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QUATERNARY STRATIGRAPHY OF THE MOOSE RIVER BASIN, ONTARIO

R. G. Skinner

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By
R. G. Skinner

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PREFACE

In order to assist in effective use and conservation of resources and in the management and preservation of our environment, the Geological Survey provides geologically-based information on land resources and terrain performance derived from geological, geomorphic, geophysical, geotechnical and related studies.

In this report, the author presents the results of a study of the surficial deposits of about 14,500 square miles of the Moose River basin of northern Ontario. At least five distinct till-sheets are present; these are separated by non-glacial deposits. The thickness of Quaternary succession varies from about 60 feet to more than 700 feet.

Although at one time it was thought that certain of these Quaternary beds contained lignite deposits, it was later shown that the principal fuel potential lies in strata of Mesozoic age. However, there are Pleistocene sands containing lignite derived from the Mesozoic deposits and also Pleistocene interglacial peat deposits.

Y.O. Fortier,
Director,
Geological Survey of Canada

Ottawa, May 26, 1972

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QUATERNARY STRATIGRAPHY OF THE MOOSE RIVER BASIN, ONTARIO

ABSTRACT

In the Moose River basin of northern Ontario, there are at least five till sheets separated by nonglacial sediments. The sequence consists of, from bottom to top, Till I, intertill sediments I-II, Till II, intertill sediments II-III, Till III, interglacial Missinaibi Formation, Adam Till, Friday Creek nonglacial sediments, Kipling Till, and late- and postglacial glaciolacustrine, marine, and terrestrial units. The pre-Missinaibi sequence, exposed only in the southwestern portion of the area, was deposited when the fluctuating margin of a southwestward flowing ice sheet stood in a proglacial lake. The presence of marine shells in at least one of the pre-Missinaibi tills indicates that James Bay was occupied by a sea during the Quaternary before Missinaibi time.

The Missinaibi Formation, of probable Sangamon age, includes a ubiquitous buried soil and forest bed developed on glacial, marine, and fluvial sediments and is overlain by lacustrine beds. The interval began with incursion of the Bell Sea to an altitude at least 100 m above present sea level, followed by recession to a level probably near present sea level. As the land emerged, rivers incised, cutting alluvial terraces on which the soil and forest developed. Finally, an extensive lake, dammed in front of a slowly advancing ice sheet flooded the land. Lake sediment mantled the pre-existing topography and eventually was overridden by the advancing glacier. The Missinaibi interval is believed to be interglacial because it displays many features similar to the present.

Adam Till, overlying the Missinaibi Formation, was deposited by a southwestward flowing glacier. Later, Friday Creek sediments were laid down as the ice margin retreated to north of Kwataboahegan River, but the glacier did not leave Hudson Bay, as indicated by southward currents recorded in the sediments. Ice flowing again from the northeast deposited Kipling Till, the uppermost till of the region. The age of Friday Creek sediments is unknown. A late Wisconsin age (i.e., immediately pre-Cochrane) would require very rapid rates of retreat and advance; alternatively, a Middle Wisconsin age (Port Talbot) requiring considerable shrinkage of the ice sheet would imply high Middle Wisconsin sea levels, a subject of current controversy.

As the last glacier retreated from the area, glacier ice was grounded in Hudson Bay between a lake to the south and marine water to the north. The Tyrrell Sea suddenly replaced the lake, an event marked by a density flow of salt water under the lake water. The bottom currents were apparently strong enough to erode the lake clays and form a gravel of clay and silt clasts. This took place about 7,800 C^{14} - years ago. Marine limit was formed synchronously in a vast area south of James Bay, which was ice-free but isostatically depressed. The former water plane represented by marine limit is now isostatically warped upward to the northeast at a gradient of about 30 cm/km.

RÉSUMÉ

Il existe au moins cinq couches de till séparées par des sédiments non glaciaires dans le bassin de la rivière Moose, en Ontario. En coupe généralisée, du bas vers le haut, la séquence se présente comme suit: till I, sédiments intertills I-II, till II, sédiments intertills II-III, till III, formation interglaciaire de Missinaibi, till d'Adam, sédiments non glaciaires de Friday Creek, till de Kipling et des couches tardi- et postglaciaires glacio-lacustres, marines et continentales. La séquence de dépôts pré-Missinaibi affleure uniquement dans le secteur sud-ouest du bassin et a été mise en place dans un lac proglaciaire dans lequel aboutissait un glacier s'écoulant vers le sud-ouest. La marge de ce glacier était fluctuante. La présence de fossiles marins dans au moins un des tills pré-Missinaibi laisse penser qu'avant la mise en place de ce dernier dépôt la baie James fut occupée par une mer.

La formation de Missinaibi, d'âge probablement Sangamon, comprend un lit de débris forestiers reposant sur un paléosol formé dans des sédiments glaciaires, marins et fluviatiles. Le début de l'intervalle fut marqué par l'incursion de la mer Bell. Cette mer a atteint un niveau se trouvant à au moins 100 mètres de plus que le niveau actuel de la baie d'Hudson. Par la suite la mer Bell s'est retirée jusqu'au niveau actuel. Durant l'émersion des terres les cours d'eau ont creusés leurs lits et sculptés des terrasses alluviales sur lesquelles un sol et une forêt se développèrent. En dernier lieu, un vaste lac, retenu par un glacier en lente progression innonda la région. Des dépôts glacio-lacustres recouvrirent la topographie pré-existante avant d'être chevauchés par le glacier. L'intervalle de Missinaibi doit être interglaciaire car il présente plusieurs caractéristiques de l'époque actuelle.

Le till d'Adam qui recouvre la formation de Missinaibi a été déposé par un glacier à écoulement sud-ouest. Par suite, les sédiments de Friday Creek furent déposés alors que la marge du glacier se retirait jusqu'au nord de la rivière Kwataboahegan. Le glacier ne quitta cependant pas la baie d'Hudson comme en font foi les structures sédimentaires qui témoignent d'un écoulement vers le sud. Une nouvelle ré-avancée depuis le nord-est déposa le till de Kipling, le plus récent de la région. L'âge des sédiments de Friday Creek n'est pas connu. Si on leur attibue un âge tardi-glaciaire (immédiatement avant la récurrence de Cochrane) il faut supposer des avancées et des retraits forts rapides; si par contre on leur attribue l'âge du Wisconsin moyen (Port Talbot) il faut supposer un retrait considérable du glacier ce qui implique une hausse importante du niveau de la mer, point qui porte actuellement à controverse.

Au cours du dernier retrait glaciaire, les restes de l'inlandsis s'ancrèrent dans la baie d'Hudson entre un lac s'étendant vers le sud et la mer au nord. Par suite la mer de Tyrrell a remplacé ce lac. Cet événement a eu lieu lorsqu'une masse d'eau salée plus dense pénétra sous les eaux du lac. Les courants de fonds semblent avoir été suffisamment puissants pour éroder les argiles lacustres et former un gravier composé de particules argileuses et limoneuses. Cet événement s'est probablement produit il y a environ 7,800 ans. Au sud de la baie James la limite de submersion fut atteinte de manière synchrone dans une vaste région qui bien que libre de glace était en dépression isostatique. L'ancien plan d'eau représenté par la limite de submersion a été isostatiquement déformé et accuse une pente qui s'élève vers le nord-est à raison de 30 cm/km.

INTRODUCTION

The presence of extensive glacial and interglacial sediments in the James Bay lowland has been known for nearly a century. This region is of special importance to Quaternary geology because of its location close to the former centre of the Laurentide Ice Sheet. Nonglacial episodes here should correlate with interglacials and major interstadials in areas farther south.

The objective of this study was to determine the age, character and stratigraphic relationships of Quaternary deposits, and environments and events they record in the Moose River basin. This objective included 1) determination of the number of till sheets and directions of ice flow associated with each, 2) assessment of buried organic beds as interstadial or interglacial, and 3) elucidation of the nature of deglaciation, marine incursion, and postglacial isostatic uplift.

The study area (Fig. 1, in pocket) is in the Hudson Bay Lowland (Bostock, 1970, p. 15) and is that part of the Moose River basin north of 49°N Latitude. Throughout this report "Moose River basin" refers to the drainage basin, not the Phanerozoic sedimentary basin (Sanford et al., 1968, p. 3). It includes the north half of Cochrane-Hearst 42 SE and all of Moosonee 42 NE 1:500,000 map-sheets of the National Topographic System of Canada. Most of the field work was concentrated north of the limit of Precambrian outcrop. Ontario Northland Railway provides limited access to the field area along its route between Cochrane and Moosonee. Smoky Falls on Mattagami River, at the southern edge of the study area, can be reached by motor vehicle along Highway 807 north from Smooth Rock Falls.

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Previous Studies

The region around James Bay was first investigated geologically almost a century ago when Robert Bell began a series of explorations that took him down nearly every major river west and south of James Bay (R. Bell, 1877, 1896, 1898). He was followed in the early twentieth century by many others including Borron (1891), J.M. Bell (1904), Wilson (1906), Keele (1920), and McLearn (1927). Recent government surveys, 'Operation Kapuskasing' (Bennett et al., 1967) and 'Operation Winisk' (Sanford et al., 1968; Craig, 1969; McDonald, 1969) have added greatly to our understanding of the geology of northern Ontario. No attempt will be made here to review all the literature; for a complete bibliography of work done in Hudson Bay Lowland prior to 1967, the reader is referred to Norris et al. (1968). Useful summaries of bedrock and surficial geology are provided by Stockwell et al. (1970, p. 137-145) and Prest (1970, p. 687-690 and 731-739).

Although early studies concentrated on Quaternary deposits, they emphasized the fuel potential of the nonglacial organic deposits then referred to as 'lignites'; little was known of the number of till sheets, ice-flow directions, paleoenvironments, or postglacial events. Early geologists confused Quaternary peat and Mesozoic lignite describing them together as interglacial lignite (R. Bell, 1877, and later papers; J.M. Bell, 1904; Wilson, 1906; Borron, 1891) or Cretaceous lignite (Keele, 1920). McLearn (1927) finally distinguished the Quaternary and Mesozoic ages of the buried organic deposits. Terasmae and Hughes (1960a) recognized five Pleistocene units exposed along Missinaibi and Opasatika rivers: 1) lower drift, 2) middle drift, 3) interstadial Missinaibi beds consisting of peat, organic silt, and clay, 4) upper drift, and 5) marine clay, sand and silt. Prest (1966, p. 138) and McDonald (1969) reported marine beds associated with the Missinaibi beds. Controversy has arisen among various geologists as to whether the Missinaibi beds, more than 54,000 C^{14} years old, are interstadial or interglacial.

Studies south of the lowlands by Antevs (1925, 1928), Hughes (1959, 1965), and Boissonneau (1966) confirmed the occurrence of a local, late-glacial readvance that deposited the Cochrane Till. The northern limit of retreat of the Cochrane lobe prior to readvance has never been determined.

R. Bell (1896) noted widespread evidence of a postglacial marine incursion south of James Bay and suggested that the land there was emerging. Later, Lee (1962) and Terasmae and Hughes (1960b) obtained dates for marine shells from the James Bay region that provide the basis for a postglacial chronology for northern Ontario, as well as a measure of the rate of isostatic uplift.

Bedrock Geology

The bedrock of the area has received considerably more attention than have the Quaternary sediments because the region has high economic mineral potential. Large reserves of nonmetallic minerals including kaolin, fireclay, silica sand, lignite, and gypsum are present. Niobium has recently been discovered and explored for possible development (Bennett et al., 1967).

The lowland region south of James Bay is underlain by Ordovician, Silurian, and Devonian limestones, dolostones, shales, evaporites, and sandstone, cut locally by Mesozoic lamprophyric intrusions. Lower Cretaceous

or Upper Jurassic continental beds consisting of unconsolidated quartz sand, lignite and underclays overlie the Paleozoic rocks. Relatively resistant Precambrian rocks form a plateau south of the lowlands. The northern limit of this plateau is defined by a fault scarp where many falls and rapids occur in the rivers. The oldest Precambrian rocks are folded metavolcanics, metasediments, and related gneisses, intruded by mafic to felsic rocks. According to Bennett et al. (1967) Archean granulites have been faulted into a northeast-trending horst structure. Later, the granulites were intruded by Proterozoic carbonatites and post-Middle Devonian lamprophyric rocks. Stockwell et al. (1970) have recently summarized the bedrock geology of this region.

Control on the outcrop distribution of distinctive indicator lithologies is inadequate for determining provenance of tills. Boulders with unique concretions have been described by R. Bell (1877, p. 325) and Hogg et al. (1953, p. 50) along Kenogami and Missinaibi rivers. Hogg et al. thought they were derived from the Belcher Islands, near the east coast of Hudson Bay; they probably occur along the belt of Proterozoic rocks from Ottawa Islands to Long Island and west to Sutton Ridges.

Field and Laboratory Techniques

Field work for this project was done during the summers of 1969 and 1970 and consisted primarily of canoe and helicopter traverses along rivers. River-bank exposures were measured, described, sampled and later recorded on fence diagrams (Figures 2A to E). Station locations are shown on Figure 1 or on inset maps on the fence diagrams.

Some 180 till samples were analyzed mechanically in the Sedimentology Laboratory of the Geological Survey of Canada. The reader is referred to McDonald and Kelly (1968) for a description of laboratory procedures. Besides grain size analyses, calcite and dolomite determinations on the 44-63μ fraction (Chittick method), heavy mineral separations from the 125-250μ fraction were performed by the laboratory. A table in Appendix A lists the following data for each till sample:

1) sample number (also on fence diagrams)
2) station numbers (also on Figure 1 and fence diagrams)
3) graphic statistical parameters of Folk and Ward (1957)
   a) graphic mean (M_z) in ϕ units
   b) inclusive graphic standard deviation (σ_I) in ϕ units
   c) inclusive graphic skewness (SK_I)
   d) graphic kurtosis (K_G)
4) per cent sand, silt, and clay
5) per cent calcite, dolomite, and total carbonate (%[CO_3])
6) per cent siderite grains in heavy mineral separates (for lower tills only).

In determining the statistical parameters of Folk and Ward, percentiles 5, 16, 25, 50, 75, 84, and 95 were read off cumulative grain-size curves on arithmetic probability paper. Where higher percentiles (84 and 95) were not attained, they were interpolated by extrapolating the last 2 points of the probability curve in a straight line to the 14ϕ size. This was performed on arithmetic paper.

Preliminary examination of heavy mineral separates indicated that percentage of siderite in pre-Missinaibi tills varied sufficiently to warrant further study. Heavy mineral separates of approximately 50 samples of lower tills were systematically counted for siderite. Three counts of 250 to 550 grains for each sample were averaged to obtain the values given in Appendix A.

Values of M_z and $\%[CO_3]$ for each till were plotted on maps but, except for Kipling Till, inspection did not reveal any meaningful trends; therefore, only maps for Kipling Till are given in Appendix E.

Station and sample numbers will be mentioned below. A key to station numbers is given in Appendix A. To find if till samples are available from a given point in the basin, a station number near the point of interest can be found on Figure 1. Noting the river, the station can be located on the appropriate fence diagram, and sample numbers (if any) checked beside till units shown in the station's stratigraphic column. The till (Kipling, Adam or lower till) can be noted and the sample number found in Appendix A. All data in Appendix A are on computer cards, available on request from the Geological Survey of Canada, Ottawa.

Ice-flow Direction Indicators

Because the study area is approximately 40,000 km^2, no attempt was made to measure till fabrics on a comprehensive scale. Instead, well-preserved striations and stoss-and-lee features on the upper surfaces of large boulders within and at the bases of till sheets were considered valid because a) striations on 3 or 4 different boulders at the same locality and at different stratigraphic levels within a till indicated the same direction of ice flow within 15 to 20°, and b) in the same till, striations on approximately 25 boulders, a two-dimensional till fabric (approximately 50 pebbles), and grooves and striations on bedrock directly beneath the till, all indicated the same general direction of ice flow. Striation and till fabric directions are shown on fence diagrams and also are plotted on maps for Adam Till and Kipling Till (see below).

QUATERNARY STRATIGRAPHIC RECORD

The Quaternary record of the Moose River basin consists of a series of tills, intercalated with nonglacial sediments, both organic and inorganic. The various units are identified primarily on the basis of stratigraphic position relative to two marker beds: 1) interglacial peaty sediments, and 2) postglacial basal marine clay-pebble gravel. Texture, colour, and compactness aid locally in discriminating among tills but cannot be applied regionally. Mean grain size (M_z) and per cent total carbonate ($\%[CO_3]$) are useful locally in differentiating tills.

Thickness of Quaternary sediments varies in the region. Closely spaced drill holes at Onakawana reveal 20 to 30 m of local relief on the bedrock surface (Dyer and Crozier, 1933, p. 68). Unpublished drill records in McBrien township, on upper Missinaibi River, indicate more than 35 m of drift below river level and relief of at least 35 m within 70 m horizontal distance. Hogg et al. (1953, p. 117) reported 212 m of Quaternary sediments in a well at Campbell Lake, between Mattagami and Missinaibi rivers.

Table I.

Rock-stratigraphic units and inferred events, Moose River basin

ROCK-STRATIGRAPHIC UNIT	INFERRED EVENT	AGE C^{14} years B.P.
Terrestrial unit	weathering; peat and forest growth eolian activity	
Marine unit	stream incision and deposition marine recession marine incursion	7,800
Glaciolacustrine unit	glacial retreat	
KIPLING TILL	glacial advance	
Friday Creek sediments	retreat	
ADAM TILL	glacial advance	
MISSINAIBI FORMATION: Lacustrine member	lacustrine transgression	
MISSINAIBI FORMATION: Forest-peat member (buried soil)	weathering; peat and forest growth	>54,000
MISSINAIBI FORMATION: Fluvial member	stream incision and deposition	
MISSINAIBI FORMATION: Marine member	marine recession marine incursion glacial retreat	
TILL III	advance	
Intertill sediments II-III	retreat	
TILL II	advance	
Intertill sediments I-II	retreat	
TILL I	advance	

glaciation

Quaternary units, listed in stratigraphic order in Table I, will be described and discussed from oldest to youngest. This sequence is based on stratigraphic sections shown on fence diagrams.

SEDIMENTS OLDER THAN MISSINAIBI FORMATION

Quaternary sediments underlying the Missinaibi Formation include at least three tills separated by silt-and-clay rhythmites, sand and gravel. These sediments are exposed in the southwestern part of the study area along Coal Creek and Missinaibi, Pivabiska, and Soweska rivers. Station 24M of Terasmae and Hughes (1960a, p. 3) provides a representative section where all three pre-Missinaibi tills outcrop (Fig. 3). The tills are designated informally from bottom to top, as Tills I, II and III. Nonglacial sediments between Tills I and II, and II and III are referred to as intertill sediments I-II and II-III, respectively. These five units comprise Terasmae and Hughes, lower and middle drifts (1960a, p. 1). Their lower drift is Till I in this report. Units are equated from section to section primarily on the basis of their stratigraphic position relative to the Missinaibi Formation and also on their gross similarity in outcrop.

Till I

Till I at 24M is pinkish grey, very compact, sandy, and contains inclusions of contorted glaciolacustrine silt and clay. The pinkish colour is local and believed to reflect a high siderite content (see below). Elsewhere, the till is grey to brownish grey. The bottom contact of Till I at 24M was below river level when visited in 1969 and 1970; three metres were exposed

Figure 3. Station 24M, Missinaibi River. GSC photo 201915-B.

above water level. A sandy texture (M_z = 4.4-6.0 ϕ) and tendency to form steep banks are useful parameters for identification of Till I around Soweska and Missinaibi rivers; the sandy texture can be accounted for locally as being due to incorporation of Cretaceous silica sand. Elsewhere the till may be silty but it is characteristically very compact. Large boulders are rare in Till I, perhaps 5 or 6 being exposed on a cut-bank 75 m long and 5 m high.

Marine shells were found in Till I at station MS-70-36.[1]

Intertill sediments I-II

At 24M, intertill sediments I-II overlie Till I with a sharp contact and consist of 30 cm of silt and clay rhythmites at the base, directly overlain by 7 m of bright orange to yellow coarse to medium sand with lenses of brown, sandy, pebbly diamicton 20 to 30 cm thick. The diamicton lenses are similar in colour and texture to overlying Till II. In places, the sand is cemented with iron oxide. The attitudes of cross strata in this unit indicate former current directions to the southeast, south, and west, opposite to the present gradient. The rhythmite facies at the bottom of the unit thickens westward from 24M; at Coal Creek, it is more than 12 m thick and individual rhythmites are more than 1 m thick at the bottom decreasing to 2 cm at the top of the exposure where they are deformed and incorporated into Till II.

Till II

Till II at 24M is dark greyish brown, sandy (M_z = 3.9-5.0ϕ), moderately calcareous, averages 4 m in thickness, and forms a distinctive cliff along the length of the exposure. This till unit can be traced only a few miles downstream from 24M; upstream on the Missinaibi its presence is assumed by 'counting down' from the Missinaibi Formation. On Coal Creek it overlies glaciolacustrine silt and clay and, consequently, is finer grained (M_z = 6.4-7.1ϕ) and more greyish in colour. The brown colour at 24M is believed to be local and a result of abundant siderite in the till. Till II is similar to Till I in compactness and boulder content.

Intertill sediments II-III

Intertill sediments II-III overlie Till II and, at 24M, include yellowish sand and silt and diamicton lenses. The diamicton lenses are similar to those in intertill sequence I-II. Sedimentary structures, such as climbing ripple laminations, indicate a former current toward the south, against the natural gradient.

A sand-and-gravel unit outcrops in a comparable stratigraphic position -- that is, below the till immediately subjacent to the Missinaibi Formation -- in several sections west of 24M on Missinaibi and Pivabiska rivers and on Coal Creek. It is assumed to be intertill unit II-III. North of 24M along Soweska River the unit is coarser, poorly sorted, and resembles till except that it contains very little clay-sized sediment, and faint bedding is visible.

---

[1] MS-70-36 refers to Station 36 on Missinaibi River. For key to rivers, see Appendix A.

Till III

Till III at 24M is brown to grey with lenses of yellowish to orange sand. It is commonly sandy (M_z = 4.8Φ) although finer texture (M_z = 7.1-7.6Φ) was encountered on Soweska River and Friday Creek. It is usually oxidized and very friable, breaking into thin flakes parallel to the exposed surface. Tills I and II are not as easily excavated and do not appear as oxidized. The oxidation is probably related to weathering during the Missinaibi interval; however, percolating groundwater after the Missinaibi interval cannot be ruled out as causing some oxidation. The till is calcareous throughout except near the top where it is directly overlain by Missinaibi peat or forest bed.

Discussion of pre-Missinaibi Stratigraphy

The age of these sediments is unknown. No macroscopic organic remains were found in them. The sequence from Till I to Till III is believed to represent a series of local oscillations of an ice margin. General southward current directions indicate that natural drainage to the north was blocked. No evidence from paleocurrent data, marine deposits, or weathering was found to suggest withdrawal of ice from Hudson Bay during either retreat interval I-II or II-III. The intertill units are interpreted as glaciolacustrine sediments. The northward coarsening of unit II-III near Soweska River is believed to reflect increasing proximity to the ice margin which perhaps then did not retreat much farther north than Soweska River. The diamicton lenses in the intertill sediments are interpreted as having been derived from nearby ice, perhaps as local flow tills.

The three tills in the western part of the basin possibly combine to form the one pre-Missinaibi till observed in the eastern part. This is highly speculative, for at most exposures in the east (Abitibi, Mattagami and Moose rivers), the Missinaibi Formation's base is below or close to river level leaving little pre-Missinaibi record exposed.

Till fabrics and striated boulders suggest that direction of ice flow for all three tills was from the northeast quadrant. Several boulders in Till II at Station 24M (MS-69-16) had striations oriented north-south and northwest-southeast. In general, though, no significant differences of carbonate content, heavy mineral content, or texture were observed among the tills to infer widely divergent sources. During retreat of the glacier that deposited Till I, the glacier margin is inferred to have oscillated into a proglacial lake in the western part of the area, depositing a sequence of tills intercalated with glaciolacustrine sediments.

The presence of Quaternary marine shells in at least one of the pre-Missinaibi tills suggests that James Bay basin was occupied by marine waters sometime earlier than the Missinaibi interval. This is consistent with McDonald's (1969, p. 89) observation of marine shells in all tills in northwestern Hudson Bay Lowland.

Siderite in heavy mineral separates of pre-Missinaibi tills

Varying percentages of siderite were encountered in heavy mineral separates from pre-Missinaibi tills. Siderite is known to occur in the Moose

River basin at Grand Rapids, on the Mattagami River (R. Bell, 1877, p. 32; Bennett et al., 1967, p. 59) where it is found as fillings in solution cavities in Devonian limestone. There, siderite is altered in places to limonite, and intermixed with silica sand. The siderite occurs in the tills as reddish brown, euhedral, single tabular, and composite crystals ('roses') and as massive-grained, globular, and earthy masses, commonly enveloping or attached to quartz grains. Many siderite grains are abraded and fragmented suggesting transport. Because siderite in the till samples was observed attached only to silica grains, the siderite probably was reworked and not formed as a primary mineral within till; otherwise, additional minerals would be covered with siderite.

The samples were obtained mostly from the western part of the basin. Abundant siderite (>50%) was observed in tills around 24M. The source for this siderite is probably not Grand Rapids because samples along Opasatika River, between Grand Rapids and 24M contain less than 3 per cent siderite. Other siderite deposits very likely occur near the confluence of Soweska and Missinaibi rivers. As Cretaceous deposits outcrop there, Paleozoic rocks with siderite-filled solution cavities may also be present.

Summary

A sequence of glacial events preceded the Missinaibi nonglacial interval. A multiple-till sequence in the western part of the basin may record oscillations of a retreating ice margin. Marine shells in at least one till indicates that James Bay basin was occupied by marine waters earlier than Missinaibi time. Direction of ice flow was from the northeast, up the regional topographic slope; consequently, glaciers blocked northward flow of streams and proglacial lakes developed.

Analyses of heavy minerals suggest that siderite, similar to the Grand Rapids iron-formation, may occur near the mouth of the Soweska River.

MISSINAIBI FORMATION

Robert Bell (1877, p. 314) first reported buried organic beds in the James Bay lowland. James MacIntosh Bell (1904) subsequently studied the deposits for their fuel potential and referred to them as interglacial lignites. Keele (1920) confirmed that some of the lignites were Mesozoic and assumed those studied by J.M. Bell to be of similar age, thereby introducing a conflict over ages. McLearn (1927) finally resolved the conflict by distinguishing three types of lignite: 1) Mesozoic lignite, 2) Pleistocene sand containing detrital Mesozoic lignite, and 3) Pleistocene interglacial peat. In 1954 O.L. Hughes examined and sampled buried peat along Missinaibi and Opasatika rivers. Terasmae and Hughes (1960a) later discussed the palynology and age of the beds which they informally named the Missinaibi beds. McDonald (1969) discovered many more exposures of these or similar beds throughout Hudson Bay Lowland.

In the present study, the Missinaibi beds and their equivalents in the Moose River basin were examined in detail to determine facies relationships, environments and events that the various facies record, and whether the beds were deposited during an interglaciation or an interstade.

The Missinaibi beds and related nonglacial sediments are divided into four members: (a) marine, (b) fluvial, (c) forest-peat, and (d) lacustrine. The Missinaibi beds, as defined by Terasmae and Hughes (1960a, p. 1) included "...layers of peat, organic silt, and clay..."; therefore, employed strictly, this definition excludes all of (a) and parts of (b) and (d). It is proposed here to refer to all members collectively as the Missinaibi Formation. Section 24M of Terasmae and Hughes (Figs. 3, 4) is one of the best exposures of the formation and is described as the type section in Appendix B with other representative sections.

Marine member

Description

Marine sediments have been found in situ at only a few locations, so details of marine stratigraphy are virtually unknown. Marine deposits are best exposed along Kwataboahegan River near the mouth of Mistuskwia River where they were first discovered by J.M. Bell's party in 1904.[1] There the

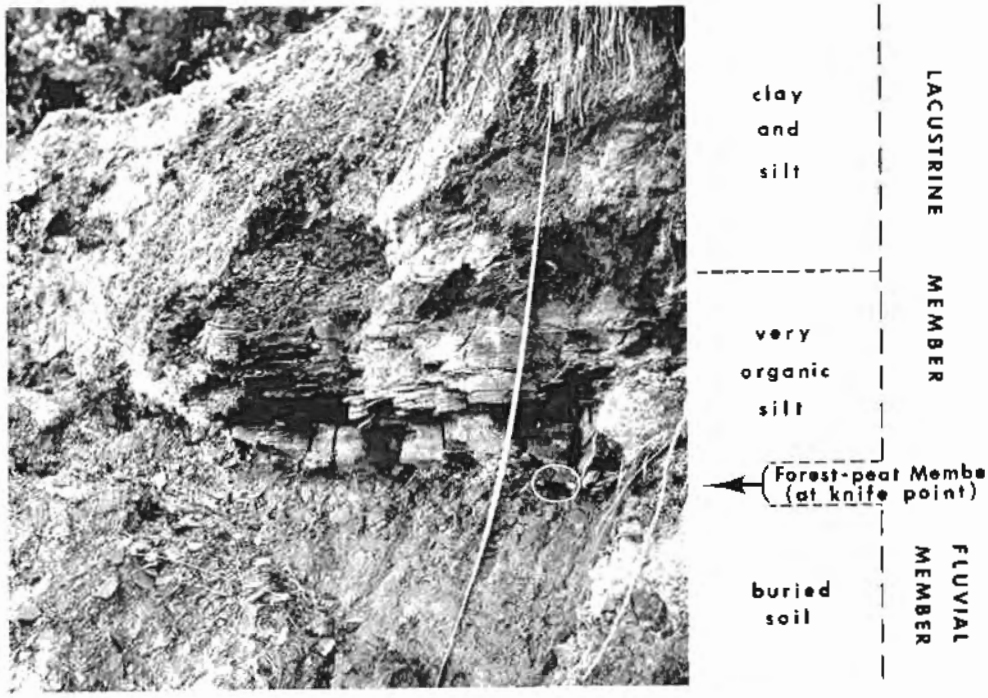

Figure 4. Missinaibi Formation, Station 24M, Missinaibi River. Tape showing approximately 120 cm. GSC photo 154878.

[1] Although Bell (1904, p. 168) did not state specifically that the shells he found were marine, others assumed them to be (Coleman, 1926, p. 26; 1941, p. 128; McDonald, 1969, p. 82), and McDonald confirmed their marine character. Freshwater shells are also present in the Missinaibi Formation, so the distinction between marine and freshwater is important.

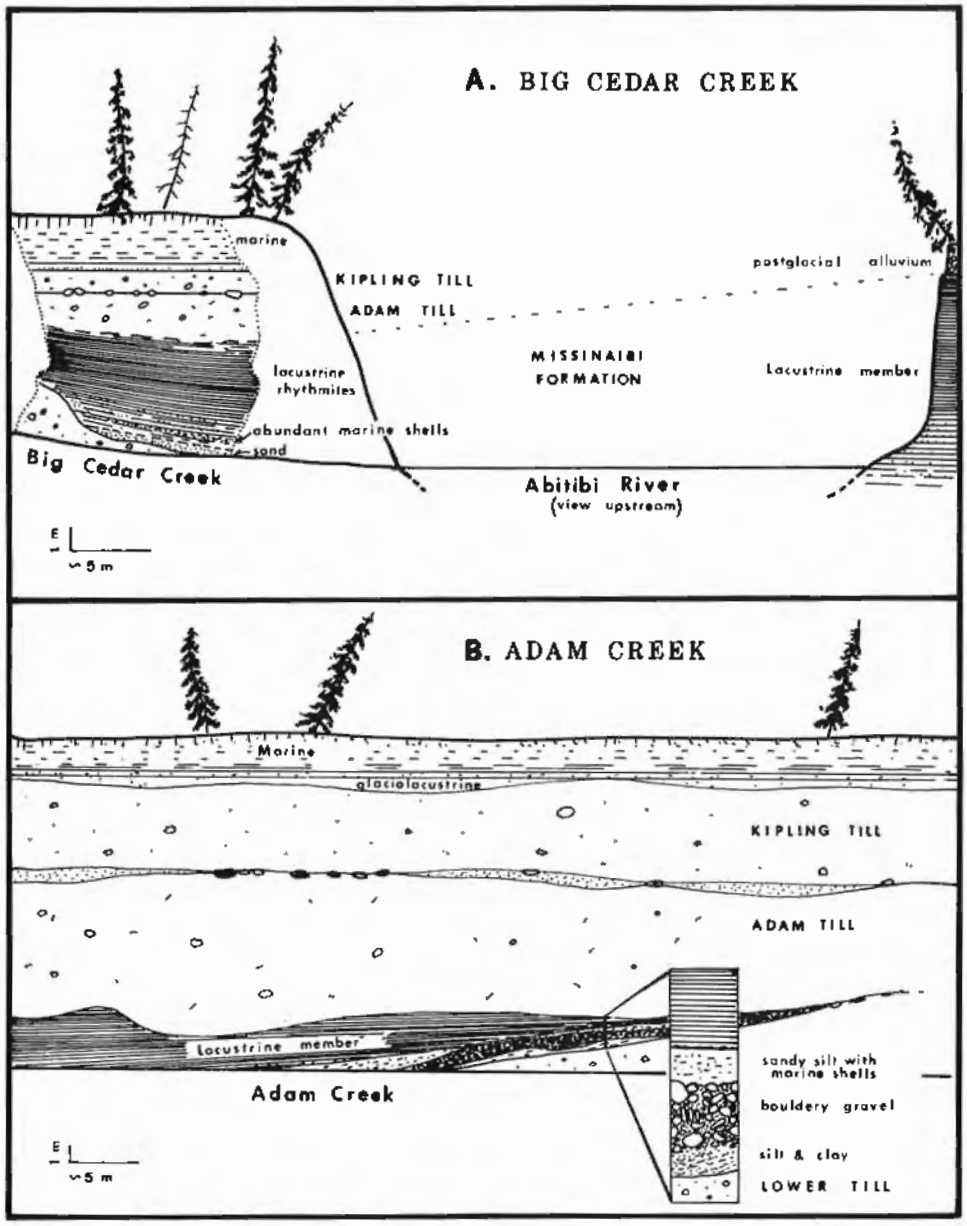

Figure 5. Two sections with marine fossils in Missinaibi Formation.

member consists of at least 80 cm of fossiliferous, bluish grey, very compact sand and silt. An undulating bed of marine mollusc shells occurs near low river level about 40 cm below the top of the unit. The whole formation here is badly deformed, probably by overriding glacier ice.

At the following two marine fossil localities fossils are believed to have been reworked and incorporated in younger members of the Missinaibi Formation:

1) At the mouth of Big Cedar Creek (Fig. 5A), abundant marine fossils including more than 15 species (Appendix C) were found in a poorly sorted bed 3-4 cm thick, about 1.5 m above low river level. The bed is in a sequence of reddish brown to yellow, organic sandy silt and clay couplets which rest on nonfossiliferous, compact sand underlain by compact, sandy till. The till surface slopes steeply westward beneath Abitibi River. The couplets grade up into rhythmites of the lacustrine member suggesting they are not in situ marine beds. The worn and fragmented nature of the marine shells supports this interpretation.

2) At Station AC-69-85 (Adam Creek; Fig. 5B) fragmented marine shells, mostly Hiatella arctica, were observed in a bed of olive-grey silty clay directly overlain by the lacustrine member and underlain by about 50 cm of bouldery gravel, lying on 30 cm of very hard, bluish grey silt and clay, in turn resting on till. The bouldery gravel is interpreted as fluvial member but could well be marine or glaciofluvial. Because the bluish grey silt and clay may be marine, extensive search in it might reveal marine fossils.

Prest (1966, p. 138) reported sub-till marine sediments on Abitibi River (Station AR-70-83) and related them to the Missinaibi beds. When his section was examined in 1970, slumping had obscured the stratigraphic relationships; contorted silt with marine fossils at river level appeared to have been slumped from the top of the section. However, a small sample of marine shells from the contorted silt gave a radiocarbon age of >19,000 yrs. (GSC-1535) confirming their antiquity and probable Missinaibi affinity.

Discussion

The marine member represents a marine incursion of unknown extent, age and duration. The sea that invaded the Moose River basin during the Missinaibi interval is here named the Bell Sea after Robert Bell, who first discovered and reported buried organic beds of the Missinaibi Formation in this region.

Figure 6 shows all localities[1] in the Moose River basin where marine fossils are known in the Missinaibi Formation. The occurrences along Kwataboahegan River are believed to be the only ones where the fossils actually occur in marine beds except, perhaps, for those noted by Prest (1966); elsewhere, known marine fossils are suspected of having been reworked in other members of the formation.

Fossil assemblages include Mollusca, Foraminifera, Ostracoda, and Echinodermata. A list of fauna for each locality is given in Appendix C.[2]

Dr. Frances J. Wagner identified the foraminifera collected during this study. She states: "These collections all suggest comparable conditions; that is, shallow depths (less than 100 m), salinity approximately 30-35%, and

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[1] Since this report was completed, marine shells have been discovered in Missinaibi Formation at the Moose River Crossing section. See Appendix B.

[2] Quaternary Foraminifera recovered from intertill sediments in a drillhole at Campbell Lake (Hogg et al., 1953, p. 117) and reported in Prest (1970, p. 688) are not included in the fossil list because stratigraphic details of the core are uncertain and, of the 11 species identified, none has been found in known Bell Sea assemblages. Furthermore, based on fossil lists in Wagner (1969), only one of the 11 species has been found in Tyrrell Sea sediments or in Hudson Bay.

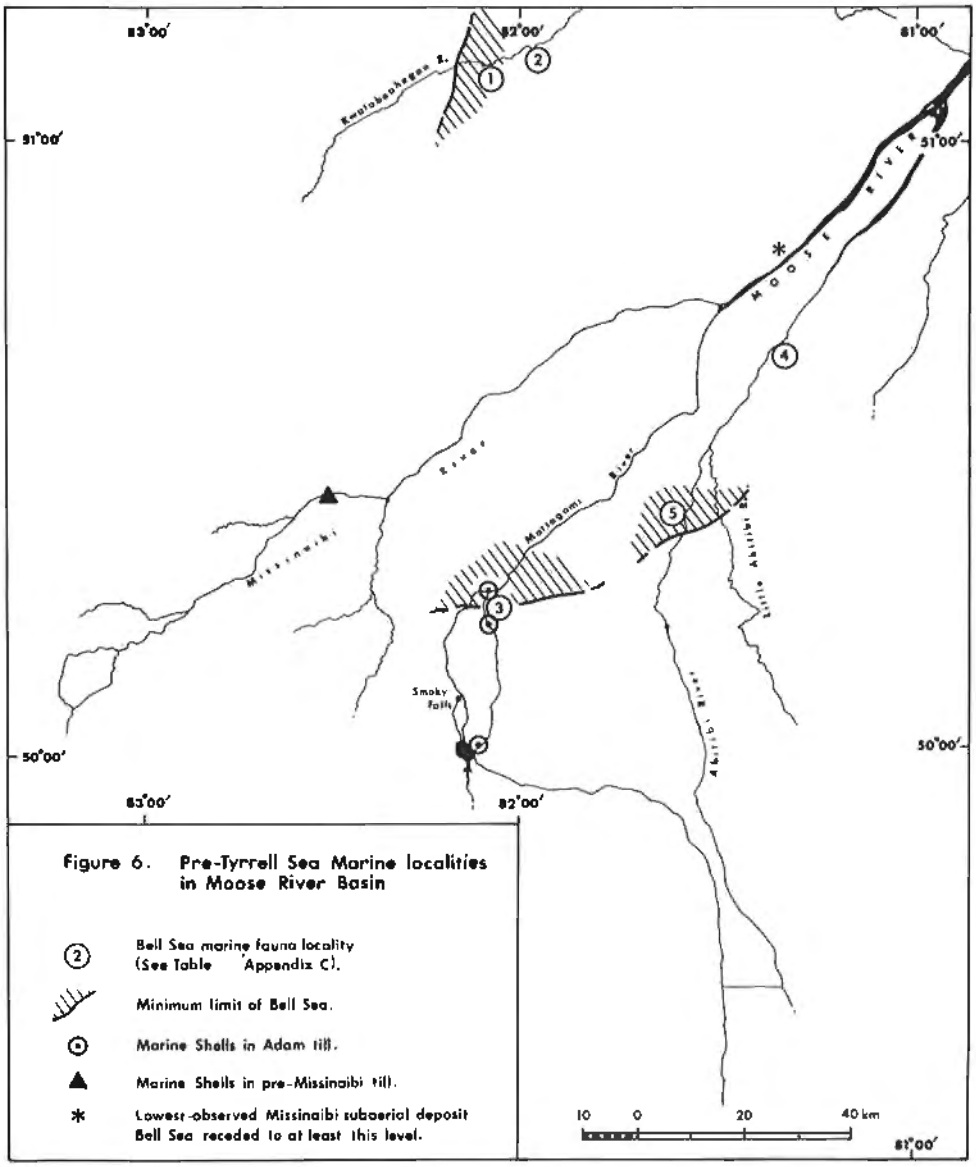

Figure 6. Pre-Tyrrell Sea Marine localities in Moose River Basin

(2) Bell Sea marine fauna locality (See Table Appendix C).

Minimum limit of Bell Sea.

Marine Shells in Adam till.

Marine Shells in pre-Missinaibi till.

* Lowest-observed Missinaibi subaerial deposit Bell Sea receded to at least this level.

temperature similar to present Hudson Bay" (F.J. Wagner, written comm., 1971). Quaternary ostracods identified by J.E. Hazel (1971, written comm.) indicate deposition in cold water. Molluscs, found in Bell Sea sediments, also occur in Hudson Bay and in Tyrrell Sea sediments. Based on faunal content, the Bell Sea was probably very similar in temperature and salinity to the Tyrrell Sea and Hudson Bay.

Although stipulation of many localities as marine is based on reworked marine fossils, the altitudes of the sites provide a minimum limit for marine incursion because the fossils were reworked most likely from higher altitudes. The highest is the Adam Creek site at approximately 90 m; presumably the marine fossils were reworked from the Missinaibi Formation and not from some older deposit. As noted earlier, marine shells were found

in pre-Missinaibi tills, so the possibility of inclusion of older, pre-Missinaibi specimens exists. However, this is considered unlikely where the fossils are abundant. A small sample of grey sand below lacustrine member on Pivabiska River (Station PR-69-29) 120 m a.s.l., contained one foram; this individual should be considered pre-Missinaibi until more abundant assemblages are found at comparable altitudes. Samples of the fluvial member from sections on Friday Creek and Soweska River, well above 90 m, contain no marine microfossils. The marine limit for the Bell Sea is placed tentatively at about 100 m. An upper limit of marine off-lap is indicated by post-marine subaerial deposits such as peat and trees at Moose River Crossing, 23 m above present sea level. A still lower limit is inferred because 2 m of peat accumulated at Moose River Crossing during which time the Bell Sea probably fell below 23 m.

In summary there was a minimum emergence of 67 m and perhaps as much as 100 m or more. This relative sea level change may have been due to isostatic uplift, to eustatic fall of sea level, or to both. Most likely it was caused by isostatic uplift, for eustatic fall probably would mean glacier growth adjacent to Hudson Bay and attendant cold conditions which are not reflected in pollen and seed assemblages at Moose River Crossing (see below).

Fluvial member

Description

Representative exposures of the fluvial member occur along Abitibi and Soweska rivers. The member consists of gravel, sand, and silt commonly oxidized to yellow or orange and is moderately calcareous to noncalcareous. Large scale trough cross-stratification and horizontal bedding are common; the cross-strata indicate a former current toward the north in the direction of the present stream drainage. The member is rarely more than 8 m thick, 2 or 3 m being the average thickness.

A fluvial subfacies consisting of concentrations of detrital organic matter occurs in a few outcrops. This organic facies is not restricted to any specific level within the fluvial member. It commonly outcrops as a lenticular body with an erosional base. The organic content varies from a few freshwater molluscs to an assemblage of wood, mosses, seeds, leaves, freshwater sponge spicules and molluscs, arthropods, and finely disseminated organic detritus. Figure 7 illustrates the stratigraphic position of this deposit within the Missinaibi Formation as exposed on Soweska River (Station SR-69-60). This facies in the Moose River Crossing section (in Appendix B) contained abundant organic matter including a fish (Family Cyprinidae), several species of freshwater molluscs, Coleoptera (3 species), diatoms, mosses, sponge spicules, as well as leaves, twigs and more than a dozen seed types, mostly from aquatic plants including Najas flexilis. In 1972, pieces of wood (Picea sp.) that had been chewed by beaver were discovered in the Moose River Crossing section.

McLearn (1927, p. 31C) reported freshwater molluscs from what is interpreted to be the fluvial member on Soweska River (Station SR-69-110). Mollusc species found so far in the fluvial sediment have been found in postglacial alluvium as well (F.J. Wagner, 1955, unpubl. report). No mammalian bones have yet been recovered from the Missinaibi Formation, although

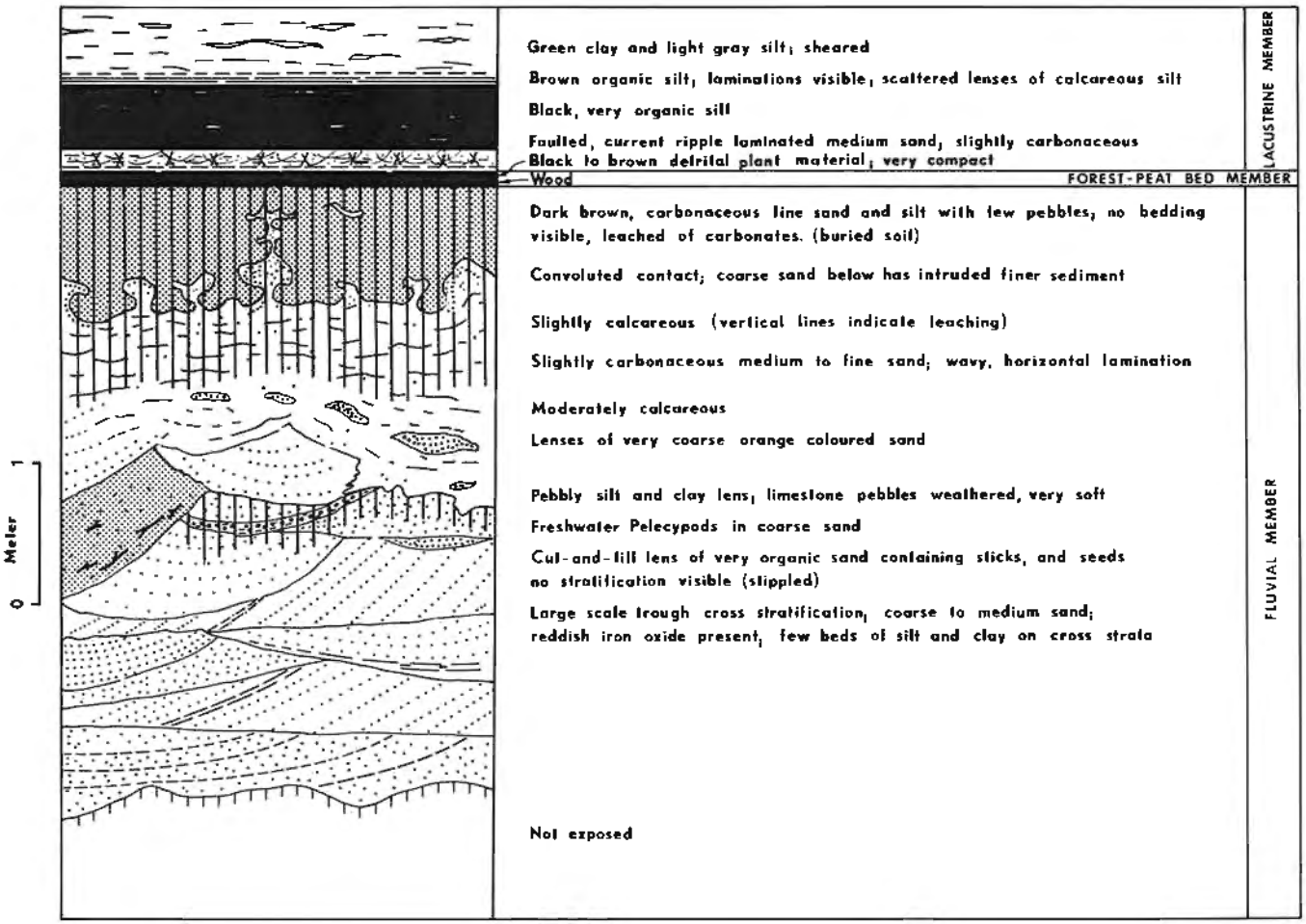

Figure 7. Station SR-69-60 showing fluvial member of the Missinaibi Formation and relationship to other members.

R. Bell (1898) reported mastodon remains from Long Island at the northeastern corner of James Bay and from the Moose River. He suggested that the latter specimen may have been derived from interglacial lignite exposed nearby. This site, 1 km below the confluence of Missinaibi and Mattagami rivers, was examined closely during the present study but no bones were found. A thick sand unit outcrops along this stretch of the Moose River but the only lignite observed was detrital Cretaceous lignite contained in the sand. Further excavation of the Moose River Crossing section (Station MR-69-107) could lead to the discovery of additional faunal remains.

Discussion

The fluvial member records an interval of stream deposition. The top of the fluvial member commonly is altered or weathered (see below) suggesting that streams became intrenched in their own alluvium. Stream piracy may explain abandonment of channels but incising to lower base-levels seems more probable, especially in view of the evidence for off-lap of the Bell Sea during this nonglacial interval. The organic subfacies is interpreted as channel fillings; as streams incised or shifted laterally they left cut-off channels of varying size that initially contained water and supported aquatic life, then gradually filled with sediment or were drained.

The regional configuration of the surface of the fluvial member provides some indication of low-points on the Missinaibi surface relative to the levels of modern rivers. For example, this surface falls from about 30 m above present river level at 24M on Missinaibi River to about 5 m above river level near the mouth of Opasatika River. As the surface is traced up the Opasatika River it disappears below river level some 8 km from the mouth and suddenly reappears 10 m above river level at Friday Creek (see fence diagrams, in pocket). This suggests that a topographic low existed somewhere between Friday Creek and Missinaibi River and that former streams here cut to or below the level of the modern stream. At many exposures of the Missinaibi Formation, the base of the lacustrine member occurs below river level indicating that the pre-lacustrine erosion surface was lower than the modern one.

Forest-peat member and weathered substrate

Description

The forest-peat member consists of mosses, sedges, sticks, logs, and stumps. It marks a ubiquitous unconformity that truncates Missinaibi fluvial and marine sediments and older tills. The forest-peat bed averages 2 to 5 cm in thickness but locally reaches 2 m where it mostly consists of peat. Wood from this unit has been identified as larch or spruce.[1] In places, stumps were observed in growth position resting on a mineral substrate (Fig. 8).

Stumps and logs with diameters up to 12 cm have been found in the Missinaibi Formation. Larger specimens, more than 50 cm in diameter,

[1] Reliable differentiation of spruce and larch wood is difficult, if not impossible, when the samples are compressed and partly lignitized (R. Mott, pers. comm., 1971).

have been reported in the past as interglacial, but the specimens probably were collected from the Mattagami Formation (Cretaceous) in which large diameter trees are common. The maximum diameter of modern Populus and Picea (80-90 cm) far exceeds that of trees collected by the author from the Missinaibi Formation.

Discussion

The small diameter of trees in the forest bed may reflect a cold climate toward the end of the Missinaibi interval. The apparent absence of larger trees could also be a function of sampling. The presence of hydrophytic plants such as moss and sedge and small diameter spruce and/or larch suggests wet conditions during growth of the forest-peat bed. Lake sediments overlie the forest bed so perhaps it represents growth during the last few years before flooding, when soil conditions were wet.

The weathered substrate or buried soil

Description

The forest bed everywhere rests on an altered zone in older deposits. This is commonly a noncalcareous, dark greenish brown to greenish grey diamicton, up to 80 cm thick. It typically contains abundant disseminated, fine organic matter as well as larger fragments of wood and roots. Abundant

Figure 8.

Forest peat member, Missinaibi Formation. Note stump (arrow) in growth position. Scale 20 cm. Lacustrine member overlies stump (Station MA-70-114). GSC photo 201915-D.

pollen grains were extracted from only a few grams of diamicton at several localities; all the assemblages were similar and herbaceous pollen made up a large percentage of total pollen (see p. 25).

The lower boundary of the diamicton is gradational to sharp and, in places, is involuted or penetrated by underlying sediments. Texture varies and seems related to the texture of underlying sediments. For example, where the underlying sediment is coarse sand, the diamicton is also sandy but contains more clay, is coloured dark brown to green, and is more massive in appearance. On drying, the diamicton typically breaks into prisms, flakes, or joint blocks, the size of the fragments being dependent on the texture; the finer the texture, the larger the fragments. Pebbles are found in the diamicton where they also occur in underlying sediment. Calcareous pebbles are rare and, where preserved, are chalky white, very soft, easily cut with a knife, and still slightly calcareous.

Thin sections and carefully shaved oriented samples of the diamicton were examined. They reveal organic staining, abundant disseminated organic detritus, alteration rinds around non-quartz sand grains and pebbles, clay-skins around pebbles, abundant fungal sclerotia, uneven texture (example: irregular blebs of fine sand contained in a matrix of coarse, clayey sand), and mottles of reddish iron oxide.

Discussion

The origin of the diamicton has been uncertain. Bell (1877, p. 4c), McLearn (1927, p. 33c), and Hughes (in Terasmae, 1958, p. 31) described it but did not attempt to explain its origin although Hughes suggested that its 'till-like' texture may have been partly the result of frost action (op. cit., p. 32). McDonald (1969, p. 86) reported a calcareous, lenticular, shell-bearing diamicton below lacustrine beds and above stream gravel on the Hayes River and believed the diamicton to be a subaqueous slump deposit. It is unlikely that the widespread noncalcareous diamicton underlying the forest bed in the Moose River basin had a similar origin. Terasmae and Hughes (1960a) drew attention to this unit when they discovered it contained a pollen assemblage similar to modern assemblages.

The diamicton is here interpreted as a buried soil because 1) a forest bed in growth position rests on it, 2) it is leached of carbonate (sediment immediately above the forest bed is not leached, ruling out significant leaching after the Missinaibi interval), 3) it contains abundant non-arboreal pollen and a similar pollen assemblage at 6 different points within the Moose River basin,[1] and 4) it represents alteration of deposits of diverse origins and ages. In addition, clay skins, organic staining and alteration rinds around pebbles all suggest weathering. The fungal sclerotia may be from soil fungi that assumed the sclerotial (resting) stage when the soil was flooded.

Frost action and biological activity probably contributed to soil mixing by blending pollen into the soil, resulting in a fairly uniform pollen assemblage and, at the same time, incorporating wood and plant fragments. The interpenetration of lower lying sediments at the base of the diamicton

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[1] Most pollen grains are resistant to weathering, especially in non-alkaline, unaerated environments. Under such conditions, pollen can be concentrated, provided that accumulation of other sediment is comparatively insignificant. The diamicton contains abundant pollen of herbaceous plants (grasses, ferns, chenopods, etc.) indicating a probable soil environment (see p. 25).

Figure 9.

Lacustrine member, Missinaibi Formation overlain by Adam Till, Adam Creek. Lacustrine beds are silty and calcareous with disseminated organic debris. (Station AC-69-85). GSC photo 154890.

Figure 10.

Clump of Drepanocladus sp. moss on bedding plane of lacustrine member, Missinaibi Formation. Abitibi River (Station AR-70-73). GSC photo 201915-C.

may have been caused by frost action, glacial loading, or both. Frost action to a depth of a metre or so might be expected in this region even during a nonglacial interval as 'warm' as today.

The buried soil probably formed under moist, cool conditions. This is indicated by the abundant pollen of hydrophytic plants (mosses, sedges, and ferns) and pollen of boreal forest species such as spruce and pine (Fig. 10). There may have been some eluviation of organic material and clay producing the generally dark, clayey nature of the diamicton. The greenish colour implies reduction or gleying as would occur under cool, humid, poorly drained conditions. The buried soil is considered to be a humic gleysolic soil (Can. Dept. Agric., 1970, p. 138-140) and similar to the modern soils of the region which are gleysolic to mesisolic except on well drained, sandy sites where they are podzolic.

In summary, a soil similar to the modern soil in this area is inferred to have developed during the Missinaibi interval. The soil probably represents a major portion of the nonglacial interval, especially at higher elevations.

Lacustrine member

Description

The lacustrine member is the thickest and most prominent member of the Missinaibi Formation, its cliff-forming character being very distinctive (Fig. 9). Thicknesses of more than 30 m have been observed in the Moose River basin. The lower 30 to 40 cm generally consist of dark brown, compact, platy, very carbonaceous, almost peaty laminae which grade upward into rhythmites of brown organic silt and dark green clay, then into rhythmites of grey, noncarbonaceous, calcareous silt and greenish grey clay. This gradation from very organic slightly calcareous beds at the base to noncarbonaceous, strongly calcareous beds at the top occurs in nearly every exposure of the formation and is a useful aid in correlating sections. The upper metre or so is commonly a massive green clay with lenses of calcareous silt and a few rafted pebbles. Tiny calcareous ripple-laminated silt lenses occur in the lower brown 'peaty' silt; these are interpreted as impoverished ripples (Coleman and Gagliano, 1965, p. 134).

The individual clay-silt couplets are <1 cm to 20 cm thick and average 1.5 cm. They appear to be thickest where the total unit is thickest; for example, on the east bank of the Missinaibi River, just below Long Rapids, silty and sandy couplets 3 to 15 cm thick are exposed from river level to a height of 20 m. The west wall of the valley here is bedrock which suggests local high relief on the sublacustrine surface; the thick lacustrine section probably lies in a buried valley. Confinement of sediment in the gorge of an ancestral Missinaibi River would account for the local large volume of sediment. Thick lacustrine beds also were observed along the upper Opasatika River near a possible buried valley and along the Pivabiska, Soweska, upper Abitibi, and Little Abitibi rivers. The thickness of lacustrine beds is irregular along Pivabiska River, relief of 10-20 m over a distance of only 50 m on the sublacustrine till surface being observed.

The massive green clay at the top of the lacustrine sequence is interpreted as a shearing phenomenon due to glacial overriding. Intensive shearing along the bedding planes of silt and clay couplets resulted in a massive

green clay with 'augens' of grey silt 0.1 to 3 m thick and up to 3 m long. Close examination reveals intricate folding and faulting within the augens and clay. Evidence of shearing was observed throughout the lacustrine sequence. At station MS-69-18, wood and moss from the forest bed are sheared upward into the lacustrine beds.

Discussion

The lacustrine member occurs throughout the study area. It was observed in the Harricanaw basin in Quebec, and from descriptions by others (J.M. Bell, 1904, p. 161; Prest, 1970, p. 688-689; and McDonald, 1969, p. 83) it probably outcrops along the Nettogami, Albany, Kapiskau, and Attawapiskat rivers, and possibly along Severn and Hayes rivers in Ontario. Equivalents of these beds in the Moose River basin were described by early geologists as "interglacial lignite". J.M. Bell (1904, p. 143) referred to them, probably together with the forest-peat member, as "coal-bearing mesures" including "blue clays, arenaceous shales, lignitic clay shales, and lignite". He speculated that the beds were deposited "in numerous, shallow, unconnected freshwater basins". V. Auer, who examined McLearn's (1927, p. 47c) peat samples, concluded that most of the "peat" beds were allochthonous, deposited in a fluviatile environment. Terasmae and Hughes (1960a, p. 8) similarly concluded that the beds were "deposited along shallow, wide river channels where frequent flooding occurred, perhaps annually". McLearn's (1927, p. 31C) interpretation was probably nearest to that offered here for he suggested that lake clay capping Missinaibi Formation along the Soweska River "was laid down in a lake formed by the ponding of northward flowing waters by an advancing glacier". I interpret all sediment overlying the diamicton and forest bed as proglacial lake sediment, not just the upper, nonorganic rhythmites. As the nonglacial interval neared an end, a glacier advancing southwestward, up the regional slope (as indicated by ice-flow indicators for the overlying till), blocked northward drainage and ponded a lake. The lake flooded a land surface that was covered with vegetation and leached of carbonates; therefore, the first beds deposited at any one point were low in carbonate and charged with organic matter. The approaching glacier became increasingly important as a source of calcareous, noncarbonaceous sediment. Meanwhile the shoreline source of organic matter shifted farther away (south). A coarse 'beach' facies was not formed at the base of the lacustrine unit, probably because the forest dissipated wave energy and protected the underlying mineral sediment. Also, in view of the low slope of the lowlands any one site may not have been in the surf zone for very long. A few rounded pieces of wood were found above the forest bed and may reflect wave action in the transgressing lake.

Lacustrine sediments of Missinaibi Formation equivalents elsewhere in the Hudson Bay Lowland probably were deposited in a similar or the same proglacial lake. The distribution and uniform character of lake sediments in the Moose River basin is best explained if they were deposited in one lake rather than a series of small separate lakes. Conceivably, the whole of Hudson and James Bay basins could have contained a single large lake if glaciers blocked off the outlet from Hudson Bay.

The duration of the inferred lake is unknown but can be estimated if the silt-clay couplets are assumed to be varves. An annual origin is suggested by small (10 cm diameter), bioherm-like masses of Drepanocladus moss, observed in growth position within the silt part of some couplets (Fig. 10).

Section AR-70-73 across from Big Cedar Creek, exposes approximately 10 m of varves averaging 1.5 cm in thickness. The bottom of the unit lies below river level and the top is truncated by postglacial alluvium. If the rhythmites are truly annual, this section represents at least 600 to 700 years. Another

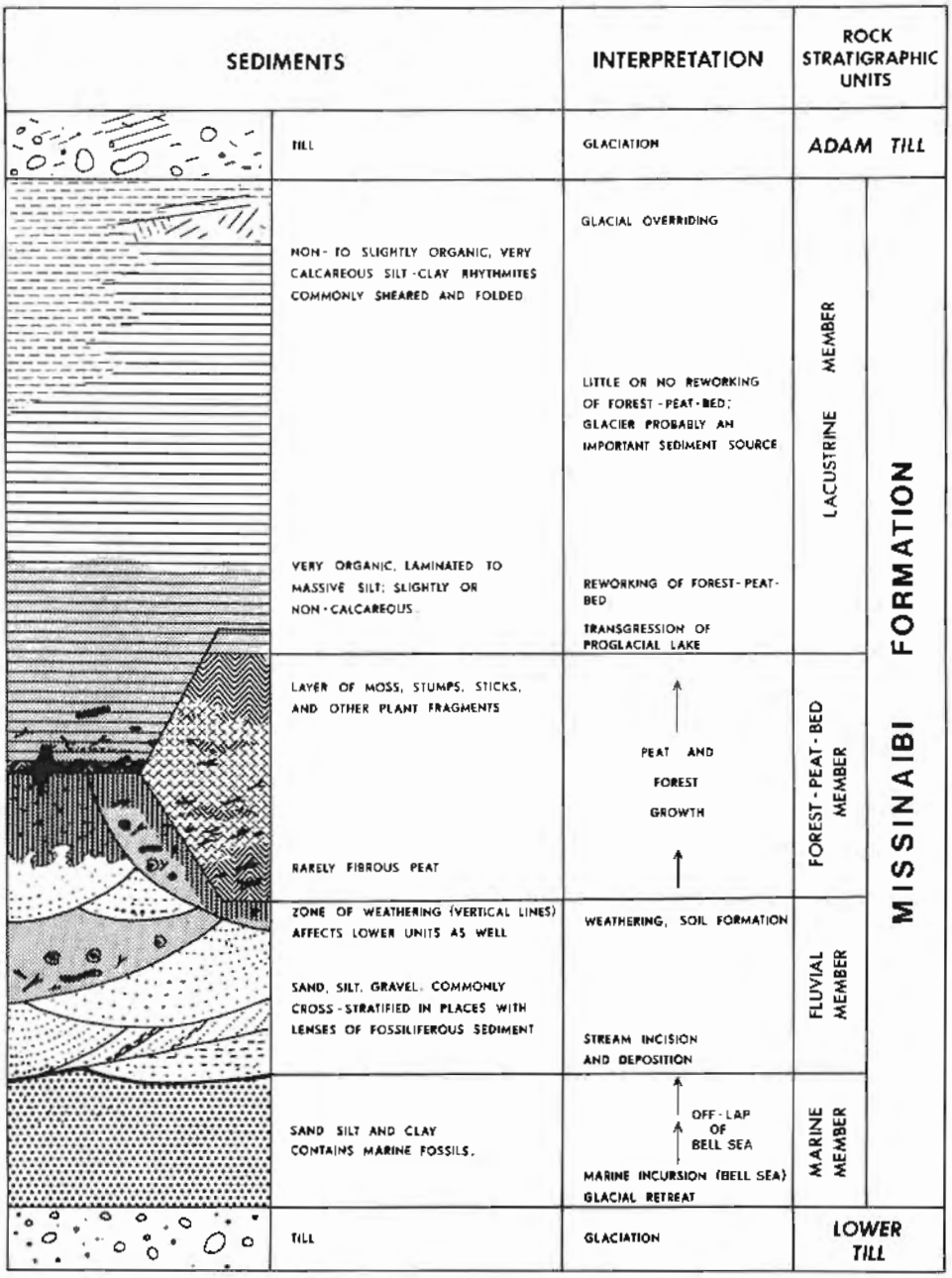


Figure 11. Hypothetical composite section of Missinaibi Formation.

section on Pivabiska River exposes 25 m of silty rhythmites that are 10 cm thick at the bottom of the exposure and decrease to 2 cm at the top; perhaps 500 years are represented by this section.

Summary of environments and events

Figure 11 is a composite section of the Missinaibi Formation illustrating the sequence of sediments and corresponding environments. The events represented by this section are: 1) incursion of the Bell Sea to an altitude at least 100 m above present sea level, 2) recession of the Bell Sea to a level probably near present sea level. Meanwhile rivers flowed north to the sea and deepened their valleys as the land emerged. As streams incised, they cut alluvial terraces. Soil developed on fluvial deposits, till, and emerged marine sediments, and supported a hydrophytic vegetation. 3) Towards the end of the nonglacial interval a large lake, dammed in front of a slowly advancing ice sheet, flooded the land. Sediment deposited in the lake mantled the pre-existing topography and ultimately was overridden by the advancing glacier.

Age and rank of Missinaibi Formation

Determination of age and rank of the Missinaibi Formation is an important objective of this study. Unfortunately, as all C^{14} determinations on wood and peat from the formation so far have yielded infinite dates, the age remains unknown. McDonald (1971, Table I) gives a list of dates; GSC-1185, >54,000 C^{14} yrs., provides a lower limit to the age of the formation. In the absence of finite dates, assessment of rank -- whether interstadial or interglacial -- on paleoecological grounds, is probably the only available means of suggesting possible ages. A cooler climate than the present is often considered to indicate interstadial conditions; also, the continental ice sheet is assumed to have been much greater in extent than at present. Deep weathering profiles and especially climate as warm as or warmer than the present are considered evidence of an interglaciation.

As noted above, R. Bell, J.M. Bell and McLearn referred to these nonglacial beds as interglacial. Terasmae and Hughes (1960a, p. 11) believed the beds to be interstadial because 1) the pollen record did not indicate to them a climate warmer than present as suggested for the interglacial Don Formation of Toronto, and 2) the time interval was inferred to be short (Terasmae, 1958, p. 33). However, McDonald (1969, p. 89) considered an open Hudson Bay, among other evidence, as indicative of conditions sufficiently nonglacial to warrant giving the Missinaibi Formation interglacial rank.

Various types of paleoecologic data were sought including pollen analyses and identification of plants and seeds. Terasmae and Hughes (1960a) studied two pollen profiles through the formation of which profile 24M is of special interest because it includes the buried soil. Before doing additional pollen analyses it was considered important to understand the sedimentary environments of the various units in order that important units could be selectively sampled, and Terasmae's interpretations could be reviewed in a regional lithostratigraphic framework.

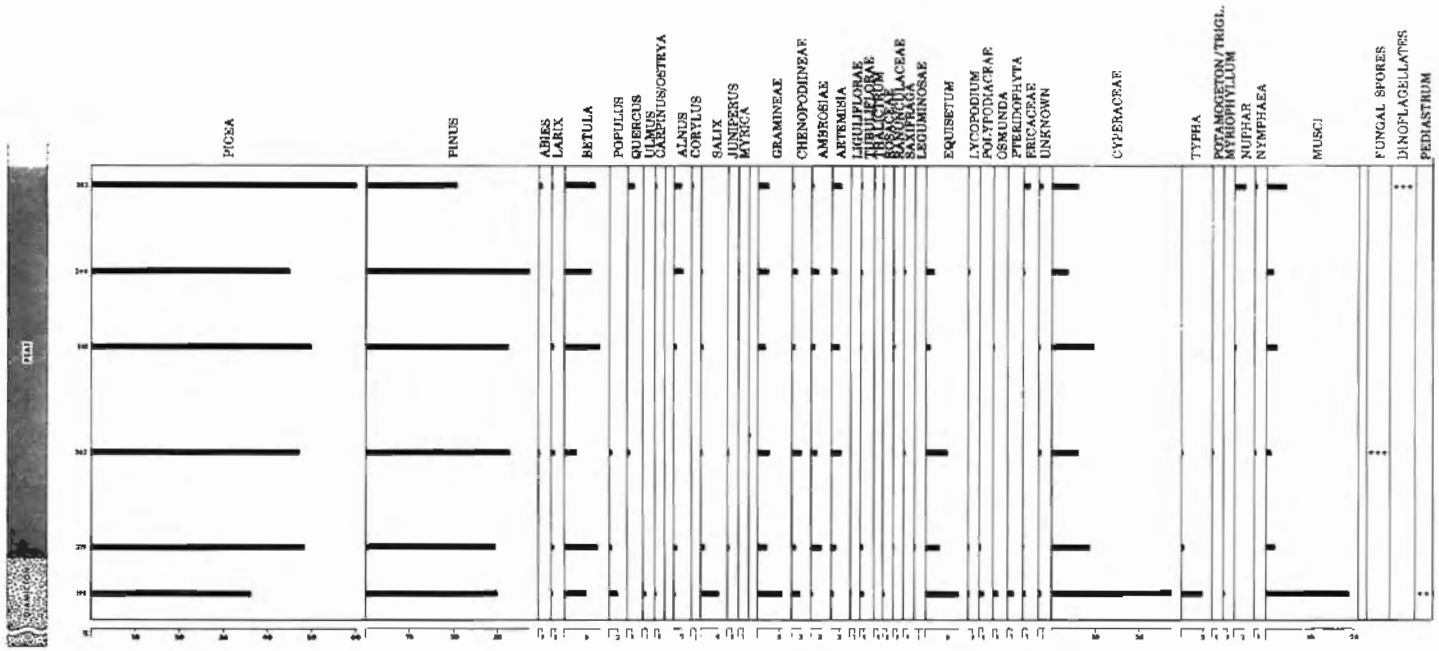
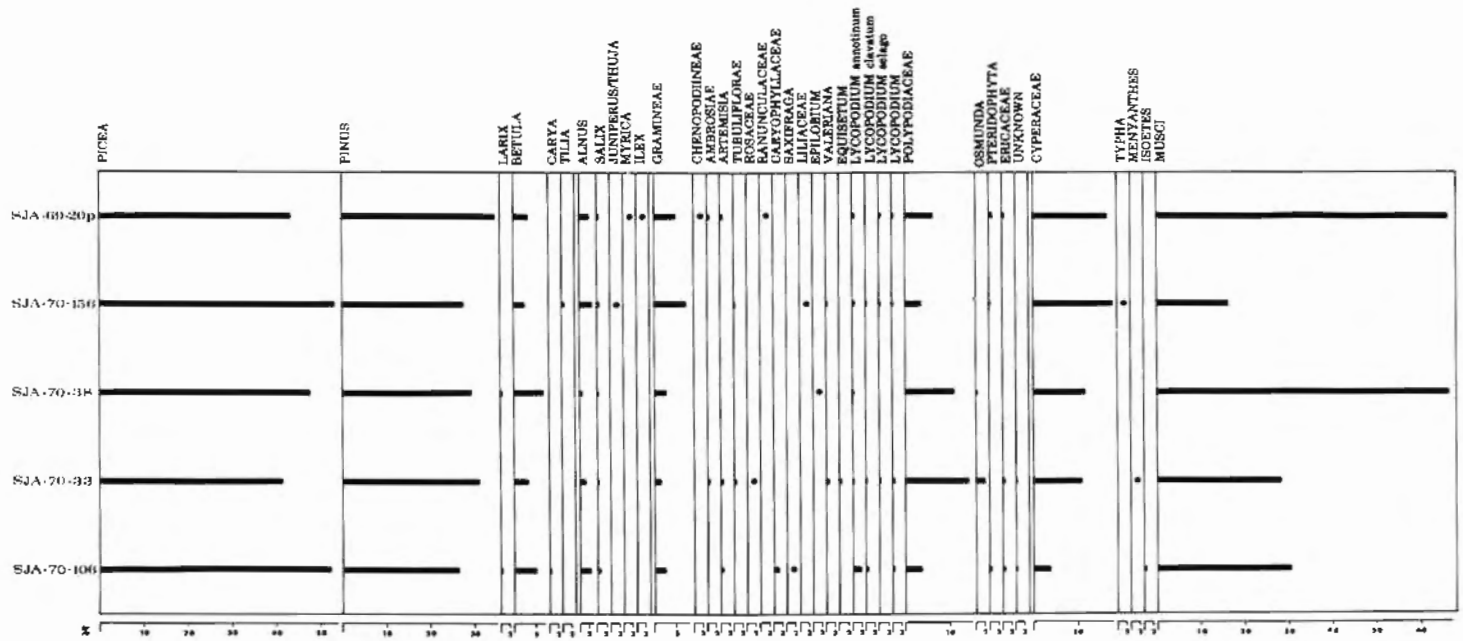


Figure 12. Pollen spectra of Missinaibi Formation, Moose River Crossing Section. Sediment column at left; numbers at each level indicate height (in cm) above river level.



SJA-69-20p is from Station PR-69-24. (See Key, Appendix A)
SJA-70-156 " " " SR-69-60. (also shown in Figure 5)
SJA-70-38 " " " MS-70-34.
SJA-70-33 " " " OR-70-8.
SJA-70-106 " " " MO-69-107. (Moose River Crossing Section, see Appendix B)

Figure 13. Pollen spectra from buried soil, Missinaibi Formation.

A significant conclusion of the present study is that the upper peaty beds (lacustrine member) of the Missinaibi Formation are glaciolacustrine and deposited at the very end of the nonglacial interval, not during the major part as inferred by Terasmae (1958). Therefore, it is not surprising that a climate similar to or cooler than present should be reflected by pollen contained in these lake sediments (see 24M in Terasmae and Hughes, 1960a). The pollen sampled is probably a mixture of pollen from vegetation that grew south of the transgressing lake, and older pollen, reworked during transgression. Hence, paleoclimatic interpretation of the resulting assemblages would bear little relationship to the actual paleoclimate. If a climate as warm as or warmer than today's prevailed at any time during the Missinaibi interval, it should be represented at a stratigraphic level below the lacustrine member.

Terasmae (1958, p. 32) found a concentration of hardwood pollen and Abies below the lacustrine bed in "till-like material", here interpreted as a buried soil. Terasmae pointed out that "the low values of birch and alder, and the conspicuous presence of pollen of temperate deciduous trees (Quercus, Ulmus, Tilia, Carpinus) in the bottom part of this layer may be interpreted as an indication of climatic conditions very nearly duplicating those of the present time". He could offer "No explanation ... for the abundance of fern spores and NAP (predominantly Chenopodiaceae)" at the same level. In a later paper, Terasmae and Hughes (1960a, p. 7) attributed this hardwood assemblage to long-distance transport by an ancient Missinaibi River. If so, the pollen had to be carried to the present level at 24M early in the nonglacial interval, before the ancestral Missinaibi River abandoned the alluvium containing the hardwood pollen and cut more than 40 m below this elevation. Alternatively, the pollen was transported by a tributary stream that flowed into the ancestral Missinaibi River. In this case, the hardwood pollen may have been derived from within the Moose River basin. A simple and attractive explanation is that the pollen was wind-transported from deciduous-coniferous (mixed) forests just south of the lowlands and settled on the soil developed in abandoned alluvium, was worked into the soil, and preserved.

The pollen assemblage of the buried soil is likely a mixture of pollen contained in the original fluvial sediment, abundant pollen from local herbaceous plants (grasses, weeds, and ferns on the soil), and airborne pollen from local and distant vegetation. In this way, the total assemblage conceivably represents a mixture of several otherwise distinctive pollen assemblages, for example, a deciduous assemblage mixed with a younger and/or older boreal assemblage. The resulting pollen assemblage would not necessarily reflect the actual pollen production and preservation during the interval represented by the buried soil. The possibility of preferential destruction of certain pollen types and indeed of whole assemblages under certain conditions of soil chemistry, renders paleoclimatic interpretation of pollen from the buried soil very tenuous.

A search was made in the Missinaibi Formation for true, ombrogenous peat which generally contains representative spectra of airborne arboreal pollen (Oldfield, 1970). Unfortunately, significant thicknesses of such peat were not found, although a section at Moose River Crossing includes very fibrous peat without mineral matter interbedded with detrital peat, and woody peat resting on weathered till. This section is illustrated and described in

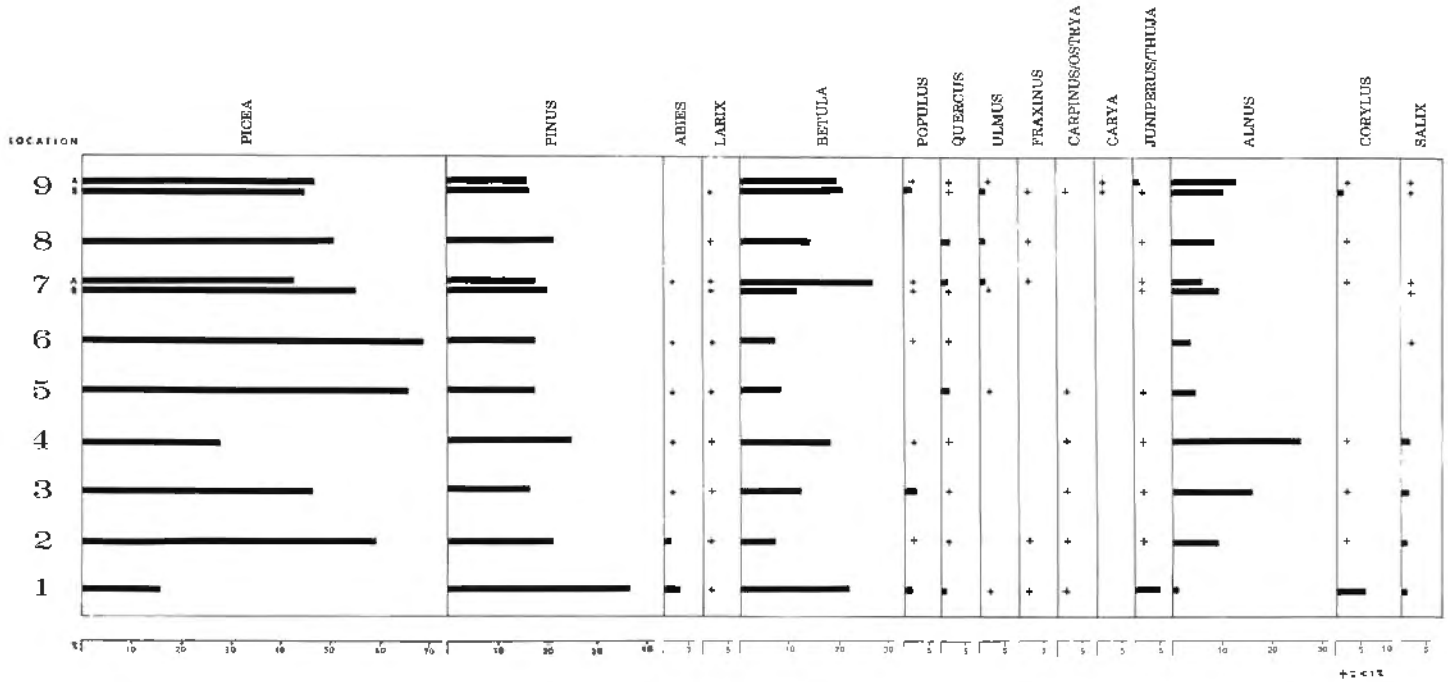
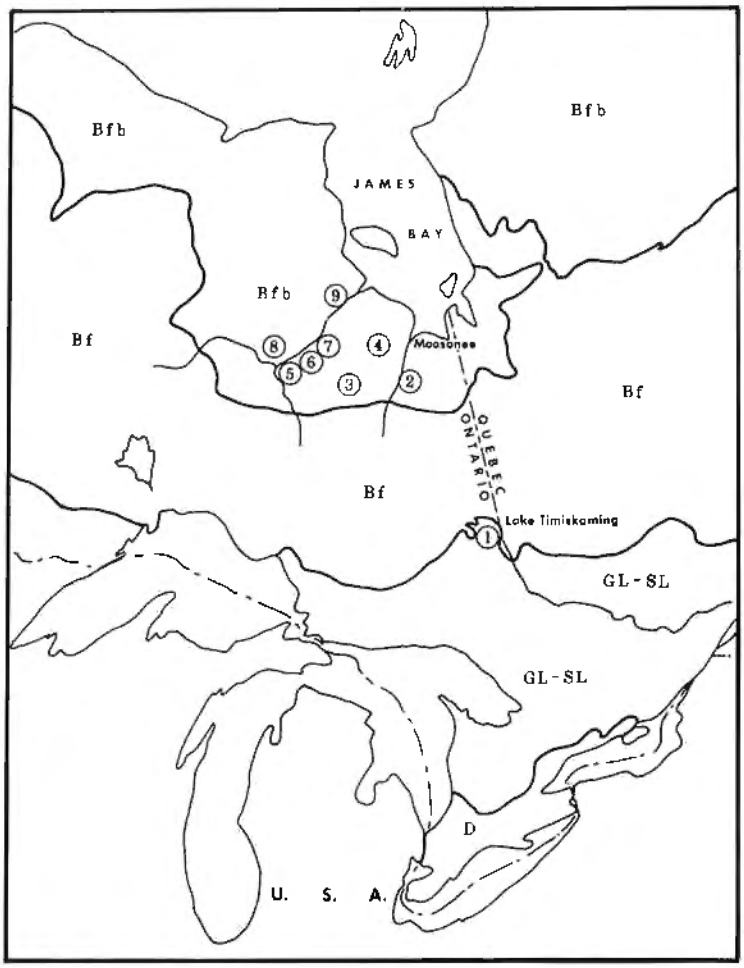


Figure 14. Modern pollen spectra, northern Ontario.



③ - Sample location (see site descriptions, Appendix D).
Bfb - BOREAL FOREST: forest and barren; white and black spruce, larch.
Bf - predominantly forest; white and black spruce, balsam fir, jack pine, white birch, and trembling aspen.
GL-SL - GREAT LAKES - ST LAWRENCE FLORA: red pine, eastern white pine, eastern hemlock, yellow birch, maple, and oak.
D - DECIDUOUS FLORA: beech, maple, black walnut, hickory, oak, basswood.

Figure 15. Modern pollen sample locations and forest regions (after Hosie, 1969; Native Trees of Canada).

Appendix B. It records an unknown span of time during the Missinaibi interval. Pollen from six levels in the section (Fig. 12) were analyzed by Dr. S. Lichti-Federovich who states:

"These spectra suggest a forested landscape dominated by closed-crown boreal forest almost entirely composed of spruce with only minor elements of pine, birch and larch. The very low frequencies of all other pollen types except sedge, can be accounted for in terms of either long distance dispersal or (minor) local plant communities (Lichti-Federovich, G.S.C. Palynological Report No. 1971-5)".

Seeds of birch (Betula sp., probably a shrub species, J. McAndrews, pers. comm., 1971), one whole cone of Picea mariana (black spruce) and two cone fragments of Picea glauca (white spruce) (R.J. Mott, Wood Identification Report No. 72-66, unpubl. internal. rept.), were found in fluvial sediments approximately 200 m upstream from the peat section. Although Populus pollen is minor in the peat section, Populus sp. wood was found in the peat (R.J. Mott, Wood Identification Report No. 71-5, unpubl. internal. rept.). The buried soil is exposed upstream from the outcrop of fluvial sediment, capped by the forest layer of flattened logs of spruce and/or larch, Salix sp. and Populus sp. The pollen assemblage of the soil (diamicton) (SJA-70-106, Fig. 13) is similar to that of the diamicton or weathered till at the base of the peat just downstream (level 198 cm, Fig. 12) and similar to the assemblage in Terasmae and Hughes' "till-like deposit" (24M). Noteworthy in the buried soil is the variety and abundance of nonarboreal pollen and spores, especially ferns (Polypodiacea) and mosses (Musci). Four additional pollen spectra from buried soil samples from various localities in the region are shown in Figure 13; Dr. Lichti-Federovich states of them:

"The main feature of the assemblages is that they show no significant variation between samples. The preponderance of spruce (up to 50%) is the salient feature. On the basis of comparison with modern spectra, these pollen frequencies suggest a landscape dominated almost entirely by spruce. The relatively low pine frequencies (20-30%) indicate that pine made up less than 5% of the forest. Likewise, birch either in shrub or tree form, was a very minor component. The very low frequencies of pollen of other tree species can only be explained in terms of long distance dispersal. The grass and sedge pollen probably reflect the local vegetation. Similarly fern and moss spores probably had a local origin. These assemblages are reasonably similar to modern assemblages from the northern boreal forest. Notable differences are that the modern assemblages show higher frequencies of alder and birch. The climate was likely similar to that of the modern northern boreal forest (S. Lichti-Federovich, G.S.C. Palynological Report No. 1971-4)".

For comparison with Missinaibi spectra, several modern pollen spectra are shown in Figure 14. Their locations with respect to the Forest Regions of Canada (Hosie, 1969) are shown in Figure 15, and their site descriptions are given in Appendix D. Only percentages of tree and shrub pollen are shown. Percentages of NAP and spores are not given because their relative abundances are so variable. Variation is dependent on sample site which included open bogs, lakes, rotten stumps, and moss polsters. The relative paucity of Betula and Alnus in buried soil samples may be due partly to poor preservation.

The usefulness of pollen analysis in comparing past and present climates in the boreal region is questionable. So few tree species occur, especially climatically sensitive species, that pollen analysis may not be sufficiently definitive to detect differences in climates. The boreal forest presently exists within a very broad range of temperatures; therefore, if mean temperatures during the Missinaibi interval were a few degrees higher or lower than present, the boreal flora may not have differed appreciably from that of the present--at least not enough to be reflected in pollen spectra.

Ecotones are generally considered climatically sensitive (Bryson and Wendland, 1967) and indication of ecotone-shift should be sought. The 'ecotone' between the forest and barren (Bfb) and predominantly forest (Bf) sections (Fig. 10) is probably not now climatically controlled. The limits of flat-lying Paleozoic rocks and postglacial marine clays coincide with the ecotone suggesting that it is strongly edaphically controlled. Poor drainage of the marine clays, cool temperature and possible maritime influence of Hudson Bay have led to the development of bog land with few tree types. Search for evidence of past shifts of this ecotone, therefore, might prove unproductive for paleoclimatic studies.

In summary, the pollen evidence suggests that a boreal forest existed in the Moose River basin during the Missinaibi interval; the climate was probably similar to that of today. The 'requirement' of higher temperature than present for an interglaciation may not be justified in this region where the maritime influence of an ancestral Hudson Bay may locally have overridden any effect of higher global temperatures. The discovery of Najas flexilis in the Missinaibi Formation at Moose River Crossing indicates, however, that climate might have been warmer. Najas flexilis is presently found within the boreal forest but not in the northern boreal forest of James Bay lowland (Baldwin, 1959; Hultén, 1958). Ritchie (1964, p. 193) reports Najas flexilis only in the southeastern part of Manitoba. Seeds, pollen, diatoms, a fish, and wood from the Moose River site are presently being studied to gain better insight into the paleoclimate of the Missinaibi interval. Because the available evidence suggests that a boreal forest existed in the region, the climate is inferred to have been close to that of today and therefore of interglacial character.

McDonald (1969, p. 89) listed several reasons for considering the Missinaibi Formation as interglacial. These include: 1) the formation rests between till sheets; 2) it includes marine strata, subaerial deposits at low altitudes, and deposits laid down at low altitudes by north-flowing streams, all features that require that Hudson Bay and Hudson Strait be glacier-free (i.e., the ice caps must have been sufficiently restricted to warrant calling the climatic environment interglacial); and 3) Terasmae and Hughes' (1960a, p. 11) pollen studies indicated a vegetation "similar to that now present in the region". In a later paper, McDonald (1971, p. 340) correlated the Missinaibi Formation with St. Pierre beds thereby implying an interstadial rank (assuming St. Pierre is interstadial), although he again pointed out the possibility that the Missinaibi Formation is interglacial.

Accepting that the present is an interglacial, the Missinaibi interval is also believed to be interglacial because it displays several features similar to the present. These include: 1) pollen assemblages indicating a similar flora and, therefore, probably a similar climate, 2) incursion and recession of the Bell Sea in a manner like the postglacial Tyrrell Sea; furthermore, as noted above, marine incursion requires an open Hudson Bay and therefore

significant diminution of the Laurentide Ice Sheet, 3) incision of interglacial streams to elevations equal to or lower than modern stream levels, and 4) weathering comparable to postglacial weathering.

POST-MISSINAIBI DEPOSITS

Post-Missinaibi deposits, encompassing all units above the lacustrine member of the Missinaibi Formation, include from bottom to top, 1) Adam Till, 2) Friday Creek sediments, 3) Kipling Till and 4) late- and postglacial sediments.

Adam Till

The lower till of the post-Missinaibi sequence is here named Adam Till after Adam Creek where the unit is well exposed. Excellent reference sections can be found along Opasatika and Abitibi rivers. Along Adam Creek the till is very compact, silty (M_z = 5.2-7.0Φ, = 6.0Φ, n = 9), moderately calcareous (% $[CO_3]$ = 12-22%, $\bar{x}$ = 16.6%, n = 9), grey to greyish green, and up to 15 m thick. The lower contact is exposed on the west side of Adam Creek about 3 km above the mouth. On Opasatika River and Abitibi River the till is clayey, greenish grey, rests on greenish rhythmites of the Missinaibi Formation, and contrasts sharply with the overlying brown, silty Kipling Till. Like other tills of the regions, Adam Till contains few large boulders.

The character of Adam Till varies considerably within the study area. No single parameter could be used alone to distinguish Adam Till. Stratigraphic position immediately above Missinaibi Formation is the most useful criterion, but often can only be established after careful observation of several adjacent sections. The fine texture, greenish colour, and low carbonate content of the lacustrine beds apparently have been transmitted to Adam Till. Inclusions of Missinaibi Formation within the till are common; in many exposures, Adam Till appears as massive silt and clay with very little coarser sediment. In exceptionally clean exposures along Adam Creek, marine shells, including whole valves of Hiatella arctica were found in the till. Probably they were derived from Bell Sea deposits. They occur in Adam Till on Adam Creek more than 50 m above the limit of postglacial marine invasion, a situation which emphasizes the need for caution in this area when collecting shells intended for radiocarbon dating and when interpreting the dates.

Ice-flow direction indicators for Adam Till are shown in Figure 16 as well as on the fence diagrams. The data, although few, suggest that ice which deposited Adam Till flowed from the northeast, perhaps from Labrador.

Friday Creek nonglacial sediments

The break between Adam and Kipling tills is in many places accentuated by a distinct boulder pavement (Fig. 17). Commonly deposits of sand and silt more than 20 m thick also occur at this stratigraphic level. This stratified unit is here referred to informally as the Friday Creek sediments. Representative exposures can be found along Friday Creek, Abitibi River,

Adam Creek, Opasatika River, Kwataboahegan River, and along the lower 2 km of Soweska River. The nonglacial unit along Abitibi and Opasatika rivers (e.g., Stations AR-70-71, OR-70-10, 11, 28) consists of loose, medium- to fine-grained, cross-stratified sand. Along Friday Creek (Stations FC-70-20 and 69-116) and Soweska River (SR-69-70, 71) the unit includes rhythmites, 50 cm thick at the base of the section, which gradually thin to 3 cm at the top where they are severely contorted. Climbing ripple laminations (south-flowing current) are present in lower, thicker rhythmites. Each rhythmite consists of very light brown fine sand at the base grading up into pink silt overlain by dark grey clay. This coloration is believed due to differential oxidation controlled by variation in mineralogy and grain size at different levels in the

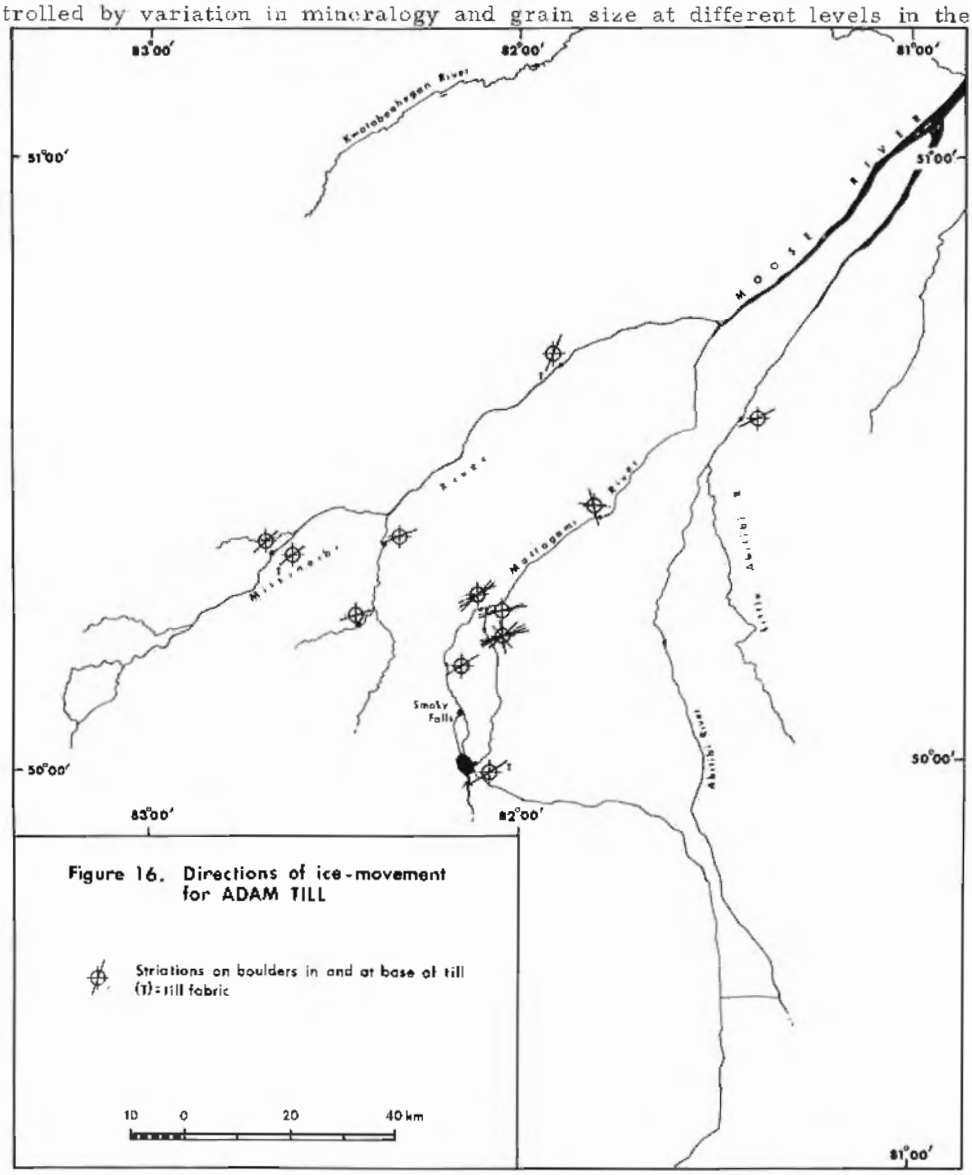


Figure 16. Directions of ice-movement for ADAM TILL

Striations on boulders in and at base of till
(T) = till fabric

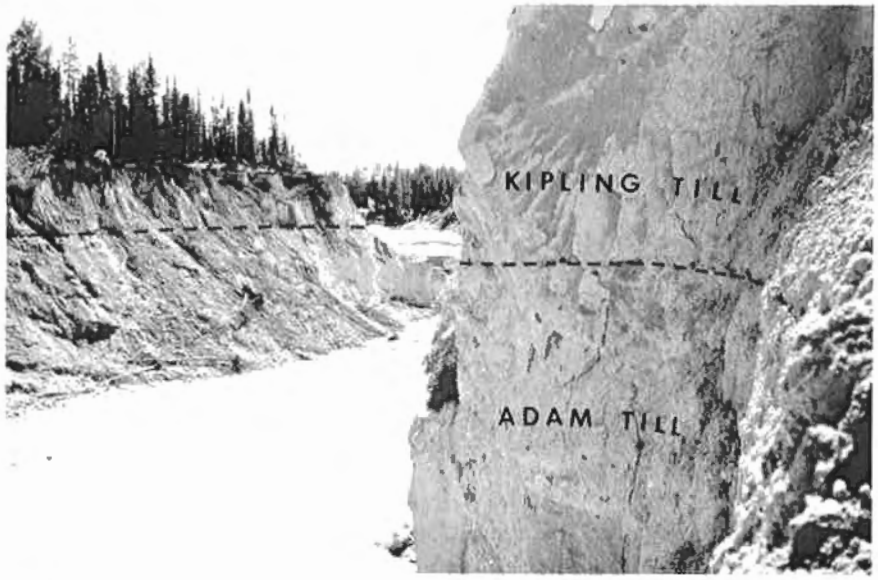


Figure 17. Contact between Adam and Kipling tills, type locality Adam Creek diversion channel. GSC photo 201915-A.

rhythmites. A similar sequence occurs along Sowoska River where approximately 25 rhythmites were counted.

In a few sections, the upper 5 or 6 cm of the Friday Creek sediments are cemented into a very hard crust by $CaCO_3$, but generally the unit lacks compaction. Although the sediments are calcareous throughout, the clay layers are only slightly so.

On Kwataboahegan River, two tills overlie the Missinaibi Formation and are separated by light brown to faint yellow, cross-laminated sand. This two-till sequence was noted also by McDonald (1969, p. 94) and is correlated tentatively with the Adam and Kipling Tills in the southern part of the area.

Sedimentary structures consistently indicate a former current to the south against the regional gradient. An ice sheet is inferred to have blocked drainage to the north, the nonglacial unit being deposited by glacial meltwater. No datable organic material was found in the Friday Creek sediments so the age of the nonglacial interval is unknown.

Kipling Till

The upper till of the region was described and sampled as far south as Smooth Rock Falls. The upper till south of the limit of Precambrian outcrop has been named Cochrane Till (Hughes, 1965; Boissonneau, 1966). North of the limit of Precambrian outcrop, the upper till is here named Kipling Till after the type locality on Adam Creek in Kipling Township (Fig. 17). There, Adam Creek flows through a gorge more than 30 m deep with vertical walls composed largely of till (see Appendix B). At the type locality Kipling Till is 2 to 5 m thick, brownish where oxidized, greyish brown where fresh, and rests with sharp contact on either sand and gravel or a boulder pavement. It is overlain by late-glacial glaciolacustrine pebbly silt and clay similar to

Kipling Till; the contact between the two units is often difficult to delineate. Four till samples from the Adam Creek section have mean grain sizes of 6.1, 5.9, 6.1, and 6.1$^{\Phi}$ and total carbonate values of 50, 33, 32, and 32 per cent respectively.

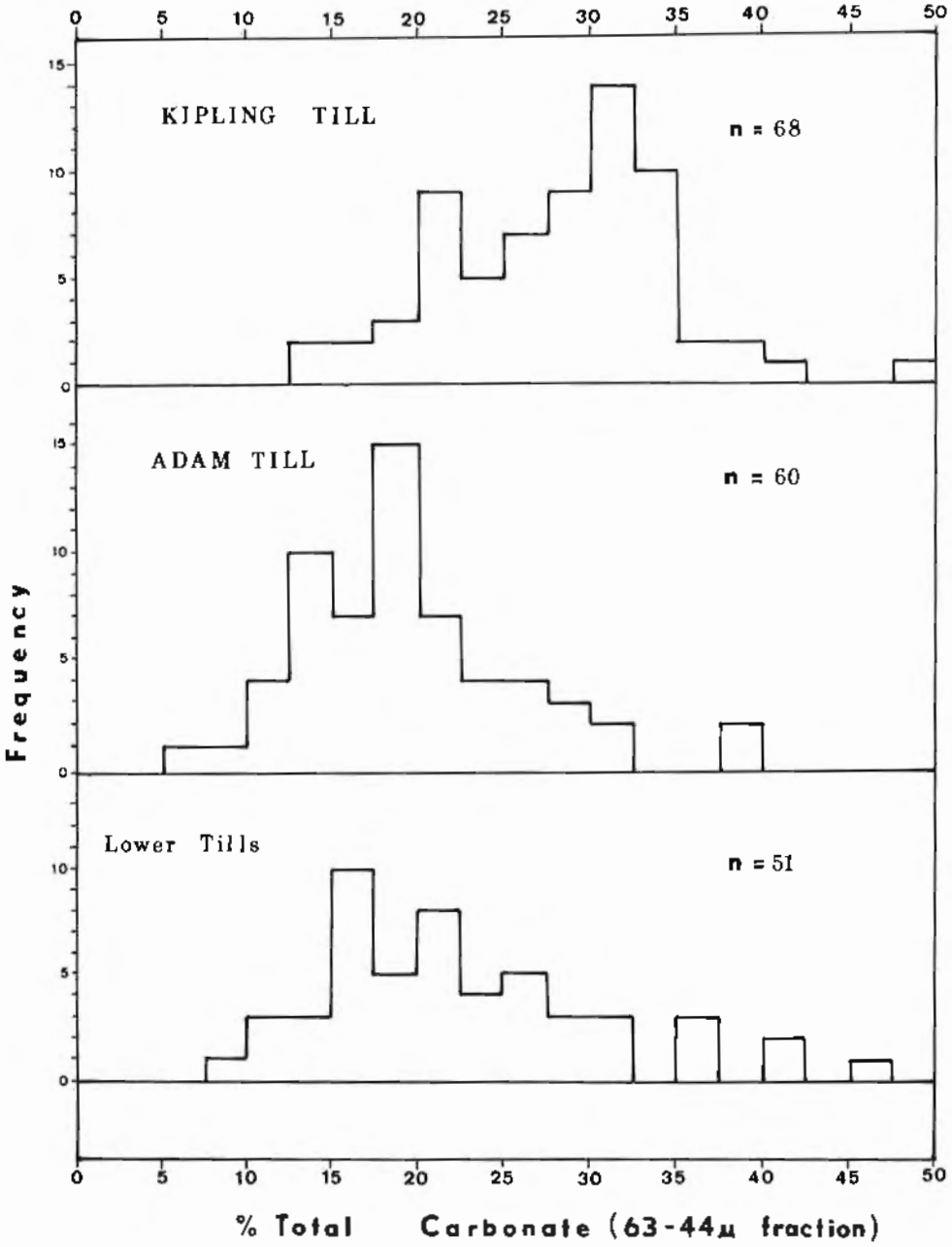


Figure 18. Per cent Total Carbonate of tills in Moose River basin.

Regionally, Kipling Till is recognized by a combination of parameters including low compaction, brownish colour, and stratigraphic position (it is the youngest or uppermost till in the region). Texture and carbonate content are not diagnostic, although Kipling Till generally is more calcareous than older tills, especially Adam Till (Fig. 18). Values of %[CO_3] and M_z are plotted on maps (Figs. 28 and 29, Appendix E). On lower Abitibi River (sample SJA-70-82, station AR-70-71) M_z = 4.6Φ and is very calcareous (% [CO_3] = 48). Proceeding southward, near Adam Creek, M_z increases (till becomes finer-grained) and %[CO_3] decreases. Samples SJA-70-124, 125, and 126 on the Pinard moraine (see below) are coarser (M_z = 4.7-5.8Φ) due to incorporation of underlying sand comprising the moraine; %[CO_3] is low, perhaps indicating the influence of the Canadian Shield as a source for the sand. Farther south, at Smooth Rock Falls, %[CO_3] values decrease to 14% and M_z increases to 8.8Φ. The fine grain size here probably is due to the incorporation into the till of Glacial Lake Barlow-Ojibway silt and clay which is apparently also only slightly calcareous.

In the region of Soweska and Missinaibi rivers the upper till is fine grained (M_z = 7.9, 7.1 Φ) and not very calcareous. These characteristics, plus the till's greenish colour, suggest that locally the lacustrine member of the Missinaibi Formation influenced the texture and lithology of both post-Missinaibi tills.

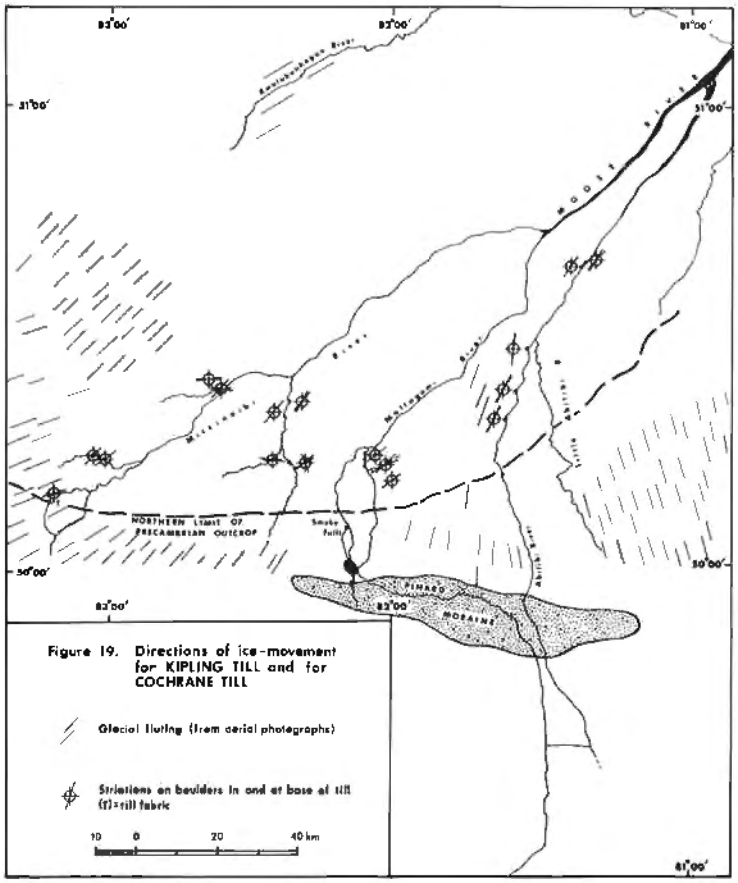


Figure 19. Directions of ice-movement for KIPLING TILL and for COCHRANE TILL

Direction of ice flow

Frequent exposure of a boulder pavement at the base of the Kipling Till provided many opportunities for determining local directions of ice-flow. These are shown on Figure 19 along with surface ice flow features on the Cochrane Till plain south of the study region. The inferred direction of flow as shown for the base of the Kipling Till appears similar to that of the Cochrane Till, compatible with their having been deposited during the same readvance, but correlation of Kipling Till with Cochrane Till is not possible on this basis alone.

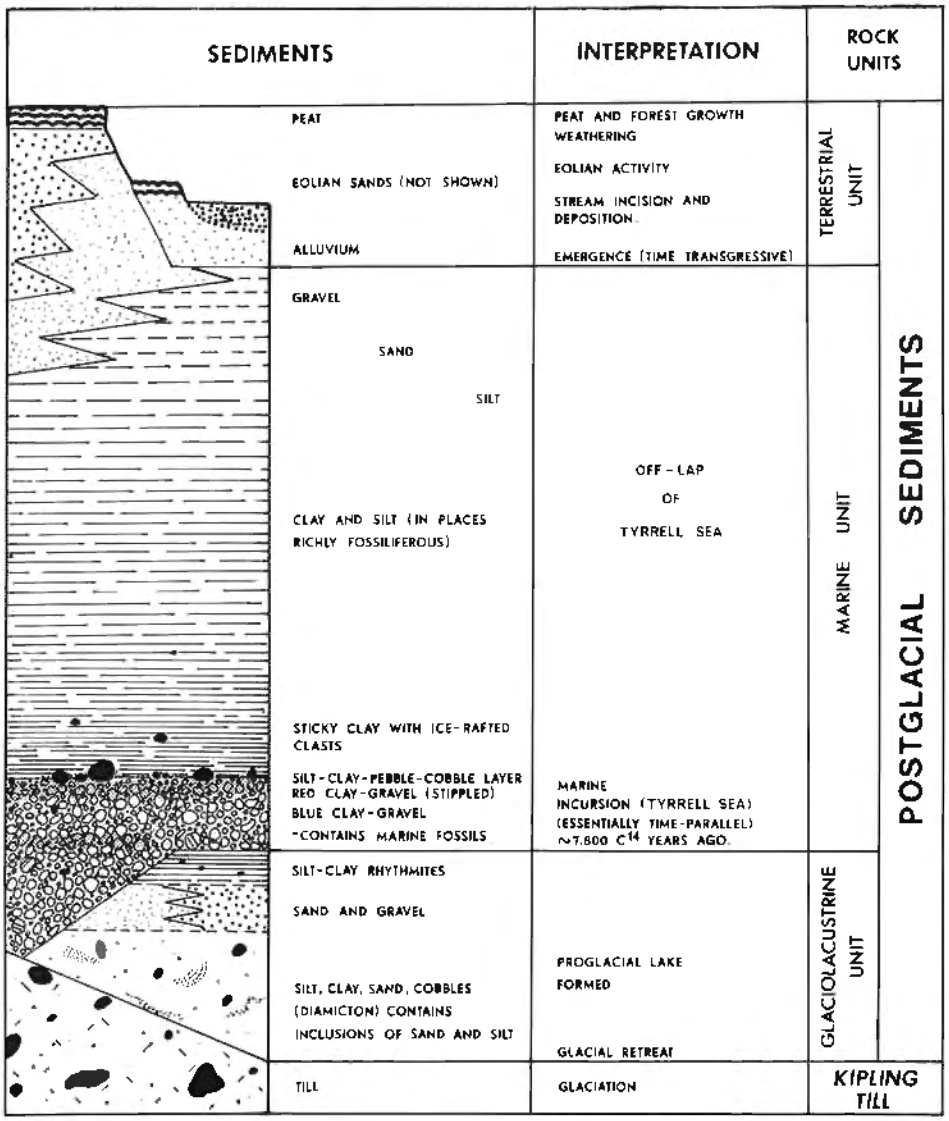


Figure 20. Hypothetical composite late- and postglacial section.

LATE-GLACIAL AND POSTGLACIAL STRATIGRAPHY

Late-glacial and postglacial deposits in the Moose River basin are divided into (from oldest to youngest): 1) a glaciolacustrine unit, 2) a marine unit, and 3) a terrestrial unit. Figure 20 is a generalized late- and postglacial section.

Description

1) Glaciolacustrine unit

The glaciolacustrine unit directly overlies Kipling Till and comprises from bottom to top a) silty diamicton, b) sand and gravel, and c) silt-clay rhythmites. Rarely are all three facies present in any one outcrop. The diamicton and rhythmite facies are the most widespread. As much as 6 m of the glaciolacustrine unit have been observed in the Moose River basin.

The glaciolacustrine diamicton is texturally similar to the Kipling Till but differs in having lenses and inclusions of waterlaid sand and silt. The contact between till and diamicton is frequently gradational. Evidence is lacking for an interval of subaerial weathering after deposition of the till. The diamicton ranges up to 2 m in thickness.

Sand and gravel commonly overlie the diamicton and grade upward into silt-and-clay rhythmites. One exposure (Station KR-70-55) on Kwataboahegan River consists of 5 m of sand and gravel deposited as large cross-strata indicating former currents toward the west and southwest.

Rhythmically bedded silt and clay rest conformably on diamicton, sand, gravel or lower stratigraphic units; however, the rhythmites generally have been reworked into an overlying clay-pebble gravel. Locally as many as 20 rhythmites have been preserved. Thicknesses of individual couplets decrease upward from 4 to 0.5 cm. The colour grades from brown in lower couplets to bluish grey in upper ones. The bluish grey colour is very distinctive and persists in the unoxidized parts of the overlying marine clay-pebble gravel.

2) Marine unit

Lee (1960) gave the name Tyrrell Sea to the late-glacial and postglacial sea that occupied the Hudson Bay basin. Deposits of this sea constitute the greatest volume of the late-glacial and postglacial sediments in the Moose River basin. They lie below approximately 145 m a.s.l. and gradually thicken toward the present coast. More than 7 m of marine sediment occur in the vicinity of Pivabiska River and Missinaibi River. Lee (1968, p. 516) reported 60 m of marine sediment at Fort George, east of James Bay. Comparable thicknesses probably can be expected near Moosonee.

The marine sediments consist of three facies: a) clay-pebble gravel, b) clay and silt, and c) beach and shallow-water sand and gravel. The clay-pebble gravel is the oldest; the clay, silt, sand and gravel are lateral facies equivalents.

Fossils are present in all facies but are numerous in the silt and sand. Wagner (1969, p. 14-18) has presented lists of species from the Tyrrell Sea. Many of the fossils, including molluscs and driftwood collected in the present study, were used for radiocarbon dating.

Figure 21.

Clay-pebble gravel. Knife 23 cm long, inserted in top of reddish clay-pebble gravel. Light sand and some pebbles at horizon near knife-point. Note clast (arrow) with laminations. (1 km downriver from station SR-69-46.) GSC photo 201915.

A distinctive blue and red clay-pebble gravel 20 to 100 cm thick forms the basal part of the marine beds throughout the Moose River basin, serving as a marker bed at altitudes below marine limit (Fig. 21). Rounded clasts of rhythmically laminated clay and silt comprise 65 to 75 per cent of the gravel and are enclosed in a clayey matrix. Clasts, which attain diameters as large as 4 cm, are so disoriented that original laminations are no longer horizontal.

The clay-pebble gravel typically consists of a basal blue, unoxidized zone and an upper red to reddish brown oxidized zone. Occasionally there are 2 or 3 intercalated red and blue zones. At such exposures, oxidized clasts, apparently derived from lower oxidized zones were observed enclosed in blue matrix. Other than presence or absence of oxidation, no recognizable differences were seen between the red and the blue zones. The clay-pebble gravel appears to be restricted to that part of the lowlands where pre-marine glaciolacustrine sediments occur. Foraminifera and echinoderm spines identified in the matrix of the clay-pebble gravel confirm a marine origin.

A thin, nonsorted, discontinuous layer of silt, sand, pebbles and cobbles rests on the clay-pebble gravel. It occurs as lenticular patches without internal lamination or evidence of channeling at the base. These features seem more diagnostic of an ice-rafted deposit than a traction deposit or lag concentrate.

Horizontally bedded marine clay or silt overlies the clayey gravel and rafted layers with a contact that is everywhere sharp and readily discernible. The lowest clays are often very dark grey to black, sticky and give off a musty odour presumably due to decaying organic matter. Where thick, as near the mouth of Pivabiska River, they form unstable slopes subject to large slides and mudflows. The clay grades up into silty clay, then into sandy silt and sometimes gravel. These facies are also lateral equivalents of one another.

Large volumes of gravel and sand were deposited in beaches, especially near marine limit close to where major rivers emptied into the sea.

3) Terrestrial unit

Terrestrial deposits include peat, alluvium and eolian sand. Peat blankets most of the region but is thin or nonexistent near river banks, on raised beaches, and in similar well-drained areas. As much as 4 m have been recorded in river banks and in drillholes at various points in the basin. Postglacial peat stratigraphy was not included as part of this study. Earlier investigations were made by Sjörs (1959, 1961, 1963) who studied bogs and fens near Attawapiskat River north of the Moose River basin, and by Terasmae and Hughes (1960a) who discussed three postglacial pollen profiles from the James Bay area. Potzger and Courtemanche (1956) did pollen studies southeast of James Bay.

Alluvial sedimentation has been minor, the rivers having tended to cut and maintain canal-like channels rather than develop flood plains, although some rivers occasionally abandoned their channels and cut new ones as land emerged. The lack of significant lateral erosion is probably a function both of isostatic uplift and cohesive bank materials. Abitibi and Moose rivers have eroded laterally in their lower reaches, developing numerous bars and islands. There, marine silt and clay rest on resistant flat-lying limestone and dolomite. Apparently, the rivers erode laterally into the unconsolidated marine deposits more readily than they do vertically into the carbonates; however, farther up the Abitibi and Moose rivers incision into bedrock is indicated by islands (e.g., Williams Island) composed mostly of bedrock.

A field of stabilized sand dunes, observed from the air 3 km west of Otter Rapids, covers an area of approximately 10 km^2 in a region of raised beaches and a former delta of Abitibi River. Thickness of the sand is unknown. The dunes appear to be parabolic and their orientation suggests effective winds from the southwest. Except for a few active deflation areas, the dunes are stabilized under a cover of lichens and jack pine (*Pinus banksiana*).

Discussion

During retreat of the Cochrane lobe, grounded glacier ice in Hudson Bay lay between a lake to the south and marine water to the north. Eventually this ice barrier was breached and the Tyrrell Sea replaced the lake. Isostatic rebound then gradually caused emergence of the land.

1) Glaciolacustrine-marine transition and origin of marine clay-pebble gravel

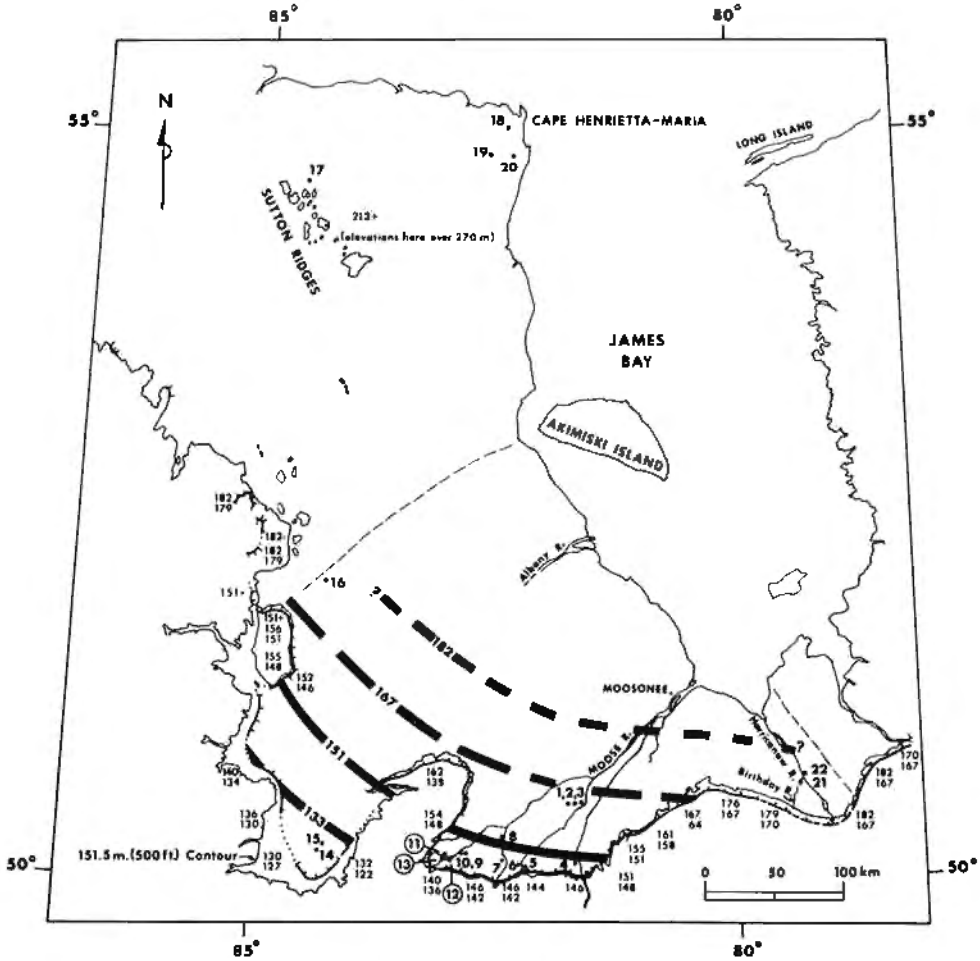
Craig and McDonald (1968, p. 162) first reported lacustrine beds below the marine beds in the James Bay lowland, and McDonald (1969, p. 92) outlined their distribution which can now be expanded eastward to include occurrences in the Harricanaw River basin. The overlying marine clay-pebble gravel apparently has a similar distribution, at least in the Moose River basin, and possibly is related in some way to the lacustrine-marine transition.

Because clasts in the clay-pebble gravel are composed of lacustrine rhythmites, bottom current velocities apparently rose from zero or relatively low values during rhythmite accumulation to higher values during erosion of rhythmites and transport of clasts, then back to zero during marine clay deposition. The occurrence of sudden erosive conditions at the base of the marine sequence probably is related to incursion of salt water into the lowlands. Two hypotheses could account for the clay-pebble gravel. The lake may have drained, the clay-pebble gravel being deposited later during marine transgression. This allows for oxidation of the upper part of the gravel in the surf zone during transgression. However, this hypothesis appears untenable because, at the time of deglaciation (7,800 C^{14} yrs. B.P.), a) lake level was controlled by, and therefore was higher than, sea level, and b) marine history is one of offlap only because, since marine incursion, more than 150 m of isostatic recovery has occurred compared with only an estimated 16 to 20 m of eustatic rise (Fairbridge, 1961; Shepard, 1963; Milliman and Emery, 1968; Moran and Bryson, 1969). The clay-pebble gravel is present in the Moose River basin at least as low as 30 m a.s.l., providing a minimum level at which marine transgression would have had to have started. It was observed near sea level at the mouth of Albany River (J.D. Mollard, pers. comm., 1971).

Ruling out a transgression, any alternate hypothesis must explain the inception of bottom currents with velocities sufficient to erode and transport silt and clay clasts as large as 4 cm in diameter beneath 150 m of water. According to Ippen (1966, p. 605) "... as long as density differences of a given magnitude exist between fresh and sea water, there must always be net upstream current along the bottom...." He was referring to the salt-water wedge found in many estuaries. When the Tyrrell Sea breached the remnant ice sheet in the Hudson Bay basin, a density flow of saline water under lake water presumably began. This inferred underflow may have been strong enough to erode the lacustrine rhythmites producing the clay-pebble gravel. Bottom erosion would have ceased when mixing was complete or at least sufficiently advanced to induce flocculation of the marine clays which rest with sharp contact on the clay-pebble gravel. The marine clays indicate an abrupt return to quiet bottom conditions. The patches of pebbles, cobbles and sand immediately overlying the clay-pebble gravel probably were derived from melting icebergs that must have calved in abundance during disintegration of the ice barrier between lake and sea.

Oxidation probably occurred when the freshwater silt and clay clasts were exposed initially to salt water. An Eh-pH change probably accompanied the transition from fresh to salt water, but whether the change was sufficient to suddenly trigger oxidation or precipitation of ferric oxide is unknown. Oxidation was confined to the interval of bottom erosion, as evidenced by isolated red clasts enclosed within unoxidized blue matrix, where more than one red

zone occurs. A later episode of oxidation is apparently precluded because one clast probably could not be oxidized without adjacent, texturally similar clasts being affected. Modern sediment on the bottom of Hudson Bay is reddish brown and, according to Leslie (1965), is oxidized while settling through oxygenated water. Conceivably, the sudden influx of sea water during ice disintegration also was sufficiently oxygenated compared to the bottom water of the lake, that it oxidized the lake sediments.



•16 - C^{14} date location (see Table II).

- 151.5 m (500 ft) contour.

- Marine limit (numbers are estimated elevations; see text for explanation).

182 - Provisional isobases on marine limit (in meters); 167 m and 182 m isobases partly based on spacing and curvature of 133 m and 151 m isobases.

----- - Pre-Tyrrell Sea Lake between dashed lines.

Figure 22. Locations of C^{14} dates, elevations of marine limit, isobases, and region occupied by pre-Tyrrell Sea Lake.

Table II. Radiocarbon dates from the James Bay lowland

Locality (see Fig. 22)	Lab. No.	Altitude[1]	Material Dated	Age ($\pm 2\sigma$)	Reference	Comments
1	GSC-1323	46±2m(3) (152±6 ft.)	Wood *Abies balsamea*	4,160±140	this report	Wood near base of 2.7 m bed of sand and silt resting on gravel over marine clay over till. North bank of Mattagami River, 6.5 km (4 mi.) west of east boundary of Morrow township. (C^{13} correction = 4,180±140)
2	GSC-1531	46±2m(3) (152±6 ft.)	Wood	4,120±130	this report	At above locality; gravel over marine clay and below GSC-1323.
3	GSC-1396	46±2m(3) (152+6 ft.)	*Macoma balthica* whole shells and fragments	4,900±130	this report	At above locality in silt unit 25 m downriver from GSC-1323.
4	GSC-1241	133±1m(1) (440+3 ft.)	*Hiatella arctica*	7,100±160	this report	On surface of borrow pit in gravel beach (?) at Otter Rapids, 300 metres west of railway section shed, at same level (±1 m) at track. Bench marks nearby therefore +1 m control. (C^{13} correction = 7,160±160)

5	GSC-1430	124±2m(1) (410±5 ft.)	Macoma calcarea whole shells and fragments	7,380±160	this report	On and below surface in shelly gravel in borrow pit 350 m southeast of east abutment of Kipling Dam, Mattagami River. 5 ft. (1.8 m) contour maps and proximity to bench marks provide ±2 m control.
6	I-1256	112 m (370 ft.)	Marine shells	7,523±400	O.L. Hughes, unpublished	West of Kipling Dam, Mattagami River.
7	GSC-1499	100±4m(1) (330±12 ft.)	Mytilus edulis whole valves, fragmented during sampling	6,620±240	this report	On Opasatika River, Acres Township, Station OR-70-28. In bed of cobbles, gravel and sand 1 m below surface.
8	GSC-1489	86±4m(1) (285±12 ft.)	Hiatella arctica	6,890±220	this report	On Opasatika River, McCausland Township, Station OR-70-10. In bed of sand, pebbles, and red clay-pebble gravel, overlain by sandy silt. Thought date would give age of basal marine clay-pebble gravel, apparently, was reworked during off-lap and sample was a mixture of differently aged specimens.

Table II (cont.)

Locality (see Fig. 22)	Lab. No.	Altitude[1]	Material Dated	Age (±2σ)	Reference	Comments
9	Gro-1698	102±3m(2) (335±10 ft.)	Marine shells	7,280±160	Terasmae and Hughes, 1960b	This date was mislocated on map in Terasmae and Hughes,1960b; it came from south bank of Missinaibi River 3.2 km (2 mi.) below mouth of Pivabiska River, not on Opasatika R. as published (Owen Hughes, oral communication). Also the altitude is 102m±3m instead of 91m. GSC-1436 from same section.
10	GSC-1436	102±3m(2) (335±10 ft.)	Abundant *Hiatella arctica*. Many shells with both valves	7,390±240	this report	Shells in coarse sand bed at top of marine section. Same locality as 6. (GSC-1436 was recounted after preparation of this table. The new date is 7,280±150 which agrees very well with Gro-1698 from this locality.)
11	GSC-1309	112±4m(1)	*Hiatella arctica* Many shells with both valves	7,630±170	this report	From bed of medium to coarse sand partly within modern weathering profile; north bank Pivabiska River 1 km (.6 mi.) west of east boundary of McBrien Township, Station PR-69-50

12	I(GSC)-14	106±5m (350±17 ft.)	Marine shells	7,875±400	Terasmae and Hughes, 1960b	Altitude originally published as 400 ft. (121m). Recent maps, areal photographs, and measurement with altimeter indicate a lower altitude (350 ft.).
13	GSC-1418	109±3m(1) (360±7 ft.)	Macoma calcarea whole shells and fragments, often with periostracum	7,500±160	this report	Upriver from I(GSC)-14; shells in growth position fragmented during sampling. From sand and clayey silt beneath coarse to medium sand. Located on north bank Missinaibi River 7.2 km (4.5 mi.) east of boundary separating Burstall and McBrien townships.
14	GSC-897	ca. 105m (345 ft.)	Hiatella arctica	7,760±160	Craig, 1969, p. 69; Lowdon & Blake, 1970, p. 63	
15	GSC-915	ca. 98m (325 ft.)	Hiatella arctica	7,540±140	ibid.	
16	GSC-880	ca. 121m (400 ft.)	Macoma calcarea	7,720±140	ibid.	
17	GSC-247	ca. 129m (425 ft.)	basal peat[2]	5,580±150	Dyck et al., 1965	Date is minimum for emergence of site. Site is above 400 ft. (121 m) contour.

Table II (cont.)

Locality (see Fig. 22)	Lab. No.	Altitude[1]	Material Dated	Age (±2σ)	Reference	Comments
18	GSC-231	ca. 14m (46 ft.)	basal peat[2]	1,210+130	Dyck et al., 1965	Date is minimum for emergence of site.
19	I-3989	40.6m (134 ft.)	Mytilus edulis	2,310+200	Webber et al., 1970, p. 320	Site levelled from modern coast.
20	I-3983	22.6m (75 ft.)	Mytilus edulis	1,430+190	Webber et al., 1970, p. 320	Site levelled from modern coast.
21	GSC-1493	60±5m (200+15 ft.)	basal peat	3,960+130	this report	On north bank of Birthday River, Québec 1 km from mouth, 50°42'N Lat., 79°20'W Long. Altitude interpolated from contour map. Compare with Y-1164 (4,110+100), basal peat from this or nearby site (see reference below).
22	GSC-1492	60+5m	Macoma balthica	4,790±140	this report	On east bank of Harricanaw River, Québec 6.5 km downstream from mouth of Birthday River, 50°46'N Lat., 70°19'W Long. In sandy gravel 1 m below top of section.

Footnotes

[1] All locations in the Moose River basin were measured with a Wallace and Tierran altimeter during periods of clear, stable weather. A control altimeter was read at 10 to 15 minute intervals in base camp at an elevation determined by bench marks. Meanwhile sample sites were visited by helicopter and their altitudes measured. Variation of altitude error depends on nearness to bench marks, number of measurements, plus operator errors and atmospheric pressure differences over great distances. A + range is given for only those localities measured by the author. The numbers within brackets refer to number of measurements; for example, 46+2m(3) means all 3 altitude determinations for that site fell between 48m and 44m a.s.l.; where the number is 1, a + 4m range is given unless explained otherwise in comments.

[2] In addition to these peat dates, the following basal peat and gyttja dates are from the James Bay region: The year in the right column refers to the date of publication in Radiocarbon.

GSC-7	6,910±120	(above marine limit)	1962
GSC-31	5,670±110	(below marine limit)	1963
GSC-272	6,920±140	(above marine limit)	1965
GSC-308	5,880+140	" " "	1966
GSC-309	7,150+140	" " "	1966
GSC-487	7,760±140	" " "	1966
GSC-624	7,380±140	" " "	1967
GSC-670	7,650±180	" " "	1968
GSC-831	7,140±170	" " "	1970
GSC-885	5,820±150	" " "	1970
I(GSC)-183	5,230±110	" " "	1962
L-391B	4,750±250	" " "	1959
L-4336	5,300±120	" " "	1959
OWU-10	6,756±111	" " "	1958
W-136	6,380±350	" " "	1955
W-176	5,300+300	" " "	1955
Y-1164	4,110±100	(below marine limit)	1963

[3] The various radiocarbon dating laboratories are identified by the following letters: Gro - Groningen; GSC - Geological Survey of Canada Radiocarbon Dating Laboratory; I - Isotopes, Inc.; L - Lamont Geological Observatory, Columbia University; OWU - Ohio Wesleyan University; W - U.S. Geological Survey; Y - Yale University Radiocarbon Laboratory.

2) Warping of marine limit and postglacial uplift

The James Bay lowland provides a unique opportunity to study isostatic warping because synchronous shore features are present. A large region shown in Figure 22 was occupied by a glacial lake before sudden incursion of the Tyrrell Sea, thereby permitting formation of a synchronous marine limit over a distance of some 800 km. Identification and accurate measurement of marine limit would permit measurement of isostatic tilt. However, the marine limit is difficult to delineate because the area is heavily forested, and because marine and lacustrine shore features are easily confused. The lack of thick glaciolacustrine sediments, especially silt-clay rhythmites, indicates that the pre-marine lake was short-lived, and therefore distinct shorelines may not have had time to form. The marine limit was mapped on the basis of the highest persistent beach compatible with marine fossil localities. Isobases were drawn on this limit in order to approximate the amount and direction of tilt (Fig. 22). Presence of a few marine shells confirmed marine origin for many of the highest beaches in the Moose River basin. Some of the elevations on the marine limit are from Craig (1969, p. 67) whereas others were interpolated between contours. A few were measured with altimeter with respect to bench marks. High and low numbers at points represent maximum and minimum values of marine limit elevations estimated by inspection of aerial photos and contour maps. Such values are only approximate. Where smaller maximum-minimum differences are shown, better control was available (e.g., 1.5 m contour maps and bench marks).

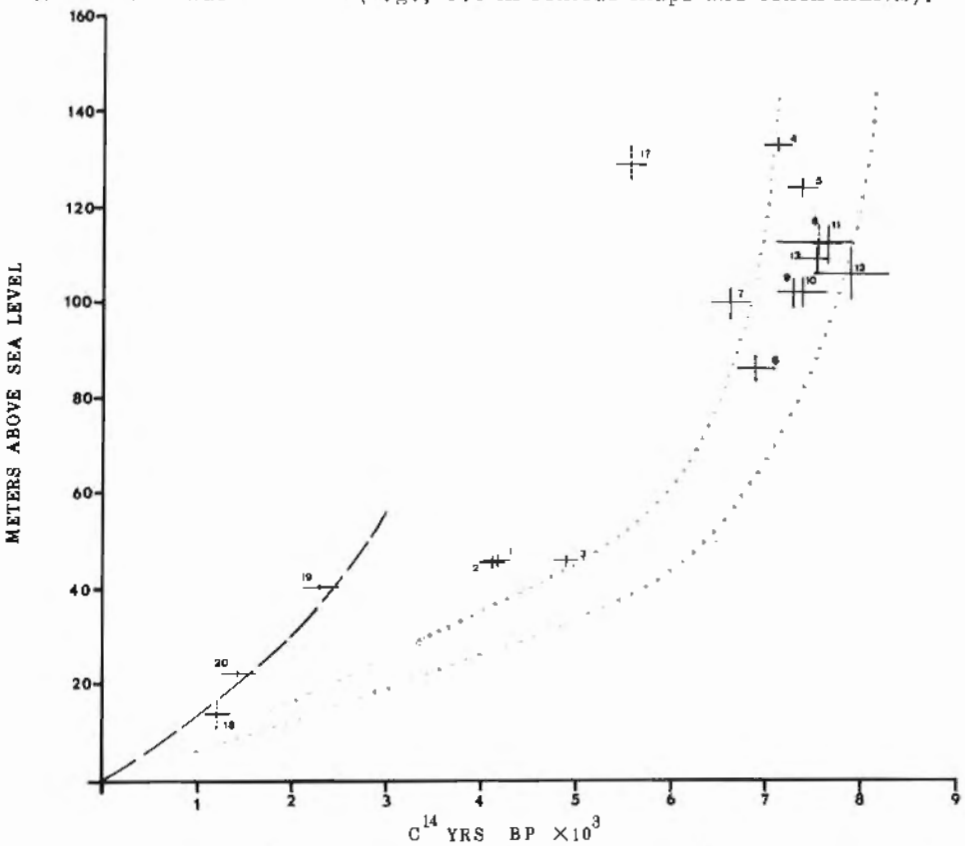


Figure 23. Time-altitude graph for James Bay.

Because precise marine limit determinations are not available, isobases shown on Figure 22 are provisional. Based on these data, isobases on the highest marine water plane appear to be convex southwest and indicate upward tilting to the northeast with a gradient of approximately 30 cm/km. If the contours are considered concentric, the centre of the uplift can be estimated by extrapolation and is placed to the east or northeast of James Bay, approximately coincident with a centre of maximum uplift inferred by Andrews (1969, p. 53).

Figure 23 is a time-altitude curve of some C^{14} dates from the James Bay region. Sample locations are shown on Figure 22 and described in Table II. Elevations have not been corrected for eustatic rise of sea level. A tentative uplift envelope has been drawn on Figure 23 to fit available data from the southern part of the Moose River basin. From Figure 22, it can be seen that marine limit over the locality for dates 1, 2 and 3 is higher than over localities 4 to 13; therefore, more uplift has taken place per unit time at 1, 2 and 3, so the rate of uplift is greater. If uplift curves were drawn for localities closer to the centre of downwarp, they would be above or steeper than the Moose River curve on Figure 16. For example, the Cape Henrietta Maria curve (Webber et al., 1970) is above the Moose River curve. Consequently, dates 1, 2 and 3 (Fig. 23) are above the curve based on dates 4-13 from the southern part of the basin.

3) Chronology and sequence of events

Several C^{14} dates relate to the Tyrrell Sea in James Bay lowland (Fig. 22; Table II). The oldest date, I(GSC)-14 (Location 12, Table II), interpreted with a 2σ error, falls between about 8,300 and 7,500 years.[1] More recent dates (Craig, 1969; this report) from equivalent and higher elevations in the area fall within the lower half of this range suggesting that the sea inundated James Bay lowland sometime between 7,900 and 7,700 years ago.

The location of the initial waterway south of Hudson Strait is uncertain. Prest (1969, 1970) showed it trending from Hudson Strait to the vicinity of Hayes River during or prior to the Cochrane readvance. Lee (1968, p. 521) suggested a break along a north-south "demarcation line" 64 km (40 miles) east of Fort George. Andrews and Falconer (1969, p. 1274) envisaged the ice sheet breaking along a bathymetric deep between Mansel and Coats islands and west of the Ottawa Islands, then south to James Bay. Radiocarbon dates on marine samples are oldest in the James Bay lowland and become progressively younger to the northwest (Craig, 1969), indicating that the southeastern Hudson Bay Lowland probably was inundated before the northwestern lowland. This requires a waterway somewhere in the eastern half of Hudson Bay. The precise location, configuration, and dimensions of the waterway, and the process of breaking are unknown; however, the ice sheet probably broke where it was thinnest, possibly over a topographic high. Such an area of high submarine terrain trends from Cape Henrietta Maria north to Mansel Island in the form of a cuesta of resistant Paleozoic rocks, much like the Niagara escarpment (B.V. Sanford, oral comm., 1971). Although an eastern waterway is presently preferred based on available C^{14} dates, a western one cannot be ruled out.

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[1] I(GSC)-14 was an Isotopes determination for the Geological Survey. Only 1σ errors were published. All Geological Survey dates have a 2σ error when reported.

Summary of late-glacial and postglacial events

1) As the Cochrane lobe retreated northward, a lake was impounded in front of the ice.

2) This lake lasted until about 7,900 to 7,700 years ago when the ice sheet in Hudson Bay was breached, probably along a zone trending south to Cape Henrietta Maria, allowing the Tyrrell Sea suddenly to replace the lake in James Bay lowland. A synchronous marine limit formed over a distance of some 800 km.

3) During marine incursion, relatively dense sea water flowed under lake water and reworked lake sediments into a clay-pebble gravel.

4) As the land emerged due to isostatic uplift, the margin of the Tyrrell Sea receded northward. Uplift was differential resulting in tilting of the marine limit so that it currently rises northeast with a gradient of approximately 30 cm/km.

5) The emerged terrain has been modified by river incision, eolian deposition, and development of peat bogs and spruce forest.

CORRELATION WITH SEQUENCES IN SOUTHEASTERN CANADA

Location of the James Bay region near the centre of former ice sheets makes it of special importance to Quaternary history because major nonglacial events here should be related to significant nonglacial events farther south. Four nonglacial intervals are recorded in the Moose River basin that date prior to 8,000 C^{14} years B.P.; the lower three are at least older than 54,000 C^{14} years.

Correlation with sequences in southeastern Canada is hampered by a lack of critical C^{14} dates; however, if one accepts the Missinaibi Formation as Sangamon, then some time-stratigraphic 'control' is obtained. The three-till sequence (Lower Tills I, II and III) below the Missinaibi, may be Illinoian in age. The two tills (Adam and Kipling) above the Missinaibi are Wisconsin, and the Friday Creek sediments, between the tills, represent an interval of retreat of the Laurentide Ice Sheet. When this retreat took place is unknown. Three possible intervals are: 1) St. Pierre (Early Wisconsin?), 2) Port Talbot (Middle Wisconsin), and 3) immediately pre-Cochrane (Late Wisconsin).

The first possibility is not preferred owing to the uncertainty of the age of the St. Pierre beds in the St. Lawrence Lowlands. The 'finite' dates associated with the St. Pierre beds should be considered with caution until confirmed or rejected by additional radiocarbon dates from different laboratories. The St. Pierre beds could be late Sangamon in age or even correlative with the Port Talbot. The author prefers correlation of the St. Pierre beds with the erosional break at the top of the Scarborough Formation at Toronto (Karrow, 1967, p. 47). If the St. Pierre beds are early Wisconsin, perhaps the lacustrine member of the Missinaibi Formation is in part correlative with them; on the other hand, the Moose River basin could have been ice covered during the St. Pierre interval.

Possibilities 2 and 3 are shown in Figure 24. Are the Friday Creek sediments equivalent to Glacial Lake Barlow-Ojibway sediments (i.e., deposited immediately prior to the Cochrane readvance) or are they Middle

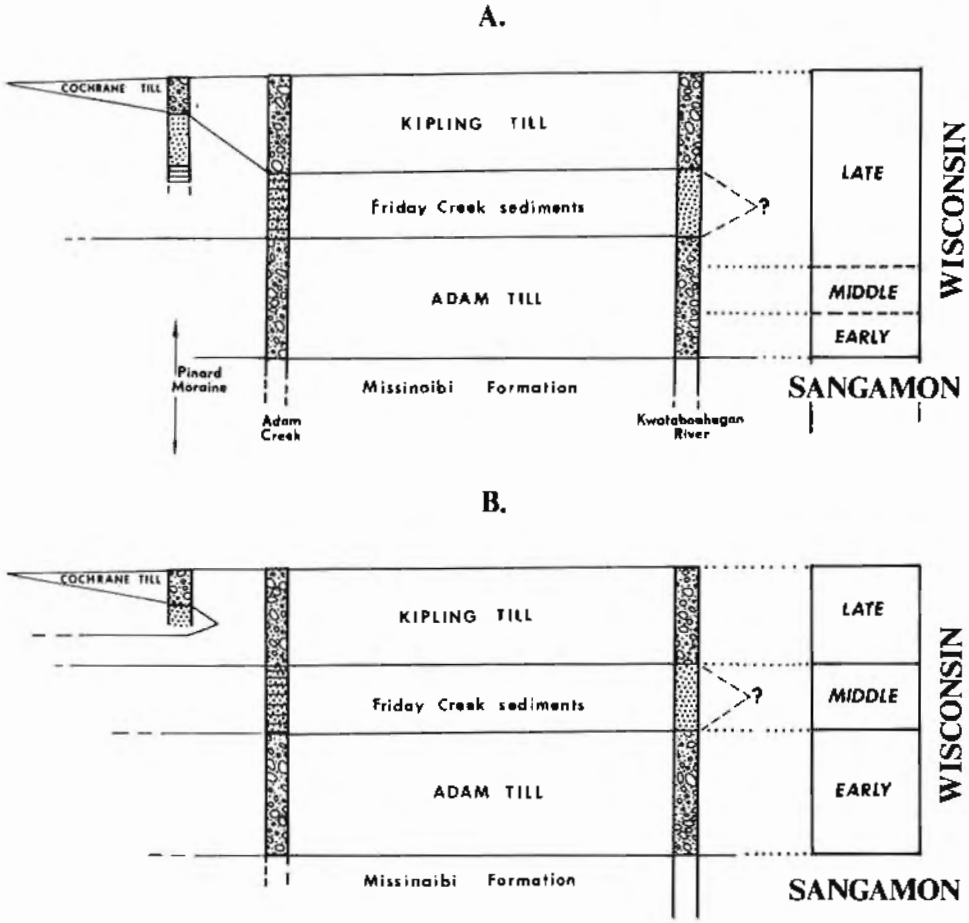

Figure 24. Possible correlations of Wisconsin sediments in Moose River basin.

Wisconsin (deposited during the Port Talbot interval)? The latter interpretation implies that just prior to the Cochrane readvance the ice sheet did not retreat north of the Pinard moraine. Without C^{14} dates, there is little reason for preferring one interpretation to the other. In making a judgment, several factors should be considered:

a) Possibility A (Fig. 24) would require considerable retreat of the Cochrane lobe prior to readvance. If this alternative is accepted, the rates of retreat and readvance shown in Figure 25 are required. An average rate of retreat of 300 m per year is not exceptional, based on the spacing of DeGeer moraines east of Hudson Bay (Lee, 1968, p. 516) and on the rate of retreat calculated for the Cochrane region by Hughes (1965, p. 561). According to Prest (1970, p. 720) the ice sheet retreated from North Bay about 10,500 years ago and Montreal River about 10,000 years ago. The base of Antevs' (1925, 1928) varve record is at Montreal River. Antevs and later Hughes (1959, 1965) counted approximately 2,050 varves encompassing the

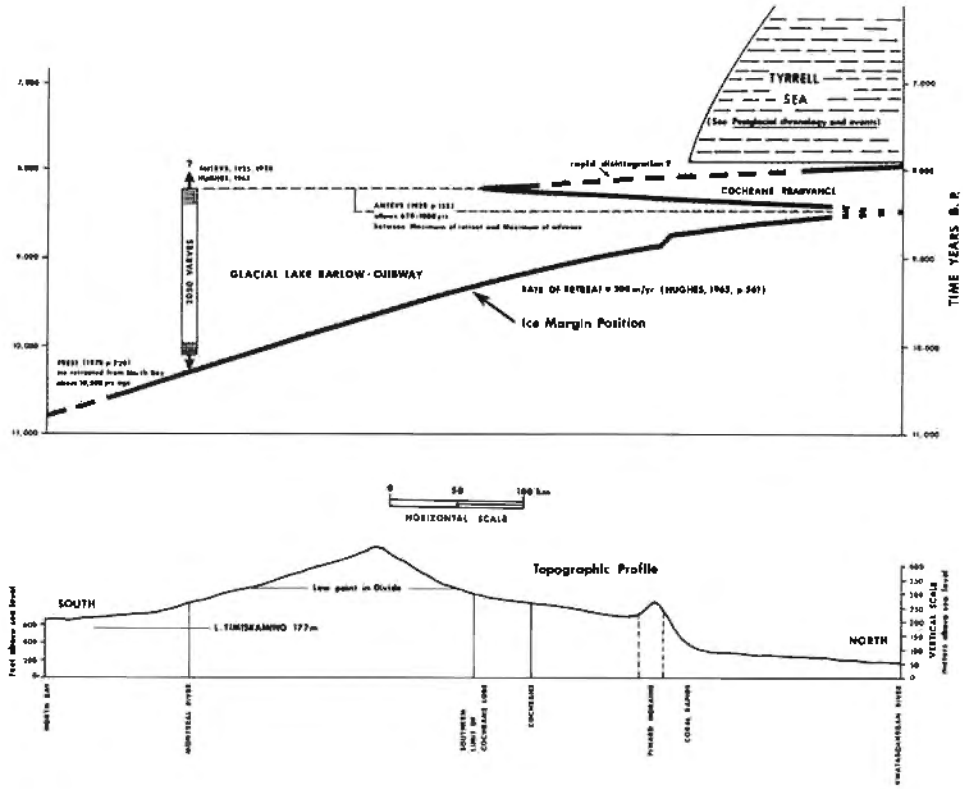

Figure 25. Topographic profile and time-distance graph illustrating inferred retreat of ice margin across northern Ontario.

time from deposition of the first varve at Montreal River to the last post-Cochrane varve, deposited in the Timmins region. Based on radiocarbon dates on shells of the Tyrrell Sea, the ice sheet had disintegrated in James Bay by about 7,800 years B.P.; this allows approximately 2,200 C^{14} years to account for 2,050 varves. Meanwhile, the ice margin had to retreat 410 km, then readvance 250 km, and then retreat more than 300 km.

Hughes, who defined Cochrane Till, did not propose a northern limit for it. Boissonneau (1966, p. 576) discovered Cochrane-like till capping the Pinard 'moraine', a broad, sand-cored ridge, situated parallel to and just south of the fall-line. Prest (1970, p. 734) interpreted as Cochrane Till a "clayey till overlying varved sediments" north of the moraine, near Coral Rapids. Although Kipling Till is similar in appearance to Cochrane Till, and they are probably at least partly correlative, they were not necessarily deposited during the same rapid readvance, as implied by Figure 24. Prest (1970) has suggested that the Cochrane readvance represents a surge of a lobe of the continental ice sheet.

b) A three-till sequence is exposed along Kenogami River in the upper Albany River basin (McDonald, 1969, p. 93). The tills are in direct contact and the upper till exactly fits Hughes' description of Cochrane Till. Possibly all three tills are Wisconsin in age; however, without the Missinaibi Formation

for control, the lowermost till could be older. This also is the region of the Cochrane I and II readvances (Boissonneau, 1968; Prest, 1970) which the upper two tills may represent.

c) There are two tills above the Missinaibi Formation throughout the Hudson Bay Lowland. McDonald speculated that the hiatus between them was Middle Wisconsin. The upper till in the northwestern part of the Hudson Bay Lowland may be late-glacial, similar to, but not necessarily synchronous with the Cochrane readvance. Available C^{14} dates suggest that between 10,000 and 6,000 years ago, the ice sheet disintegrated very rapidly. A series of rapid lobate readvances into glacial lakes Agassiz and Barlow-Ojibway, and perhaps later into Tyrrell Sea, would certainly hasten thinning and break-up of the ice sheet and, at the same time, account for a Wisconsin two-till sequence throughout most of northern Ontario.

d) Sea level during Middle Wisconsin time was supposedly nearly as high as present (Curray, 1961; Shepard, 1963; Milliman and Emery, 1968). Mörner (1971), however, contests this on glaciologic-climatic grounds and the possibility of contamination of C^{14} samples. The outer fraction of Missinaibi shells was dated at 38,000 ± 2,000 C^{14} years; the inner fraction was >37,000 C^{14} years (GSC-1475); yet subaerial peat and wood, stratigraphically above the shells, produced a >54,000 years date suggesting that shell dates more than 25,000 years may be unreliable. Olson (1968, p. 251) cautioned against accepting such old shell dates.

In summary, until critical radiocarbon dates are available from the Friday Creek sediments, their age will remain unknown. To assume they are Late Wisconsin in age requires rapid rates of retreat and advance; alternatively, a Middle Wisconsin age requires considerable diminution of the Laurentide Ice Sheet which, in turn, implies high Middle Wisconsin sea levels, a subject of current controversy.

Although there is firm evidence of a Late Wisconsin readvance south of the region (the Cochrane), no evidence has been found to suggest that the Kipling Till bifurcates in the vicinity of Pinard moraine. The presence of thin distal varves beneath sand and gravel, capped by Cochrane Till on the north flank of the Pinard moraine (Station SS-70-88) suggests that the glacier retreated north of the moraine before the Cochrane readvance. Therefore, possibly the Kipling Till was wholly deposited during the Cochrane readvance and the pre-Cochrane limit of retreat was north of Kwataboahegan River. However, this does not necessarily imply that the upper till(s?) in the Hudson Bay Lowland to the northwest is (are?) also Late Wisconsin.

CONCLUSIONS

The principal conclusions drawn from this study are:

a) Three pre-Wisconsin tills in the southwestern portion of the study area were deposited when the margin of a southwestward flowing ice sheet fluctuated into a proglacial lake.

b) The Missinaibi Formation was deposited during an interglaciation, probably the Sangamon. The formation includes an ubiquitous buried soil developed on glacial, marine, and fluvial sediments; a forest growing on the

soil was killed and buried beneath thick deposits of a proglacial lake. The bulk of interglacial time is recorded beneath the lake sediments, not in them as previously thought.

c) Two Wisconsin tills, both deposited by southwestward flowing ice, outcrop in the area. A nonglacial unit between the tills is either Middle or Late Wisconsin in age. A Middle Wisconsin age implies a significant decrease in volume of the world's ice sheets and relatively high sea levels. A Late Wisconsin age requires rapid rates of glacial advance and retreat during a time of rapid deterioration of the Laurentide Ice Sheet.

d) A lake preceded the Tyrrell Sea in a large area south of James Bay. About 7,800 years ago when the Tyrrell Sea entered the region, sea water wedged under fresh water, apparently creating a current strong enough to rework lake clays into a clay-pebble gravel.

e) A synchronous marine limit was established over a vast area. The inferred former water plane defined by marine limit is now warped up to the northeast having a gradient of about 30 cm/km in the direction of the supposed former ice centre.

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APPENDIX A

Till Sample Data

SAMPLE AND STATION IDENTIFICATION KEY (see table of data on following pages).

SAMPLE NUMBER

SJA-69- Samples taken in 1969
SJA-70- Samples taken in 1970

STATION NUMBER

AC Adam Creek
AR Abitibi River
CC Coal Creek
FC Friday Creek
HR Harricanaw River
KR Kwataboahegan River
LA Little Abitibi River
MA Mattagami River
MO Moose River
MS Missinaibi River
NF North French River
OR Opasatika River
PR Pivabiska River
SR Soweska River
SS Smoky Falls-Smooth Rock Falls Road
-69- 1969 Station
-70- 1970 Station
-2 Station number (see index map and fence diagrams)

STATISTICAL PARAMETERS (Graphic measures after Folk and Ward, 1957).

M_z Mean Grain Size
σ Standard Deviation
Sk Skewness
Kr Kurtosis

SAND, SILT, CLAY - given in per cent

% Calcite, % Dolomite, % Total carbonate (Chittick Method on 63 to 44 μ fraction)

% Siderite - grain count of heavy mineral separate from <250 - >125 μ fraction;
- .01 means less than 1%; O means sample not counted.

Sample Number	Station Number	Mean	Standard Deviation	Skew-ness	Kurto-sis	Per Cent: Cal-cite	Dolo-mite	Carbon-ate	Sand	Silt	Clay	Sider-ite
Kipling Till												
SJA-69- 2	MS-69- 4	6.77	3.68	.06	1.13	10.75	11.71	22.46	20.75	46.74	32.51	0
SJA-69- 5	MS-69- 12	6.90	3.84	.02	1.12	14.42	15.23	29.65	22.11	42.88	35.01	0
SJA-69- 8	MS-69- 14	7.10	3.82	.02	1.06	12.21	12.75	24.96	20.04	42.66	37.30	0
SJA-69- 23	PR-69- 34	6.73	3.84	.02	1.10	21.10	17.92	39.02	22.20	43.64	34.16	0
SJA-69- 37	SR-69- 56	7.93	3.64	0	.89	5.20	7.90	13.10	14.68	37.89	47.43	0
SJA-69- 58	SR-69- 70	6.47	3.81	-0.02	1.10	11.98	13.10	25.08	24.98	43.72	31.30	0
SJA-69- 63	MA-69- 83	6.10	3.62	0	1.14	18.93	16.77	35.70	25.77	47.53	26.70	0
SJA-69- 68	AC-69- 85	6.10	3.64	.01	1.17	26.53	23.38	49.91	25.39	48.08	26.53	0
SJA-69- 86	AR-69-104	6.00	3.63	.05	1.06	19.50	13.60	33.10	27.92	45.60	26.48	0
SJA-69-106	CC-69-114	6.57	3.72	.07	1.16	22.50	17.70	40.20	22.46	46.90	30.64	0
SJA-69-110	PC-69-116	6.87	3.26	.17	1.20	11.60	18.60	30.20	17.29	52.28	30.43	0
SJA-69-118	KR-69-122	5.20	3.13	.08	1.17	10.00	11.20	21.20	32.63	50.63	16.74	0
SJA-69-123	NF-69-124	5.67	3.56	-0.01	1.03	21.50	11.60	33.10	29.68	45.54	24.78	0
SJA-69-131	LA-69-128	5.50	3.60	.07	1.06	20.60	13.50	34.10	32.41	44.53	23.06	0
SJA-70- 6	MO-69- 96	6.27	4.21	.07	.85	7.04	11.50	18.84	31.91	33.82	34.27	0
SJA-70- 7	MS-70- 2	5.73	3.35	.03	1.32	11.50	18.60	30.10	25.08	53.02	21.90	0
SJA-70- 9	MS-70- 5	5.77	3.34	.01	1.21	13.40	15.20	28.60	26.11	51.72	22.17	0
SJA-70- 11	OR-70- 6	6.13	3.52	.02	1.23	13.10	18.50	31.60	23.71	50.21	26.08	0
SJA-70- 13	OR-70- 9	6.37	3.66	.01	1.15	12.76	15.20	27.96	24.07	45.95	29.98	0
SJA-70- 16	OR-70- 10	6.93	3.76	.01	1.13	11.80	18.10	29.90	21.30	43.05	35.65	0
SJA-70- 25	OR-70- 28	6.87	3.71	-0.01	1.18	16.04	16.10	32.14	20.19	44.36	35.45	0
SJA-70- 27	OR-70- 30	7.10	3.69	.06	1.07	15.44	15.40	30.84	18.64	44.49	36.87	0
SJA-70- 28	OR-70- 31	6.60	3.76	.01	1.15	12.70	18.50	31.20	23.03	45.40	31.57	0
SJA-70- 31	OR-70- 27	6.70	3.80	.01	1.16	12.10	22.54	34.64	22.00	44.62	33.38	0
SJA-70- 34	MS-70- 32	6.57	3.71	.01	1.15	14.94	20.90	35.84	22.82	46.23	30.95	0
SJA-70- 45	MS-70- 39	5.80	3.88	.01	.99	7.50	13.10	20.60	30.98	42.99	26.03	0
SJA-70-861	-70- 52	5.07	3.16	.07	1.11	12.00	13.70	25.70	33.74	49.94	16.32	0
SJA-70-63T	KR-70- 58	5.63	3.17	0	1.39	6.40	14.42	20.82	24.33	57.06	18.61	0
SJA-70- 66	KR-70- 60	5.53	3.23	.04	1.26	8.30	14.22	22.52	27.06	53.66	19.28	0
SJA-70- 68	HR-70- 62	5.73	3.51	.08	1.03	9.30	11.30	20.60	30.00	45.92	24.08	0
SJA-70- 70	HR-70- 64	6.40	3.67	.03	1.09	12.98	9.96	22.94	24.79	45.34	29.87	0
SJA-70- 76	AR-70- 66	5.27	3.61	.09	1.05	17.62	11.62	29.24	33.22	45.31	21.47	0
SJA-70- 82	AR-70- 71	4.60	3.20	.09	1.15	20.80	26.90	47.70	41.11	45.20	13.69	0
SJA-70- 83	AR-70- 72	4.60	3.42	.10	1.00	18.70	13.44	32.14	43.77	40.89	15.34	0
SJA-70- 87	AR-70- 75	6.63	3.51	.32	.97	19.60	18.80	38.40	21.10	47.97	30.93	0
SJA-70- 90	AR-70- 79	4.97	3.45	.11	1.08	16.60	9.20	26.80	39.28	42.94	17.78	0
SJA-70- 92	AR-70- 80	5.53	3.60	.04	1.04	19.75	14.75	34.50	32.24	44.22	23.54	0
SJA-70- 96	AR-70- 83	5.53	3.39	.05	1.10	19.20	12.70	31.90	29.74	49.06	21.20	0
SJA-70- 97	AR-70- 85	5.73	3.60	.03	1.06	19.36	14.60	33.96	29.57	45.42	25.01	0
SJA-70-114	MA-70- 86	6.33	3.86	.05	1.15	17.00	14.90	31.90	26.11	47.23	26.66	0
SJA-70-115	MA-70- 86	7.73	3.76	-0.03	.99	17.50	16.40	33.90	16.48	37.43	46.09	0
SJA-70-117	MA-70- 86	7.70	3.67	-0.04	1.07	17.50	15.20	32.70	15.73	38.92	45.35	0
SJA-70-118	SS-70- 88	7.30	3.66	.02	1.03	13.54	11.20	24.74	17.65	42.81	39.54	0
SJA-70-119	MA-70- 90	6.97	3.79	-0.01	1.07	16.40	12.96	29.36		40.99	37.10	0
SJA-70-120	MA-70- 91	7.50	3.92	-0.05	.93	14.70	12.64	27.34	19.42	35.49	45.09	0
SJA-70-122	SS-70- 96	6.50	3.83	.15	.94	7.30	9.40	16.70	27.59	40.27	32.14	0
SJA-70-123	SS-70- 99	7.80	3.26	.14	1.01	11.50	8.20	19.70	10.93	47.64	41.43	0
SJA-70-124	SS-70-100	4.70	3.14	.33	1.13	9.44	7.24	16.64	46.47	37.85	15.68	0
SJA-70-125	SS-70-101	5.77	3.20	.18	1.15	10.96	11.16	22.12	26.85	50.26	22.89	0
SJA-70-126	SS-70-102	5.00	3.20	.32	.97	10.90	9.82	20.72	44.06	37.61	18.33	0

Sample Number	Station Number	Mean	Standard Deviation	Skew-ness	Kurto-sis	Per Cent: Cal-cite	Dolo-mite	Carbon-ate	Sand	Silt	Clay	Sider-ite
Kipling Till												
SJA-70-127	SS-70-103	6.17	3.54	.03	1.14	17.60	11.30	28.90	25.59	46.94	27.47	0
SJA-70-128	SS-70-104	6.77	3.68	.03	1.18	16.56	12.10	28.66	20.37	46.94	32.69	0
SJA-70-129	MA-69- 84	6.37	3.75	.01	1.13	16.96	16.84	33.80	24.56	46.23	29.21	0
SJA-70-135	AC-69- 85	5.87	3.68	0	1.10	16.68	16.74	33.42	28.05	46.32	25.63	0
SJA-70-137	AC-69- 85	6.13	3.65	.02	1.19	18.20	14.06	32.26	25.19	47.44	27.37	0
SJA-70-142	AC-70-113	6.10	3.67	0	1.11	16.78	14.80	31.58	25.56	46.29	27.15	0
SJA-70-145	SS-70-117	7.00	3.50	.10	1.23	13.60	11.60	25.20	17.31	49.18	33.51	0
SJA-70-146	SS-70-118	7.20	3.19	.12	1.29	11.50	10.30	21.80	13.74	52.89	33.37	0
SJA-70-147	SS-70-119	7.10	3.27	.12	1.24	11.70	12.80	24.50	15.03	52.47	32.50	0
SJA-70-148	SS-70-120	7.70	3.11	.16	1.11	11.40	7.20	18.60	8.91	51.60	39.49	0
SJA-70-149	SS-70-121	8.80	3.51	-0.09	1.03	7.20	6.80	14.00	10.57	28.08	61.35	0
SJA-70-152	MA-70-123	6.90	3.83	-0.04	1.31	14.92	14.58	29.50	19.88	44.55	35.57	0
SJA-70-161	LA-70-125	5.83	3.52	.04	1.12	18.78	14.42	33.20	27.72	47.38	24.90	0
SJA-70-163	LA-70-126	6.43	3.71	.04	1.15	20.78	12.22	33.00	23.73	46.61	29.66	0
SJA-70-164	LA-70-127	6.97	3.59	.03	1.18	16.26	10.42	26.68	18.34	47.23	34.43	0
SJA-70-166	AC-70-128	6.17	3.69	.02	1.12	18.72	13.18	31.90	25.39	46.33	28.28	0
SJA-70-170	CC-69-114	7.00	4.11	-0.05	.97	12.32	13.70	26.02	22.95	37.57	39.48	0
SJA-70-171	CC-69-114	7.27	3.42	.11	1.18	10.78	10.62	21.40	15.85	50.12	34.03	0
Adam Till												
SJA-69- 14	MS-69- 16	8.80	3.60	-0.13	1.04	21.65	6.51	28.16	11.88	25.30	62.82	0
SJA-69- 18	PR-69- 19	6.97	3.93	.01	1.02	12.70	13.50	26.20	21.95	40.39	37.66	0
SJA-69- 19	PR-69- 23	6.37	3.72	.11	1.00	7.89	9.78	17.67	27.88	43.03	28.99	0
SJA-69- 24	PR-69- 34	6.97	3.80	.01	1.09	21.92	17.26	39.18	20.41	44.01	35.58	0
SJA-69- 29	PR-69- 44	6.63	4.07	.04	.91	6.20	7.10	13.30	27.08	37.77	35.15	0
SJA-69- 31	PR-69- 45	7.47	3.67	.05	1.02	13.39	12.49	25.88	16.67	42.97	40.36	0
SJA-69- 38	SR-69- 56	8.53	3.55	-0.08	.94	3.50	5.50	9.00	11.07	31.75	57.18	0
SJA-69- 48	SR-69- 64	6.27	4.07	-0.06	.95	9.28	8.55	17.83	29.38	37.83	32.79	0
SJA-69- 52	SR-69- 65	6.80	4.13	-0.04	.94	8.80	10.90	19.70	25.38	36.81	37.81	0
SJA-69- 62	MA-69- 83	7.20	3.83	-0.03	1.00	9.34	9.86	19.20	20.72	39.17	40.11	0
SJA-69- 64	MA-69- 84	5.67	3.80	.17	1.02	7.51	9.58	17.09	34.85	40.75	24.40	15.00
SJA-69- 67	AC-69- 85	5.20	3.39	.13	1.17	11.85	4.61	16.46	27.92	50.58	21.50	0
SJA-69- 70	AC-69- 85	6.10	4.06	.09	.91	16.22	10.95	27.17	31.88	37.98	30.14	0
SJA-69- 73	MA-69- 91	4.40	3.63	.13	.90	5.80	9.60	15.40	47.35	35.96	16.69	0
SJA-69- 76	MA-69- 92	6.33	3.93	.06	.96	8.30	12.00	20.30	29.00	40.75	30.25	0
SJA-69- 80	MA-69- 94	5.40	3.64	.03	1.01	17.20	15.60	32.80	34.59	42.74	22.67	0
SJA-69- 81	MA-69- 95	6.10	3.27	-0.14	1.15	20.80	17.80	38.60	23.39	44.79	31.82	0
SJA-69- 83	AR-69- 98	7.50	3.03	.25	1.18	6.40	8.40	14.80	9.05	57.19	33.76	0
SJA-69- 90	MO-69-107	7.73	3.93	-0.08	.81	8.20	12.90	21.10	19.19	31.63	49.18	0
SJA-69- 93	MO-69-108	5.40	3.51	.12	1.05	5.98	7.20	13.08	33.28	45.72	21.00	0
SJA-69-103	PR-69- 29	6.83	3.84	.01	1.07	12.70	15.60	28.30	22.21	42.28	35.51	0
SJA-69-119	KH-69-122	5.00	2.58	.02	1.23	10.50	12.60	23.10	30.75	59.37	9.88	0
SJA-69-124	NF-69-124	7.13	4.04	0	.87	10.20	12.60	22.80	23.36	35.90	40.74	0
SJA-69-125	AR-69-125	7.07	3.59	-0.02	1.26	8.60	12.50	21.10	18.30	45.61	36.09	0
SJA-70- 14	OR-70- 9	7.67	4.12	-0.10	.83	8.54	12.10	20.64	20.67	29.90	49.43	0
SJA-70- 17	OR-70- 11	8.43	2.79	.22	1.05	6.08	8.20	14.28	5.04	46.96	48.00	0
SJA-70- 22	FC-70- 21	7.47	3.81	-0.04	.99	4.00	14.10	18.10	17.94	38.34	43.72	0
SJA-70- 29	OR-70- 31	6.80	3.09	.04	1.23	4.90	8.04	12.94	16.50	53.31	30.19	0
SJA-70- 30	OR-70- 27	4.93	2.78	.09	1.13	6.90	12.34	19.24	35.54	52.43	12.03	0
SJA-70- 32	OR-70- 8	6.47	4.06	.09	.91	8.36	10.34	18.70	29.47	37.77	32.76	0
SJA-70- 36	MS-70- 34	6.23	4.00	.03	.93	8.84	13.56	22.40	30.94	37.56	31.50	0

Sample Number	Station Number	Mean	Standard Deviation	Skew-ness	Kurto-sis	Per Cent: Cal-cite	Dolo-mite	Carbon-ate	Sand	Silt	Clay	Sider-ite
Adam Till												
SJA-70- 56	MS-69- 16	8.00	3.90	-0.11	.91	11.38	14.43	25.81	16.80	30.14	53.06	0
SJA-70-860	KR-70- 52	5.23	3.39	.05	1.10	9.16	10.02	19.18	33.10	47.03	19.87	0
SJA-70- 61	MS-70- 43	6.63	3.73	.06	1.15	14.20	14.12	28.32	22.32	45.93	31.75	0
SJA-70- 64	KR-70- 59	6.57	3.97	.13	.93	13.10	10.20	23.30	25.97	39.55	34.48	0
SJA-70- 65	KR-70- 60	6.83	4.10	.05	.91	7.28	10.44	17.72	24.92	37.86	37.22	0
SJA-70- 69	HR-70- 62	6.77	3.35	.12	1.15	1.00	6.38	7.38	18.22	51.62	30.16	0
SJA-70- 77	AR-70- 66	6.20	3.82	.17	1.00	6.72	7.34	14.06	29.95	39.03	31.02	0
SJA-70- 79	AR-70- 68	5.93	3.71	.02	1.05	22.90	13.20	36.10	28.66	44.56	26.78	0
SJA-70- 80	AR-70- 69	6.07	3.76	.16	.94	8.30	8.98	17.28	30.77	39.98	29.25	0
SJA-70- 84	AR-70- 72	7.90	3.85	-0.06	.94	8.20	14.60	22.80	16.08	35.42	48.50	0
SJA-70- 86	AR-70- 74	8.17	3.74	-0.07	.98	7.96	10.90	18.86	14.79	32.66	52.55	0
SJA-70- 88	AR-70- 76	6.93	3.65	.03	1.14	7.70	12.44	20.14	20.09	44.73	35.18	0
SJA-70- 89	AR-70- 77	6.03	3.65	.10	1.00	7.10	10.70	17.80	29.35	42.86	27.79	0
SJA-70- 91	AR-70- 79	6.70	3.66	.05	1.12	9.50	8.40	17.90	20.94	46.72	32.34	0
SJA-70- 93	AR-70- 80	7.80	2.63	.33	1.20	8.20	9.60	17.80	4.53	59.69	35.78	0
SJA-70- 95	AR-70- 83	6.77	3.66	.13	1.07	4.04	5.56	9.60	21.35	46.71	31.94	0
SJA-70-105	MO-69-108	5.77	3.64	.16	1.01	6.62	5.98	12.60	32.29	43.02	24.69	0
SJA-70-116	MA-70- 86	5.87	3.52	.32	.98	4.80	7.00	11.80	34.92	40.17	24.91	0
SJA-70-130	MA-69- 84	5.87	3.80	.16	1.00	8.60	9.96	18.56	32.68	41.45	25.87	0
SJA-70-132	AC-69- 85	5.67	3.87	.16	1.00	5.60	10.20	15.80	34.99	40.09	24.92	0
SJA-70-133	AC-69- 85	7.00	3.51	.14	1.11	4.80	8.00	12.80	17.74	49.71	32.55	0
SJA-70-136	AC-69- 85	6.33	3.86	.12	.97	10.22	9.10	19.32	27.88	41.45	30.67	0
SJA-70-138	AC-69- 85	6.23	3.82	.25	.95	4.80	9.00	13.80	30.42	40.21	29.37	0
SJA-70-141	AC-69- 85	5.70	3.71	.22	.99	6.18	6.36	12.54	34.23	40.79	24.98	0
SJA-70-143	AC-69- 85	5.73	3.78	.22	.97	5.42	10.42	15.84	34.64	39.82	25.54	0
SJA-70-153	MA-70-123	5.80	3.75	.18	.98	4.92	9.90	14.82	33.18	41.25	25.57	0
SJA-70-157	SR-69- 56	8.20	3.49	-0.08	1.01	6.10	6.22	12.32	12.94	33.65	53.41	0
SJA-70-162	LA-70-126	5.33	3.26	.29	1.05	4.80	9.60	14.40	38.13	41.77	20.10	0
SJA-70-165	MA-69- 91	6.13	3.83	.12	.94	9.38	7.48	16.86	29.94	41.19	28.87	2.00
SJA-70-167	AC-70-128	6.37	4.03	.10	.92	8.58	6.90	15.48	28.75	38.76	32.49	0
Lower Till												
SJA-69- 3	MS-69- 4	5.23	3.32	.10	1.07	8.82	8.48	17.30	33.83	47.31	18.86	8.00
SJA-69- 6	MS-69- 12	6.87	3.82	.05	1.11	15.09	15.33	30.42	20.96	44.25	34.79	4.00
SJA-69- 9	MS-69- 14	6.57	4.01	.03	.96	11.76	12.48	24.24	27.46	38.47	34.07	7.00
SJA-69- 10	MS-69- 16	6.70	2.21	.19	2.72	28.55	13.00	41.55	6.92	74.32	18.76	59.00
SJA-69- 11	MS-69- 16	4.80	3.83	.12	.88	24.55	8.48	33.03	43.91	34.39	21.70	18.00
SJA-69- 15	MS-69- 16	4.83	3.73	.14	.89	12.28	7.68	19.96	46.50	33.65	19.85	34.00
SJA-69- 16	MS-69- 16	4.50	3.72	.14	.81	17.78	8.76	26.54	47.09	34.76	18.15	37.00
SJA-69- 17	MS-69- 18	4.77	3.83	.12	.89	9.10	8.80	17.90	43.36	35.85	20.79	19.00
SJA-69- 20	PR-69- 24	7.13	4.07	-0.04	.93	9.49	5.55	15.04	22.88	35.80	41.32	7.00
SJA-69- 22	PR-69- 32	5.27	3.83	.12	.96	10.30	11.40	21.70	39.35	37.08	23.57	12.00
SJA-69- 25	PR-69- 34	5.40	3.42	-0.06	1.07	16.16	10.86	27.02	30.55	49.44	20.01	17.00
SJA-69- 32	PR-69- 45	7.63	3.94	-0.08	.95	9.50	11.30	20.80	18.23	34.68	47.09	0
SJA-69- 45	SR-69- 62	5.23	3.78	.06	.91	9.00	6.00	15.00	37.74	38.62	23.64	23.00
SJA-69- 47	SR-69- 63	4.43	3.75	.15	.86	6.70	4.90	11.60	48.31	33.65	19.04	12.00
SJA-69- 53	SR-69- 67	4.63	3.62	.09	.95	21.44	15.16	36.60	43.25	39.37	17.38	6.00
SJA-69- 55	SR-69- 67	8.00	4.00	-0.14	.88	16.41	11.46	27.87	17.41	29.04	53.55	13.00
SJA-69- 56	SR-69- 67	7.13	4.10	-0.06	.95	27.25	10.23	37.48	22.47	35.66	41.87	3.00
SJA-69- 59	SR-69- 70	5.67	4.32	.02	.78	7.58	8.04	15.62	39.50	30.63	29.87	7.00

Sample Number	Station Number	Mean	Standard Deviation	Skew-ness	Kurto-sis	Per Cent: Cal-cite	Dolo-mite	Carbon-ate	Sand	Silt	Clay	Sider-ite
Lower Till												
SJA-69- 66	AC-69	9.27	3.02	-0.03	.86	8.38	7.71	16.09	4.86	31.11	64.03	.01
SJA-69- 91	MO-69-107	7.60	4.07	-0.07	.78	4.20	8.80	13.00	21.95	29.87	48.18	.01
SJA-69- 92	MO-69-108	5.83	3.47	-0.04	1.17	17.60	14.10	31.70	26.93	49.11	23.96	0
SJA-69- 96	SR-69-110	8.90	3.52	-0.13	.96	8.98	9.54	18.52	10.35	27.87	61.78	.01
SJA-69- 97	SR-69-110	4.97	3.74	.08	.92	11.01	9.75	20.76	40.46	38.73	20.81	6.00
SJA-69-108	CC-69-114	5.60	3.47	.07	1.12	25.75	20.13	45.88	29.16	48.57	22.27	3.00
SJA-69-109	CC-69-114	6.43	3.73	.06	1.08	20.25	21.73	41.98	24.61	44.09	31.30	3.00
SJA-69-113	KR-69-118	5.77	3.65	-0.03	1.08	17.00	11.10	28.10	29.32	45.22	25.46	.01
SJA-69-130	AR-69-125	4.90	3.58	.15	.99	8.70	9.10	17.80	42.36	38.47	19.17	0
SJA-70- 12	OR-70- 7	7.03	3.85	.03	1.04	12.30	13.44	25.74	20.71	42.37	36.92	3.00
SJA-70- 20	FC-70- 21	7.20	4.07	-0.05	.91	12.00	14.20	26.20	21.78	35.21	43.01	7.00
SJA-70- 23	OR-70- 24	5.50	3.75	.19	.98	6.36	9.20	15.56	36.90	38.19	24.91	2.00
SJA-70- 35	MS-70- 32	5.63	4.27	.08	.86	8.80	13.50	22.30	36.81	34.94	28.25	6.00
SJA-70- 37	MS-70- 34	6.70	4.16	.02	.86	7.06	14.20	21.26	27.93	35.37	36.70	.01
SJA-70- 42	MS-69- 18	5.07	3.73	.05	.96	8.86	14.40	23.26	38.53	40.11	21.36	7.00
SJA-70- 46	MS-70- 39	4.87	3.79	.09	.88	10.44	9.42	19.86	43.04		20.53	13.00
SJA-70- 47	MS-70- 40	7.60	4.13	-0.11	.88	13.66	12.44	26.10	20.11	31.18	48.71	8.00
SJA-70- 48	MS-70- 40	3.93	4.05	.58	.93	4.56	5.38	9.94	65.87	14.48	19.65	39.00
SJA-70- 49	MS-70- 40	5.80	4.22	.08	1.01	12.40	7.70	20.10	29.66	40.87	29.47	10.00
SJA-70- 50	MS-70- 41	5.00	3.49	.04	1.05	15.30	12.66	27.96	35.94	45.25	18.81	6.00
SJA-70- 51	MS-70- 41	4.73	3.70	.14	.94	9.22	7.40	16.62	43.44	37.32	19.24	17.00
SJA-70- 52	MS-69- 16	5.03	4.16	.20	.78	6.00	4.16	10.16	46.33	27.12	26.55	39.00
SJA-70- 53	MS-69- 16	4.73	3.66	.11	.90	7.60	6.40	14.00	43.11	37.65	19.24	26.00
SJA-70- 54	MS-69- 16	4.80	3.76	.16	.88	10.22	5.60	15.82	44.56	34.46	20.98	23.00
SJA-70- 57	MS-69- 16	4.40	3.75	.23	.86	4.20	7.80	12.00	50.09	31.09	18.82	30.00
SJA-70- 58	MS-69- 16	5.00	3.84	.09	.87	11.78	4.98	16.76	41.13	35.30	23.57	24.00
SJA-70- 60	MS-70- 43	5.80	3.80	.02	1.06	11.40	11.00	22.40	29.20	44.77	26.03	0
SJA-70- 81	AR-70- 70	5.37	3.52	.03	1.05	13.62	10.62	24.24	32.03	46.51	21.46	.01
SJA-70- 94	AR-70- 81	5.40	2.12	-0.07	1.54	7.04	8.10	15.14	18.78	72.55	8.67	0
SJA-70-139	AC-70-112	6.43	3.89	.10	.93	9.50	10.60	20.10	28.36	40.00	31.64	10.00
SJA-70-172	CC-69-114	5.57	3.30	.08	1.11	12.94	18.78	31.72	28.32	49.91	21.77	6.00
SJA-70-173	CC-69-114	7.07	3.39	.03	1.18	10.82	10.62	21.44	17.37	49.97	32.66	6.00
SJA-70-176	FC-70-130	7.20	4.11	-0.02	.88	13.02	12.40	25.42	28.80	34.02	43.18	5.00
SJA-70-177	FC-70-131	5.83	4.25	.13	.84	7.02	7.94	14.96	36.67	33.26	30.07	22.00

APPENDIX B

Stratigraphic Sections

The following three sections are described: 1) 24M on Missinaibi River, 2) the lower 4 km of Adam Creek, and 3) the Moose River Crossing section. 24M is an excellent exposure of pre-Missinaibi units. Along Adam Creek, Missinaibi Formation and post-Missinaibi units are clearly exposed. Moose River Crossing section exposes Missinaibi Formation, is a potential source of fossils, and should be studied in detail by Quaternary paleontologists. This section is the most accessible of the three.

1) STATION 24M, MS-69-16, right bank of Missinaibi River, Amery Township, 50°19'N Lat., 82°42'W Long.

This section was described by Terasmae and Hughes (1960a, p. 3) and is the site of one of their pollen profiles in the Missinaibi Formation. The section is several hundred metres long and thicknesses of units vary along the section; therefore, thicknesses reported by Terasmae and Hughes do not necessarily correspond to thicknesses reported here. Station 24M is shown in Figures 3 and 4.

Sediments	Bed thickness (metres)	Unit thickness (metres)
covered at top		
Silt and clay: brownish grey, calcareous, horizontal bedding, probably marine, not well-exposed.	1.5	1.5
Till: (Kipling Till) (Adam Till): brownish, silty till at top; bluish grey to dark olive-grey (Munsell notation, 5Y-4/1 to 5Y-4/2), very clayey, calcareous, massive jointing, contains very few pebbles or boulders. See samples SJA-69-14, 3 m above lower contact, SJA-70-56, 4 m above lower contact; no contact observed between brownish, silty till at top and grey, clayey till below.	6.0	6.0
Clay and silt (lacustrine member, Missinaibi Formation): greenish grey clay with augens of buff calcareous silt, badly sheared, very little plant material.	1.0	

Sediments	Bed thickness (metres)	Unit thickness (metres)
-greenish grey clay and tan silt rhythmites, not disturbed, contains plant material in silt component of rhythmites towards bottom half of unit, gradational with beds below, jointed, reddish iron oxide on joint surfaces.	2.2	
-fissile, brownish grey peaty silt.	0.28	
-very compact, platey, peaty silt, noncalcareous except in a few non-peaty, silt lenses; cliff-former.	0.33	
-blackish brown, peat laminated sand and silt, noncalcareous, contains flattened sticks, and moss at base (forest-peat bed member).	0.19	4.0
Sand, gravel, and diamicton: (fluvial member?): variable thickness (up to 2 m at 24M). -greenish brown to grey diamicton, noncalcareous, contains plant fragments, a few coarse sand lenses with reddish iron oxide, rotten carbonate pebbles in lower few cm where diamicton contains lenses of partially leached gravel, contact vague to sharp, and irregular. (This is interpreted as 'buried soil' and is described as a "till-like deposit" in Terasmae and Hughes' (1960a) pollen profile; note pollen content.)	0.31	
-gravel and sand, vague stratification, in places accentuated by brown, organic, silty sand lenses, slightly calcareous (variable thickness).	0.69	1.0
Till (Till III): olive-grey (5Y-5/2 to 2.5Y-3/2, grey) with red ferric oxide sand lenses, oxidized, crumbly, variable thickness, contains a few boulders (samples SJA-69-11 and SJA-70-54).	2.0	2.0

Sediments	Bed thickness (metres)	Unit thickness (metres)
Gravel, sand, and silt (intertill sediments II-III): yellowish grey fine sand and silt, horizontally laminated to ripple-laminated, current southward, overlying gravel and sand (25 cm) over yellow sand (75 cm) with brownish grey till-like lenses up to 15 cm thick, unit erodes to form bench along section, also aquifer.	1.0	2.0
Till (Till II): olive-grey (5Y-4/2), gritty, compact, appears reddish brown from distance, breaks into 10 x 2 x 4 cm prisms, calcareous, contains a few cobbles, a prominent cliff-former along section (samples SJA-69-16, SJA-70-52 + 58).	5.0	5.0
Sand, gravel, silt, clay (intertill sediments I-II):		
-coarse sand, slightly calcareous, oxidized.	0.50	
-till-like lenses similar to till above and lenses in intertill unit II-III.	0.30	
-compact, medium, yellow sand.	1.90	
-coarse, rusty, cemented sand and gravel.	2.00	
-till-like lens, pebbly (35 cm).		
-coarse yellow (oxidized) sand, vague cross-strata indicate current toward south.	1.50	
-grey silt-green clay rhythmites, iron stain on joint surfaces, 12 rhythmites counted, unit thickens 300 m downstream, 40 some rhythmites, 1 m total thickness.	0.30	6.5
Till (Till I): sandy, extremely compact, calcareous, oxidizes to a mauve colour, contains contorted grey sand and silt lenses (samples SJA-69-10, 15, SJA-70-53, 57). Note: sample 10, 66% clay may have been in an inclusion of clayey sediment. Lower contact below low river mark.		4.0
Total Thickness		32 m

2) ADAM CREEK, Station AC-69-85, along the lower 4.5 km of Adam Creek, Sanborn and Kipling Townships, 50°13'-14.5'N Lat., 82°06'W Long.

Adam Creek is used as a diversion channel for high spring discharge around Little Long, Smoky Falls, Harmon and Kipling dams on Mattagami River. There is almost continuous exposure for some 30 km. It is accessible by canoe for the lower 3 km, then it can be traversed on foot (with difficulty) or by helicopter. The units are described in general. Figure 26 is a fence diagram showing the relative location of samples; the 'posts' represent measured sections. Fence diagram legend, Figure 2A, applies in Figure 26.

Sediments	Range of thickness (m)
Top of Section	
Terrestrial unit	
Peat: not shown on fence diagram	0.25-1.5
Sand and gravel (alluvium = a): in most cases was deposited when creek first used as a diversion channel.	0.50-2.0
Marine unit	
Clay and silt: brownish grey to buff, calcareous, in places contains many marine shells.	1.0 -2.5
Clay-pebble gravel: red to reddish brown, pink on drying, clay-pebble gravel on top, overlying bluish grey gravel, calcareous, contains marine foraminifera.	0.20-0.50
Glaciolacustrine unit	
Clay and silt rhythmites, greyish brown to bluish grey.	0-0.50
Diamicton: brownish grey pebbly silt and clay, in places with inclusions of coarse to medium sand, up to 1.5 m long, 40 cm thick. - a 15 cm thick bed of clean, pea-gravel was observed locally, directly beneath marine clay-pebble gravel and above Kipling Till.	0-1.5
KIPLING TILL	
Till: silty, brownish grey where fresh, light brown to pinkish brown where oxidized, calcareous, breaks off in flakes, striated boulder pavement at base, very few boulders.	2.0-5.0

Sediments	Range of thickness (m)
Friday Creek sediments	
Gravel, sand, silt and clay: buff gravel and sand, overlain by ripple laminated silt and bluish grey clay and tan silt rhythmites (about 12 counted); otherwise a very compact, non-stratified bluish grey sand and silt with boulders; an aquifer.	2.0
ADAM TILL	
Till: silty to clayey, grey to olive-grey, or greyish green, moderately calcareous, compact, very few boulders, contains marine shells.	10.0-15.0+
MISSINAIBI FORMATION	
Silt and clay rhythmites (lacustrine member): grey, silt and clay, some plant material in silt component, becoming very organic, massive, almost peaty at base where sticks and moss occur, a few calcareous, cross-laminated, light tan silt lenses in lower 30 cm, bottom contact dips gently (2 to 5°) upstream and passes below water level. - sharp contact.	4.0+
Silty clay: olive-grey (oxidized) to bluish grey (fresh) upper few cm stained blackish brown and non-calcareous; contains wood fragments (Picea or Larix, ident. R. Mott, G.S.C., Wood Ident. Rept., No. 71-6, SJA-70-140, unpubl. intern. rept.), fragments of unidentified gastropod shells, Hiatella arctica shells and fragments, marine foraminifera and ostracoda.	0.05-0.60
Gravel: oxidized, compact, matrix of sand and silt, a few carbonate boulders are cracked apart along bedding, fragments still parallel and voids filled with matrix, boulders, some very angular, up to 40 cm diameter.	0.20-1.2
Silt and clay: bluish grey, very compact, calcareous, hint of silt-clay rhythmites, but very contorted, sheared and bedding very faint.	0.30

Sediments	Range of thickness (m)
Lower till (undifferentiated)	
Till: variable texture and colour due to incorporation of sand, kaolin and lignite of Mattagami Formation (Cretaceous?), black, sandy till near mouth of creek along bottom of section, dark green clayey near falls (sample SJA-69-66).	
BEDROCK	
Cretaceous (?) silica sand, gravel, kaolin, and lignite. Gravel (chert and quartz clasts) up to 3.5 cm diameter; all non-silica minerals have been completely weathered out leaving 'vuggy' pebbles.	2m+
Devonian (?), Sextant Formation, feldspathic sandstone pink to reddish brown, contains lignitized wood fragments.	1.0+
Total Thickness	about 30 cm

2) MOOSE RIVER CROSSING SECTION, Station MO-69-107, on the northwest side of Moose River 1 km (.6 mi.) downstream from bridge at Moose River Crossing, Canfield Township, 50°19'N Lat., 81°18'W Long.

Section about 5 m high but extends for more than 450 m along bank. Gypsum of the Middle Devonian Moose River Formation crops out along this stretch of the river. The present irregularity of the interglacial surface may be due to solution of the gypsum; the modern surface here is pitted with sink holes.

Figure 27 illustrates most of the section. The peat bed is slightly exaggerated horizontally; it is exposed for about 25 m. The columns in the fence diagram represent points where the section was trenched and measured. Samples located on Figure 27 are discussed below after general description of units. The reader should refer to Figure 12 in text for pollen diagram of peat bed.

Note: This section was revisited in 1972, and was sampled and measured in detail.

Sediments	General thickness (m)
Top of Section	
Sand and gravel (alluvium): noncalcareous in upper 20 cm, contains a few marine shell fragments, oxidized.	1.0-1.2

Sediments	General thickness (m)
Silt and clay (marine): brownish grey, calcareous, contains a few marine fossils, mostly eroded away.	<1.0
Till (Adam or Kipling Till or both; interpreted tentatively as Adam Till): clayey, silty, olive-grey, (5Y-5/2) with red iron oxide mottles; contains fragments of Missinaibi Formation.	1.0-1.5m
Missinaibi Formation	
Silt-clay rhythmites: lacustrine member, green clay, tan silt with plant debris, more organic toward base where it rests on either forest bed (upriver end of section) or on peat (downriver). Beaver-chewed wood fragments near base of peat. Forest-peat bed rests on weathered silt, sapropelic mud (>2m), or till (see descriptions of samples 106, 107, 108 below).	0.2-1.5
Sand, silt and clay: bluish grey, diamicton; contains marine shell fragments (Hiatella arctica); extreme upriver end of section.	<.5
Till (lower till): clayey, slightly calcareous (sample SJA-69-91, 1.5 m below peat-till contact); non-calcareous in upper 40 to 60 cm, very dark grey (5Y-3/1) bluish grey colour when dry is very distinctive feature for local identification; unknown thickness.	>2.0
Bedrock: sucrosic gypsum and brecciated dolostone, limestone and gypsum.	

Sample No.	Comment
SJA-70-106	greenish grey massive silty clay with fine organic detritus; leached of carbonate. See pollen assemblage in Figure 13. Has forest bed on top (SJA-70-107); interpreted as buried soil.
SJA-70-107	Wood of Picea or Larix sp. (Spruce or Tamarack) slightly compressed and humified (Ident. R. Mott, G.S.C., Wood Ident. Rept. No. 71-5, unpubl. intern. rept.).
SJA-70-108	Fossiliferous sandy, silty muck, compact.

Sample No.	Comment
	a) Arthropoda: Coleoptera (Beetles); 2 genera, Donacia and Hydrobius, indicate aquatic environment, semi-permanent pond (Ident. J. Mathews, Univ. of Alberta). b) Mollusca: Gastropoda and Pelecypoda, at least 4 species, unidentified. c) Porifera: sponge spicules. d) Diatoms, Epithemia sp. most abundant (Ident. S. Lichti-Federovich, G.S.C., Diatom Report SLF 70-2, unpubl. intern. rept.). e) Many seeds including: Najas flexilis, Scirpus cf. fluviatilis, Scirpus validus; Potamogeton sect. Eupotamogeton and P. sect. Coleogeton, Ranunculus? Hypericum sp., Eleocharis cf. palustris, Polygonum cf. sagittatum, Chenopodiaceae seeds and Chara oogonium, seeds of Betula sp. and female catkin of Betula cf. pumila or B. cf. glandulosa. f) Mosses; Drepanocladus exannulatus most frequent. g) Pollen assemblages: Picea = Pinus = Betula = approx. 21%; abundant Graminae, Chenopodiaceae, and Cyperaceae. (Seeds ident. J. McAndrews, Royal Ontario Museum; mosses examined by M. Kuc, G.S.C.; pollen counted by S. Lichti-Federovich, G.S.C.).
SJA-70-108	Comments of the various specialists can be summarized as such: The fossil assemblage indicates an oligotrophic, semi-permanent pond or small lake. Beaver-chewed wood and a species of fish (family Cyprinidae) were discovered in 1972 (National Museums of Canada specimen no. 21333). Paleoenvironmental studies on this section are presently underway.

APPENDIX C

Fossil list of the Bell Sea (compiled from unpublished reports).

Species (X = if present)	Locality (Figure 6)				
	1	2	3	4	5
Protozoa					
Foraminiferida					
Elphidium incertum (Williamson)	X				
Elphidium incertum clavatum Cushman	X	X	X		X
Protoelphidium orbiculare (Brady)	X	X	X	X	X
Elphidium bartletti Cushman	X			X	
Dentalina frobisherensis Loeblich and Tappan				X	
Dentalina ittai Loeblich and Tappan				X	
Esosyrinx curtus (Cushman and Ozawa)				X	
? Sigmorphina undulosa (Terquem)				X	
Glandulina laevigata d'Orbigny		X		X	
Islandiella teretis (Tappan)				X	
? Fissurina sp.		X			
Lagena parri Loeblich and Tappan		X			
Oolina hexagona (Williamson)		X			
Buccella frigida (Cushman)		X			
Quinqueloculina norvangi Boltovskoy?					X
Mollusca					
Gastropoda (undetermined)				X	
Pelecypoda					
Clinocardium sp.	X				
Hiatella arctica (Linné)	X		X	X	X
Macoma sp.	X			X	
Mya sp.	X				
Arthropoda					
Cirripedia					
Balanus sp.	X				
Ostracoda					
Heterocyprideis sorbyana (Jones)				X	
Palmanella limicola (Norman)		X		X	
Acanthocythereis? cuspidata (Brady and Crosskey)				X	
Eucytheridea macrolaminata Elofson				X	
Normanicythere leioderma (Norman) or N. concinella Swain				X	
Cytheropteron pyramidale Brady				X	X
Elofsonella concinna (Jones)		X			
Semicytherura cf. S. concentrica (Brady, Crosskey and Robertson)			X		X
	KR-61	KR-54	AC-85	AR-125	AR-83
Locality 1 is GSC-Loc no. 86500 Locality 2 is GSC-Loc no. 86502 Locality 3 is GSC-Loc no. 86503 Locality 4 is GSC-Loc no. 86501 Locality 5 is GSC-Loc no. 86504	Station Number (Figure 1)				

APPENDIX D

Location and site descriptions of modern pollen samples (see Figure 15).

1. From King and Kapp, 1963. Their composite assemblage for Lake Timagami region, collected from stumps, lakes and open bogs.

2. 13 km east of Otter Rapids, 50°12'N, 81°28'W. Open Sphagnum bog (no trees within 100 metres of sample). Sampled water and Sphagnum about 20 cm below surface. Collected by R.G. Skinner, August 26, 1969.

3. 12 km north of Algocen Mines, between Pivabiska and Soweska rivers, 50°16'N, 82°55'W. In open Sphagnum and sedge (Eriophorum) bog; a few black spruce (Picea mariana) present less than 2 m high. Sampled water and Sphagnum 20 cm below surface. Collected by R.G. Skinner, August 24, 1969.

4. Between Kwataboahegan River and Onakawahegan River, 51°12'N, 81°52' W. In open Sphagnum bog. Sampled water and Sphagnum 20 cm below surface. Collected by R.G. Skinner, August 25, 1969.

5. 21.5 km southeast of Forks of Albany, 51°02'N, 84°23'W; lake bottom. Collected by J. Terasmae, 1967.

6. 65 km east of Forks of Albany, 51°07'N, 84°03'W; lake bottom. Collected by J. Terasmae, 1967.

7. 64 km south-southeast of Ghost River, 51°13'N, 83°35'W. a) lake bottom, b) bog surface. Collected by J. Terasmae, 1967.

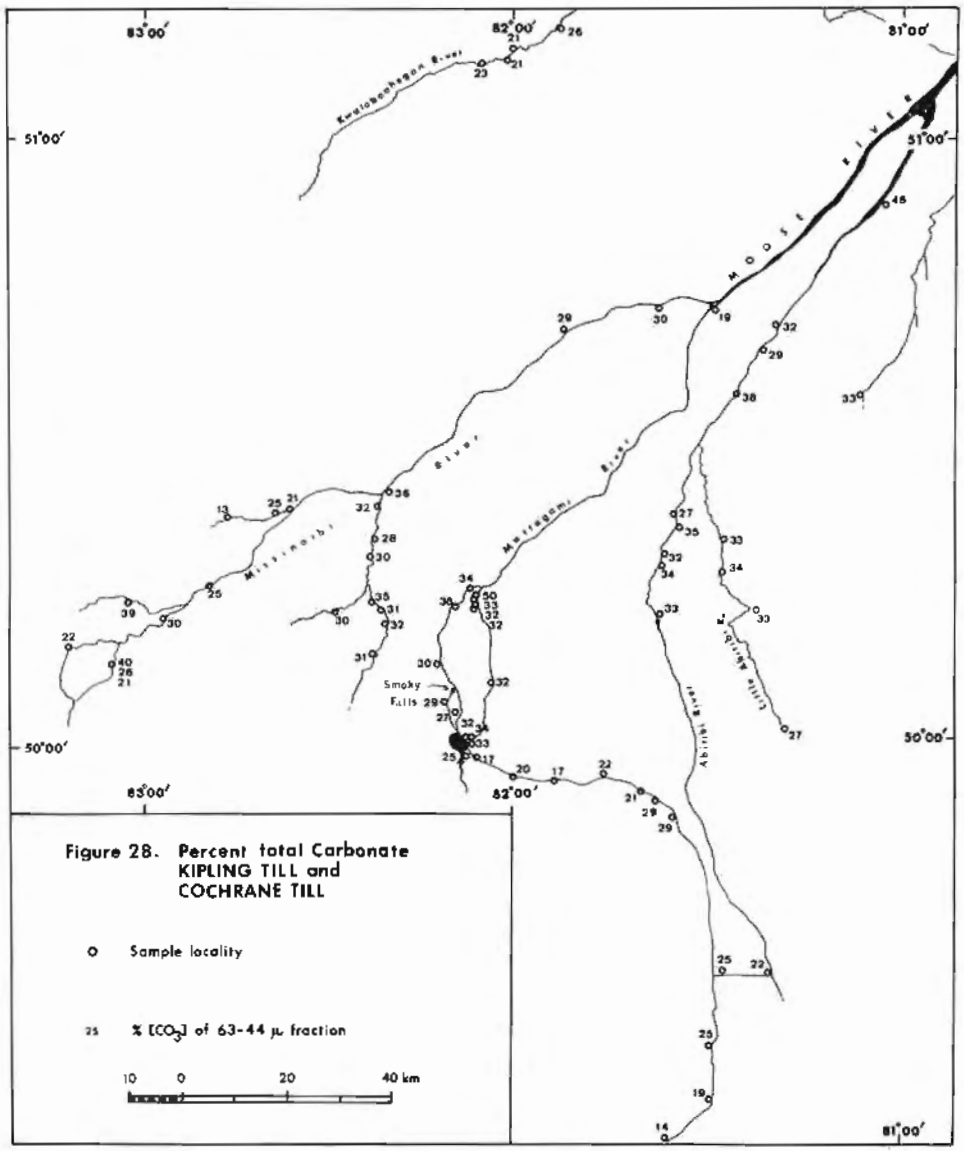
8. 73 km northwest of Forks of Albany, 51°23'N, 83°43'W, bog surface. Collected by J. Terasmae, 1967.

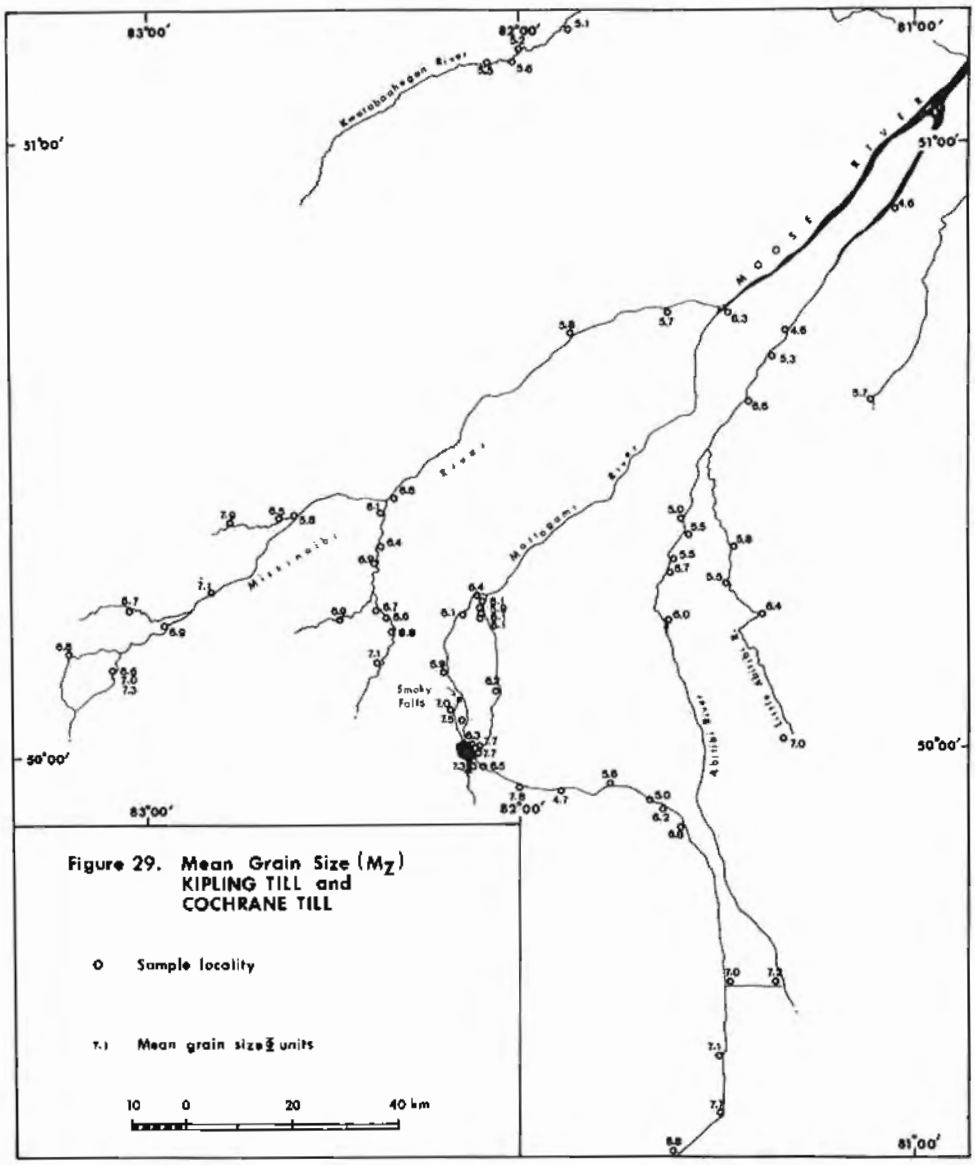
9. 12 km northeast of Fishing Creek Island, Albany River, 51°57'N, 82°42' W. a) lake bottom, b) bog surface. Collected by J. Terasmae, 1967.

Sample 1 counted by King and Kapp, 2 to 4 by R.G. Skinner, and 5 to 9 by S. Lichti-Federovich.

APPENDIX E

Maps showing %[CO_3] and M_z for Kipling and Cochrane tills (Figures 28 and 29).




83°00'
82°00'
81°00'
51°00'
50°00'
Kwataboahegan River
MOOSE RIVER
Missinaibi River
Mattagami River
Abitibi River
Little Abitibi River
Smoky Falls
Figure 29. Mean Grain Size (M_Z)
KIPLING TILL and
COCHRANE TILL
Sample locality
Mean grain size Φ units
10 0 20 40 km

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