

Sangamon and Pre-Sangamon Interglaciations in the Hudson Bay Lowlands of Manitoba

Les interglaciations du Sangamonien et du pré-Sangamonien dans les basses terres hudsoniennes du Manitoba

Interglaziale des Sangamonium und Präsangamonium im Tiefland der Hudson Bay

Lynda A. Dredge, Alan V. Morgan and Erik Nielsen

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The Last? Interglaciation in Canada
Le dernier (?) interglaciaire au Canada

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Article abstract

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SANGAMON AND PRE-SANGAMON INTERGLACIATIONS IN THE HUDSON BAY LOWLANDS OF MANITOBA*

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ABSTRACT The manuscript documents voluminous new and published stratigraphic and paleontologic data from a region unique in North America, and possibly the world, in that it has abundant natural exposures recording a long and consistent succession of Quaternary tills and fossiliferous intertill sediments. Two major non-glacial intervals have been recognized under tills. Various non-glacial sediments have been correlated using their stratigraphic position, pollen analysis, and beetle assemblages, and are found to be equivalent to the Missinaibi Formation in Ontario. Non-finite high pressure radiocarbon dates, and aspartic acid ratios on wood suggest that the uppermost and most prevalent interval is of Sangamonian age. The Sangamonian record begins and ends with cool intervals, separated by a warmer period when climates were similar to or slightly warmer than present, and when the northern treeline was near its present position. The interval began with a high glacioisostatic sea, which regressed to levels below present Hudson Bay datum. The Sundance paleosol and silt beds below the Amery till relate to an earlier interglaciation characterized by cool tundra conditions. As an analogue for predicting future global change, the record preserved in the Hudson Bay Lowlands is second to none: additional intensive research is strongly recommended.

RÉSUMÉ *Les interglaciations du Sangamonien et du pré-Sangamonien dans les basses terres hudsoniennes du Manitoba.* L'article renferme une très grande quantité de données stratigraphiques et paléontologiques inédites ou déjà publiées sur une région unique en Amérique du Nord, voire dans le monde, en raison des nombreux affleurements naturels qu'elle renferme et qui témoignent d'une longue succession continue de tills quaternaires et d'intertills fossilifères. On a reconnu deux intervalles non glaciaires sous les tills. Sur la base de leur position stratigraphique, de l'analyse pollinique et des assemblages de coléoptères, on a corrélé les divers sédiments non glaciaires à la Formation de Missinaibi, en Ontario. Les datations au radiocarbone obtenues à haute pression et les taux d'acide aspartique sur bois laissent voir que l'intervalle supérieur dominant date du Sangamonien. Le début et la fin du Sangamonien étaient des intervalles froids séparés par une période plus chaude pendant laquelle le climat était aussi chaud ou un peu plus que maintenant et que la limite des arbres était à peu près à la même latitude. Le début de l'intervalle a été marqué par la présence d'une mer glacioisostatique, qui a par la suite régressé à des niveaux inférieurs au niveau actuel de la baie d'Hudson. Le paléosol de Sundance et les lits de silt sous-jacents au till d'Amery datent d'une interglaciation antérieure caractérisée par un climat froid de toundra. Comme point de comparaison à l'étude des changements à l'échelle du globe, les données préservées dans les basses terres de la baie d'Hudson sont uniques: on doit donc y effectuer des recherches intensives.

ZUSAMMENFASSUNG *Interglaziale des Sangamonium und Präsangamonium im Tiefland der Hudson Bay.* Der Artikel enthält umfangreiche neue und schon publizierte stratigraphische und paläontologische Daten über eine einzigartige Gegend in Nordamerika und möglicherweise in der ganzen Welt; dies wegen ihrer zahlreichen natürlichen Aufschlüsse, die eine lange und beständige Folge von Quaternär-Grundmoränen und fossilhaltigen Zwischentill-Sedimenten belegen. Zwei grössere nichtglaziale Intervalle wurden unter den Grundmoränen festgestellt. Verschiedene nichtglaziale Sedimente wurden mittels ihrer stratigraphischen Position, Pollen-Analyse und Käfer-Ansammlungen mit der Missinaibi Formation in Ontario korreliert, mit der sie übereinstimmen. Nicht begrenzte, unter Hochdruck gewonnene Radiokarbon-Daten und der Anteil aspartischer Säure auf Holz lassen darauf schliessen, dass das oberste und beherrschende Intervall aus dem Sangamonium stammt. Der sangamonische Beleg beginnt und endet mit kalten Zwischenzeiten, unterbrochen durch eine wärmere Periode, während der das Klima ähnlich oder etwas wärmer als das gegenwärtige war und die nördliche Baumgrenze sich in der Nähe ihrer heutigen Position befand. Das Intervall begann mit einem hohen glacioisostatischen Meer, welches auf niedrigere Niveaus als das heutige Hudson Bay-Datum zurückging. Der Paläoboden von Sundance und die Schlammbetten unter der Amery-Grundmoräne gehören zu einem früheren Interglazial, welches durch kühle Tundra-Bedingungen gekennzeichnet ist. Als Vergleichsbasis für die Voraussage einer künftigen weltweiten Veränderung ist der im Tiefland der Hudson Bay erhaltene Beleg von einzigartigem Wert: zusätzliche intensive Forschung wird nachdrücklich empfohlen.

* Geological Survey of Canada Contribution No. 48688

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INTRODUCTION

In recent years, predicting global change has become increasingly important for long term environmental planning. Since we presently live part way through an interglaciation which began more than 10,000 years ago, a first step towards predicting future change is to examine the course of previous interglacial intervals and evaluate the present against them. This paper explores the range of climatic and environmental conditions experienced in mid-Canada during the last interglaciation. The thick Quaternary sequences exposed along rivers in the Hudson Bay Lowlands of Manitoba provide a long record of waxing and waning ice sheets, and climatic changes. Because this area lies in the central part of the region covered by the Laurentide Ice Sheet, the record of non-glacial events preserved here is a good indicator of true interglaciations. Note that throughout this paper we refer to interglaciations as times when the continental ice sheets had disappeared, not necessarily as times of warm climates; likewise, interstades are regarded as times of partial ice cover, and not necessarily cool climates.

The sediments consist of till sheets representing multiple glaciations and/or changing ice flow patterns, and intertill sediments. The intertill sediments are of two types. First, and of chief concern, are sequences of silt, peat, gravel, clay, and marl, containing pollen, wood, beetle parts, and other microfossils. These sediment sequences are considered to have been deposited during non-glacial intervals. The second type consists of sand and gravel seams deposited between till sheets and intercalated with them; they tend to be either barren of biota, or contain reworked organics. These units are thought to be subglacial or englacial in origin, and are not discussed further.

This paper reviews what is known about the last and penultimate interglaciations in northern Manitoba, concentrating on an inventory of the interglacial sites, including diagrammatic descriptions of each site, and more detailed descriptions of the interglacial units. The Manitoba non-glacial units are correlated with similar deposits from other parts of the Hudson Bay Lowlands and some conclusions about the Sangamonian climate and paleogeography are drawn.

PRESENT CLIMATE AND VEGETATION

The southern part of the area shown on Figure 1 has a boreal climate, while that of the northern part is subarctic. Conditions are more rigorous near the coast than farther inland. The mean annual air temperature is -7.3°C at Churchill and -4.8°C at Gillam. Daily means at Churchill range between 12°C for July and -28°C for January; at Gillam they range from 15°C to -26°C . The frost-free period is 110 days at Churchill and 116 days at Gillam. Precipitation averages 400 mm annually at the Churchill airport, and 280 mm at Gillam. At both localities, about half the precipitation falls as snow. Prevailing winds are from the northwest both winter and summer, at an average velocity of 22 km/hour (Environment Canada, 1975).

The vegetation in the northeasternmost part of the region (Figs. 1 and 2, Table I) consists primarily of tundra shrub heath, although there are areas of grass and sedge in wetlands near

the coast, and scattered stunted trees. The tundra areas farther south are covered with thick bog deposits containing abundant quantities of ground ice forming polygons (Fig. 3). The surface vegetation there is a lichen-heath association, with scattered alders, tamarack and spruce. An open forest-tundra transition zone runs diagonally from northwest to southeast across the region (Fig. 4). The boreal forest consists of stands of black spruce (Fig. 5) with a *Ledum-Sphagnum-Vaccinium* ground cover. Tamarack, birch, sedge, alder and grasses are also common in wet areas.

STRATIGRAPHIC FRAMEWORK

The lithostratigraphic record for northern Manitoba has been described in detail in other publications (Dredge and Nielsen, 1985, 1987; Nielsen *et al.*, 1986; Dredge *et al.*, 1986, Klassen, 1986, and Dredge and Nixon, in press). The oldest till, the Sundance till of Nielsen *et al.* (1986; and Fig. 6), is a sandy till with granitic clasts, and was emplaced by a southward-moving glacier that crossed the entire region. The paleosol in the Sundance till exposed in the Sundance section and the correlative lower clay bed in the Limestone section developed during a succeeding non-glacial interval. The silty, calcareous grey Amery Till (Klassen, 1986), directly above these units marks a major ice flow towards 200 or 225° as indicated by striated boulder pavements at Sundance. The Sangamonian interglacial beds, called variously the Nelson River sediments along the Nelson River by Nielsen *et al.* (1986) and the Gods River Sediments along the Gods River by Klassen (1986), overlie the Amery Till. The Wigwam Creek Formation (Klassen, 1986), the silty, grey, calcareous Long Spruce till, and the overlying brown clayier Sky Pilot till are considered to be products of the Wisconsin Glaciation and were emplaced by ice flow from

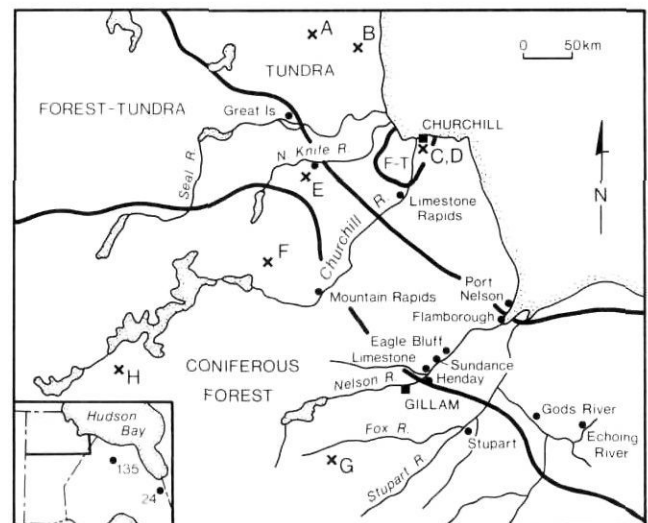


FIGURE 1. Location map showing regional vegetation types for northern Manitoba (after Rowe, 1972), interglacial sites (●), and contemporary pollen spectra sites (xA) listed on Table I.

Carte de localisation des différents types de végétation trouvés au nord du Manitoba (selon Rowe, 1972), les sites interglaciaires (●) et les sites de spectres polliniques modernes (xA) énumérés au tableau I.



FIGURE 2. Tundra vegetation at site A (Fig. 1): sedge and grass communities with ericaceous shrubs and scattered stunted trees (GSC 204735-E).

Végétation de tundra au site A (fig. 1): communautés de carex et d'herbes avec des éricacées et des arbres rabougris dispersés (GSC 204735-E).



FIGURE 3. Vegetation at Limestone Rapids: extensive areas of lichen heath on sphagnum bog with sporadic stands of stunted spruce. Ice wedge cracks in foreground (GSC 204735-D).

La végétation aux Limestone Rapids: vastes étendues recouvertes de lichens sur tourbière à sphaigne et parsemées de bosquets d'épinettes rabougrées. Au premier plan, fissures de coins de glace (GSC 204735-D).



FIGURE 4. Forest-tundra transition at site E (Fig. 1): spruce forest growing on bog and punctuated by open bogs, fens, and thermokarst ponds (GSC 204035-J).

Transition entre la forêt et la toundra au site E (fig. 1): forêt d'épinettes croissant en milieu de tourbière et parsemée de tourbières ouvertes ombrothropes et minérothropes et d'étangs thermokarstiques (GSC 204035-J).

FIGURE 5. Boreal forest at Gillam: black spruce forest with willow and dwarf birch on wetter sites, and ground cover of ledum, vaccinium, and hummock forming mosses (GSC 204735-C).

La forêt boréale à Gillam: forêt d'épinettes noires avec saules et bouleaux nains dans les sites plus humides et couverture de sol composée de lédon, de vaccinium et de mousse formant des tertres (GSC 204735-C).

TABLE I

Contemporary pollen spectra from northeastern Manitoba (after Lichti-Federovich and Ritchie, 1968); Numbers express frequency as percent of total site locations are shown on Fig. 1

Site	Picea	Pinus	Betula	Total AP	Alnus	Salix	Total Shrubs	Graminae	Artemisia	Cyperaceae	Total NAP	Biome
A	31	20	16	67	15	1	16	1	1	0	17	Tundra
B	13	15	29	57	22	2	25	2	2	7	18	
C	33	26	5	64	6	1	7	1	2	14	29	Forest-Tundra
D	21	22	4	48	3	0	3	1	0	42	49	
E	35	29	7	72	13	2	16	1	0	6	12	Open Forest
F	42	24	13	80	11	1	11	0	3	5	9	
G	41	37	6	85	7	1	8	1	2	2	7	Closed Forest
H	40	50	2	92	3	1	4	0	1	1	4	

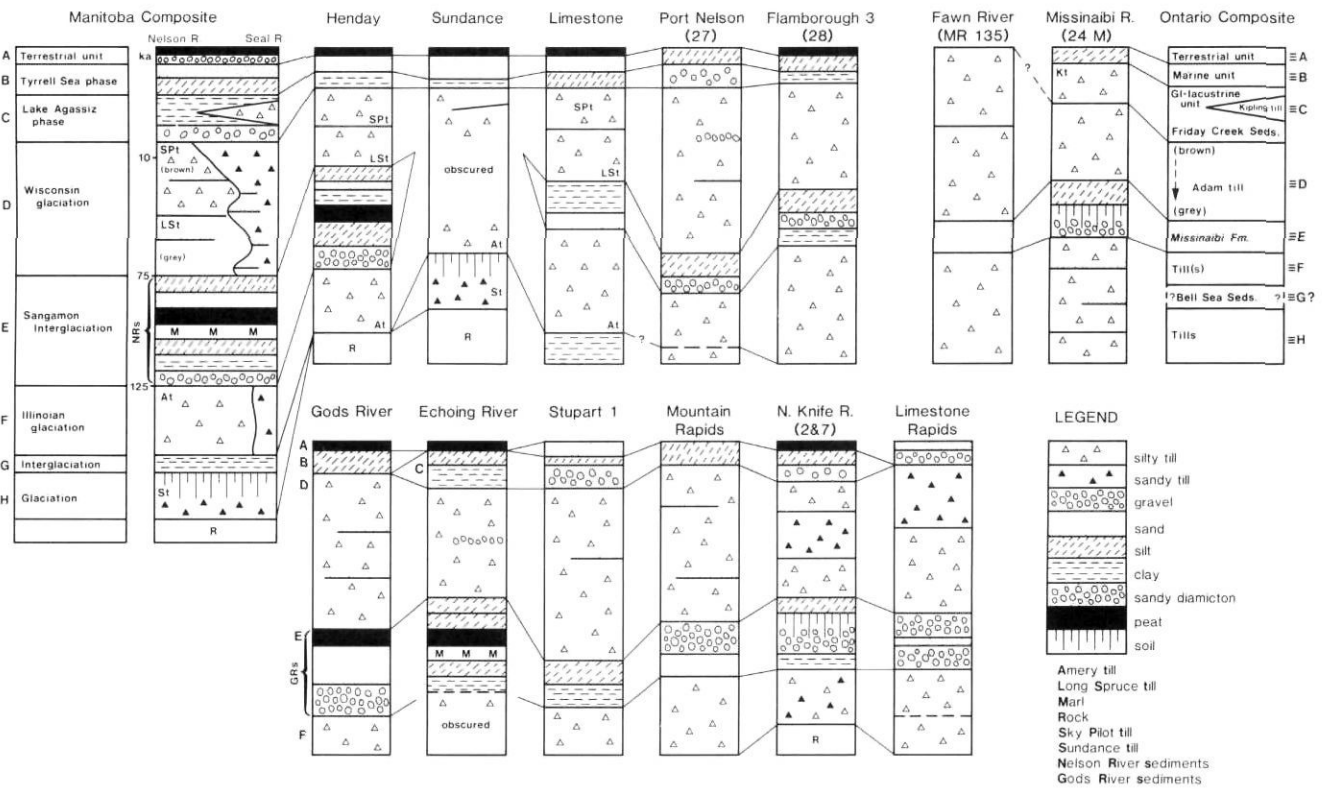


FIGURE 6. Lithostratigraphy of the Hudson Bay lowlands of Manitoba, and reference sites in Ontario. *Lithostratigraphie des basses terres hudsoniennes du Manitoba et sites de références en Ontario.*

Labrador or Hudson Bay. Differences in colour and lithology are attributed to changing ice flow directions during the latter part of the Wisconsin Glaciation. The westward flowing Wisconsinan Labradorean/Hudsonian ice sheet merged with the southward flowing Keewatin ice sheet in the Churchill River/North Knife River area. The interlobate area is characterized by multiple till sheets of silty calcareous, and sandy granitic till, and by subglacial glaciofluvial deposits. North of the convergence zone, in the Seal River area, a sandy, granitic till, laid down by southward moving Keewatin ice, is the principal glacial deposit. Lake Agassiz deposits, consisting chiefly of sandy turbidites and varved clays, mark the progressive recession of Wisconsinan ice towards the north and east. Marine silt and littoral sand cap most sections. These last sediments were deposited into the high glacioisostatic Tyrrell Sea that inundated the region following the break-up of the Hudsonian glacier. The offlap sequence of sediments records the regression of this sea to the present level of Hudson Bay as the region rebounded.

THE INTERGLACIAL RECORD

The interglacial deposits consist of one or more beds of clay, laminated and massive silt, marl, peat and detrital organics, sand and gravel, or soil horizons. These units also contain pollen, wood, beetle parts and other microfossils. Attempts to date these units have been made using aspartic and isoleucine amino acids on wood and shells, U/Th techniques on wood,

thermoluminescence of fine-grained sediments, and conventional ¹⁴C methods (Table II). Both high pressure and conventional ¹⁴C techniques yielded 'greater than' dates. The remaining methods gave inconsistent results, due to problems with the techniques, possible incorrect correlations of units, and inclusions of reworked fossil materials from older deposits. Reworking of Quaternary foraminifera is indicated by their presence in almost all the tills (Nielsen *et al.*, 1986, 1988) and by the presence of both Quaternary and Paleozoic microfossils in the interglacial beds. Hence, both date assignments and paleoenvironmental interpretations must be treated carefully.

In most sections there is only one main non-glacial sequence (the Nelson River sediments, Fig. 6), containing only some of the units in the sedimentary sequence mentioned above. This non-glacial sequence is correlated from one section to another on the basis of its lithostratigraphic position and geologic character of the tills directly above and below it, similarity of biotic assemblages from one section to another, and to a much lesser degree, on chronologic data. The unit is assigned to the Sangamon Interglaciation, which, for purposes of this paper, is considered to represent the whole Sangamonian Stage (*i.e.* oxygen isotope substages 5a to 5e), and contains both warm climate and cooler climate phases. In some sections there is evidence for a second, earlier, interglaciation (unit G, Fig. 6), separated from the main non-glacial beds by a till sheet. The interglacial (as opposed to interstadial) status and Sangamonian and pre-Sangamonian age assignments of these sediments are discussed under **Synthesis**.

TABLE II

Radiocarbon ages and amino acid ratios from wood and shells in presumed Sangamonian interglacial deposits and in the tills above (UT) and below (LT) them

Site	Material	¹⁴ C	Aspartic acid*	Total D/L Isoleucine**
Henday	wood	>49000; GCC-4420HP	0.17, 0.18, 0.19, 0.21, 0.22	
	shells		LT (Amery Till): 0.42	UT: 0.04 Hiatella
Sundance	shells		LT (Amery Till): 0.42	LT: 0.15-0.16 Mya
Limestone	wood		0.31,0.37,0.38	
	shells			UT near section: 0.10,0.11,0.15,0.16,0.18 Hiatella
Gods	wood	>41000; GSC-1737; >49000; GSC-4471HP	0.08,0.08,0.11,0.14, 0.16,0.17	
	shells			UT: 0.16 Hiatella; 0.19, 0.20 Macoma
Echoing	wood	>37000; GSC-892; >51000; GSC-4444HP	0.24,0.26,0.27	
	shells			UT: 0.16 Hiatella; 0.19, 0.20 Macoma
Stupart	wood	>37000; GSC-2481		
	shells			LT: 0.11, 0.20, 0.23, 0.27 Hiatella; 0.25, 0.35 Macoma
Flamborough	wood		0.18	
	shells			UT: 0.11, 0.12, 0.14, 0.15 Macoma
Mountain Rapids	wood	>3200; GSC-3074		
	shells			LT: 0.11, 0.11 Hiatella
Cofferdam	shells			LT: 0.20, 0.20 Macoma
The Fours	shells			0.19, 0.22, Macoma

* Analyses by N. W. Rutter, University of Alberta

** Analyses by G. Miller, INSTAAR

THE GILLAM SECTIONS

Henday Section

The 30 m high Henday section (Figs. 1,6) extends for about 100 m along the Nelson River. One of the exposures at Henday was described previously (Nielsen *et al.*, 1986; Nielsen and Dredge, 1987). A similar exposure across a small gully has since been excavated and examined. This exposure reveals a more extensive interglacial record. The top of the bluff exposes Holocene Tyrrell Sea sand and glaciolacustrine clay. The upper glacial unit is a grey-brown oxidized till (Figs. 6,7). It overlies several metres of weakly stratified silt, which in turn overlies about 15 cm of compact peat containing wood (spruce) fragments. The wood has been radiocarbon dated as greater than 49,000 years BP (GCS-4420 HP; Nielsen *et al.*, 1988). Aspartic acid determinations on wood yielded D/L values between 0.1766 and 0.2159. About one metre of grey-brown silt underlies the peat layer, and grades downward into a poorly sorted gravel. The lower part of the section consists of 12 m

of poorly exposed compact grey till, called the Amery Till. Ordovician dolomite is exposed along the river bank.

The pollen profile from the interglacial unit (Fig. 8 and R. J. Mott, Palynological Report No. 81-3) is dominated throughout by *Picea* (spruce) pollen; *Pinus* (pine) pollen, which is probably *P. banksiana/resinosa* type (jack or red pine), is also plentiful. *Betula* (birch) is present in smaller amounts, and all other trees and shrubs, including *Alnus* (alder) and *Salix* (willow) occur as minor constituents. Graminae (grass) and *Artemisia* (sage) are abundant herb taxa. Cyperaceae (sedge) pollen is relatively abundant, as are *Sphagnum* (sphagnum) spores. *Picea* pollen increases slightly above the base, whereas nonarborescent pollen and *Sphagnum* spores are less plentiful. The centre of the profile has significantly less *Picea* and Cyperaceae pollen, and more *Betula*, Graminae, *Artemisia*, and nonarborescent taxa. *Picea* and *Pinus* increase slightly towards the top. The pollen spectra and wood pieces suggest the presence of spruce trees. The spectra are similar to those from the present forest tundra zone (Lichti-Federovich and Ritchie, 1968). Black spruce prob-

ably dominated the landscape, with tamarack on wet areas, and white spruce, jack pine, birch, poplar and aspen on drier sites. Open areas would have supported herbs and grasses. Sedges and sphagnum were abundant on wet or boggy sites. Spectral changes in the Henday profile do not indicate significant changes in vegetation cover. The percentage of spruce

increased from the earliest time, then decreased. This decrease is probably associated with more open space and increased shrubs and herbs. A reversion to more trees is possible in the upper part of the profile, judging by the increase in *Picea* pollen, but this may be a result of poor local pollen representation resulting in overrepresentation of exotic taxa transported long distances.

The spectra are very similar to those described for the Missinaibi Formation by Terasmae (1958), Terasmae and Hughes (1960), and by Lichti-Federovich (*in* Skinner, 1973) which show spectra dominated by *Picea* and *Pinus* as well. The less abundant taxa are also similar in variety and abundance.

Previously, fossil insects from the Nelson River sediments were recovered from small samples collected in 1981 and 1983 at the Henday section (Nielsen *et al.*, 1986). A further 11.5 kg of blocky compressed silts were collected by Nielsen and Dredge in 1985 and a few additional beetle taxa were extracted. Three interesting additions to the previously described carabid fauna are *Elaphrus americanus* Dejean, *Bembidion sordidum* Kirby, and *Amara alpina* Paykull. All of these species are northern. *Elaphrus americanus* is a transcontinental species which ranges to the northern limit of trees. *E. americanus* does not range onto the northern tundra but has a northern limit running from Kuujuaq (Fort Chimo) in the east to Fort Severn (Ontario), Churchill (Manitoba), and west to Aklavik in the Northwest Territories. *E. americanus*, like many other carabids of the Henday fauna, is found at the wet or moist borders of standing or slowly flowing water bodies. The species is usually found on highly organic substrates, and is heliophilous (Lindroth, 1961; Goulet, 1983).

Bembidion sordidum is a small carabid with a northern transcontinental distribution similar to *E. americanus*. It does, however, range into the tundra to Coppermine and Bathurst Inlet and to the Alaskan North Slope. The species is usually found on shaded river banks with sparse vegetation (Lindroth, 1966). *Amara alpina* ranges across northern north America,

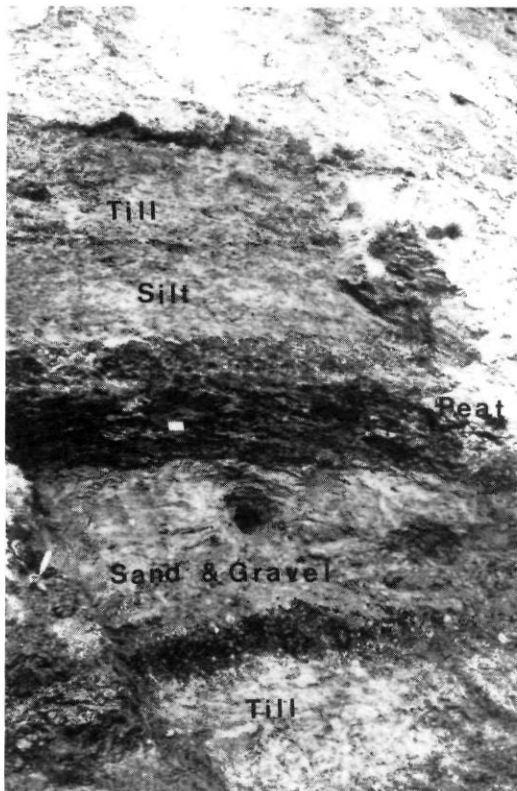
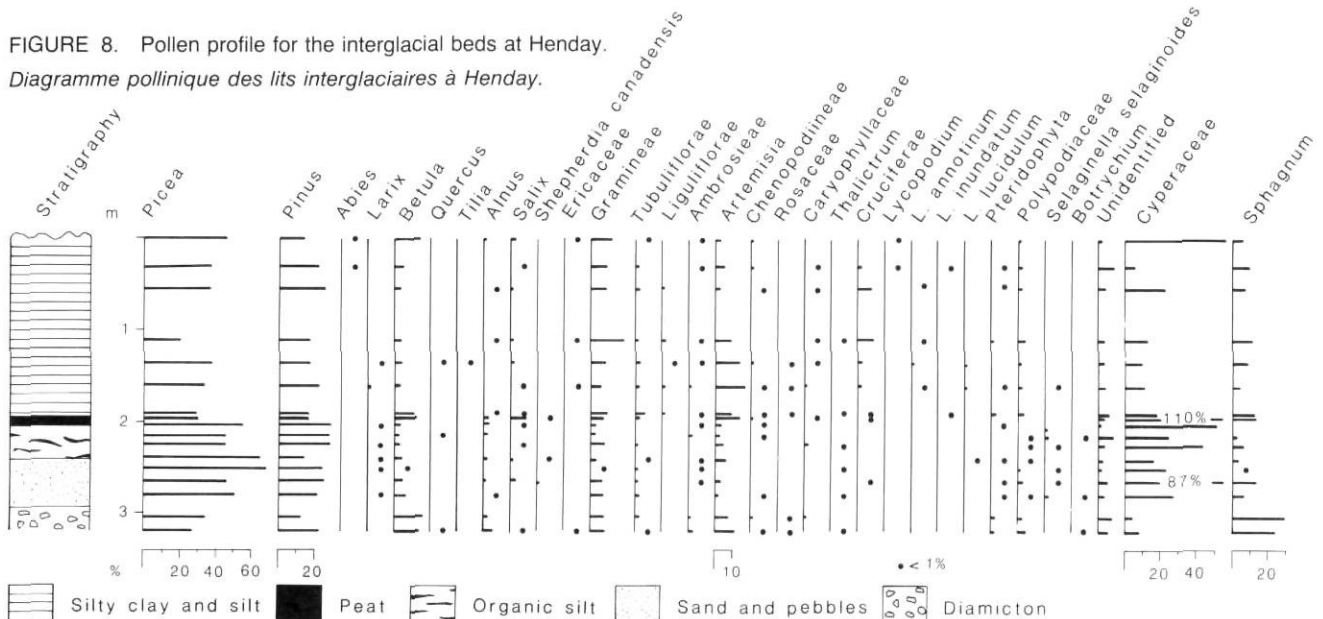


FIGURE 7. Interglacial beds at Henday (scale bar is 9 cm long).
Lits interglaciaires à Henday (l'échelle mesure 9 cm de long).

FIGURE 8. Pollen profile for the interglacial beds at Henday.
Diagramme pollinique des lits interglaciaires à Henday.



and southward in the mountains of both western and eastern North America. The southern limit of the species generally coincides with the northern limit of trees. *A. alpina* is found on rather dry tundra, frequently on sandy or gravelly substrates and often in the dry inundation zone of large rivers (Lindroth, 1968).

Other carabids also found in the 1985 materials include *E. parviceps* Van Dyke, *Pterostichus costatus* Menetries, and *Cryobius* spp. These species have been described in Nielsen *et al.* (1986). Non-carabid beetles recovered from the 1985 samples include the aquatic genera *Hydroporus*, and *Heliophorus*, and the staphylinid *Stenus*. All of the above were found in earlier samples (Nielsen *et al.*, 1986).

The new finds of Coleoptera confirm the original analyses from the Henday section. The site is believed to have been deposited close to treeline. The closest modern analog for the species recovered from the site would be near Churchill. Further examination of the sediments in the Henday section during the summer of 1988 revealed several lithological units. Samples were removed systematically for paleoentomological analysis, and are currently being examined at the University of Waterloo.

Sundance Section

The lithostratigraphy and microfossil content of the tills in the Sundance section (Fig. 1) have been described previously (Nielsen *et al.*, 1986). The main units are shown on Figure 9. A calcareous silty till of eastern provenance, correlated with the Amery Till at Henday, is underlain by the Sundance till, a compact sandy till of northern provenance containing abundant granitic clasts. The Sundance till overlies Paleozoic carbonate bedrock. The upper two metres of the Sundance till are leached and oxidized, and are considered to be the base of a paleosol traceable for 150 m along the bluff. The upper part of the paleosol shows some organic carbon depletion (Fig. 10) and a decrease in ferromagnesian and other elements. This may be the lower part of the A horizon. The zone directly below shows an accumulation of ferromagnesians, and may represent the B zone. The Ao horizon is believed to have been incorporated

into the Amery Till as there is a 5% increase in organic carbon in the lower part of the till unit.

Microscopic examination of organic fragments from the paleosol indicates an abundance of charcoal fragments and some pollen grains and spores (R. J. Mott, Palynological Report No. 83-2). The most common taxa are *Sphagnum* (moss) spores, and pollen of Cyperaceae (sedges), Graminae (grass), and *Betula* (birch). Smaller amounts of other herbs and shrubs are represented, but arboreal taxa are scarce. The assemblage differs markedly from the other non-glacial assemblages reported in this paper. The overwhelming numbers of herbaceous taxa, abundant shrubs, and few trees suggest a tundra environment.

The correlation of lithic units in the Sundance section with those in the Henday section indicates that the till above the paleosol is the Amery Till, which underlies the Sangamonian

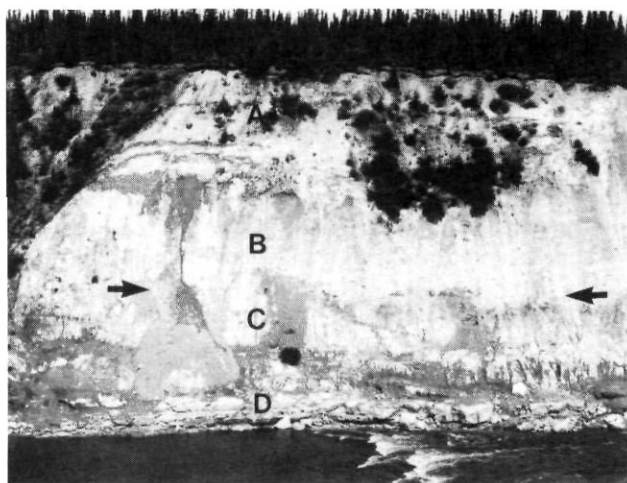


FIGURE 9. Sundance section: A) Tyrrell Sea deposits; B) Amery till; C) Sundance till; D) bedrock. Arrows show location of the paleosol.
 La coupe de Sundance: A) dépôts de la Mer de Tyrrell; B) till d'Amery; C) till de Sundance; D) substratum. Les flèches montrent l'emplacement du paléosol.

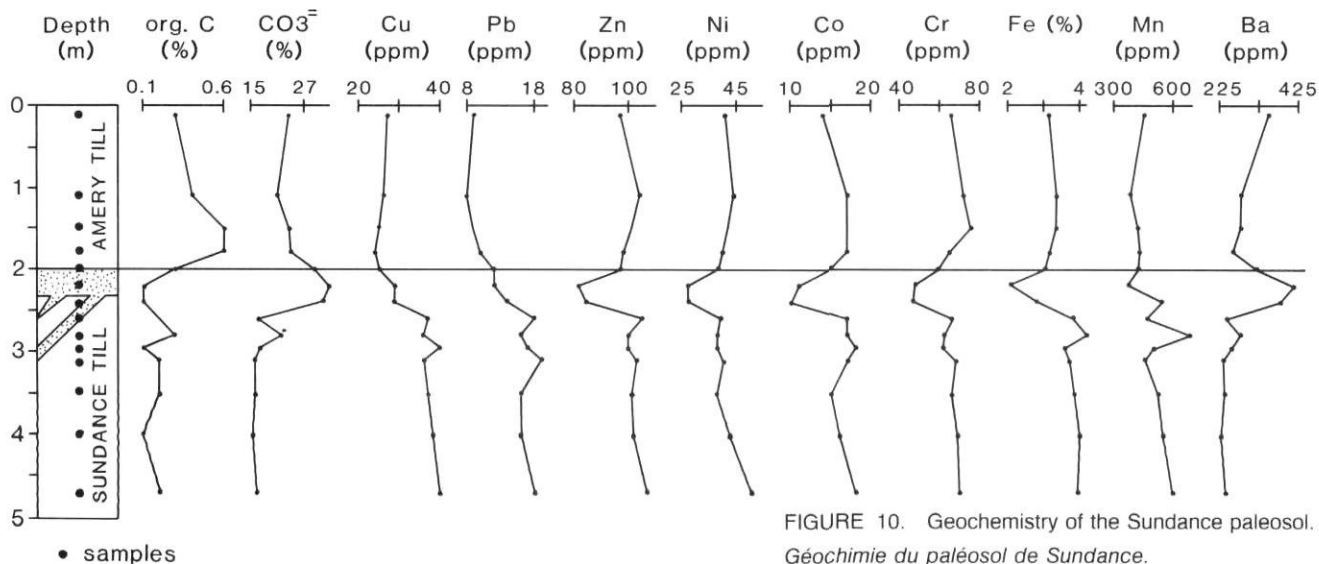


FIGURE 10. Geochemistry of the Sundance paleosol.
 Géochimie du paléosol de Sundance.

beds at Henday. The stratigraphic position of the paleosol, as well as its pollen signature, indicate that it represents a separate, earlier, cool non-glacial interval. The presence of a paleosol demands free drainage of the area (rather than a glacial lake), hence an ice free Hudson Bay. The soil is therefore considered to represent a cool interglaciation rather than an interstade.

Limestone Section

The Limestone section (Fig. 11) is a high cliff near the mouth of the Limestone River exposing two non-glacial intervals. Tyrrell Sea and Lake Agassiz sediments are underlain by brown unoxidized and oxidized tills similar to those exposed in the Henday section. These in turn overlie 1-3 m of non-glacial sediments consisting variously of clay, sand, and gravel at different places along the bluff. A bed of grey, wet, sticky clay is traceable sporadically along the bluff. Organics including moss and carbonized spruce twigs are associated with fluvial sand and gravelly sand. The wood was deposited on the lee side of pebbles and the plant remains and organic silts occur as thin discontinuous lenses within the sandy part of the unit. The wood has aspartic D/L ratios between 0.376 and 0.3075, the highest recorded in the western lowlands. These ratios indicate either that the wood in this section is older than in other exposures, or more likely, that there has been more racemization. Pollen analysis on a pod of organic silt indicates an abundance of *Picea* (spruce) pollen, and much less *Pinus* (pine) pollen than at some of the other sites (R. J. Mott, Palynological Report No. 83-1), but an assemblage that is generally similar to other beds assigned to the Sangamonian in this area. Some *Betula* (birch) pollen is also present, as well as Cyperaceae (sedge), *Artemisia*, (sage) and small amounts of other herbs and *Sphagnum* (moss) spores. A northern boreal type of environment is indicated, with some trees present as well as open areas. The presence of twigs suggests that trees were present in the vicinity. One wood fragment was identified as *Picea*.

Slightly over 24 kg of silty black-brown compressed organic detritus were washed from the Limestone site. Very few insects were recovered. The only carabids identifiable to the species level were *Elaphrus parviceps* and *Elaphrus americanus*. There are at least two other species of *Pterostichus* (one of the subgenus *Cryobius*) in the site, together with one species of *Bembidion*. The site also contains the staphylinid genus *Stenus*, the hydrophilid *Helophorus cf. sempervarians*, fragments of the sedge-eating chrysomelid *Donacia* (or *Plateumaris*), as well as possible remnants of a curculionid. Non-beetle fragments include the remains of a corixid "bug" and a solitary hymenopteran (ant) mandible. In general terms the fauna is similar to that of the Henday section. It is likely that all the elements would be found close to treeline, and may represent an open ground assemblage marginally south of treeline.

The unit below the organic sand and the grey silt beds is blocky, grey, oxidized till correlated with the Amery Till in the Henday and Sundance sections. The Amery Till in the Limestone section is about 10 m thick and overlies a bed of grey, blocky laminated silt at least four metres thick exposed at the base of the section. The silt contains pollen indicative

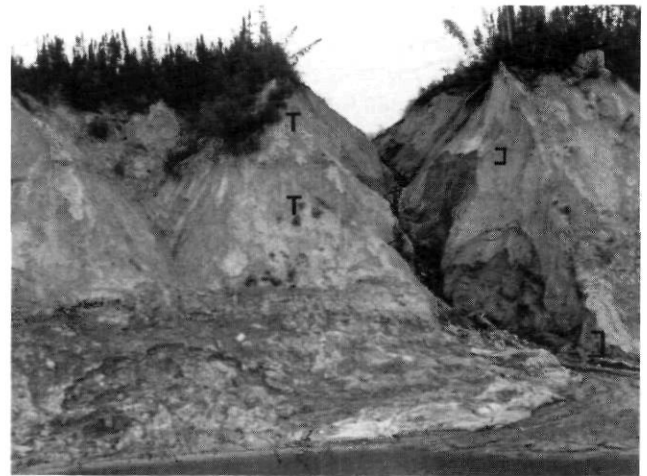


FIGURE 11. Limestone section: brackets surround interglacial beds (T = till).

Coupe de Limestone: les crochets délimitent les lits interglaciaires (T = till).

of cool tundra conditions (R. J. Mott, pers comm.). Preliminary examination of the silt did not reveal any microfauna. The deposit is tentatively assigned to an early non-glacial interval, and is correlated with the Sundance soil.

Other sites in the Gillam area containing both glacial and non-glacial deposits were found on the south side of the Nelson River downstream from the mouth of the Limestone River (Johnston, 1918), on the north side of the river near the Limestone cofferdam, and at Eagle Bluffs (Fig. 1). At Eagle Bluffs a bed of greasy, smelly, blue-green clay outcrops at river level, which is about 45 m asl. The clay lies directly above carbonate bedrock and underlies about 50 m of poorly exposed glacial deposits. The clay contains pollen but no microfauna. The pollen assemblage is high in nonarborescent taxa such as Graminae (grass), *Artemisia* (sage), and Cyperaceae (sedge), and low in *Picea* (spruce) and other arboreal taxa, indicating a cool tundra-like environment with few trees (R. J. Mott, Palynological Report No. 88-14). Relatively high concentrations of vanadium and boron suggest that it may be a marine interglacial deposit; it may correlate either with other units assigned to the Sangamon Interglaciation, or may represent an earlier non-glacial interval, such as that which produced the paleosol at Sundance and the grey clay at Limestone.

A woolly mammoth molar retrieved from a point bar in the Limestone River is thought to derive from the interglacial sediments in the vicinity (Nielsen *et al.*, 1988).

SECTIONS IN THE GODS RIVER AREA

Gods River Sections

Interglacial sediments exposed along the Gods River were the first to be described in detail in the western Hudson Bay Lowlands. Netterville (1974; Klassen, 1986) proposed the name Gods River Sediments for organic-rich beds, and the name Twin Creeks Sediments for thin intertill sand and gravel seams occurring higher up in the sections. He considered the Gods River Sediments to be deposits of the Sangamon

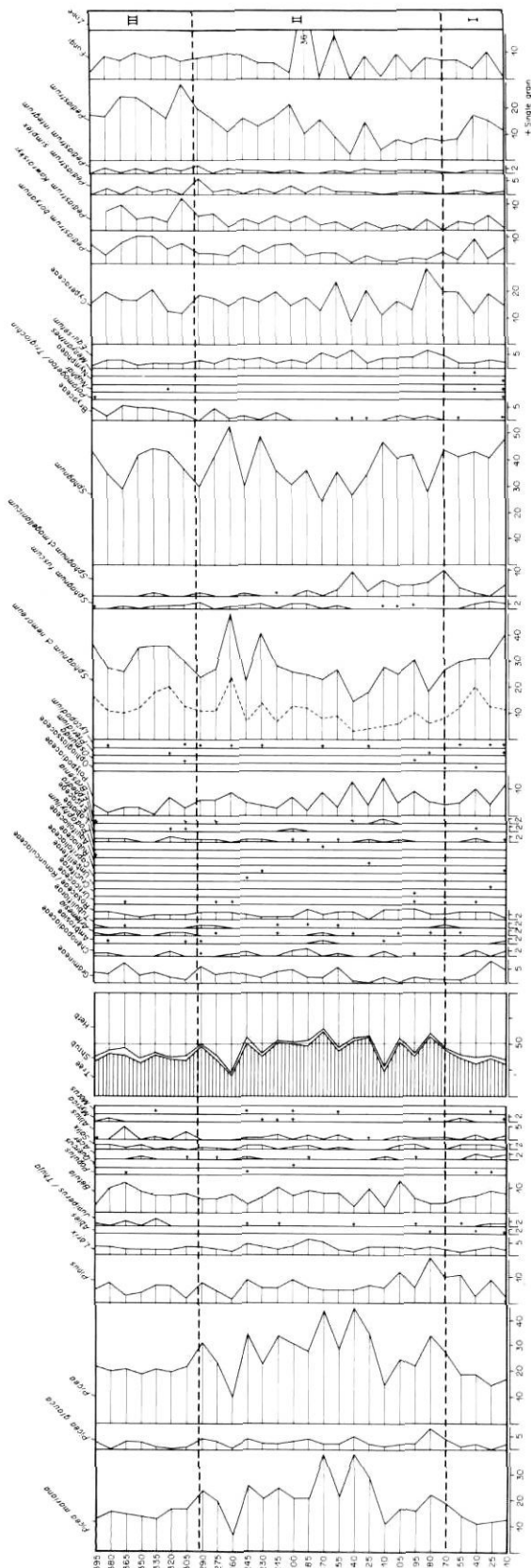


FIGURE 12. Pollen profile from Gods River section (Netterville, 1974).
 Diagramme pollinique de la coupe de Gods River (Netterville, 1974).

Interglaciation, and suggested that the Twin Creeks deposits represented more recent interstadial. We consider the barren Twin Creeks units to be meltwater deposits indicative of a sub-glacial environment, rather than non-glacial deposits (Dredge and Nielsen, 1985).

The Gods River Sediments consist of an upper silt unit approximately 2 m thick, with beds of sand and organic detritus. This is underlain by about 1 m of peaty and woody detritus, including mosses, flattened twigs and beaver-chewed logs. The logs are up to 15 cm in diameter. *In situ* woody peat occurs within this horizon downstream from the main section. The woody peat and the organic detritus overlies oxidized sand and gravel, which grade downwards into a thin basal unit of sand containing lenses of silty peat. Netterville (1974) concluded that the silt unit was lacustrine in origin, and that it overlies fluvial deposits. He believed that the detrital peat and wood accumulated as vegetation fell into slow moving water, possibly along floodplains, and that the compressed peat was a bog deposit.

Netterville analysed the pollen from several sections. Extremely low amounts of *Picea* (spruce) and *Pinus* (pine) pollen and abundant *Sphagnum* and *Cyperaceae* (sedge) in the lower zone of the pollen profile (Fig. 12) suggest that the vegetation during the time interval represented by this zone was similar to that which exists today in tundra regions of southern Keewatin and northeastern Manitoba, although there were less *Betula* (birch) and *Alnus* (alder) pollen than is found in pollen spectra from those areas today (Lichti-Federovich and Ritchie, 1968). The vegetation in the area appears to have been a *Sphagnum* tundra with scattered shrubs of birch and alder. Poorly drained sites were occupied by sedges, ferns and grasses. The increase in *Picea* pollen towards the top of the zone indicates that the treeline was moving northwards.

The pollen assemblage in the middle part of the profile is similar to spectra from stations in the forest-tundra. There is an increase in the number of spruce, both black and white, and a decrease in the amount of *Sphagnum*. Conditions were similar to those in the area at present, although the low percentage of pine relative to spruce suggests that pine trees did not extend as far north as they do today. The maximum arboreal cover probably did not exceed 50% before the climate became colder and tundra mosses and sedges reinhabited the region. The pollen assemblages in the upper part of the profile are similar to those from recent tundra sites.

Preliminary studies by Matthews (Plant Macrofossil Report 84-27) suggest that the seed and mollusc assemblages in the peaty detrital unit are suggestive of boreal environments or forest-tundra, and are similar to species found in the area today. The seeds include *Cyperaceae* (sedge), *Ranunculaceae* (crowfoot), *Potamogetonaceae* (pondweed), *Gentianaceae* (gentian), and *Haloragaceae* (milfoil).

The floral record suggests an increase, and then a subsequent decline, in temperature. During the spruce maximum, the length of the growing season and mean summer temperatures were at least as mild as present. On this basis Netterville concluded that the Gods River Sediments were products of the Sangamon Interglaciation. Radiocarbon dates on *Picea* (spruce) logs from the sections yielded ages of greater than

41,000 (GSC-1736), and greater than 49,000 (GSC-4471 HP). Aspartic acid determinations on wood gave anomalously low results between 0.0776 and 0.1753.

A sample of 13.5 kg of silty-sandy organic detritus with abundant wood fragments was rich in terms of Coleoptera diversity, with a number of species not yet found in other northern Manitoba sites. Carabid beetles are very poorly preserved, but enough remains to recognize several distinctive genera, including one specimen of *Bembidion*, a crumpled pronotum of *Elaphrus*, two species of *Pterostichus*, and one *Agonum* sp.

Staphinids (rove beetles) are represented by *Stenus*, *Gymnusa*, *Philonthus*, *Myllaena* and at least three omaline species including *Olophrum consimile*. The latter is found throughout the boreal forest ranging to treeline at Aklavik, Churchill, and the Koroc River mouth in Ungava (Campbell, 1983; Morgan, 1989).

Aquatic and wet substrate species are represented by individuals from the following genera: *Gyrinus*, *Cercyon*, *Hydraena/Ochthebius* and *Hydroporous* cf. *griseostriatus*. Representatives of all the above genera are commonly found in the boreal forest. Chrysomelids are seen in the aquatic genera *Donacia/Plateumaris*, and curculionids are represented by at least three species of weevils.

The Gods River sediments are the only deposits so far described in northern Manitoba which contain the remains of wood-inhabiting Coleoptera. Three species of scolytids (bark beetles) have been found in these deposits. *Carphoborus andersoni*, *Scolytus* cf. *picaea* and *Phloeotribus* are common residents of the boreal forest across northern Canada, although *C. andersoni* is today known only from northwestern North America (Wood, 1982; Morgan et al., 1983). The beetle remains reported here indicate a boreal environment. It is conceivable that the Coleoptera from the site could be found in the same geographic region today. As such, the organic material probably represents an interval with temperatures as warm as present. Netterville (1974) examined macrofossil remains from the silt deposits above the organic detrital layers. These yielded beetles and weevils suggestive of tundra environments. The climatic sequence suggested by the pollen spectra is therefore corroborated by the beetle record.

Non-beetle remains from the organic sediment include Trichoptera (caddis) fragments, and mandibles, *Daphnia* ephippia, oribatid mites, and Heteroptera ("bugs").

Echoing River Section

The Echoing River section, exposed in a meander cut in a tributary creek flowing into Echoing River, is one of the thickest interglacial sequences in the western Hudson Bay Lowlands. The section exposes Holocene glaciolacustrine silt and clay, two tills, a major non-glacial sequence, and possibly a lower poorly exposed till in the basal part of the section. The nonglacial beds comprise, from top to bottom, grey, massive clayey silt, brown irregularly laminated silt, compact platy peat with wood, white marl with freshwater molluscs, varved brown silt and black clay with rip-up structures, contorted sand beds, and blocky, black, stonefree clay (Fig. 13). The clay becomes blockier and stonier below a depth of about 40 cm. The lowermost 4 m of the section are covered.

Concentrations of vanadium and boron in the lower blocky clay are higher than in other units in the section. These elevated values suggest that the unit may be marine, although this is not totally supported by the microfossil data.

Picea (spruce) twigs and branches from the peat unit were radiocarbon dated to be greater than 37,000 years (GSC-892, McDonald, 1969) and greater than 51,000 years (GSC-4444 HP). Aspartic acid ratios on the wood yielded values between 0.2438 and 0.2862. Amino acid determinations were also made on shell chips of *Macoma calcarea* extracted from the lower part of the till overlying the non-glacial units, giving D/L isoleucene ratios between 0.191 and 0.205.

Macro and microfossils were examined throughout the section. Small numbers of well-preserved foraminifera were extracted from samples taken from the lower parts of the section. The presence of foraminifera suggests a marine environment, but their small numbers may indicate that they are allochthonous. The assemblage is typical of a relatively warm water (i.e. boreal) environment; arctic species such as *Cassidium reniforme* are absent (D. H. McNeil, Report 4-1988). Foraminifera were not found in the upper laminated silt, which however contained transported redeposited brackish water diatoms. Gastropods and ostracods indicating freshwater environments were recovered from the intermediate sand and silt units, the marl, and the silt overlying the marl. Thus, the paleontological and geochemical data taken together suggest that the lower black clay and stony clay may be marine and glaciomarine. The rest of the non-glacial unit is terrestrial or freshwater in origin. Both the marine and freshwater fossils indicate relatively warm (i.e. boreal) conditions.



FIGURE 13. Interglacial beds (below arrow) at Echoing River. P denotes peat unit (GSC 204037-G).

Lits interglaciaires (sous la flèche) de Echoing River. Le P montre une unité de tourbe (GSC 204037-G).

The pollen stratigraphy of the Echoing River section is shown in Figure 14 (R. J. Mott, Palynological Report No. 85-6 and 85-10). The lowermost sample contains more non arboreal and less arboreal pollen than the overlying samples, suggesting an early, open tundra-like environment. In the overlying unit, *Pinus* (pine) values (about 60%) are significantly higher, indicating either the proximity of closed coniferous forests or over-representation of grains transported from a distant source. This element in the pollen record differs from the profiles from some of the other sites (e.g. Henday) in the western Hudson Bay Lowlands, and from the Missinaibi Formation in Ontario (Terasmae and Hughes, 1960). The upper part of the diagram is dominated by *Picea* (spruce), less *Pinus*, and more herbaceous pollen, and indicates a change to an open coniferous forest environment similar to the present. The presence of trees at the site is corroborated by the spruce wood in the compressed peat.

Two samples from the Echoing River site were processed for beetles; the largest consisted of 23 kg of woody peat, and the second consisted of 1.6 kg of the marl. The peaty detritus contained *Elaphrus*, *Dyschirius*, three *Bembidion* species including *Bembidion sordidum*, and a specimen tentatively identified as *B. quadrifoveolatum* Mannerheim; *Pterostichus* (*Cryobius*), and at least one other carabid genus. The distribution of *B. sordidum* has been mentioned earlier (see Henday section). *B. quadrifoveolatum* is a strictly riparian species, found today in western North America, usually within the boreal zone but extending above timber limit in the Chilkat Pass region (Lindroth, 1961).

Aquatic species include the dytiscids *Hydroporus griseos-triatus* and *Colymbetes cf. dolobratus*, at least two species of

hydrophilids (*Helophorus*), and the chrysomelid *Donacia/Plateumaris*.

Staphylinids include *Stenus* and at least five omaline species including *Olophrum boreale*, *O. consimile*, *O. cf. latum*. All three species are common residents of western North America with *O. latum* confined to the region north and west of Churchill. One of us (AVM) collected *O. boreale* and *O. consimile* together at a treeline locality at the Koroc River, Ungava (Morgan, 1989). All of the species can be found in moist leaf litter, particularly from *Alnus* (alder) and *Salix* (willow). The insect fauna of the peat suggest boreal conditions close to treeline.

Non-beetle remains include at least two species of Trichoptera (caddisflies); fragments of a crustacean (cf. *Lepidurus*), cladoceran ephippia (*Daphnia*), and stratoblasts from the bryozoan *Cristatella*.

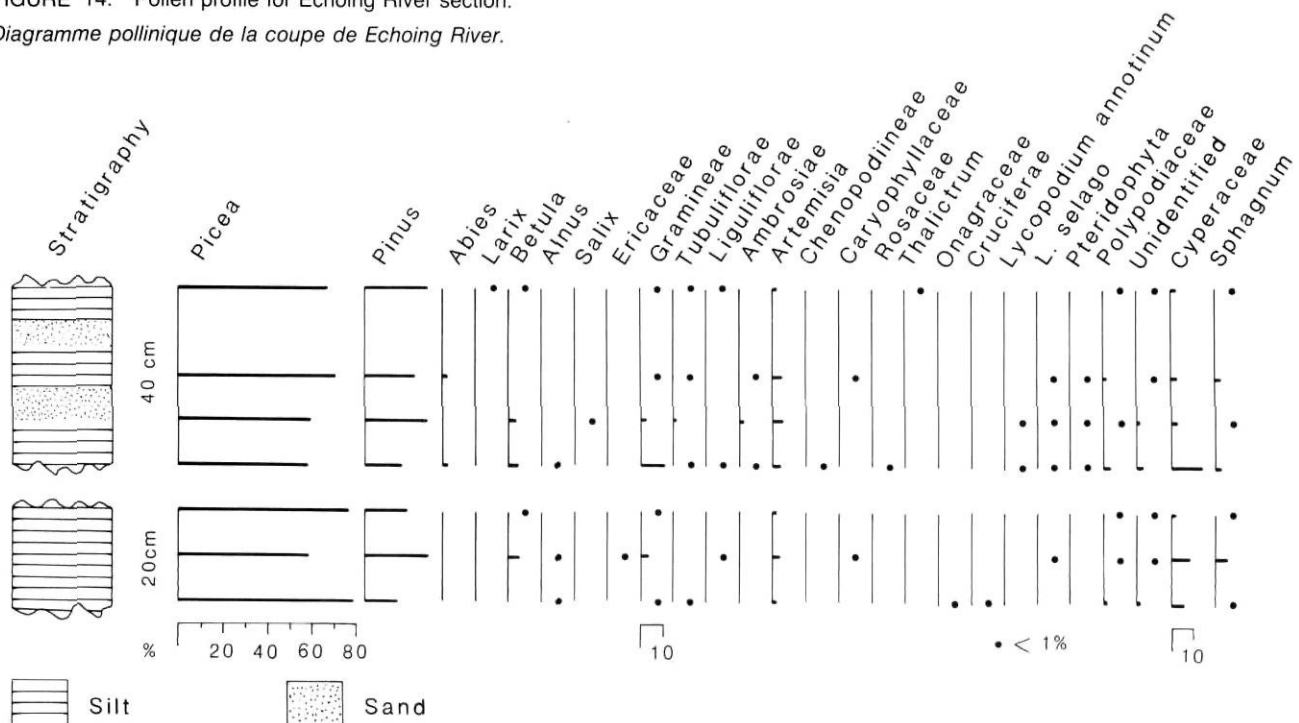
The silty marl deposit contained a few Coleoptera, oribatid mites, and at least one species of Trichoptera. *Chara* oogonia were common in both marl and peat.

Stupart River Sections

Three exposures with glacial/nonglacial sequences were logged along the Stupart River near its confluence with Fox River (Dredge and Nielsen, 1985). The highest and most extensive exposure shows multiple brown tills with interbedded horizontal, structureless sand beds similar to those on Gods River. The lowermost well-exposed unit is a massive grey lacustrine clay.

The clay layer stratigraphically correlates with a sub till silt and clay bed at the third, less extensive exposure. At this loca-

FIGURE 14. Pollen profile for Echoing River section. Diagramme pollinique de la coupe de Echoing River.



tion non-glacial beds are exposed together with their upper and lower contacts. Above the beds is a grey-brown relatively stony till. The till grades downwards into a set of 20 couplets of buff silt and grey silty clay, interpreted as varves. The couplets are of variable thickness up to 10 cm, are draped over irregularities in the underlying deposits, and have some internal erosional contacts. The upper varves have been deformed by glacier overriding. Below the varves are 2 m of grey, crumbly lacustrine clay with dark mottles. The clay contains some *Elphidium* foraminifera which are probably allochthonous, since they are less abundant in this unit than in the tills above and below. A sharp contact separates the clay from 5 m of blocky, grey, moderately stony till with thick, brick red oxidation rinds.

As the till stratigraphy of the Stupart sections is similar to that exposed along the Gods and Nelson Rivers, the fine-grained sediments have been tentatively correlated with the interglacial beds there. The nature and thickness of the silt and clay beds suggest that they might have been deposited at the close of the last interglaciation as glaciolacustrine deposits in front of a glacier advancing out of Hudson Bay. The non-glacial deposits have not been dated directly. *Picea* wood from the till directly overlying the silt unit on Stupart River gave a radiocarbon age of greater than 37,000 years (GSC-2481; Lowdon and Blake, 1978). Total isoleucine ratios from fragments of *Macoma* in the till directly above the interglacial beds gave a value of 0.253; those in the till below gave values ranging from 0.198 to 0.217 on *Hiattella*, and 0.348 on an unidentified species.

NELSON RIVER ESTUARY SECTIONS

Port Nelson Section

The Port Nelson section is continuously exposed along a 2 km long bluff between Port Nelson and Harts Creek at the mouth of the Nelson River. The lithostratigraphy is summarized by Figure 6. Holocene marine and glaciolacustrine units overlie a crumbly, stony brown till with inclined injection structures dipping 45° towards the southwest. Sand beds also dipping southwest mark former melt zones within the glacier. The loose nature and internal bedding indicates that the till was deposited largely by basal melt out. This upper till unit is either separated from an underlying brown till by a layer of imbricated cobbles dipping towards Hudson Bay, or in some places, grades into the underlying till. This second till is also brown and calcareous but is noticeably less stony and shows brown oxidation along joints. Some zones within this till are substratified and intercalated with the underlying non-glacial deposits. The non-glacial beds consist of 1.5 m of stonefree massive and laminated silt. The silt overlies sand grading down into a massive granitic pebble gravel. The gravel is thought to be a stream deposit because its lithology indicates shield sources; however, it might be outwash deposited during the advance or retreat of Hudsonian Ice. The overlying silt is considered to be a shallow-water alluvial, overbank or pond deposit. The silts and gravels lie 2-4 m above present high tide and indicate that base level and sea level were below an elevation of +2 m when the sediments were deposited. The lowest unit in the section is a compact stony till. The upper 40 cm of this unit is brownish grey, but it becomes redder with depth. Grey till with abundant pre-

Cambrian clasts is exposed along the tidal flat. This till is the lowest till of the sequence and has significantly more granitic clasts than any of the overlying tills.

All tills in the Port Nelson section contain Quaternary and Paleozoic microfossils (Table III). The Quaternary foraminifera are more abundant in the till below the non-glacial unit and indicate colder water conditions than those in the till above the non-glacial unit.

Preliminary pollen work on these section shows that the samples are dominated by *Picea* (spruce) pollen, with *Pinus* (pine) present in smaller amounts (Fig. 15). Other tree taxa are present in minor amounts, and shrub and herbaceous plant pollen are present in low amounts. The results reflect northern forest to forest-tundra conditions. This site presently lies near the treeline, so that the pollen spectra are similar to those of today. Abundant remains of the alga *Pediastrum* indicates a freshwater environment.

No datable organics were found in the section. On the basis of the lithostratigraphy and the character of the pollen spectrum, the non-glacial beds at this site are tentatively correlated with the Henday and other Sangamonian beds.

Flamborough Section

The Flamborough section consists of a 4 km stretch of bluffs along the Nelson estuary northeast of Flamborough Head. The stratigraphic succession is similar to that described for the Port Nelson section, but in some places, organic units are visible. Flamborough exposure 3 consists of Holocene fossiliferous marine and non-fossiliferous glaciolacustrine deposits overlying loose, brown calcareous till. Under the brown till a thick sequence of horizontally bedded grey silt and thin sand beds conformably overlies poorly sorted sand and well-sorted peat gravel. Both cap a 10 cm thick bed of steel grey clay. The non-glacial sequence overlies grey-brown oxidized till with red joints. Grey till with abundant pre-Cambrian clasts outcrops on the tidal flat. The pollen assemblage from the clay layer is similar to that shown for Flamborough 1, except that additional *Pediastrum* (algae) indicate a freshwater environment (R. J. Mott, Palynological Report No. 88-15).

A second exposure (Flamborough 1, Fig. 16) about 100 m west of Flamborough 3 exposes a less complete stratigraphic sequence but includes peat and organic layers under the brown till. In the upper part of the non-glacial unit, consisting mostly of silty sand, organic stringers and pods are fibrous, thin, discontinuous and undulating; near the bottom they are up to 60 cm thick and consist of platy brown-black peat with some compressed spruce twigs. The peat unit is interpreted as a bog deposit whereas the overlying stringers are transported elements. The lower 50 cm of these non-glacial beds consist of coarse sand and gravel, abruptly overlying reddish oxidized till. The gravel and silt beds at site 3 are correlated with the organics at site 1.

Aspartic acid determinations on wood from Flamborough 1 gave a ratio of 0.1881. Total isoleucene ratios on *Macoma* fragments from the overlying till range from 0.11 to 0.15.

The pollen profile from the sand and peat unit (Fig. 17) is similar to that obtained from the Port Nelson section. The abun-

TABLE III

Foraminifera in interglacial sediments and tills (identifications by D. N. McNeil, ISPG)

site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Foraminifera																								
<i>Alabamina</i> sp.								1																
<i>Buccella frigida</i> Cushman	2				1				1							1	1		1					
<i>Cassidulina reniforme</i> Norvang		1			1											1	1		1	2		1		
<i>Dentalia</i> sp.																							1	
<i>Elphidiella arctica</i> Parker and Jones										1														
<i>Elphidiella gorbunovi</i> Stschedrina																		2	2			1	1	
<i>Elphidiella groenlandicum</i> Cushman																					2			1
<i>Elphidium albiumbilicatum</i> Weiss																								1
<i>Elphidium asklundi</i> Brotzen													1	1		1	2			1			4	
<i>Elphidium bartletti</i> Cushman																							1	
<i>Elphidium clavatum</i> Cushman	14	8			3	2		4		1			4			5	4	2		4	2		4	3
<i>Elphidium excavatum</i> Terquem					3			1								2	2		6	1	2	1		3
<i>Elphidium gunteri</i> Cole																			1					
<i>Elphidium subarcticum</i> Cushman																							1	
<i>Elphidium ustulatum</i> Todd										1												3		1
<i>Elphidium</i> sp.		1				3		2		4				1		5	7	3	4	3			3	
<i>Guttulina lactea</i> Walker and Jacob		1															1							
<i>Haynesina orbiculare</i> Brady					1				3				2		5	1		1			7		4	
<i>Islandiella helenae</i> Feyling-Hanssen	2																		1					
<i>Islandiella islandica</i> Norvang																						1		
<i>Islandiella norcrossi</i> Cushman										1							1		1	1				3
<i>Melonis barleeianum</i> Williamson										1														
<i>Melonis</i> sp.				1																				
<i>Nonion labradoricum</i> Sawson																	1							
Charophytes									1															
Ostracods								1															13	
Gastropods										1	5	8												
Paleozoic microfossils			1	3	14	13	6	5		5			5	20	7	39	7	3	54	43	1	1	1	6

1) Henday Long Spruce till; 2) Amery till; 3) Sundance Amery till; 4) Limestone interglacial clay; 5) Eagle Bluff upper brown till; 6) grey till; 7) lower grey till; 8) Echoing River stony clay; 9) black clay; 10) sand; 11) marl; 12) brown silt; 13) Port Nelson upper brown till; 14) middle brown till; 15) gravel; 16) silt; 17) red till; 18) Flamborough Holocene marine silt; 19) upper till; 20) lower till; 21) silt; 22) Stupart lower till; 23) ssilt; 24) upper till.

dance of *Sphagnum* spores at Flamborough reflects the peaty nature of the microenvironment rather than regional differences in vegetation. Northern boreal forest to forest-tundra conditions are otherwise indicated.

Insect analysis of the peat and organic detritus revealed that carabids are represented by at least three species (2 *Bembidion* spp.); staphylinids by *Stenus*, *Gymnusa*, *Olophrum* cf. *latum*; and *Micropeplus sculptus* leConte. The locality for this last species is farther north and west of the current known range, which extends north to Moosonee and the Black Sturgeon Lake area north of Lake Superior (Campbell, 1978). Aquatic beetles recovered belong to the genera *Colymbetes*, *Ochthebius/Hydraena*, and *Helophorus*. There are two fragments of weevil. Non-beetle remains include the cephalothoraces of several spiders, and a single Trichopteran frontoclypeus. The faunal composition suggests that the sediments were deposited in a northern boreal, forest-tundra to treeline environment, probably rather similar to the present.

Foraminifera are present in Holocene Tyrrell Sea sediment (arctic species) and in small numbers in all the pre-Holocene units. Most species indicate inner shelf boreal to arctic envi-

ronments. A notable exception is the occurrence of *Elphidium gunteri* in the till directly above the sand unit at Flamborough 1. This species is associated with very warm water conditions (Miller, 1983) and indicates interglacial conditions as warm as those off the coast of Georgia, U.S.A. If this fossil was incorporated into the Early Wisconsinan till from interglacial sediments then it indicates that at some time Hudson Bay was significantly warmer than present.

NORTHERN SECTIONS

Mountain Rapids Section

Mountain Rapids lies within the Canadian Shield about 50 km west of the Paleozoic/Precambrian contact. The 30 m high bluff along the Churchill River exposes multiple till units separated by sand and gravel beds, the lowermost of which are thought to be interglacial (Dredge and Nixon, in press) (Fig. 6). The tills are characteristically silty, have calcareous matrices and clasts, and contain shell chips. These attributes suggest an eastern provenance. The upper till is brown, unoxidized, relatively uncompacted, and has few stones. It truncates a 40 cm thick bed of silt and sandy gravel with small peat balls

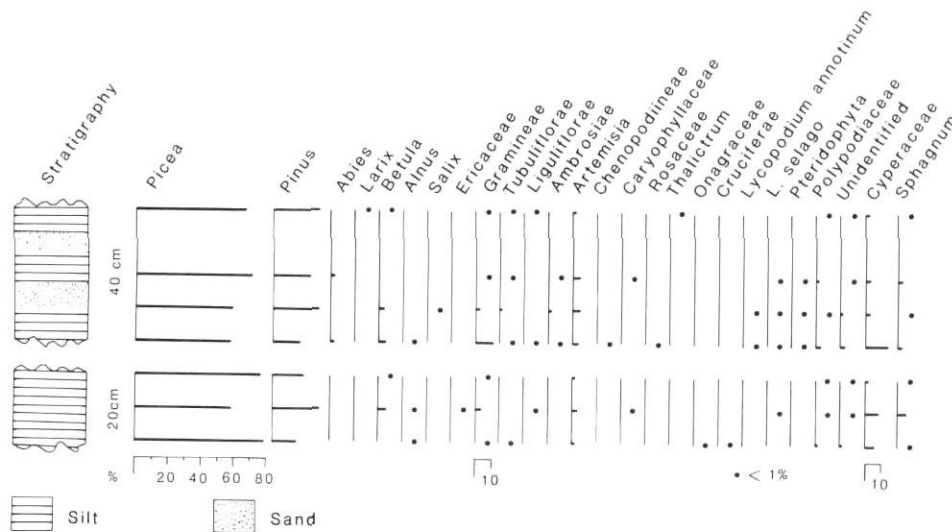


FIGURE 15. Pollen profile for Port Nelson section.

Diagramme pollinique de la coupe de Port Nelson.

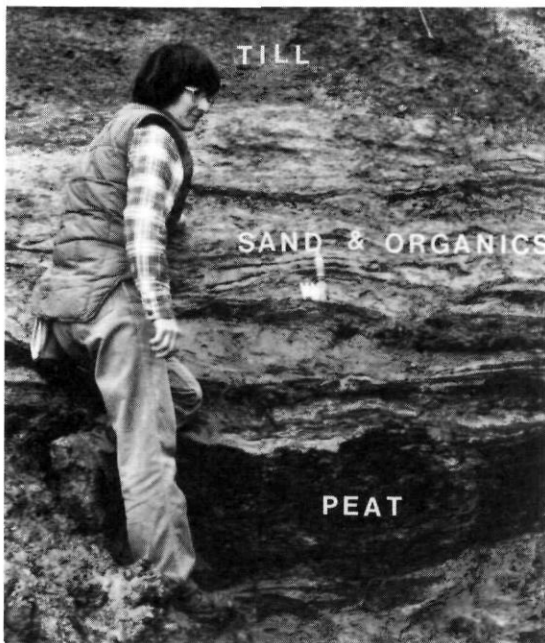


FIGURE 16. Organic sands and peat beds at Flamborough I exposure (GSC 204735-B).

Sables organiques et lits de tourbe à la coupe de Flamborough I (GSC 204735-B).

and partly flattened carbonized sticks radiocarbon dated greater than 32,000 years (GSC-3074). The three tills underlying this unit are stony, compact, and brown to grey in colour, although the lowest has a reddish hue. Shell fragments of *Hiatella* from the lowest till have total isoleucine ratios of 0.112 to 0.114. These lower tills are separated by unfossiliferous sand and gravel. The upper of these beds consists of sand intercalated with till, and is considered to be of subglacial origin. The lower consists of 7 m of fluvial sand and gravel. The top of this lower sand and gravel unit has been deformed by glacier overriding, but the remainder of the unit consists of plane and cross-bedded sediments whose structures indicate paleocurrents towards the east. The lower unit is believed to be interglacial as paleocurrents toward the east require an ice-free Hudson

Bay. The interval is tentatively correlated with the Sangamian beds in the Gillam sections on the basis of the till stratigraphy, and by the pollen assemblage described below.

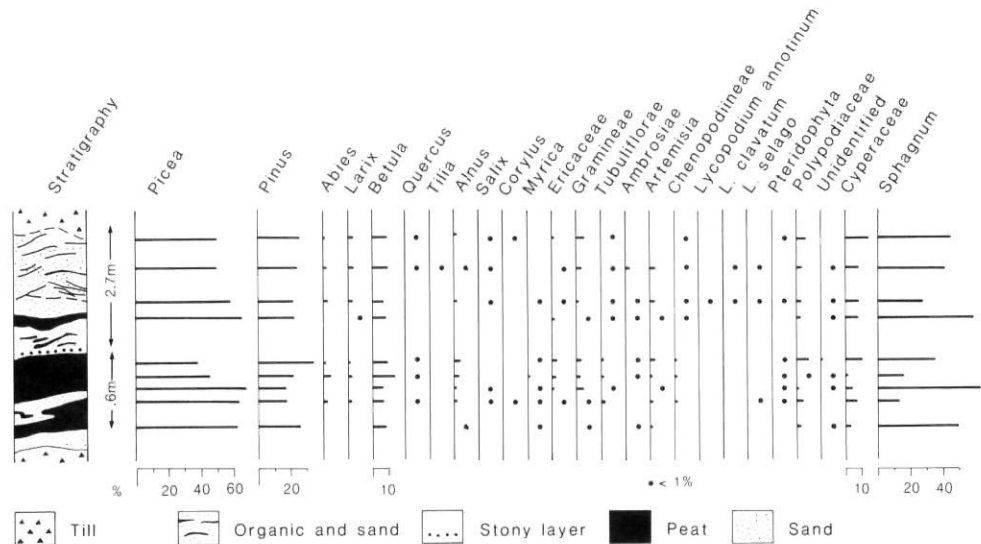
Mott (Palynological Report No. 81-5) examined organic fragments in the silt and sandy gravel encountered higher in the section. These included small dark diamictic inclusions within the sand, small rounded organic nodules, and discrete peaty fragments. The dark diamictic inclusions are dominated by *Picea* (spruce) pollen, with abundant *Pinus* (pine) and with *Betula* (birch) and *Alnus* (alder) present in small quantities. Herbaceous taxa are also present. The organic nodules, on the other hand, differ noticeably in that herbaceous taxa dominate. Graminae (grass), Cyperaceae (sedge), Tubuliflorae (composite) and *Artemisia* (sage) are abundant. *Pinus* is also abundant, but *Picea* pollen is a minor component. The pollen assemblage of the peaty fragments is different as well: *Betula* dominates along with *Picea*, and *Pinus* is a minor pollen taxa. Cyperaceae is abundant, and several herbaceous taxa have low values. The spectra in the diamictic inclusion are similar to those of the Sangamian interglacial deposits along the Nelson River. The other samples are not, although all three types of assemblages could be found in a northern boreal forest to tundra environment. All organic fragments appear to be reworked "clasts" or transported detritus within the sandy bed. They may all belong to one interglacial unit and represent different types of organic environments, or they may be a mixture of material from different age deposits. The preferred interpretation at present is that the dark inclusions, at least, are Sangamian organics eroded from interglacial deposits, transported by glaciers and meltwater, and redeposited as clasts in the sandy intertill bed. The organic may be time equivalent to the fluvial beds lower in the section.

Great Island Section

Sections along the Seal River record several advances of ice flowing southwards from a centre in Keewatin. Interglacial beds outcrop at several locations (Fig. 1). They appear in section as barren silty lacustrine beds beneath one or two till sheets, and as organic bearing gravel deposits. At Great Island, the interglacial unit was described by Taylor (1961) as being

FIGURE 17. Pollen profile for Flamborough Point, exposure I.

Diagramme pollinique de Flamborough Point, coupe n° 1.



an oxidized conglomerate, probably a river gravel, consisting of Precambrian boulders in a goethite matrix and containing clasts and impressions of leaves, twigs, wood and moss. J. Terasmae reported (*in* Taylor, 1961) that leaves of Ericaceae such as *Chamaedaphne* (leather leaf), *Kalmia* (dwarf laurel) and *Arctostaphylos* (bearberry) are abundant, and he concluded that the assemblage is similar to that of the present boreal environment in the area.

North Knife River Sections

The North Knife River area lies within the zone of convergence of Wisconsinan Keewatin and Labradorian-Hudsonian ice. The stratigraphic record reflects the interaction of these two ice masses, so that the upper part of the sedimentary record consists of layers of sandy granitic and silty calcareous till, beneath Holocene glaciolacustrine sediments. Intertill sand beds deposited by subglacial meltwater are common in this interlobate situation. Sections containing units which have been ascribed to the Sangamon Interglaciation on the basis of their non-glacial character and stratigraphic position have been logged and reported by Dredge and Nixon (*in press*) and Dredge *et al.* (1986). Interglacial deposits outcrop directly above present river level, and in most sections, consist of fluvial gravel of mainly granitic lithologies. In several sections a more complex sedimentary record including fine-grained point bar overbank deposits is present, although no organic deposits have been found. At other sites the uppermost unit is a grey plastic lacustrine silt which could be a glaciolacustrine unit deposited at the end of the interglaciation in front of a glacier advancing out of Hudson Bay. The silt overlies several metres of fluvial gravel which is strongly rubified, oxidized, and cemented at the top, but which becomes unoxidized at depth. The gravel overlies stratified sand and silt or fine sand in graded, plane and massive beds, which probably also represent alluvial facies and changing flow regimes. The eastward current direction of the gravel and sand units indicates that drainage towards Hudson Bay was unimpeded either by ice, by high level glacial lakes, or the Ocean. The oxidation suggests that a podzolic soil may have developed later in the interglaciation, although groundwater origins for the cementation cannot be ruled out.

Limestone Rapids Section

Sections along the lower reaches of the Churchill River also expose an interglacial alluvial unit about 8 m above present river level. This unit lies between silty calcareous tills of Hudsonian-Labradorean provenance, which can be correlated with the *Amery and Long Spruce tills on the Nelson River*. The north-south orientation of till fabrics and high percentage of pre-Cambrian clasts in the uppermost part of the till sequence may suggest late overriding of this area by Keewatin ice. On the east bank the interglacial unit consists of a cobble gravel; on the west bank it consists variously of beds of partly stratified sand and gravel, crossbeds of fine sand with detrital organics, and massive units of cobble and pebble gravel (Nielsen and Young, 1981; Dredge and Nielsen, 1985).

The organic detritus contains fragments of beetles, in particular *Bembidion*, and *Stenus* species, flies, tadpole shrimp and *Daphnia* and small mammal bones (J. V. Matthews Jr., Arthropod Report 79-2). Examination of plant macrofossils revealed the presence of *Betula* (birch) samaras, and seeds of *Potamogeton* (pondweed), Cruciferae (mustard family), *Ranunculus* (crowfoot), *Potentilla* (cinquefoil), *Dryas integrifolia* (mountain avens), and *Achillea*.

Pollen extracted from the unit is suggestive of forest-tundra conditions (R. J. Mott, Palynological Report No. 79-14). Some trees were present but these were scattered among open areas, as indicated by an abundance of herbaceous taxa. Spruce trees were prominent in the landscape, and birch were probably present. Willow and alder shrubs were present and grasses were abundant. *Sphagnum* spores indicate boggy conditions. Similar modern spectra from the Churchill area (Lichti-Federovich and Ritchie, 1968, p. 308) suggest that the interglacial environment at Limestone Rapids was very similar to the present.

CORRELATIONS ACROSS THE HUDSON BAY LOWLANDS

A complex sequence of glacial and non-glacial beds in the James Bay area was first described by R. Bell (1887) and J.

Bell (1904). The interglacial beds, known as the Missinaibi Formation, have been studied in detail by Terasmae and Hughes (1960) and Skinner (1973 and Figure 6). Skinner summarized and interpreted the sediments and divided the units into marine, fluvial, forest peat, and glaciolacustrine members. The peat units are similar to those from the Nelson River and Gods River areas of Manitoba. Both are dominated by species representing northern forest-tundra conditions. The Missinaibi spectra are also dominated by *Picea* (spruce) and *Pinus* (pine), with lesser amounts of *Betula* (birch) and *Alnus* (alder). Herbaceous taxa are well represented but there are less Cyperaceae (Sedge). The Missinaibi Formation has been correlated with the more recent of the two interglacial units in northern Manitoba on the basis of their sedimentary and bioclimatic records and their stratigraphic position. At each exposure they bear the first (and usually the only) organic beds below till. In addition, aspartic acid ratios on wood samples from most sites in Manitoba are similar to wood ratios from the Missinaibi Formation in Ontario. In both areas the deposits are considered to be interglacial and to be of Sangamonian age (about 74-125 ka) although Terasmae and Hughes (1960) originally thought that the Missinaibi beds were 'interstadial' because the pollen did not indicate a climate warmer than present. The 'interstadial' assignment has been ruled out by paleogeographic considerations discussed below in assigning the nonglacial units in Manitoba to the Sangamon Interglaciation, and also on further consideration of the insensitivity of the taxa in boreal areas to slight changes in climate.

The marine member of the Missinaibi Formation exposed along the Abitibi and Kwataboahagan rivers (Skinner, 1973) may in fact belong to a separate interglaciation, such as the earlier one recorded in Manitoba, or to a separate part of the three-phase Sangamon Interglaciation; the marine member was not seen in the same sections as the other Missinaibi beds, and the stratigraphic assignment of the tills enclosing the marine unit are also indefinite.

Other sediments, consisting mainly of fluvial gravels whose cross-beds indicate current flow towards Hudson Bay, have been reported on the Fawn and Severn rivers in northwestern Ontario (McDonald, field observations, 1968). These sediments have also been correlated with the Sangamonian units (Dredge and Cowan, 1989, and Fig. 6). Deposits associated with the Sangamon Interglaciation are therefore preserved at numerous sites across the entire Hudson Bay Lowlands.

SYNTHESIS: NATURE OF THE SANGAMON AND PRE-SANGAMON INTERGLACIATIONS

The correlation of nonglacial units shown in Figure 6 is based on their stratigraphic position, the character of the till sheets above and below them, and consistencies in character of the interglacial beds themselves. Based on field relations, the simplest working hypothesis is that there are two nonglacial intervals. The possibility that there are more than two intervals, and that there has been a mis-correlation, should not be ruled out entirely, however, particularly since no section contains a complete record.

Both non-glacial intervals are considered to represent interglaciations, rather than interstades, on the basis of paleogeographical considerations; specifically, that low base levels, soils, and terrestrial peat beds demand low sea levels and unrestricted drainage into Hudson Bay. There could not have been ice in Hudson Bay ponding glacial lakes. The fact that this area, lying in the heart of the Laurentide Ice Sheet, was free of ice when the sediments were deposited itself indicates that the great ice sheets had essentially disappeared. As noted earlier, we use the term interglaciation to denote an ice-free condition, rather than a warm climate. The non-glacial intervals are further considered to be interglaciations climatically because of the degree to which the biota resemble that of our present interglaciation.

Although the absolute ages of the two interglacial units have not been determined, the later and stratigraphically upper unit is considered to be Sangamonian. It may encompass all of the Sangamonian Stage (isotope substages 5a to 5e) or only one part of it. There is evidence for climatic conditions both cooler and warmer than present. The cool units could either represent a relatively cool interval (e.g. substage 5a or c), or could be the beginning or end phases of a warmer substage (5e). The earlier and stratigraphically lower interglacial unit is presently thought to be a pre-Sangamonian interglaciation rather than being simply the earlier (5e) Sangamonian substage, because the climate indicators suggest that the earlier event was both cooler than our present interglaciation, and cooler than the other interglaciation recorded in the sections: oxygen isotope substage 5e was supposed to have been at least as warm as present and warmer than 5a. In addition, the lower interglacial deposits are separated from the upper ones by a thick and apparently extensive till sheet.

THE PRE-SANGAMON INTERGLACIATION

The pre-Sangamon interglaciation recorded at Sundance, Limestone, and Eagle Bluff sections near Gillam is characterized by cool tundra biotic conditions. The pollen is predominantly Cyperaceae (sedge), Graminae (grass), *Sphagnum* (moss) and *Betula* (birch); *Picea* (spruce) and *Pinus* (pine) pollen are minimal. Also, the Amery Till and its correlatives, which stratigraphically overlie the interglacial units, contain more arctic foraminiferal species, specifically *Elphidium clavatum* and *Cassidulina reniforme*, than tills above the Sangamonian beds. These microfossils may have been living in Hudson Bay during the interglaciation and were subsequently incorporated into the till by glacial ice flowing across Hudson Bay. If the lower clay beds at Limestone are marine, then sea level was at least 58 m above present sea level at some time during the interglaciation. Vanadium and boron values in the clay at Eagle Bluff suggest that this deposit is marine. If the Eagle Bluffs clays are pre-Sangamonian, then these also indicate a sea level more than 45 m above present. Equally, sea level had to be lower than about 54 m at some other time for the paleosol at Sundance to develop. The thickness of the paleosol raises another interesting point; the horizons preserved are at least twice as deep as those which have developed on similar substrates during the Holocene. This development indicates either that there was a longer period of soil development, and/or that the climate was warmer than present for part of the interglaciation.

THE SANGAMON INTERGLACIATION

The Sangamonian interglacial landscape was likely similar to the present landscape of the Hudson Bay Lowlands and surrounding shield. Hudson Bay was open; rivers deposited alluvial channel gravels and overbank sands and silts; the land was covered with forests and peatlands with small ponds, and some of the lakes were marly. There is evidence for glacial lakes at the close of the interglaciation and beginning of the next (Wisconsinan) glacial epoch. Clays having high boron and vanadium contents and extending to 120 m asl at Echoing River suggest that there may have been a high glacioisostatic sea at the beginning of the interglaciation. By comparison, Holocene postglacial seas extended to elevations of 120 to 150 m in those same areas. The sea subsequently regressed to a lower and probably reached a base level below present sea level. Alluvial gravels at Port Nelson indicate base level was at least as low as +2 m asl. Because these are cobble gravels indicative of a high energy environment, base level was probably considerably lower and thus the mouth of the estuary was probably seaward (*i.e.* eastward) of its present position. Furthermore, exposures of pond and peat deposits along the Nelson River at and below present river level also indicate river base levels lower than present.

Extensive old alluvial deposits along the North Knife River suggest that the present river partly coincides with an ancestral valley of probable Sangamonian age, although no evidence for the river following a northward course was found along its lower reaches. The ancestral Nelson River system was somewhat different from the river today, where the present channel is very wide, and the banks are steep and up to 40 m high. The pond deposits, thin alluvial beds, overbank silts, and peat suggest a smaller river, with gently sloping or very low banks. The discontinuous nature of alluvial units along the bluff suggests that the course of the main river was different from that of today, although both the present Nelson River and its Sangamonian antecedent may have occupied part of a major Tertiary valley.

A coniferous forest with a sphagnum understory probably developed during the middle part of the interglaciation in the Gillam and Gods River areas. The early and late stages were characterized by tundra conditions. Areas farther northeast supported tundra peatlands dominated by shrubs, mosses and grasses. Woolly mammoths, beaver, small mammals, weevils and beetles inhabited the region. Gastropods and ostracods lived in the freshwater ponds, and molluscs and foraminifera lived in the ancestral Hudson Bay.

Evidence of soil development is limited to the oxidized gravels exposed along parts of the North Knife River. If the rubified and cemented horizon is the B zone of a soil then a mature podzol similar to that which has developed in the area in the last 8000 years, developed during the Sangamonian. The varves and silty diamicton in the upper part of some units suggest that a proglacial lake developed in the waning stages of the Sangamon Interglaciation as a result of the growth of an ice sheet which must by then have crossed and occupied Hudson Bay.

The climate during much of the Sangamon Interglaciation was similar to, but not entirely analogous to, the present cli-

mate. For much of the time the area was in an open forest biome, near treeline. In many sections, where only a small part of the record is preserved, there is little evidence for climatic cycles; in more complete sections, there are indications of progressive changes of climate. Pollen profiles at Echoing River, Gods River, and Henday record an early tundra-like environment similar to that in southern Keewatin today, but with more spruce and less birch and alder, and more scattered shrubs. The beetle remains from this interval are similar to modern subarctic species. The early period was followed by a time when pine may have reached the area, and the forest may have been more closed than that in the same region today. The climate may have been slightly warmer than present, and the treeline was probably north of its present position. Other evidence for temperate boreal conditions are the existence of marl beds and the microfossil species within them, and the presence of the foraminifer *Elphidium gunteri* in the till overlying the interglacial bed at Flamborough. This species indicates warm water temperatures comparable to those south of Cape Cod. The relatively warm part of the climatic cycle described here may be similar to the Holocene hypsithermal interval.

This interval was followed by a lengthy period when the growing season and summer temperatures appear to have been similar to those of today. These conditions are reflected in that part of the pollen profile dominated by boreal species, especially *Picea* (spruce). *Pinus* (pine) pollen was plentiful, although pine trees may not have actually been in the area; *Betula* (birch) was present. Herb pollen and sphagnum spores were abundant, and were more common than in the boreal forest today, suggesting that the interglacial forest was more open. Spruce trees had diameters of at least 15 cm. The position of the treeline during this phase was similar to present. The vegetation varied considerably from site to site, and a wide variety of habitats were present. Sites at Gillam, Gods River and Seal River lay within an open boreal forest, while those at Limestone Rapids and Port Nelson, just outside the treeline today, experienced marginal tundra conditions. The final part of the climatic cycle is recorded as a return to more tundra-like conditions throughout the region. This cooling is reflected in the pollen and beetle assemblages and in the marine microfauna, which include species (*C. reniforme* and *E. clavatum*) typical of present arctic environments.

In summary, the extensive evidence documented here indicates that the Sangamon Interglaciation of the Hudson Bay region began as a cool interval, which is followed by an interval warmer than present, then a period when conditions were similar to today's, and finally a return to cool conditions. The Holocene interglaciation has so far gone through the first three parts of the Sangamonian cycle. If the pattern is similar, we can expect a further cooling. On the basis of beetle species, we estimate that the middle to late cool Sangamonian phase experienced July temperatures 3-4°C cooler than present, and mean annual temperature of about 3° cooler. If the Holocene trend is similar to the Sangamonian, we can expect a return to cooler, tundra-like conditions in northern Manitoba. Should future sea levels be comparable to minimal Sangamonian levels as a result of continued crustal rebound, then the shallow parts of Hudson Bay may become dry land.

Unfortunately, Quaternary research has not yet reached the state of being a predictive art. We are all aware of human interference with the natural systems of the planet. The Holocene will be the first interglaciation of the 17 or more that have already occurred (Fink and Kukla, 1977) where the natural progression of the cycle may be seriously affected by anthropogenic change. Predictive meteorological models suggest that with a doubling of CO₂ the Hudson Bay lowlands will experience summer and winter warming trends of 7 and 9°C respectively. The effects on this region, and on the permafrost regimes farther north could be truly catastrophic. We hope that this initial synthesis of the paleohistory of the western Hudson Bay lowlands will provide the impetus for further research in this little known part of Canada.

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