mineral deposits by detecting and tracing dispersal patterns resulting from glaciation.

A fundamental consideration in this technique is to establish the direction of glacial flow operative during the time the indicator rock or mineral was in transport from its source. This may be a relatively straightforward procedure if the indicator rock was transported from its source during the last ice movement; however, should there have been several or numerous changes in ice movement direction, whether related to the last glaciation or several glaciations, the problem becomes highly complex.

Mineral tracing projects with the greatest potential for success will be focused on indicators that completed their entire transport cycle during the last glacial advance and thus are probably within several kilometres (approximate transport distance of most glacial debris) of the bedrock source. The largest concentration of such indicators will be in the till deposited from the bottom (lodgment till) or lower zone (basal till) of the glacier. Field sampling procedures should therefore be restricted to these types of till. The ablation types diluted with far travelled material should not be included in the sample. Lodgment or basal tills in this region generally can be recognized by their compactness in contrast to the thinner and less compact ablation till. In localities where streamlined, drumloid features occur, ablation till is commonly thin or absent and samples taken along the side of the up-ice ends of the features will likely be in lodgment or basal till.

Extensive patches of lodgment or basal till occur at or near the surface throughout the study area, except in lacustrine basins where thick clays and bogs mask the tills. The best control can be established where drumloid features occur, although in areas where bedrock outcrops are numerous, thin patches of lodgment till on the up-ice ends of bedrock knolls, which are commonly marked by glacial striae, also are good sampling sites.

Mineral tracing by means of sampling eskers has been successfully applied in the Shield area of Ontario (Lee, 1965, 1968). This method would likely give the best results where applied to the smaller, distinctive eskers in this region. The large esker-like segments of the kame moraine systems most likely include more far-travelled material and results of sampling may not be as definitive as those from sampling of small eskers.

Peat harvesting

The great expanse of peat, which averages about 1.5 m in thickness over much of this region, undoubtedly has future economic potential, primarily as an energy source. Although economics to date have not encouraged the development of this resource, detailed studies of the potential of peat in general were initiated by the Canadian government in the early decades of this century (Haanel, 1912, 1925). Currently escalating costs and depletion of fossil fuels have revived interest in the development of this natural resource (Moneco Ontario Limited, 1981).

Agriculture

The clay basins of the southwestern part of the study area have some agricultural potential, but it is rather limited mainly because of frost hazard, low arable acreage, and low natural fertility of the soils (Ehrlich et al., 1959, p. 45). Limited quantities of cereal grains, forage crops, and a variety of vegetables have been grown although much more information concerning cultural aspects of soils, crop types, and climate is needed.

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APPENDIX 1

Descriptions of Sections

Unit	Description	Thickness (m)
	Section 1	
	Located along the east bank of Gods River about 21.5 km downstream from the confluence with Wigwam Creek (56°10'N, 92°32'W). Description is a composite of two exposures about 30 m apart.	
Recent sediments	Peat	0.3
	Sand, silt, and clay: bedded; pebbly zones; fluvial	1.8
	Sand and gravel: poorly sorted; includes pieces of wood (**Picea** sp.) radiocarbon dated as 490 ± 140 BP (GSC-1742 Lowdon et al., 1977); fluvial	0.5
Upper till, Wigwam Creek Formation	Till: dark greyish brown (10YR 4/2 or 5Y 4/2)[1]; jointed with limonite staining along joints; moderately stony; soft; sample KJ-116-72, 2% gravel, 53% sand, 45% silt and clay, 28% carbonate	1.8
Middle till, Wigwam Creek Formation	Till: dark grey (5Y 4/1); jointed with oxidation stains along joints; sample KJ-115-72, 3% gravel, 43% sand, 54% silt and clay, 38% carbonate; pebble fabric, preferred south-southwest direction	6.1
	Sand: lenses along contact	0.3
Lower till, Wigwam Creek Formation	Till: dark olive grey (5Y 3/2); moderately stony with boulders in lower zone; highly jointed with oxidation stains along joints; rare inclusion of wood or peat; sample KJ-114-72, 3% gravel, 59% sand, 38% silt and clay, 30% carbonate; pebble fabric, preferred west-southwest direction	3.0
Gods River sediments	Peat: silty; includes some stony horizons; weakly bedded; includes pieces of wood (**Picea** sp.); vascular plants[2] - **Juniperus, Picea, Pinus, Pseudosuga, Larix, Abies, Thuja, Chamaecyparis**; mosses - **Ditrichum flexicaule, Campylium polygamum**, cf. **Barbula rigidula, Hygrohypnum** sp., **Hypnum** sp., cf. **Drepanocladus exannulatus, Bryum** sp., **Pohlia** sp.; radiocarbon date on wood >41 000 BP (GSC-1736, Lowdon et al., 1977)	4.0
	Sand and gravel: includes wood fragments and blebs of peat and till, some wood fragments have beaver tooth marks	0.5
	Sand and gravel: poorly sorted	0.8
	Peat and sand: silty; rare pebbles	0.3
Amery Formation	Till: olive grey (5Y 5/2) or (5Y 4/2); jointed with oxidation stains along joints; sample KJ-109-72, lower zone, 1% gravel, 35% sand, 64% silt and clay, 24% carbonate; sample KJ-110-72, upper zone, 2% gravel, 48% sand, 50% silt and clay, 28% carbonate; pebble fabric, preferred orientation to the southwest	6.1
	Total thickness to river level	25.5

[1] Munsell colour chart, moist samples.
[2] Identified by M. Kuc, unpublished GSC Bryological Report No. 185.

Unit	Description	Thickness (m)
	Section 2	
	Located along east bank Gods River opposite north end of a large island about 13 km downstream from the confluence with Wigwam Creek (56°07'N, 92°27'W). Composite section of two exposures.	
Tyrrell Sea sediments	Clay and silt	0.8
	Gravel, sand and silt: includes shell fragments; marine	0.3
Upper till, Wigwam Creek Formation	Till: dark greyish brown (10YR 4/2); jointed with oxidation stains along joints; cliff forming; sample KJ-106-72, 13% gravel, 45% sand, 62% silt and clay, 27% carbonate	2.1
	Gravel, silt, and sand: poorly sorted and till-like	0.6
Lower till, Wigwan Creek Formation	Till: dark greyish brown (10YR 4/2); jointed with oxidation along joints; samples KJ-101 to -105-72 average 9% gravel, 30% sand, 62% silt and clay, 27% carbonate; sample KJ-108-72, 10% gravel, 43% sand, 47% silt and clay, 29% carbonate; contains wood fragments about 0.3 m above contact with underlying sand	6.1
Gods River sediments	Sand: fine to medium grained; massive, upper 0.6 m zone; clay bands and pebbly zones; contains wood fragments, seeds, beetle fragments, freshwater mollusc shells in upper zone	5.5
Amery Formation	Till: dark greyish brown (2.5Y 4/2); blocky fracture; hard, sample KJ-98-72, 6% gravel, 35% sand, 59% silt and clay, 25% carbonate	5.5
	Total thickness to river level	20.9
	Section 3	
	Located along east bank of Gods River about 16 km upstream from the Hayes River confluence (56°15'N, 92°45'W); surface elevation about 76 m a.s.l.; thicknesses estimated.	
Recent sediments	Peat	0.6
Tyrrell Sea sediments	Clay, silt, sand, and gravel: exposure of surface beach complex. Marine pelecypods **Hiatella arctica**[1] Linné 1767, **Macoma calcarea** Gmelin 1790, and **Mytilus edulis** Linné 1758; shells of **Mytilus edulis** were radiocarbon dated at 6610±100 BP (GSC-1955, Lowdon et al., 1977)	3.4
	Sand and gravel: stratified	3.0
	Sand: thinly bedded; highly stained by oxidation	2.4
	Clay: light grey, greasy	3.0
Wigwam Creek Formation	Till: grey, clayey to sandy	1.5
	Covered interval	18.3
	Total thickness to river level	32.2

[1] Fossil shells listed in Appendix 1 were identified by Dr. L. Kalas, formerly of Water Resources Branch, Environment Canada, Calgary, Alberta, unpublished identification Report 73-33, 1974.

Unit	Description	Thickness (m)
	Section 4	
	Type section of the Wigwam Creek Formation. Located along east bank of Gods River about 9 km above the confluence with Hayes River (56°17'N, 92°47'W).	
Recent sediments	Peat	0.9
	Gravel, sand, silt, and clay: thinly bedded	1.2
Upper till, Wigwam Creek Formation	Till: dark greyish brown (10YR 4/2); more compact in lower part; sample KJ-124-72, 5% gravel, 34% sand, 61% silt and clay, 26% carbonate	3.0
	Sand and gravel: fine gravel	0.3
Middle till Wigwam Creek Formation	Till: brown (10YR 4/3); sample KJ-123-72, 2% gravel, 34% sand, 64% silt and clay, 28% carbonate	3.0
	Sand and gravel: fine gravel; wedges out northwards along section	0.9
Lower till, Wigwam Creek Formation	Till: dark greyish brown (2.5Y 4/2); sample KJ-122-72, 2% gravel, 35% sand, 63% silt and clay, 32% carbonate	6.1
	Covered interval	3.0
	Total thickness to river level	18.4
	Section 5	
	Located along east bank of Gods River about 9 km downstream from the confluence with Wigwam Creek (56°05'N, 92°25'W).	
Recent sediments	Clay and silt: scattered pebbles; sample KJ-92-72, **Lymnaea elodes** Say 1821, rodent tooth fragment; freshwater-terrestrial environment	0.6
Upper till, Wigwam Creek Formation	Till: dark greyish brown (10YR 4/2); soft; sample KJ-91-72, 2% gravel, 50% sand, 48% silt and clay, 34% carbonate	1.5
Middle till, Wigwam Creek Formation	Gravel: includes stringers of till, dark greyish brown (10YR 4/2); sample KJ-90-72; 35% gravel, 33% sand, 32% silt and clay, 25% carbonate	0.6
	Sand: fine to medium grained	0.2
Lower till, Wigwam Creek Formation	Till: dark greyish brown (10YR 4/2); jointed with oxidation stains along joints; very hard, forms steep bluffs; sample KJ-88-72, 7% gravel, 29% sand, 64% silt and clay, 25% carbonate	4.6
Gods River sediments	Sand and gravel: fine to coarse sand; cross-bedding shows water flow to west; fluvial	12.2
	Covered interval	1.2
	Total thickness to river level	20.9

Unit	Description	Thickness (m)

Section 6

Located along east bank of Gods River about 5 km downstream from the confluence with Wigwam Creek (56°03'N, 92°23'W).

Recent sediments	Peat	0.3
	Silt: organic	0.6
Tyrrell Sea sediments	Sand and gravel: medium to coarse sand, rounded pebbles; lower clayey zone of eroded till	1.2
Upper till, Wigwam Creek Formation	Till: dark greyish brown (10YR 4/2) or dark brown (7.5YR 4/2); soft, crumbly; sharp contact with underlying till; sample KJ-54-72, 6% gravel, 32% sand, 62% silt and clay, 26% carbonate	1.5
Middle till Wigwam Creek Formation	Till: very dark greyish brown (10YR 3/2); hard; jointed with oxidation stains along joints; sample KJ-53-72, 4% gravel, 55% sand, 41% silt and clay, 34% carbonate; sand and boulders in places separate the middle and upper tills	12.2
	Covered interval	6.1
Churchill River Group (Ordovician)	Limestone: pale yellow (5Y 8/3); 8 to 30 cm thick; fossiliferous	1.2
	Total drift thickness	17.0

Section 7

Located along east bank of Gods River at the confluence with Wigwam Creek (56°01'N, 92°20'W). Composite section of two exposures about 91 m apart.

Recent sediments	Peat	0.3
Tyrrell Sea sediments	Silt, sand, and gravel: marine fossils	1.2
	Diamicton: dark reddish grey (5YR 4/2); oxidized; sample KJ-52-72, 7% gravel, 42% sand, 51% silt and clay, 13% carbonate	1.8
Upper till, Wigwam Creek Formation	Till: dark greyish brown (10YR 4/2) or brown (10YR 5/3); jointed with oxidation stains along joints; soft, crumbly; sample KJ-51-72, 6% gravel, 36% sand, 58% silt clay, 24% carbonate; sample KJ-65-72 (10YR 5/3), 8% gravel, 40% sand, 52% silt and clay, 35% carbonate, pebble count, 70% carbonate, 30% shield stones	12.8
Middle till, Wigwam Creek Formation	Till: olive grey (2.5YR 4/2); hard; jointed with oxidation stains along joints; sample KJ-64-72, 11% gravel, 44% sand, 45% silt and clay, 28% carbonate	1.8
	Covered interval	1.5
	Total thickness to river level	19.5

Section 8

Located along east bank of Wigwam Creek 7 km upstream from the confluence with Gods River (56°03'N, 92°14'W); thicknesses estimated.

Tyrrell Sea sediments	Sand, silt, and clay: thinly bedded; clay is brown (10YR 5/3) and till-like, beds 0.3 m thick	4.6

Unit	Description	Thickness (m)
	Diamicton: pale yellow (5Y 7/3); loose; fissile; sample KJ-26-72, 11% gravel, 41% sand, 48% silt and clay, 22% carbonate	3.0
Wigwam Creek Formation	Till: pale olive (5Y 6/3); sample KJ-27-72, 9% gravel, 43% sand, 48% silt and clay, 11% carbonate	4.6
	Total thickness to creek bottom	12.2

Section 9

Located along east bank of Gods River about 5 km downstream from the confluence with Wigwam Creek (56°03'N, 92°24'W).

Recent sediments	Clay: silty or sandy; organic detritus	0.6
Upper till, Wigwam Creek Formation	Till: dark greyish brown (2.5Y 4/2); jointed with oxidation stains along joints; mostly soft and crumbly; sample KJ-68-72, 5% gravel, 47% sand, 48% silt and clay, 30% carbonate	2.1
Middle till, Wigwam Creek Formation	Till: dark greyish brown (2.5Y 4/2); jointed with oxidation stains along joints; hard to moderately soft; sample KJ-67-72, 2% gravel, 45% sand, 53% silt and clay, 36% carbonate; gradational contact with upper till.	7.0
	Covered interval	1.5
	Total thickness to river level	11.2

Section 10

Located along north bank of Fox River about 4 km above the confluence with Hayes River (56°01'N, 93°20'W); surface about 91 m a.s.l.

Recent sediments	Peat: includes thin beds of silt	0.9
Tyrrell Sea sediments	Gravel and sand: fossiliferous; marine	1.2
	Sand and gravel: fine gravel and silty sand with finer sediments common in upper zone; bedding to 0.9 m thick	13.4
	Sand, silt, and clay: light grey, beds to 5 cm thick; stony in part, rare boulder	1.2
	Clay: olive grey; some thin beds of silt; sample KJ-174-72, no fossils	1.2
	Gravel: fine to medium with stones less than 8 cm diameter; sandy in part; limonite cemented in part; estuarine?	4.5
Wigwam Creek Formation	Till: dark grey (2.5Y N4/); hard; sample KJ-28-72, 4% gravel, 44% sand, 52% silt and clay, 26% carbonate	4.5
	Total thickness to river level	26.9

Unit	Description	Thickness (m)
	Section 11	
	Located along bank at confluence of Hayes and Fox River (56°03'N, 93°17'W); surface about 91 m a.s.l.	
Recent sediments	Peat	0.5
	Clay and silt: grey and red; thinly bedded, beds less than 2 cm thick; sample KJ-128-72, **Pisidium fallax** Sterki 1896 (fluvial); **Vertigo modesta** Say 1824, **Columella alticola** Ingersoll 1875, **Vallonia gracilicosta** Reinhardt 1883, **Vallomia** cf. **pulchella** Muller 1774, **Punctum minutissimum** Lea 1841; mostly terres-trial gastropods, suggest floodplain-type deposit	1.2
Tyrrell Sea sediments	Gravel and sand: sample KJ-127-72, **Hiatella arctica** Linné 1767 (water line, low tide), **Pisidium fallax** Sterki 1896, **Pisidium compressum** Prime 1855, **Sphaerium simile** Dall 1905, **Amnicola limosa** Say 1817; shells indicate deposition below water line at low tide	1.5
Wigwam Creek Formation	Till: dark greyish brown (2.5Y 4/2); hard; jointed with oxidation stains along joints; sample KJ-126-72, 3% gravel, 40% sand, 57% silt and clay, 27% carbonate	6.7
	Total thickness to river level	9.9
	Section 12	
	Located along east bank of Hayes River about 3 km downstream from its confluence with Pennycutaway River in SE¼ sec. 20, tp. 89, rge. 9 (56°44'N, 93°41'W); surface about 30 m a.s.l.; thicknesses estimated.	
Recent sediments	Peat	0.9
	Clay: massive with a few thin beds or lenses of sand and gravel; upper 0.5 m zone includes thin peat beds	1.2
Tyrrell Sea sediments	Sand, silt, and clay: beds 0.3 to 2.5 cm thick; upper 4 m mainly fine to medium sand with some silt and gravel including marine shell fragments in upper 0.5 m zone; wood fragments (sample KJ-58-72, **Picea**[1] sp.) from the middle of this unit radiocarbon dated at 4890 ± 140 BP (GSC-1745, Lowdon et al., 1977) estuarine?	13.4
	Sand: reddish; fossiliferous; marine	0.3
	Total thickness to river level	24.9
	Section 13	
	Located along the bank of Hayes River about 14 km below the confluence Fox River (56°07'N, 93°06'W). Composite of sections on opposite sides of river.	
Tyrrell Sea sediments	Clay: silty; scattered thin gravel lenses; sample KJ-129-72, **Hiatella arctica** Linné 1767 and **Balanus hameri** Ascan 1758; marine below water line of low tide	4.6
	Sand and silt: fine sand, some clay; thinly bedded with micro-crossbedding in places; no megafossils seen; estuarine?	21.3
	Total thickness to river level	25.9

[1] Wood samples identified by R.J. Mott, Geological Survey of Canada, Ottawa.

Unit	Description	Thickness (m)

Section 14

Located along north bank of Hayes River at the confluence with Gods River (56°23'N, 92°58'W); thicknesses estimated; surface about 49 m a.s.l.

Recent sediments	Peat	0.3
Tyrrell Sea sediments	Clay, silt, and sand: thinly bedded	1.2
	Gravel and sand	0.6
	Diamicton: brown; sandy; shell fragments in upper 4.6 m; some thin sand beds in lower zone	7.6
	Clay and silt: bedded to massive	1.8
	Sand: oxidized; coarse; massive; estuarine?	0.6
	Covered interval	6.1
	Total thickness to river level	18.2

Section 15

Located along north bank of Nelson River about 2.4 km downstream from Deer Island in NW¼ sec. 26, tp. 91, rge. 6 (56°56'N, 93°05'W); thicknesses estimated; surface elevation about 30 m a.s.l.

Recent sediments	Peat	0.3
Tyrrell Sea sediments	Sand and minor gravel: sand is fine to medium grained (marine?)	0.3
	Silt, clay, and sand: oxidized; contains rare stones; bed of reddish silt to 15 cm thick occurs near top; glaciomarine?	1.2
Upper till, Wigwam Creek Formation	Till: greyish brown (10YR 5/2); hard; moderately stony; blocky fracture; oxidation stains along joints	1.2
	Till: very dark greyish brown (10YR 3/2); unoxidized; clayey; soft; moderately to slightly stony; oxidation stains along joints; unit gets siltier and less massive towards top; bed of fine sand about 4 cm thick separates the till units	2.5
Middle till, Wigwam Creek Formation	Till: greyish brown (10YR 5/2), hard; moderately stony; blocky fracture; oxidation stains along joints	5.2
	Covered interval	4.6
	Total thickness to river level	15.2

Section 16

Located along south bank of Nelson River in SW¼ sec. 18, tp. 90, rge. 4 (56°48'N, 93°31'W); thicknesses estimated; surface elevation about 61 m a.s.l.

Recent sediments	Peat	0.3
Tyrrell Sea sediments	Silt: yellowish brown; clayey in part; scattered rocks to cobble size; sample KJ-3-71, marine Foraminifera **Elphidium**[1] sp.; glaciomarine?	2.4

[1] Fossil identification by L.D. Delorme (personal communication, 1974), formerly of Water Resources Branch, Environment Canada, Calgary, Alberta.

Unit	Description	Thickness (m)
	Silt: light grey; clayey; fissile; scattered rocks; marine pelecypods; sample KJ-4-71, marine Foraminifera and ostracodes **Elphidium** sp., **Elofsonella concinna** Jones 1856; glaciomarine?	13.7
Lake Agassiz sediments	Silt: yellowish brown; thinly bedded; sample KJ-6-71, non-fossiliferous; glaciofluvial	1.8
	Covered interval	9.1
	Silt: yellowish brown; thinly bedded; sample KJ-6-71, non-fossiliferous; glaciofluvial	1.2
	Silt: yellowish brown; glaciofluvial	6.7
Amery Formaton	Till: olive grey (5Y 4/2); jointed with oxidation stains along joints; hard	1.5
	Total estimated thickness to river level	36.7

Section 17

Located at the confluence of Angling and Nelson rivers in SW¼ sec. 34, tp. 89, rge. 3 (56°45'N, 93°36'W); thicknesses estimated; surface elevation about 61 m a.s.l.

Tyrrell Sea sediments	Clay: brown; samples KJ-7, 8-72 **Hiatella arctica** Linné 1767, **Clinocardium ciliatum** Fabricius 1780, **Mya truncata** Linné 1758; shells indicate marine deposition below water line of low tide	0.6
Lake Agassiz sediments?	Sand: fine; current bedding; glaciofluvial	6.1
Middle till, Wigwam Creek Formation	Till: olive grey (5Y 4/2); slightly oxidized; sample KJ-9-72, 8% gravel, 27% sand, 65% silt and clay, 24% carbonate	9.1
Lower till, Wigwam Creek Formation	Till olive (5Y 4/3); oxidized; sample KJ-10-72, 3% gravel, 28% sand, 69% silt and clay, 30% carbonate	9.1
Amery Formation	Till: olive grey (5Y 4/2); unoxidized; sample KJ-11-72, 10% gravel, 28% sand, 62% silt and clay, 33% carbonate	9.1
	Total thickness to river level	34.0

Section 18

Located along the north bank of Angling River about 3 km from the confluence with Nelson River in SW¼ sec. 28, tp. 89, rge. 3 (56°44'N, 93°36'W); thicknesses estimated; surface elevation about 61 m a.s.l.

Recent sediments	Peat	1.5
Tyrrell Sea Sediments	Clay: greenish grey; fossiliferous; marine	0.3
	Sand and gravel: fossiliferous; marine	1.5
	Clay: grey; weakly bedded; fossiliferous; marine	2.4
Upper till, Wigwam Creek Formation	Till: dark greyish brown (2.5Y 4/2); sample KJ-21-72, 24% gravel, 31% sand, 45% silt and clay, 23% carbonate	3.4
	Covered interval	9.1
	Total thickness to river level	18.2

Unit	Description	Thickness (m)

Section 19

Located along the east bank of Angling River, about 14 km above the confluence with Nelson River in NW¼ sec. 9, tp. 88, rge. 3 (56°37'N, 93°38'W); thicknesses estimated; surface elevation about 85 m a.s.l.

Tyrrell Sea sediments	Gravel: sandy, fossiliferous; marine pelecypods	0.6
	Sand: light olive, compact; fissile; stony; glaciomarine?	0.9
Upper till, Wigwam Creek Formation	Till: dark greyish brown (10YR 4/2), weakly jointed; sample KJ-22-72, 9% gravel, 24% sand, 67% silt and clay, 33% carbonate	3.1
	Total thickness to river level	4.6

Section 20

Type section for the Amery Formation. Located along the north side of Nelson River about 3 km below the mouth of Limestone River in NE¼ sec. 8, tp. 87, rge. 22 (56°32'N, 94°05'W); surface elevation about 61 m a.s.l.

Tyrrell Sea sediments	Sand and gravel: bouldery in upper 3 m; lower zone is highly fossiliferous, sample KJ-18-72 **Hiatella arctica** Linné 1767, **Nuculana pernula** Muller 1779, **Balanus balanoides** Linné 1758; shells indicate marine offshore deposition	4.6
Lake Agassiz sediments	Clay: thinly varved; forms a distinctive continuous bed along the riverbank; glaciolacustrine	0.3
	Silt and sand: massive or thinly bedded; thickness ranges from 6 to 26 m and is greatest where it fills a former channel cut into till; glaciofluvial?	25.6
Amery Formation	Till: olive grey (5Y 4/2); silty, moderately stony; jointed with oxidation stains along joints; very hard and forms steepest parts of bluffs; thickness ranges from 6 to 15 m; unit is thickest outside a former channel cut into the till where it is overlain by a somewhat darker grey till which was inaccessible because of the steep bank	6.1
Bad Cache Rapids Group (Ordovician)	Dolomite: light grey with numerous buff-coloured nodules	1.8
	Total thickness to river level	38.4

Section 21

Located along south bank of Nelson River opposite the mouth of Goose Creek in NW¼ sec. 20, tp. 88, rge. 2 (56°39'N, 93°49'W); surface elevation about 61 m a.s.l.

Tyrrell Sea sediments	Silt and sand: gravelly in part with scattered boulders; marine?	4.6
Wigwam Creek Formation	Sand, gravel, and till: beds are fairly stony throughout and in the upper 0.3 m zone it is till-like; till-like bed is greyish brown (2.5Y 5/2); fairly hard; sample KJ-20-72, 16% gravel, 43% sand, 41% silt and clay, 28% carbonate	6.1
	Till: dark grey (5Y 4/1); slightly oxidized in part; silty or clayey; moderately stony; jointed; crumbly; sample KJ-19-72, 6% gravel, 28% sand, 66% silt and clay, 22% carbonate	3.1
	Covered interval	27.4
	Total thickness to river level	41.2

Unit	Description	Thickness (m)

Section 22

Located along the north side of Nelson River near confluence with Limestone River in SE¼ sec. 12, tp. 87, rge. 21 (56°32'N, 94°09'W); surface elevation about 91 m a.s.l.

Recent sediments	Peat	0.3
Tyrrell Sea sediments	Sand: fossiliferous (marine pelecypods)	1.2
Lake Agassiz sediments	Sand: fine to medium grained; current bedding; some gravel beds 5 to 30 cm thick; glaciolacustrine	4.9
	Clay: thinly varved; glaciolacustrine	0.5
	Sand: light brown; very fine grained; massive; glaciolacustrine?	0.5
	Silt: light grey to brownish grey; sandy or clayey in part; thinly bedded up to 10 cm thick; glaciofluvial?	2.4
Upper till, Wigwam Creek Formation	Till: dark greyish brown (2.5Y 4/2); oxidized; silty; moderately stony, crumbly; hackly fracture	1.8
Middle till, Wigwam Creek Formation	Till: dark greyish brown (2.5Y 4/2); oxidized; silty; moderately stony; jointed with oxidation staining along joints	3.1
Amery Formation	Till: olive grey (5Y 4/2) or olive (5Y 4/4); unoxidized; silty; moderately stony; jointed with oxidation stains along joints; hard; sample KJ-4-72, 30% carbonate	10.3
	Total thickness to river level	25.0

Section 23

Located along the west bank of Nelson River near the mouth of Limestone River in NE¼ sec. 1, tp. 87, rge. 21 (56°31'N, 94°05'W); thicknesses estimated; surface about 85 m a.s.l.

Tyrrell Sea sediments	Clay: brown; sample KJ-2-71, **Mya truncata, Hiatella arctica**; shells indicate deposition in zone below low tide; radiocarbon date 7030 ± 170 BP (GSC-2294, Teller, 1980)	1.2
Lake Agassiz sediments	Sand and gravel: glaciolacustrine?	4.6
	Sand and silt: thinly bedded; glaciolacustrine?	12.2
Wigwam Creek Formation	Till: brownish grey; silty; moderately stony with scattered large boulders	6.1
	Total thickness to river level	24.1

Section 24

Located along the north bank of Nelson River below Spruce Rapids in NW¼ sec. 32, tp. 85, rge. 21 (56°29'N, 94°17'W).

Tyrrell Sea sediments	Silt: greyish brown (10YR 4/2); clayey; marine?	1.2
Lake Agassiz sediments	Silt and sand: thinly bedded	6.1
	Clay: thinly varved; distinctive bed	0.3
	Sand and till: sand is poorly sorted; sand grades into till-like beds, greyish brown (2.5Y 5/2); compact; fissile	4.6

Unit	Description	Thickness (m)
	Silt and sand: beds up to 0.3 m thick, some gravelly zones; sharp contact with overlying unit	4.6
Wigwam Creek Formation	Till: olive (5Y 4/4); slightly oxidized; silty; moderately stony; jointed; crumbles easily; sharp contact with overlying unit	4.6
	Covered to river level	1.5
	Total thickness to river level	22.9

Section 25

Located along the north side of Nelson River below Kettle Rapids in sec. 30, tp. 85, rge. 20 (56°23'N, 94°29'W); surface about 107 m a.s.l.

Recent sediments	Peat	0.3
Tyrrell Sea sediments	Silt and clay: pale brown (10YR 6/3 - silt) or yellowish brown (10YR 5/4 - clay); thinly bedded with thicknesses from 1 to 8 cm; becomes clayier towards top of unit; slightly fossiliferous, **Hiatella arctica** Linné 1767, **Balanus balanoides** Linné 1758; shells indicate deposition in intertidal zone	1.5
	Clay: greyish brown (10YR 5/2); slightly stony; massive with small lenses of laminated clay along contact with till; shell fragments; contact with overlying unit marked by slight concentration of stones; glaciomarine?	1.8
Upper till, Wigwam Creek Formation	Till: greyish brown (2.5Y 5/2); oxidized; sandy, moderately stony with 68% carbonate rocks and 32% igneous; jointed with oxidation stains along joints; hackly fracture; contact with overlying unit in places marked by a bouldery zone	5.5
	Covered to river level	1.5
	Total thickness to river level	10.6

Section 26

Borrow pit beside the road to Long Spruce damsite about 19 km east of Gillam (56°22'N, 94°23'W) in the Hudson Bay Lowland.

Tyrrell Sea sediments	Clay: brown (10YR 5/3); silty, massive; scattered stones	1.2
Lake Agassiz sediments	Clay: varved; brown (10YR 3/3) clay laminae and yellowish brown (10YR 5/4) silty laminae; occurs as discontinuous pockets between adjacent units	0.3
	Silt: pale olive (5Y 6/3); stony; till-like appearance	0.2
	Clay: varved; strongly contorted in part	0.6
	Silt: pale olive (5Y 6/3); stony; jointed; sharp contact with underlying clay; till-like appearance	0.6
	Clay: varved; discontinuous pockets between enclosing units	0.3
	Silt and sand: pale olive (5Y 6/3); sand is gradational into stony silt in upper 1.2 m zone; silt is jointed and has till-like appearance whereas sand is weakly bedded	2.4
	Total thickness	5.6

Unit	Description	Thickness (m)
	Section 27	
	Located along the north bank of Fox River near the confluence with Sipanigo and Gowan rivers (55°50'N, 94°13'W).	
	Sand: silty	0.3
Upper till, Wigwam Creek Formation	Till: pale brown (10YR 6/3); loose; fissile; sample KJ-176-72, 6% gravel, 35% sand, 59% silt and clay, 22% carbonate	1.2
Middle till, Wigwam Creek Formation	Till: yellowish brown (10YR 5/4); crumbles easily; most of this unit is poorly exposed; KJ-175-72, 3% gravel, 26% sand, 71% silt and clay, 25% carbonate	16.8
Bedrock (Precambrian)	Metamorphosed bedrock - chlorite and horn-blende schist; dark green	6.1
	Total drift thickness	18.3
	Section 28	
	Located along a south facing bluff about 6 km north of Limestone River (56°36'N, 94°16'W). Bluff at 122 m a.s.l. forms the boundary between marine sediments of the Hudson Bay Lowland and the till plain to the west.	
Upper till, Wigwam Creek Formation	Till: pale olive (5Y 6/3); fissile; eroded surface; sample KJ-17-72, 23% gravel, 42% sand; 35% silt and clay, 19% carbonate	1.2
Middle till, Wigwam Creek Formation	Till: light olive brown (2.5Y 5/4); moderately stony; sample KJ-16-72, 8% gravel, 34% sand, 58% silt and clay, 26% carbonate	17.0
	Total drift thickness	18.2
	Section 29	
	Located along the northwest wall of a broad spillway about 4 km wide and marked by scabland-type erosional hills; site is 10 km southwest of the Weir River siding and in sec. 29, tp. 89, rge. 20 (56°45'N, 94°23'W).	
	Gravel: sandy, scattered boulders; lag deposit	0.2
Upper till, Wigwam Creek Formation	Till: greyish brown (2.5Y 5/2) or yellowish brown (10YR 5/4) in oxidized upper zone; silty; moderately to slightly stony; crumbly in part; sample KJ-196-72, 7% gravel, 40% sand, 53% silt and clay, 19% carbonate	10.5
Middle till, Wigwam Creek Formation	Till: yellowish brown (10YR 5/4); oxidized; moderately stony; jointed with oxidation stains along joints; sharp contact with upper till; content of carbonate rocks visibly higher than that of upper till; sample KJ-197-72, 4% gravel, 28% sand, 68% silt and clay, 28% carbonate	10.6
	Total drift thickness	21.3

Unit	Description	Thickness (m)
	Section 30	
	Located along north bank of Churchill River where it cuts across the Etawney moraine (57°13'N, 96°42'W).	
Upper till, Wigwam Creek Formation	Till: brown; fissile; jointed; pebble count 64% carbonate; 36% shield; sample KJ-180-72, 4% gravel, 34% sand, 62% silt and clay, 23% carbonate	5.8
Unnamed	Till: yellowish brown; stony; less compact than underlying till; sample KJ-179-72, 16% gravel, 49% sand, 45% silt and clay, 16% carbonate	1.2
	Sand: minor fine gravel; stringers of till	3.0
	Till: olive grey; jointed; fissile; pebble count, 44% carbonate, 56% shield; sample KJ-178B-72, 10% gravel, 50% sand, 40% silt and clay, 17% carbonate	6.1
	Covered interval to bedrock at river level	5.2
	Total drift thickness	21.3
	Section 31	
	Located along north bank of Seal River about 40 km northwest of Southern Indian Lake (57°54'N, 98°45'W); thicknesses estimated.	
Unnamed	Till: light olive brown (2.5Y 5/4) or olive brown (2.5Y 4/4) in lower zone; fissile in part; sample KJ-12-73 (upper zone), 4% gravel, 53% sand, 43% silt and clay, 5% carbonate; sample KJ-13-73 (lower zone) 4% gravel, 64% sand, 32% silt and clay, 4% carbonate.	4.6
	Covered interval to bedrock at river level	15.2
	Total drift thickness	19.8
	Section 32	
	Exposure in the side of a spillway excavation on the west side of the West Channel of Nelson River near its mouth in Cross Lake (54°32'N, 98°02'W); section is exposed in a small ravine in bedrock shown in Figure 28.	
Lake Agassiz sediments	Clay: varved; beds become thinner upwards in section	3.1
Unnamed	Till: light brownish grey (2.5Y 6/2), upper 1.5 m zone is slightly browner than lower zone, difference is not evident in Munsell colour; moderately stony to stony; sample KJ-38-73 (upper zone), 14% gravel, 48% sand, 38% silt and clay, 12% carbonate; sample KJ-37-73 (lower zone), 15% gravel, 43% sand, 42% silt and clay, 12% carbonate	2.7
	Sand: stratified; very compact; scattered pebbles	0.9
	Total drift thickness above bottom of ravine in gneissic granite	6.7

Unit	Description	Thickness (m)

Section 33

Testpit in northeast end of terrace about 27 m high on the south side of Nelson River in SW¼ sec. 10, tp. 89, rge. 2, (56°42'N, 93°46'W); thicknesses estimated.

Recent sediments	Silt and sand: thinly bedded; fossiliferous, sample KJ-6-72, **Sphaerium simile** Dall 1905, **Pisidium fallax** Sterki 1896, **Amnicola limosa** Say 1817, **Lymnoea elods** Say 1821, **Valuata tricarinata** Say 1817; fluviolacustrine	0.6
	Gravel: coarse and bouldery; fluvial?	5.5
	Covered interval to river level	15.2
	Total thickness to river level	21.3

APPENDIX 2

Selected parts of a M.Sc. thesis by J.A. Netterville

Selected parts of *"Quaternary stratigraphy of the lower Gods River region, Hudson Bay Lowlands, Manitoba"* by J.A. Netterville.

A thesis submitted to the Faculty of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Science, Department of Geology, Calgary, Alberta, June 1974.

Introductory Note

The parts of Netterville's thesis included in this Appendix deal with the paleontology of the Gods River sediments and the inferred vegetational and climatic history. Although this was the focus of the thesis, it also dealt in considerable detail with the Quaternary stratigraphy. The omission of these parts of the thesis is not intended to detract from their importance, and significant data concerning other units are included and referenced in the main body of Klassen's report or are modified within its broader context. The complete Table of Contents, including tables and illustrations, is included in order to show the scope of the thesis, whereas the references are applicable only to the selected part of the thesis.

QUATERNARY STRATIGRAPHY OF THE LOWER GODS RIVER REGION,
HUDSON BAY LOWLANDS, MANITOBA

by J.A. Netterville

TABLE OF CONTENTS

<u>Illustrations</u>

GODS RIVER SEDIMENTS

Gods River sediments occur between Till A and Till B and commonly are less than 1 m thick. In the southeastern part of the study area this unit is absent and the two tills are directly in contact (Secs. 1 and 2, Fig. 4).

The surface of Till A is at a lower elevation at Sections 3, 4 and 7, than it is elsewhere along the river. Gods River sediments are correspondingly thickest at these localities and range in thickness from 3 m at Section 7 to a maximum of 12.5 m at Section 3.

Description

Throughout most of the area, Gods River sediments are composed of oxidized sand and fine gravel which lack current-direction indicators. A discontinuous boulder horizon may represent the unit at Section 2 (Fig. 4). At Sections 3, 4, and 7, Gods River sediments are thickest and consist of several facies. These exposures are described separately below.

1) Section 7 (Figs. 4-5)

The unit is represented at the base by a thin bed of fine to medium grained sand which encloses lenses of silty peat. This bed is overlain by poorly sorted sand and gravel capped by a thin layer of mosses, twigs, and beaver-chewed logs. Organic-rich clay, silt, and sand (gyttja) overlie the woody horizon. Thirty meters downstream from the measured section (see Fig. 5), Gods River sediments are represented in their entirety by 4 m of gyttja with rare occurrences of pebbles, cobbles, and thin gritty beds.

Compressed peat about 1 m thick crops out about 90 m upstream from Section 7. This exposure is the only occurrence of true ombrogenous (in situ) peat noted in Gods River sediments. It overlies a similar thickness of sand and gravel and is overlain by fine to coarse-grained sand 1 to 2 m thick. The peat is traceable upstream over a distance of about 30 m beyond which a thin bed of sand and gravel separates tills A and B.

2) Section 4 (Fig. 4)

At this exposure, massive, slightly oxidized fine to medium-grained sand nearly 5 m thick is overlain by a thin bed of fine sand enclosing silt and clay lenses. Wood fibres, seeds, beetle fragments, and fresh-water mollusc shells are preserved in thin foreset-type beds in the uppermost metre. The crossbedding indicates that current was to the north. Colluvium covers the lower part of the section.

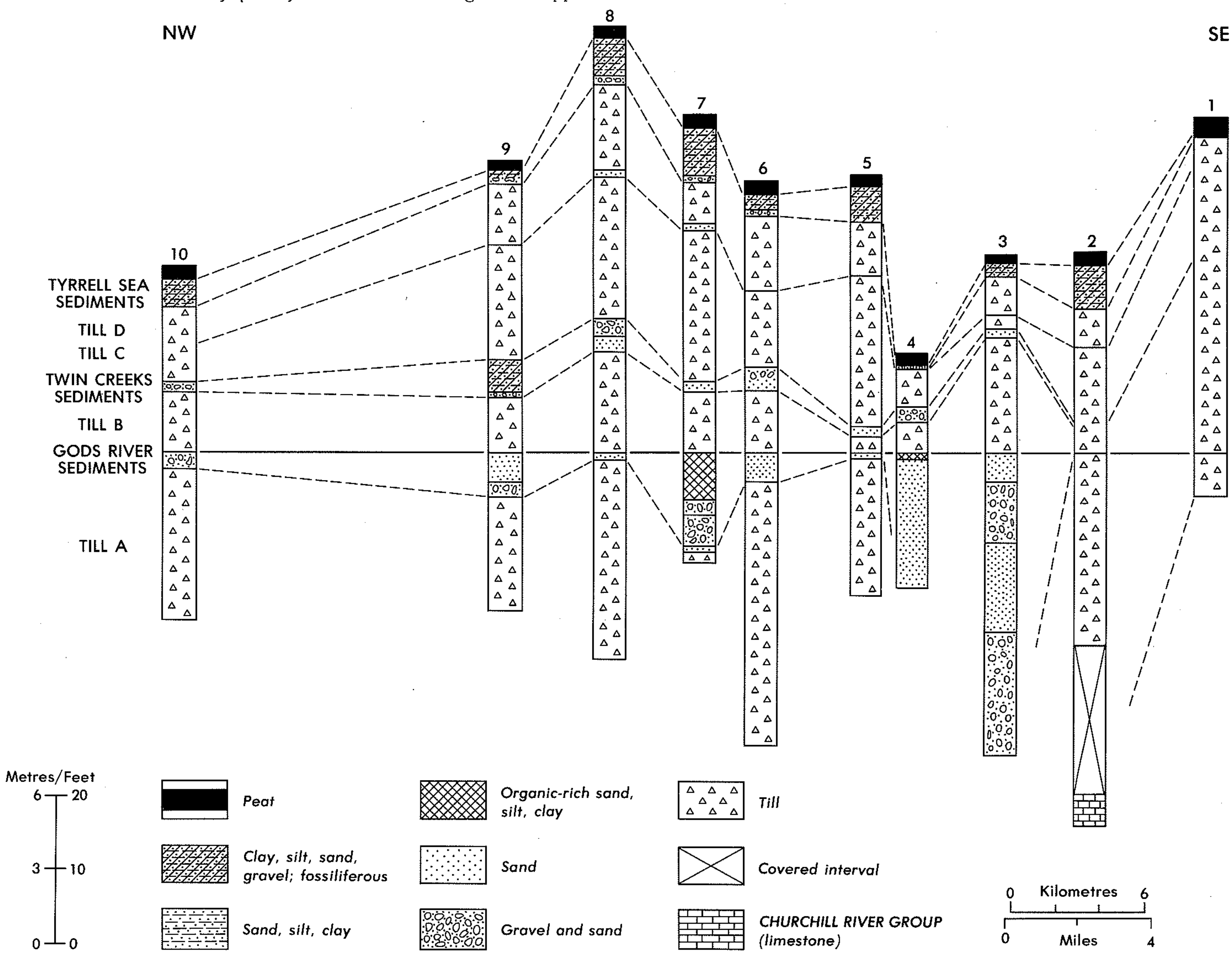

Figure 4. Local stratigraphic correlation, sections 1-10.

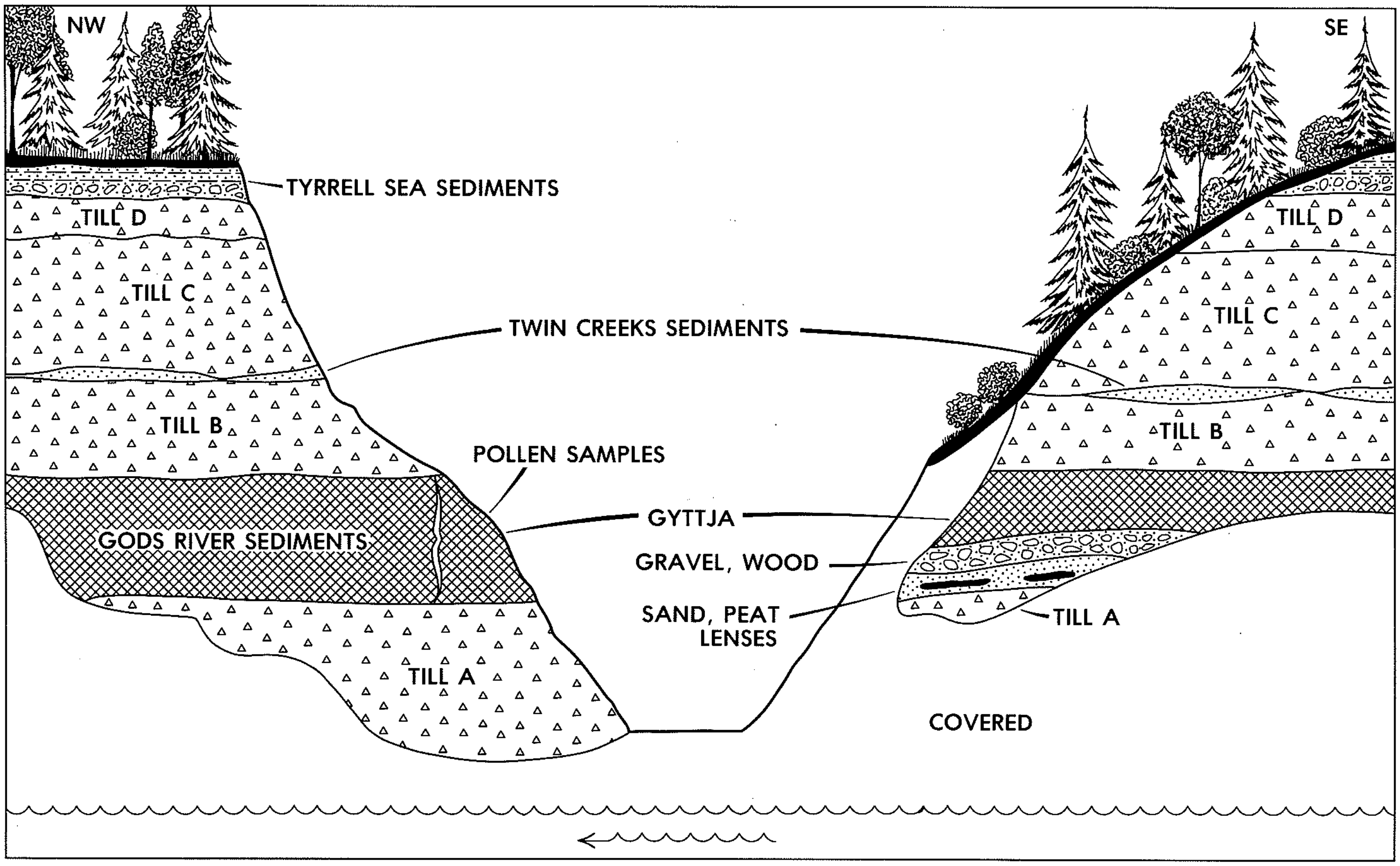

Figure 5. Section 7, showing relationship of the sediments and location of interval sampled for pollen.

3) Section 3 (Fig. 4)

Poorly sorted sandy gravel more than 5 m thick and containing numerous cobbles crops out at the base of the section. The gravel fraction is composed mainly of striated, subrounded carbonate and quartzite clasts. Weak stratification in the deposit exhibits a low dip to the west.

Three fluvial beds, deposited by a current which flowed to the west, overlie the sandy gravel. The lower bed consists of fine to coarse-grained sand 3.6 m thick and the middle bed is composed of fine sand and gravel 1.2 m thick. Both these deposits exhibit large-scale crossbedding. The uppermost bed consists of fine to mediumgrained well-sorted sand with small-scale crossbedding. It underlies Till B along a sharp and even contact.

Organic material was not seen in this exposure. Its assignment to the Gods River sediments is based on stratigraphic position.

Depositional environment

The retreat of the glacier which deposited Till A probably exposed a surface similar to the present-day topography of this region. Lakes joined by a dendritic drainage network developed and provided the setting for deposition of the Gods River sediments. Sand and gravel of a predominantly fluvial (floodplain) environment occur in most of the exposures and clay and silt deposited under lacustrine conditions are restricted to one locality. The presence of pebbles, cobbles, thin sand stringers, and gritty horizons in the latter suggests that flooding occurred periodically.

Vegetation was established in the area shortly after deglaciation, as shown by abundant organic detritus at the base of the interval at Section 7. The lower peat lenses represent accumulation of vegetation which fell or drifted into slow-moving water where a stream entered a lake. Gravel overlying the peat lenses suggests an increase in stream volume and transporting power due to change either in the climate or drainage system. The gravel is composed in part of till pebbles similar in texture and colour to Till A and probably was deposited in a small delta. Identical deposits occur where some present-day streams enter Gods River.

The sequence at Section 7 further suggests that fluvial sedimentation came to an end at this locality when lake level rose, perhaps due to damming of streams by beavers. Wood fragments and other detritus from the flooded area were reworked as shoreline deposits which were eventually buried under several meters of organic-rich lacustrine sediment.

Cobbles and large-scale crossbeds in Gods River sediments at Section 3 are indicative of rapid deposition by swiftly-moving water. Either lateral migration of the channel or a decrease in flow due to climatic change caused the current to finally decrease, as shown by the uppermost layer of finely crossbedded sand.

There is no evidence of a proglacial lake phase heralding the return of glacial conditions to the area. The ice sheet which deposited Till B may have redistributed and partly destroyed the Gods River sediments when it finally overrode them.

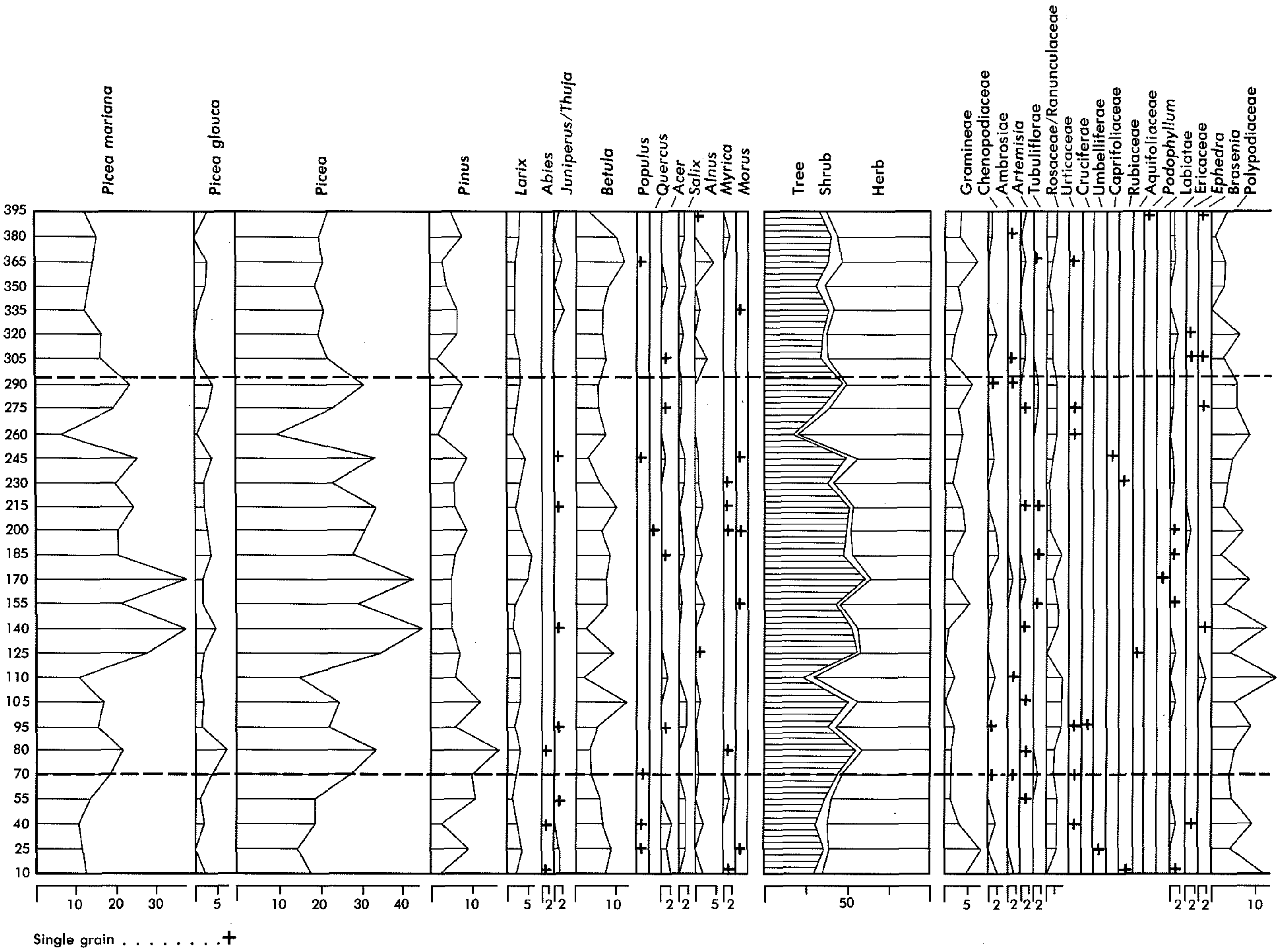

Figure 6. Pollen spectra of Gods River sediments.

Paleontology

Fossiliferous beds in Gods River sediments occur at and near Sections 7 and 4. Samples of each fossil-type were collected for identification and interpretation. These included pollen, wood, and mosses from the vicinity of Section 7, and seeds, beetle fragments, and mollusc valves from Section 4.

Figure 5 shows the location of the gyttja bed that was sampled for pollen analysis. The pollen record of this lacustrine deposit should yield a reasonably complete floral history because: 1) small lake basins commonly offer ideal traps for regional anemophilous pollen, and 2) the organic content (see below) and stratigraphic relationships at this site suggest that deposition began soon after deglaciation and continued throughout most of the nonglacial episode.

Wood fragments collected from the upper 20 cm of fluvial sediment at Section 7 were identified by R.J. Mott (Geological Survey of Canada). Drs. M. Kuc and J.V. Matthews, Jr. (Geological Survey of Canada) identified wood and mosses collected from an exposure of peat near the centre of the unit 90 m upstream from Section 7, and seeds and beetle fragments collected from the upper meter of fluvial sediment at Section 4, respectively. Identification of mollusc fragments from the upper meter of sediment at Section 4 was done by Dr. L. Kalas (Environment Canada).

1) Pollen

A pollen profile through the limnic sediments is shown in Figure 6 (in pocket). Three pollen sums were used in constructing this diagram:

(1) terrestrial pollen

(2) terrestrial pollen plus that of aquatic or semi-aquatic plants

(3) those of (2) plus fungal spores

As there is a reasonable possibility that treeless vegetation existed in the area, spores of **Sphagnum** and Bryaceae are included in the pollen sum of terrestrial plant types. Since most Cyperaceae (sedge) pollen is derived from local aquatic and lake-marginal communities (Lichti-Federovich and Ritchie, 1965; Janssen and Ijzermans-Lutgerhorst, 1973), the majority of palynologists do not include this family when calculating the sum of terrestrial pollen. In the Arctic and Subarctic this omission is questionable for in these regions species of Cyperaceae are a widespread component of the vegetation in both upland and lowland habitats (Lichti-Federovich and Ritchie, 1968). To facilitate direct comparisons of the pollen profile from Gods River sediments with the pollen spectra published by most other workers, Cyperaceae pollen is excluded from the sum of terrestrial vegetation in Figure 6.

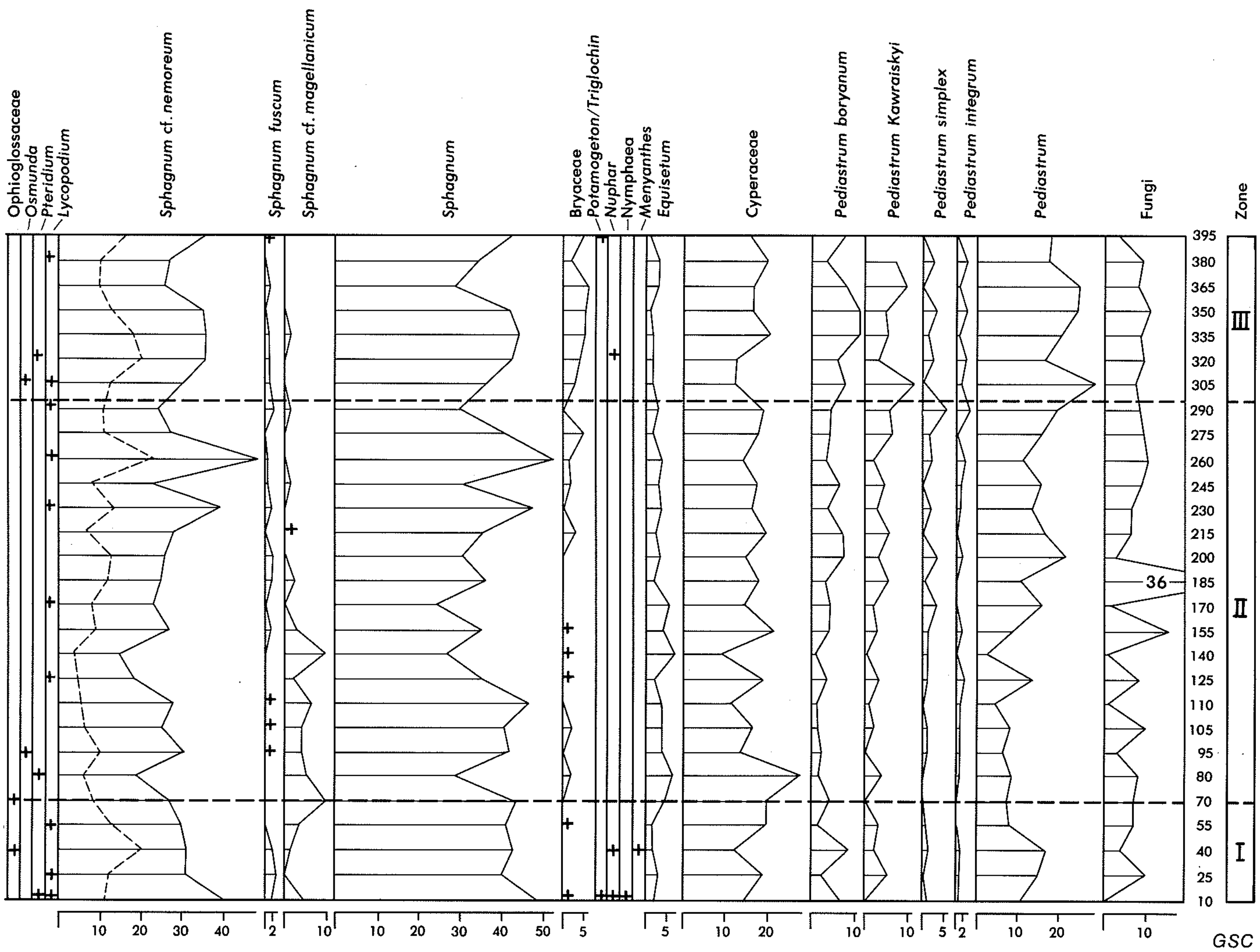

Figure 6 (cont.)

The pollen diagram is divided into three zones based on changes in: 1) the relative frequencies shown by **Picea** and **P. mariana** and, 2) the proportion of tree pollen to that of shrubs and herbs. The **Picea** curve includes values of **P. mariana** (Mill) B.S.P. (black spruce), **P. glauca** (Moench) Voss (white spruce), and undifferentiated spruce pollen.

Zone I is characterized by relatively low but generally increasing values for **Picea mariana** (13 to 20%) and **Picea** (17 to 28%). Total tree pollen increases from 30 per cent at the bottom of the zone to 44 per cent at the upper boundary.

Zone II is distinguished from Zone I by its significantly higher frequencies for these three parameters. Noticeable also is the marked inflection in the curves of **Picea** and **P. mariana.** Black spruce values increase from 20 per cent to 38 per cent in the lower half of the zone and then decrease throughout the top half to 22 per cent at the boundary with Zone III. This pattern is mirrored in the values for **Picea** which rise from 30 per cent to 45 per cent and subsequently decrease to 30 per cent. The peak in the curve for total tree pollen is much flatter than the peaks for **Picea** and **P. mariana;** this curve rises rapidly from 44 per cent to 58 per cent very near the base of the zone and then slowly climbs to a maximum of 62 per cent at the centre. A relatively steady decrease in total tree pollen is noted after this, the values falling to 45 per cent at the upper boundary of the zone.

Zone III exhibits percentages of **Picea, P. mariana,** and total tree pollen which are strikingly similar to those of Zone I; the major difference is that they decrease rather than increase upsection. **P. mariana** values drop from 22 per cent at the boundary with Zone III to 13 per cent at the contact with the overlying till. Values of **Picea** decrease from 30 per cent to 22 per cent within 12 cm of the base of the zone and then level off at about 20 per cent for the remainder of the interval. In a similar fashion, total tree pollen frequencies drop rapidly from a level of 45 per cent to 35 per cent and then essentially maintain this percentage to the top of the interval.

Small amounts of **Pinus** (pine) and large amounts of **Sphagnum** and Cyperaceae occur regularly in all three zones. **Sphagnum** percentages appear to be slightly lower in the central zone than in Zones I and III, but the change is not an obvious one and consequently it has been excluded from the zone descriptions.

2) Megafossils

The megafossils from Sections 4 and 7 do not record a continuous ecologic history of the nonglacial episode because they are localized near the centre and top of Gods River sediments. Paleoecologic inferences apply only to the time interval represented by the sediments in which they

TABLE II

Megafossils from Gods River Sediments. Dotted line indicates inferred correlation with pollen zones shown on the left.

Pollen Zones		
	seeds[1]:	beetles[1]:
	Najas sp.	**Pterostichus (Cryobius)**[5]
	Hippuris vulgaris	**caribou**? Ball
	Carex sp.	**Amara (Curtinotus)**?
	Sparganium sp.	**alpina** Payk
	Menyanthes trifoliata	Curculionidae - ?
III	**Polygonum** sp.	**Lepidophorus**
	Ranunculus	
	trichophyllus	possibly is **P. (Cryobius)**[5]
	Potamogeton pectinatus	**ventricosus** Exchz.
	P. cf. **praelongus**	
	P. richardsonii?	molluscs[2]:
	P. filiformis	Pelecypoda -
		Pisidium vertricosum
		Prime, 1851
		Gastropoda -
		Succinea sp.
· · · · · · · · · ·	· · · · · · · · · ·	· · · · · · · · · ·
	wood:	mosses[4]:
	Picea sp.[3] >41 000	**Ditrichum flexicaule**
	yrs. B.P.[5]	**Campylium polygamum**
	?**Tsuga**[4]	cf. **Barbula rigidula**
	?**Taxus**[4]	**Hygrohypnum** sp.
II		**Hypnum** sp.
		cf. **Drepanocladus**
		exannulatus
		Bryum sp.
		Pohlia sp.

[1]J.V. Matthews, Jr., written communication, 1974
[2]Kalas, 1974
[3]Mott, 1972
[4]Kuc, 1972
[5]radiocarbon date GSC - 1736

are preserved. Stratigraphic relationships provide a rough time correlation between the "isolated" megafossils and the relatively continuous pollen record. This correlation is indicated in Table II. Assuming that the fossils have not been reworked from deposits lower in the interval, interpretation of the paleoecology can be based on a synthesis of the two bodies of data.

Interpretation

Interpretation of Quaternary pollen diagrams is subject to the following conditions: 1) that an inventory of recent regional pollen assemblages be available for direct comparison, and 2) that the recent pollen data be accompanied by qualitative and quantitative accounts of the vegetation of the several zones of the region.

Limitations of the comparative method of interpreting pollen diagrams are significant and have been fully discussed by Davis (1967). In dealing with pre-Recent sediments the main shortcoming is that fossil plant assemblages may not have an exact modern analogue. The most commonly used approach is to match as many plant types as possible with those same types from contemporary aassemblages. Anomalous species must be subjectively interpreted on the basis of their known or inferred ecologic requirements. A second consideration when working with relative frequencies is that a particular pollen spectrum may be derived from two or more vegetation zones. Differences between samples collected from different landform-vegetational regions, however, are greater than differences among those from the same region (Lichti-Federovich and Ritchie, 1965).

The pollen profile from Gods River sediments is compared with pollen spectra from recent lake sediments in northern Manitoba and southern Keewatin published by Lichti-Federovich and Ritchie (1968). Their study also provides quantitative accounts of the flora from each major vegetation type in these regions.

Several spectra from tundra and forest-tundra sites are similar to those from the Gods River sediments. These are illustrated in Figure 7 along with some comparative spectra from coniferous forest. Figure 8 shows the location of the sample sites relative to major forest region boundaries (Lichti-Federovich and Ritchie, 1968; Hosie, 1969) and to the sample site of the Gods River sediments. To facilitate collation of the recent and fossil pollen spectra, the pollen frequencies have been recalculated based on a sum of terrestrial pollen which includes **Sphagnum** but excludes Cyperaceae.

1) Vegetation

Extremely low amounts of spruce and pine pollen and strong representation of **Sphagnum** and Cyperaceae in Zone 1 suggest that vegetation during the time interval represented by this zone was similar to that which exists today in tundra regions of southern Keewatin and northeastern Manitoba. Several differences in the pollen spectra are immediately apparent, however. Most noticeable are the significantly higher frequencies of **Betula** (birch) and **Alnus** (alder) pollen in recent samples. Another notable variation from tundra assemblages is the abundance of fern spores (Polypodiaceae). It appears that the vegetation in this area, following deglaciation, was a **Sphagnum** tundra with scattered shrubs of birch and alder. Poorly-drained sites were occupied by sedges, ferns, and grasses. The increase in spruce pollen towards the top of the zone indicates that Arctic tree line was approaching the area during this time.

The closest analogues to the pollen assemblages of Zone II are the spectra from stations in forest-tundra. This interpretation is supported by similarities between the recent and fossil frequencies, respectively, of **Picea, Betula, Alnus,** and Cyperaceae. During the time interval represented by sediments in the lower half of this zone, the landscape supported an increasing number of spruce, predominantly **Picea mariana.** The total area covered by **Sphagnum** tundra

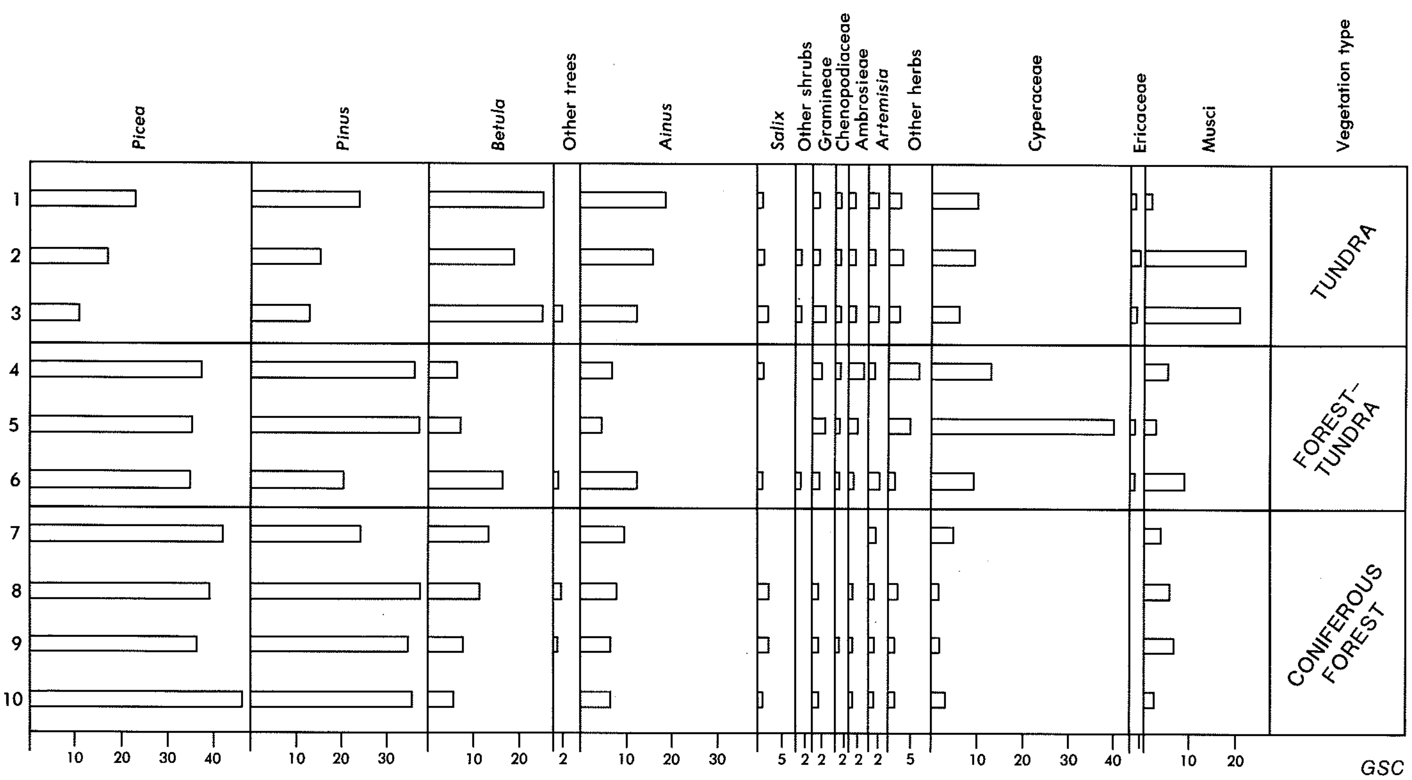

Figure 7. Contemporary pollen spectra, northeastern Manitoba and southern Keewatin.

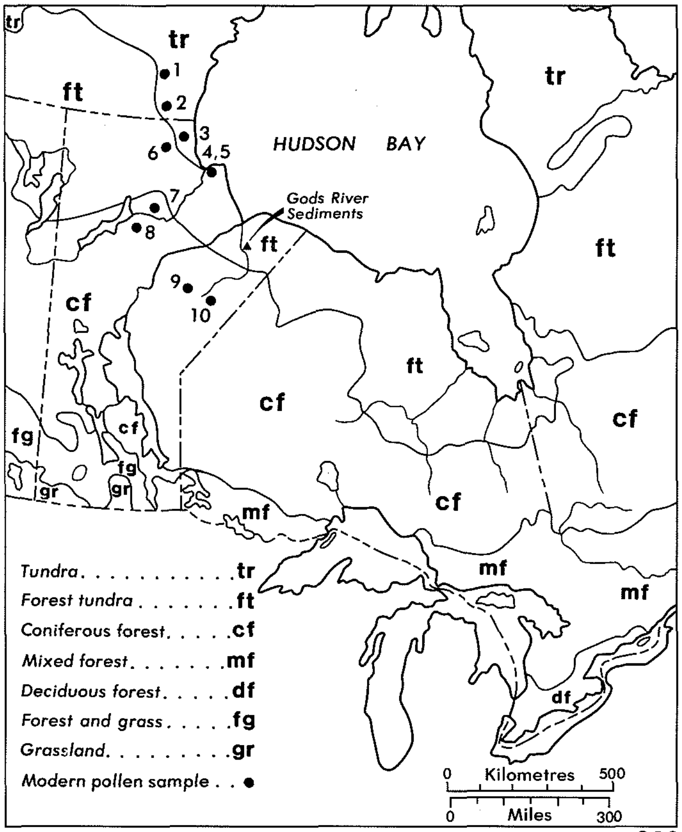

Figure 8. Pollen sample locations and forest regions.

concomitantly decreased. Small amounts of white spruce migrated into the region and occupied well drained ridges and alluvium, whereas marsh and fen communities continued to dominate wet areas. Spruce grew to a diameter of at least 12 cm.

Maximum arboreal cover probably did not exceed 50 per cent before a reversal in the northward-shifting trend of tree line occurred. Sites occupied by spruce, larch (**Larix**), and tree-birch were gradually taken over by tundra vegetation consisting mainly of **Sphagnum**, other mosses (Table II), and sedges. Timberline had migrated south of the area by the end of the time interval represented by this zone.

The extremely low pine pollen frequency (5%) when spruce was at its maximum coverage is interesting in that at recent forest-tundra sites pine pollen commonly makes up 15 to 30 per cent of the terrestrial pollen sum (Lichti-Federovich and Ritchie, 1968). Spruce and **Sphagnum** pollen are the only two species present in sufficient quantities in the fossil sediments to mask a rise in regional pine pollen representation. However, since spruce is commonly either represented in pollen spectra proportionately (Leopold, 1964) or is under-represented by a factor of 2 (Lichti-Federovich and Ritchie, 1968), and since **Sphagnum** frequencies decrease during the time in question, it is unlikely that the trend of pine pollen was influenced significantly by local vegetation. A simple interpretation is that pine trees did not extend as far north as they do today. In light of studies on pine migration during late-glacial and postglacial times (Yeatman, 1967; Wright, 1968) any or all of the following situations may account for this anomaly: 1) inadequate time for southern spruce forests to deteriorate and permit invasion of secondary vegetation, 2) a shortage of xeric and mesic habitats suitable as invasion routes for pine (abandoned well-drained shorelines, for example), 3) summer rainfall that was too great for the primarily xerophytic to mesophytic pines, 4) the possible presence of geographical barriers (such as large lakes) to pine migration, and 5) location of refugia at great distances from the study area.

Zone III pollen spectra are very similar to those from recent tundra sites. Tree line was south of the area and, as shown by the drop in frequencies of **Picea mariana** pollen in the lowermost few decimeters of sediment, continued to retreat during the early part of this interval. Other than the slight increase in representation of **Betula**, which possibly reflects a scattered influx of dwarf-birch, the **Sphagnum** and sedge communities remained unchanged for the latter half of the time interval recorded by sediments in this zone.

Data from the megafossil assemblages (Table II) are compatible with interpretation of tundra vegetation during this time. The beetle **Pterostichus (Cryobius) caribou**, for example, is presently distributed on wet and dry tundra from Alaska southeastward to Churchill, Manitoba (Ball, 1966). Similarly, **Amara alpina** is a beetle which lives in open, rather dry country, notably on the true tundra (the southern limit of its distribution coincides rather well with the Arctic tree line) (Lindroth, 1968).

The seed and mollusc collections provide less conclusive information. Of the plants, **Potamogeton praelongus** and **Hippuris vulgaris** presently range northward into tundra regions whereas the remainder are restricted to boreal sites (Fernald, 1950; Hulten, 1968). Likewise, very high percentages of the mollusc **Pisidium ventricosum** are associated at the present time with subarctic forest-tundra regions whereas succineids commonly occur as far north as timberline but occasionally are found scattered in open tundra river plains (Dr. L. Kalas, written comm., 1974). Transport by ancestral Gods River may account for the presence of species which are, at present, foreign to tundra communities.

A reasonable conclusion, based on both pollen and megafossil evidence, is that tundra vegetation existed in the region but that the Arctic tree line was not far away.

2) Climate

The physiognomy and floristic affinities of the vegetation from each pollen zone are summarized in Table III. Note that the sequence corresponds to a north-south zonation of recent vegetational types. Since temperature is probably the most important single variable that controls latitudinal distribution of contemporary vegetation (Hopkins, 1959; Bryson, 1966; Wolfe and Leopold, 1967; Hare, 1968), it is reasonable to assume that the succession of types at the fossil locality reflects an increase and subsequent decline in global temperature. Inadequate summer warmth or time required for migration from southern centres may explain the absence of spruce trees shown by Zone I assemblages. Likewise, the changes recorded in the lower half of Zone II are open to equivocal interpretation. The evidence does indicate, however, that the Zone II climate (length of growing season, mean summer temperature) during the spruce-maximum was at least as mild as at present. The transition to Zone III clearly indicates a deterioration in climate, to low-arctic conditions. Temperatures may have been stable during the time interval represented by Zone III assemblages.

3) Summary

The pollen and megafossil evidence suggests that a **Sphagnum**-sedge tundra covered the area soon after deglaciation. Tundra vegetation gradually gave way to

TABLE III

Nature of vegetation inferred from pollen assemblages Gods River Sediments.

Zone	Physiognomy	Suggested recent analogue
III	treeless communities dominated by **Sphagnum** and sedges	tundra on lowlands
II	open vegetation, roughly half of area treeless during the spruce-maximum	forest-tundra
I	**Sphagnum** and sedge communities, treeless	tundra on lowlands

northerly migration of spruce, larch, and birch (forest-tundra phase). Mean summer temperature during the spruce-maximum was similar to that of today although pine did not extend as far north in Manitoba and Ontario as it does at present. Declining temperatures eventually forced timberline to retreat and tundra vegetation once more dominated the floral community. Climate may have been stable during a late phase of the interval.

Rank of Gods River sediments

Weathering profiles and vegetation records indicative of a climate at least as warm as the present are generally considered evidence of interglacial conditions whereas a climate cooler than the present is considered indicative of interstadial conditions (Morrison, 1965). Climate during deposition of the Gods River sediments was similar to that of the present and, therefore, interglacial in character. The terms tend to be used rather loosely, however, and are based on many assumptions. One assumption that has been part of the "interglacial" definition is that continental ice sheets were similar in extent or smaller than those at present. During interstadials, glaciers are assumed to have been more extensive than at present. Since climate probably plays a large role in glacier recession (Flint, 1971), duration of climatic conditions that are suitable for ice-retreat may be as important as temperature in determining the extent of deglaciation. For example, if a climate as warm as the present existed only long enough to be reflected in the vegetational succession and then declined substantially, continental ice sheets may not have had time to recede to their present position before readvancing. Such a situation would be termed interglacial by a Quaternary palynologist studying the floral succession at a single site but only after the extent of ice-retreat was determined (and this requires regional studies) would the true nature of the interval be revealed. Consequently, interpretation of the Gods River sediments as interglacial must be considered tentative.

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