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QUATERNARY STRATIGRAPHY OF THE SEVERN AND WINISK DRAINAGE BASINS, NORTHERN ONTARIO

L.H. Thorleifson, P.H. Wyatt, and T.A. Warman

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Limestone Rapids, Severn River, 8 km downstream from the confluence with Fawn River; view to the north.

Critical reader

W.W. Shilts

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Preface

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

In this report, the authors present the results of a study of the unconsolidated sediments exposed in riverbanks in the central Hudson Bay Lowland of northern Ontario. They examined several till units with differing dispersal directions as well as interstadial deposits.

Knowledge of the sequence of former glacial ice flow directions is needed for successfully applying till sampling methods in mineral exploration. Results from Hudson Bay Lowland, where the glacial sequence outcrops, are relevant to activity on nearby areas of the Shield where exposures of the till sequence are lacking. Studies of ice flow directions and background compositional trends in tills will also facilitate kimberlite and base metal exploration within the Paleozoic carbonate terrane of the lowland. Records of climate during interstadial and interglacial episodes provide a case study regarding the range of variability of global climate in the recent geological past and hence possible scenarios for future climate.

Elkanah A. Babcock
Assistant Deputy Minister
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Préface

La Commission géologique du Canada fournit de l'information sur les ressources du sol et le comportement des terrains, en vue de contribuer tant à l'utilisation efficace et à la conservation des ressources qu'à la gestion et à la protection de notre environnement; l'information en question est tirée d'études géologiques, géomorphologiques, géophysiques et géotechniques, mais aussi d'autres travaux dans des domaines connexes.

Dans le présent bulletin, les auteurs font état des résultats d'une étude qui visait à décrire les sédiments meubles exposés sur les berges de la partie centrale des basses terres de la baie d'Hudson, dans le nord de l'Ontario. Ils ont examiné plusieurs unités de till ayant des directions de dispersion variées, ainsi que des dépôts interstadiaires.

Afin de pouvoir appliquer avec succès les méthodes d'échantillonnage des tills à l'exploration minière, il faut connaître la succession des directions d'écoulement glaciaire dans le passé. Les données recueillies dans les basses terres de la baie d'Hudson, où il y a des traces de la séquence glaciaire, servent aux travaux menés dans les régions avoisinantes du Bouclier, où il n'y en a pas. En outre, l'étude des directions d'écoulement glaciaire et des grands traits de la composition des tills peut faciliter l'exploration ciblant la kimberlite et les métaux communs dans le terrane carbonaté paléozoïque des basses terres. Les données sur les climats interstadiaires et interglaciaires permettent d'étudier comment ceux-ci ont varié dans le passé géologique récent à l'échelle du Globe et, par le fait même, offrent des scénarios éventuels de que nous réserve l'avenir sur ce plan.

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

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QUATERNARY STRATIGRAPHY OF THE SEVERN AND WINISK DRAINAGE BASINS, NORTHERN ONTARIO

Abstract

Quaternary sediments outcropping in the Severn and Winisk drainage basins of northern Ontario include postglacial sediments, five till units, and interstadial deposits. Shagamu Till, the oldest unit, is attributed to southeastward ice flow on the basis of the abundance in this sediment of Devonian red carbonate erratics derived from central Hudson Bay. Rocksand Till is slightly enriched in Proterozoic erratics derived from the east, contains Hiatella arctica (L) fragments (Ha) with total alloisoleucine/isoleucine (aIle/Ile) ratios around 0.20, which are correlated to the Bell Sea of substage 5e, and yields northwest-southeast pebble fabric, parallel to old striations at Big Trout Lake. The Fawn River sediments are best exposed on the Fawn, Severn and Beaver rivers, include marine sediments TL dated to substage 5a, yield total aIle/Ile (Ha) values around 0.14, record isostatic recovery and subaerial exposure in an environment similar to present, and are capped by glaciolacustrine sediments deposited possibly as late as mid-stage 3 at the close of the interstade. Sachigo Till, considered the deposits of ice sheet growth, yielded directional data indicating westward flow at its base and later southeastward flow implied by red carbonates. Severn Till is attributed to Late Wisconsinan southwestward ice flow on the basis of enrichment in Paleozoic debris, northeast-southwest pebble fabrics, striated boulder pavements, the younger striations at Big Trout Lake, and flutes in the Severn River area. Winisk Till only occurs under the north-south flutes that extend from the Winisk River area to Albany River. Total aIle/Ile (Ha) ratios around 0.07 from shell fragments in Severn and Winisk tills are attributed to glacial transport of shells that grew in offshore Hudson Bay at the end of the interstade.

Résumé

Les sédiments quaternaires qui affleurent dans les bassins hydrographiques de la Severn et de la Winisk, dans le nord de l'Ontario, comprennent des sédiments postglaciaires, cinq unités de till et des dépôts interstadiaires. Le Till de Shagamu, l'unité la plus ancienne, est associé à un écoulement glaciaire vers le sud-est, d'après l'abondance des erratiques carbonatés rouges du Dévonien en provenance du centre de la baie d'Hudson. Le Till de Rocksand, contenant peu d'erratiques protérozoïques dérivés de l'est, présente des fragments de Hiatella arctica (L) (Ha) dans lesquels les rapports alloisoleucine/isoleucine (aIle/Ile) dans la fraction totale sont d'environ 0,20; ces fragments sont mis en corrélation avec les dépôts de la Mer de Bell du sous-étage 5e. De plus, les cailloux de ce till sont caractérisés par une fabrique nord-ouest-sud-est, parallèle aux stries anciennes observées au lac Big Trout. Les plus beaux affleurements des sédiments de la rivière Fawn se trouvent le long des rivières Fawn, Severn et Beaver. Ces sédiments, caractérisés par un rapport aIle/Ile (Ha) dans la fraction totale d'environ 0,14, comprennent des matériaux marins qui ont été associés au sous-étage 5a à l'aide de la datation par thermoluminescence (TL); ils témoignent d'un relèvement isostatique et d'une exposition subaérienne dans un environnement semblable à celui d'aujourd'hui, et sont couronnés de sédiments glaciolacustres qui se sont peut-être accumulés aussi tard qu'au milieu de l'étage 3, à la fin de l'interstade. Le Till de Sachigo, qui serait un dépôt de nappe glaciaire en expansion, fournit des données directionnelles qui, à la base du till, attestent d'un écoulement glaciaire vers l'ouest et, à en juger par la présence d'erratiques carbonatés rouges, indiquent un écoulement subséquent vers le sud-est. Le Till de Severn est associé à un écoulement glaciaire tardi-wisconsinien vers le sud-ouest, comme en témoignent les concentrations élevées de débris paléozoïques, les fabriques nord-est-sud-ouest des cailloux, les pavages d'erratiques striés, les stries plus jeunes au lac Big Trout et les cannelures dans la région de la rivière Severn. Le Till de Winisk se rencontre uniquement sous les cannelures nord-sud qui, de la région de la rivière Winisk, s'étendent jusqu'à la rivière Albany. Des fragments de coquilles des tills de Severn et de Winisk donnent des rapports aIle/Ile (Ha) dans la fraction totale d'environ 0,07; ces chiffres indiquent un transport glaciaire de coquilles d'organismes qui vivaient au large de la baie d'Hudson à la fin de l'interstade.

SUMMARY

Riverbank sections in the central Hudson Bay Lowland expose postglacial marine and terrestrial sediments, multiple tills that record the advance and retreat of the Laurentide Ice Sheet, and fossiliferous interstadial sediments.

Shagamu Till, a red till found at the base of sections on Shagamu and Niskibi rivers, is attributed to southeastward ice flow on the basis of high concentrations of Devonian red carbonate derived from the centre of Hudson Bay. It is a probable equivalent of the Sundance Till in Manitoba.

Post-Shagamu Till deglaciation, correlated to Bell Sea sediments, which occur above present sea level on Kwataboahegan River in the Moose River basin (Skinner, 1973; Shilts and Wyatt, 1988) and to the Sundance soil of Manitoba (Nielsen et al., 1986), is only recorded in the area by shell fragments with total aIle/Ile (Ha) ratios of about 0.20 in overlying tills. Extrapolation from TL dates on marine sediments with lower amino acid ratios implies correlation of Bell Sea to oxygen isotope substage 5e.

Rocksand Till is attributed to mid-stage 5 glaciation. This lowest unit of the upper Severn River was identified at four sections on the basis of stratigraphic position, very low red carbonate content, elevated concentrations of Proterozoic clasts derived from the east, and northwest-southeast fabric. This unit is correlated with Amery Till of Manitoba. Old striations on the shield, including roches moutonées with plucked faces on their northwest side, are parallel to the fabric data and indicate ice flow to the west-northwest. Tyrrell (1913, 1914) combined this pattern of ice flow with what he thought was north-northwesterly ice flow on Fawn River to obtain a model for a Patrician ice centre in northern Ontario. This model is rejected on the basis of reinterpretation of the ice flow for the upper till on Fawn River as south-southeastward and also because additional striation sites located on the shield (Prest, 1963) indicate an ice source farther east. Shells from Rocksand Till with total aIle/Ile (Ha) ratios of about 0.20 indicate that this unit postdates Bell Sea, which yields similar ratios. Glaciation at the end of the last interglacial therefore consisted of generally westward ice flow derived from Quebec. Glacial inception models such as those presented by Flint (1943) and Ives (1957) involving growth of an ice sheet in Quebec are therefore favoured.

Fawn River sediments include marine, fluvial, organic, and lacustrine sediments. Deglaciation of isostatically depressed terrain and opening of Hudson Bay are indicated by marine sediments on Severn River, which have been TL dated to oxygen isotope substage 5a (Forman et al., 1987). Total aIle/Ile (Ha)

SOMMAIRE

Des sédiments marins et terrestres postglaciaires, des nombreux tills témoignant de l'avancée et du retrait de l'Inlandsis laurentidien ainsi que des sédiments fossilifères interstadiaires affleurent sur les berges de la partie centrale des basses terres de la baie d'Hudson.

Le Till de Shagamu, une unité rouge qui se rencontre à la base de coupes le long des rivières Shagamu et Niskibi, est associé à un écoulement glaciaire vers le sud-est, d'après sa teneur élevée en erratiques carbonatés rouges du Dévonien, dérivés du centre de la baie d'Hudson. Il est vraisemblablement l'équivalent du Till de Sundance au Manitoba.

Dans la région, le seul témoignage de la déglaciation postérieure à la mise en place du Till de Shagamu provient de fragments de coquilles trouvés dans les tills sus-jacents et ayant des rapports aIle/Ile dans la fraction totale d'environ 0,20. Il est à noter que ce till est mis en corrélation avec les sédiments de la Mer de Bell qui se rencontrent au-dessus du niveau actuel de la mer le long de la rivière Kwataboahegan, dans le bassin de la rivière Moose (Skinner, 1973; Shilts et Wyatt, 1988), et avec le sol de Sundance au Manitoba (Nielsen et al., 1986). L'extrapolation de données de datation par TL, obtenues à partir de sédiments marins qui ont des rapports d'acides aminés moins élevés, indique que la Mer de Bell correspond au sous-étage isotopique de l'oxygène 5e.

Le Till de Rocksand est associé à la glaciation du milieu de l'étage 5. Cette unité inférieure de la partie amont de la rivière Severn est reconnue dans quatre coupes d'après sa position stratigraphique, sa très faible teneur en erratiques carbonatés rouges, ses concentrations élevées de clastes protérozoïques dérivés de l'est et sa fabrique nord-ouest-sud-est. Elle est mise en corrélation avec le Till d'Amery au Manitoba. Des stries anciennes sur le Bouclier, dont notamment des roches moutonnées aux faces d'arrachement sur le flanc nord-ouest, sont parallèles à la fabrique et témoignent d'un écoulement glaciaire vers l'ouest-nord-ouest. Tyrrell (1913, 1914) a combiné cette configuration d'écoulement glaciaire et ce qu'il croyait être un mouvement de glaces vers le nord-nord-ouest, le long de la rivière Fawn, pour produire un modèle supposant un centre d'accumulation de Patricia dans le nord de l'Ontario. Ce modèle est rejeté par suite d'une nouvelle interprétation de l'écoulement glaciaire dans le cas du till supérieur le long de la rivière Fawn qui suggère un mouvement sud-sud-est, mais aussi parce que des stries trouvées à d'autres endroits sur le Bouclier (Prest, 1963) témoignent du fait que les glaces proviennent d'une autre zone plus à l'est. Des coquilles du Till de Rocksand donnent des rapports aIle/Ile (Ha) dans la fraction totale d'environ 0,20, ce qui indique que l'unité est postérieure aux dépôts de la Mer de Bell, pour lesquels les rapports sont semblables. Ainsi, à la fin du dernier interglaciaire, les glaces s'écoulaient généralement vers l'ouest, à partir du Québec. La préférence va donc aux modèles de la naissance de la glaciation qui comportent la croissance d'une nappe glaciaire au Québec, comme ceux de Flint (1943) et d'Ives (1957).

Les sédiments de la rivière Fawn sont d'origine marine, fluviatile, organique et lacustre. La présence, le long de la rivière Severn, de sédiments marins qui remontent (datation par TL) au sous-étage isotopique de l'oxygène 5a (Forman et al., 1987) témoigne de la déglaciation des zones qui avaient subi une dépression isostatique et de l'ouverture de la baie d'Hudson. Ces

ratios of about 0.14 indicate correlation of these sediments to the Prest Sea marine sediments on Abitibi River in the Moose River basin, which are considered younger than Bell Sea on the basis of differences in amino acid ratios that cannot be explained on the basis of thermal history (Shilts and Wyatt, 1988). Skinner (1973), however, correlated Missinaibi Formation organic deposits in the Moose River basin to the older Bell Sea. The Nelson River and Gods River sediments of Manitoba, however, probably correlate to the Fawn River sediments. Post-Prest Sea isostatic recovery is indicated by the Fawn River gravel and similar deposits on Beaver River, which yielded marine shell fragments with ratios equivalent to the Severn River marine sediments. Subaerial exposure is indicated by peat overlying this gravel on Beaver River. The peat, dated at >51 000 years, indicates a climate similar to present. Peat overlying gravel with Prest Sea ratios indicates that Prest Sea does not represent isostatic depression in front of an advancing ice mass at the end of the episode that began with Bell Sea. The close of this nonglacial interval occurred in late stage 5 or stage 4, or possibly as late as mid-stage 3 if TL data from Manitoba (Berger and Nielsen, 1990) are accepted despite the lack of finite radiocarbon dates. At this time, glaciolacustrine sediments, which were deposited in a lake formed by the advancing ice sheet, were deposited over subaerial deposits on Severn River.

sédiments ont des rapports aIle/Ile dans la fraction totale d'environ 0,14 et sont mis en corrélation avec les sédiments de la Mer de Prest observés le long de la rivière Abitibi, dans le bassin de la rivière Moose. Ces derniers sont considérés postérieurs à la Mer de Bell d'après les écarts dans les rapports d'acides aminés; il est cependant à noter que l'évolution thermique ne permet pas d'expliquer ces écarts (Shilts et Wyatt, 1988). Skinner (1973) a établi une corrélation entre les dépôts organiques de la Formation de Missinaibi, dans le bassin de la rivière Moose, et la Mer de Bell plus ancienne. Toutefois, il y a probablement corrélation entre les sédiments du fleuve Nelson et de la rivière Gods, au Manitoba, et ceux de la rivière Fawn. Les graviers de la rivière Fawn et les dépôts semblables de la rivière Beaver contiennent des fragments de coquilles marines dont les rapports sont équivalents à ceux des sédiments marins de la rivière Severn; ils témoignent d'un relèvement isostatique postérieur à la Mer de Prest. La tourbe qui repose sur ce gravier le long de la rivière Beaver est l'indication d'un milieu subaérien; elle remonte à plus de 51 000 ans et suppose que le climat ressemblait à celui d'aujourd'hui. La présence de tourbe sur du gravier ayant les mêmes rapports que les dépôts de la Mer de Prest implique que cette dépression ne représente pas un enfoncement isostatique devant une masse glaciaire en progression à la fin de l'épisode qui a commencé avec la Mer de Bell. Cet intervalle non glaciaire s'est terminé à la fin de l'étage 5 ou à l'étage 4, ou encore peut-être aussi tard qu'au milieu de l'étage 3, si l'on accepte les données de TL sur des échantillons provenant du Manitoba (Berger et Nielsen, 1990) malgré l'absence de datations au radiocarbone significatives. À cette époque-là, les sédiments glaciolacustres, qui se sont déposés dans un lac formé par la nappe glaciaire en progression, se sont accumulés sur des dépôts subaériens le long de la rivière Severn.

Sachigo Till, the oldest till with shell fragments yielding Prest Sea total aIle/Ile (Ha) ratios (0.14), was deposited during the advance of an ice mass that covered the area until early Holocene deglaciation. Westward ice flow is indicated by fabric at one site, a single striated cobble at another, and also by a possibly correlative boulder pavement on Shagamu River. Eastward ice flow is contradicted by Proterozoic erratics, which are at levels typical of other deposits in the area, but red carbonates imply southeastward ice flow late in this episode. Westward ice flow indicates ice emanating from Quebec at least initially unimpeded by an extensive Keewatin ice mass. Sachigo Till correlates to Long Spruce Till in Manitoba and Adam Till in the Moose River basin. It is unlikely that till sedimentation was active in the area while the ice sheet was at its maximum extent.

Le Till de Sachigo, le plus ancien qui contienne des fragments de coquilles aux rapports aIle/Ile dans la fraction totale (0,14) indicatifs de la Mer de Prest, s'est déposé au cours de l'avancée d'une masse de glace qui a recouvert la région jusqu'à la déglaciation de l'Holocène précoce. Une fabrique identifiée à un endroit, un caillou strié unique trouvé ailleurs et un pavage de blocs possiblement corrélatif reconnu le long de la rivière Shagamu indiquent que les glaces se sont déplacées vers l'ouest. L'observation d'erratiques protérozoïques à des niveaux typiques d'autres dépôts de la région réfute l'écoulement vers l'est; par contre, la présence d'erratiques carbonatés rouges suggère qu'il y a eu écoulement glaciaire vers le sud-est vers la fin de l'épisode. L'écoulement glaciaire vers l'ouest implique que les glaces sont venues du Québec et qu'elles n'ont pas été obstruées, à tout le moins au début, par une vaste masse glaciaire du Keewatin. Le Till de Sachigo est mis en corrélation avec le Till de Long Spruce, au Manitoba, et le Till d'Adam, dans le bassin de la rivière Moose. Il n'y a probablement pas eu accumulation de till dans la région pendant que la nappe glaciaire était à son extension maximale.

Severn Till, the uppermost unit of Severn River, has a consistent composition of intermediate Proterozoic and red carbonate clast content. Southwestward ice flow is indicated by flutes in the Severn River area, several fabrics within the till, striated boulders at the lower contact, and younger striations at Big Trout Lake. The till is attributed to southwestward ice flow along the flank of a saddle across Hudson Bay during

Le Till de Severn, unité supérieure de la rivière du même nom, contient partout une quantité intermédiaire de clastes protérozoïques et de clastes carbonatés rouges. Des cannelures à proximité de la rivière Severn, plusieurs fabriques au sein du till, des blocs striés au contact inférieur et des stries plus récentes observées au lac Big Trout témoignent tous d'un écoulement glaciaire vers le sud-ouest. Le till a été déposé pendant le retrait du Wisconsinien tardif, par des glaces qui se déplaçaient vers le

Late Wisconsinan ice retreat. It is correlated to Sky Pilot Till in Manitoba and Kipling Till of the Moose River basin.

Winisk Till is only present in the eastern part of the study area. It is a single massive unit commonly resting on a striated boulder pavement. It underlies the north-south flutes that occur in the Winisk River area and extend south to Albany River. Winisk Till is attributed to a late glacial ice stream flanked on both sides by stagnant ice. It is not directly associated with the Cochrane event, which has been inferred in the shield area south of the Moose River basin. Total aIle/Ile (Ha) ratios around 0.07 from shell fragments in Severn and Winisk tills are attributed to glacial transport of shells that grew in offshore Hudson Bay at the end of the interstade during which the Fawn River sediments were deposited.

Postglacial sediments consist primarily of fossiliferous marine clay-dominated sediments which thicken toward Hudson Bay. As sea level retreated due to postglacial isostatic rebound, a well-developed series of shoreline features formed. Subsequently, a nearly continuous cover of peat deposits accumulated.

sud-ouest le long du flanc d'un ensellement en travers de la baie d'Hudson. Il a été mis en corrélation avec le Till de Sky Pilot, au Manitoba, et le Till de Kipling, dans le bassin de la rivière Moose.

Le Till de Winisk se rencontre uniquement dans la partie est de la zone à l'étude. Il s'agit d'une unité massive simple qui repose en grande partie sur un pavage de blocs striés. Sa surface supérieure est délimitée par les cannelures nord-sud signalées dans la région de la rivière Winisk et il se prolonge vers le sud jusqu'à la rivière Albany. Ce till est associé à un courant tardiglaciaire que bordaient de chaque côté des glaces stagnantes. Il n'a pas de liens directs avec l'événement de Cochrane, dont l'existence a été déduite dans la région du Bouclier au sud du bassin de la rivière Moose. Des fragments de coquilles trouvés dans les tills de Severn et de Winisk donnent des rapports aIle/Ile (Ha) dans la fraction totale d'environ 0,07; ces chiffres indiquent un transport glaciaire de coquilles d'organismes qui vivaient au large de la baie d'Hudson, à la fin de l'interstade pendant lequel il y a eu accumulation des sédiments de la rivière Fawn.

Les matériaux postglaciaires sont principalement des sédiments marins fossilifères, riches en argile, qui s'épaississent en direction de la baie d'Hudson. À mesure que la mer a reculé par suite de la remontée isostatique postglaciaire, il y a eu formation d'une série de lignes de rivage bien définies. Plus tard, il y a eu accumulation d'une couverture presque continue de dépôts de tourbe.

INTRODUCTION

Rationale and scope of the project

Much research on the Quaternary geology of North America relates to the Laurentide Ice Sheet. At its maximum, it covered most of Canada and much of the northern United States. The configuration, dynamics, and history of the Laurentide Ice Sheet, however, remain poorly known partly because detailed studies have been concentrated in peripheral areas of former ice cover. Ice flow trends near the centre of this area have been little studied. Furthermore, only at the centre of the former ice sheet can major retreat or complete melting be conclusively documented. Hudson Bay Lowland, the region adjacent to the southern coast of Hudson Bay where Paleozoic rocks overlie Precambrian (Fig. 1), therefore has particular significance in the study of major fluctuations in ice volume and trends in ice flow within the Laurentide Ice Sheet. Fortunately excellent exposures of Quaternary sediments exist in this area.

Application of amino acid geochronology to the glacial sequences of Hudson Bay Lowland (Shilts, 1982; Andrews et al., 1983) raised the possibility of multiple pre-Holocene nonglacial episodes and hence more till units than previously recognized. This study was designed to test these hypotheses by examining glacial sequences in the central lowland. Priority was placed on the determination of the number of episodes of glacial ice cover represented by the sedimentary sequence and the relationship of this depositional and erosional record to nonglacial sediments. The composition of glacial sediments was analyzed in order to identify provenance of the sediments and hence further facilitate the correlation of lithostratigraphic units and the determination of the pattern of glacial ice flow. In order to date and characterize pre-Holocene nonglacial episodes, geochronological and paleoecological data were obtained from both in situ and transported organic material.

The study area extends from the Manitoba border to Sutton Ridge (Fig. 1), an inlier of Proterozoic rock, and includes Severn, Winisk, Niskibi, Beaver, Sachigo, Fawn, Shagamu, and Shamattawa rivers (Fig. 2). This area was selected on the basis of significant amino acid data obtained by Shilts (1982) and Andrews et al. (1983) from Fawn River and on the basis of a recommendation by McDonald (1969) for further work on the glacial and nonglacial stratigraphy of the Fawn and lower Severn rivers. The area lies between the Moose River basin, examined in detail by Skinner (1973), and sites in Manitoba examined by, for example, Klassen (1986) and Nielsen et al. (1986).

The project was carried out as three theses dealing with drift composition and stratigraphic correlation (Thorleifson, 1989), amino acid geochronology and paleoecology (Wyatt, 1989) and sedimentology (Warman, 1987).

Bedrock geology

One aspect of this study is the tracing of glacial erratics to their bedrock source. These determinations provide evidence regarding ice flow trends and the nature of glacial erosion, transport, and deposition. The following review of the regional bedrock geology helps in correlating erratics and their sources.

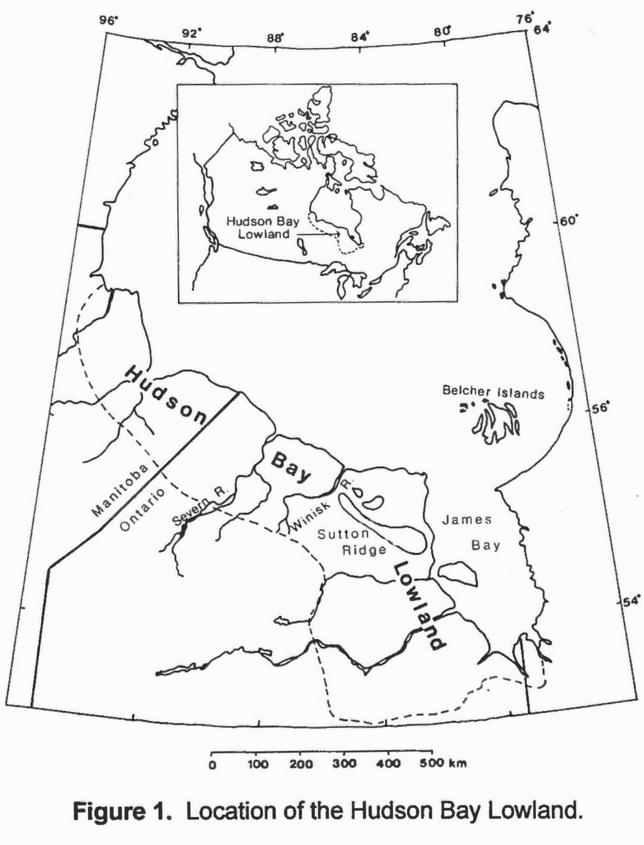


Figure 1. Location of the Hudson Bay Lowland.

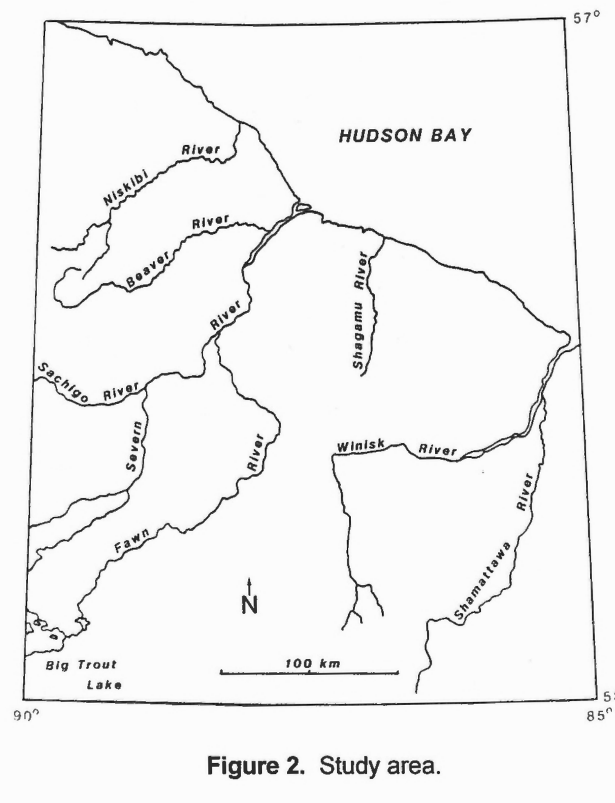


Figure 2. Study area.

The study area is underlain by Paleozoic, Proterozoic, and Archean rocks (Fig. 3). Paleozoic strata in the area range from Ordovician to Devonian in age and consist almost exclusively of carbonates. They dip gently northward from their position on the southern flank of the Hudson Bay sedimentary basin (Norris, 1986). Proterozoic rocks, dominated by slightly metamorphosed sediments and diabase, outcrop in the Sutton inlier between Winisk River and James Bay as well as throughout eastern Hudson Bay in the area surrounding and including Belcher Islands (Donaldson, 1986). Archean rocks occur as isolated outcrops of southeastern Sutton Ridge, on the exposed Ontario shield south of the study area, on the Quebec mainland to the east, and in northern Manitoba and Keewatin northwest of the study area (Fig. 3). Granitic lithologies dominated these rocks as well as narrow belts of metasedimentary and metavolcanic rocks, typically metamorphosed to greenschist facies (Donaldson, 1986).

Archean rocks located south of the study area in Ontario and east of the area in Quebec are assigned to the Superior Province of the Canadian Shield (Stockwell et al., 1970). This area is dominated by granitic batholiths ranging in composition from gabbro to granite (Ayres et al., 1969) and migmatized metasediments and metavolcanics (Thurston et al., 1979). Both the felsic intrusives and the migmatitic rocks contain biotite and hornblende as dominant accessory minerals (Thurston et al., 1979). Metasedimentary and metavolcanic rocks occur as elongate belts that make up 10-20% of the shield in this area, with mafic metavolcanics greatly predominating (Ayres et al., 1969). The metamorphic grade of these rocks varies, ranging from middle greenschist to andalusite, cordierite, and staurolite-bearing almandine amphibolite facies. Archean rocks of the Ontario Superior Province also outcrop along the southeast flank of the Sutton inlier. Bostock (1971) reported that granodiorite, quartz monzonite, granite, quartz diorite, and granodioritic gneiss outcrop in this area.

Northern Quebec, east of the study area, is underlain by rocks of the northeastern Superior Province (Eade, 1966; Stevenson, 1968; McGlynn, 1970). Extensive areas consist of granitic gneisses and metamorphic rocks of the granulite facies. The lack of recognizable sedimentary and volcanic rocks, high grade of metamorphism, and intense granitization in this area suggest that a deeper level of the crust has been exposed (McGlynn, 1970). Isolated patches of unmetamorphosed late Precambrian clastic sedimentary rocks, including red to white arkose, sandstone, and conglomerate occurring east of James Bay were named Sakami Formation by Eade (1966).

Northwest of the field area, in northern Manitoba and District of Keewatin, is the gneiss-, metasedimentary-, and metavolcanic-dominated terrane of Churchill Province. Dubawnt and Hurwitz groups consist of reddish unmetamorphosed sediments and volcanics similar to but much more extensive than the Sakami rocks of Quebec (McGlynn, 1970).

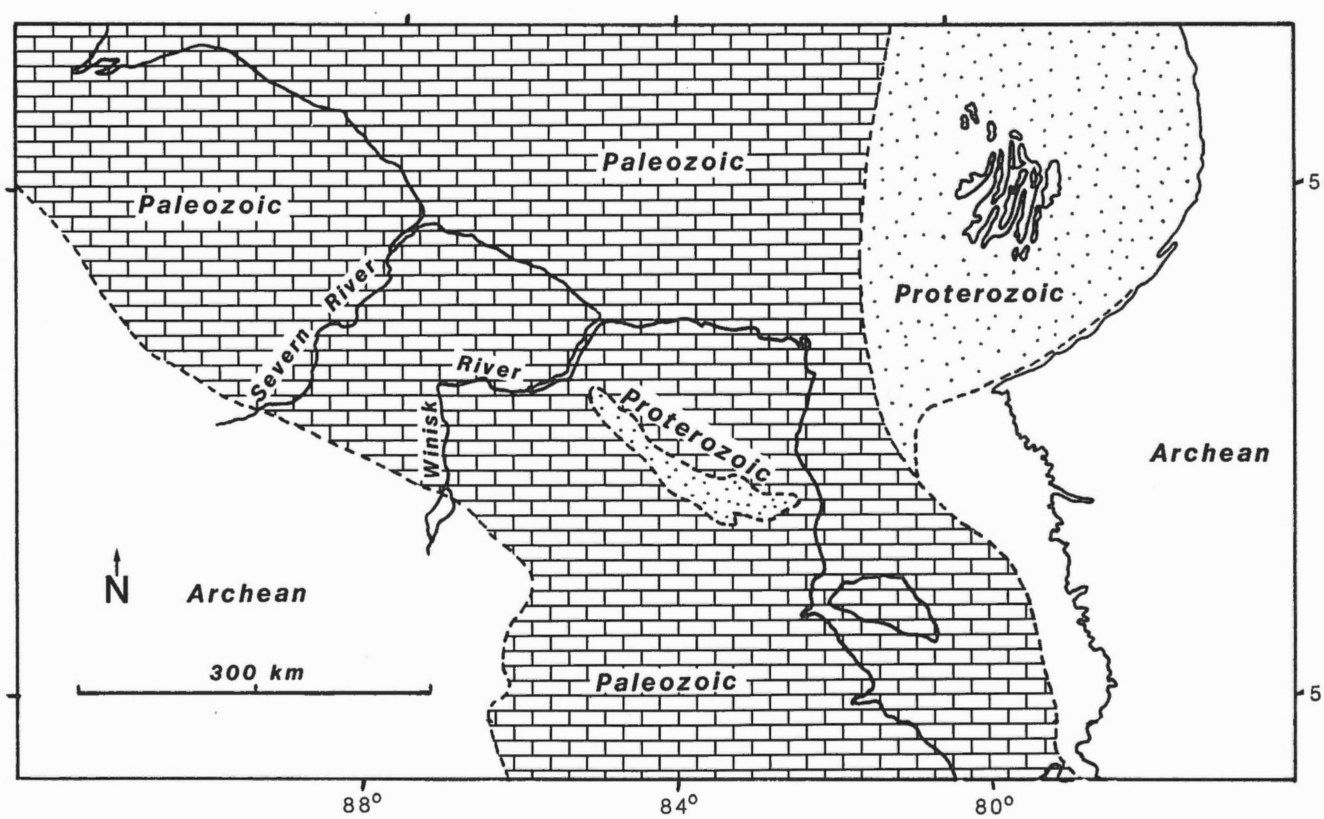


Figure 3. Bedrock geology.

Early Proterozoic strata, considered part of Churchill Province, occur within the arcuate Belcher Fold Belt, which extends along eastern Hudson Bay and into the study area, outcropping in Sutton Ridge (Donaldson, 1986). In the eastern part of this fold belt, along the arcuate coast of Hudson Bay, the strata dip gently seaward and unconformably overlie Archean basement rocks of Superior Province. These strata were named Manitounuk Group by Bell (1879a) but were later divided at a major unconformity into the older Richmond Gulf Group and the overlying Nastapoka Group (Leith, 1910; Young, 1922). Richmond Gulf Group consists mainly of fluvial red beds and associated terrestrial basalt, which were gently folded, faulted, and eroded prior to deposition of Nastapoka Group (Donaldson, 1986). The latter strata consist of arenite, dolostone, iron formation, and wacke, capped by basalt (Woodcock, 1960; Chandler and Schwartz, 1980).

Unmetamorphosed Proterozoic strata of Belcher Group, folded into doubly plunging folds, are well exposed throughout Belcher Islands (Jackson, 1960). Dolostone and basalt at the base of Belcher Group possibly correlate with Richmond Gulf Group (Chandler and Schwartz, 1980; Dimroth et al., 1970; Ricketts and Donaldson, 1981). Above these lower strata of Belcher Group is a sequence of carbonates, including well developed stromatolites, clastic sediments, iron formation, and a basalt cap, all of which have been inferred to correlate with the Nastapoka sequence (Flaherty, 1918; Moore, 1918; Woodbridge, 1921; Donaldson, 1986). The basalt cap of this sequence, Flaherty Formation (Ricketts and Donaldson, 1981), outcrops throughout most of the exposed surface of Belcher Islands.

The overlying Omarolluk Formation, more than 2000 m thick, displays structures indicating turbidity current deposition (Donaldson, 1986). This unit consists of dark green to dark grey, laminated to thick-bedded greywacke with interbedded argillite. Minor tuff beds occur in the lower part and concretionary structures are relatively abundant in several of the upper beds (Jackson, 1960; Hofmann and Jackson, 1969). The spheroidal and ellipsoidal calcareous concretions of this rock were described by McEwen (1978). Omarolluk Formation occurs as rare outcrop at the centre of a syncline in the eastern Belchers.

Above Omarolluk Formation lies Loaf Formation, thin-bedded to massive arkoses stained pink to red with interstitial hematite. This unit occurs on Bakers Dozen Islands, north of the Belchers (Jackson, 1960).

The Proterozoic rocks of Sutton Ridge have been examined by Dowling (1905), Hawley (1926) and Bostock (1969, 1971). Unconformably overlying Archean granitic rocks exposed along the southeast flank of the inlier is a sequence of dolomite, cherty dolomite, stromatolitic dolomite, some siliceous calcareous argillite, limestone, and dolomitic limestone that was named Nowashe Formation by Bostock (1971). A second unconformity, at the upper contact of Nowashe Formation, is overlain by chert breccia, conglomerate, and quartzite with minor slate apparently derived from the underlying Nowashe siliceous carbonates. The chert breccia sequence lies at the base of Sutton Ridges Formation (Bostock, 1971). Overlying the chert breccia are greywacke and other clastic sediments, jaspilitic and slaty iron formation with interbedded minnesotaite chert, some riebeckitic iron formation and minor interbedded siderite, and minor conglomerate. At the top of Sutton Ridges Formation is a 100 m thick sill of diabase and gabbro that caps the ridge.

Bostock (1971) indicated that the greywacke of Sutton Ridges Formation resembles that of Omarolluk Formation on Belcher Islands but lacked tuff and volcanic detritus typical of the latter rocks. Furthermore, the Sutton Ridges greywacke is overlain by diabase, unlike Omarolluk Formation. Bostock (1971) therefore accepted the earlier correlation by Dowling (1905) and Hawley (1926) of Sutton Ridges Formation with the Flaherty basalts and underlying sediments of Belcher Islands. This correlation was supported by the paleomagnetic work of Schwarz and Fujiwara (1981). Bostock therefore inferred that the 2000 m thick Omarolluk greywacke sequence overlies the Sutton diabase and probably occurs beneath Hudson Bay in the area between the Sutton outcrops and Belcher Islands.

Following the early observations of McInnes (1909) and Tyrrell (1913, 1914), the Paleozoic geology of the study area was examined by Savage and Van Tuyl (1919), Norris and Sanford (1969), Cumming (1975), Sanford and Norris (1975), and Sanford (1987). These rocks are a part of Hudson Platform, erosional remnants of two adjacent cratonic basins (Norris, 1986). Hudson Bay Basin is separated from the Moose River basin, adjacent to James Bay, by Cape Henrietta Maria Arch. Sutton Ridge lies at the crest of this arch.

Paleozoic rocks of the study area range from Ordovician in age at the contact with shield rocks to the south, to the Silurian rocks that cover most of the area, to Devonian rocks that occur along the coast of Hudson Bay near the Manitoba border as well as offshore in Hudson Bay. These rocks consist almost exclusively of limestone, dolomitic limestone, and dolomite. Whereas pale browns are typical of the Ordovician and Silurian carbonates, distinctive red carbonates are reported from the Devonian sequences occurring in Hudson Bay (Sanford and Norris, 1975).

Topography and drainage

Hudson Bay Lowland is a low, swampy, marshy plain with subdued glacial features and a belt of raised beaches that border the bay (Bostock, 1970). Sutton Ridge is the most conspicuous topographic feature of the lowland, rising over 150 m above the surrounding plain. Surficial materials are dominated by till, marine deposits, and peat (Sado and Carswell, 1987). Surface glacial lineations oriented parallel to former glacial ice flow direction were mapped by Prest et al. (1968) (Fig. 4). In the study area, a pattern of southwest-northeast lineation is present in the Severn River area, whereas a converging southward pattern is present in the Winisk River area.

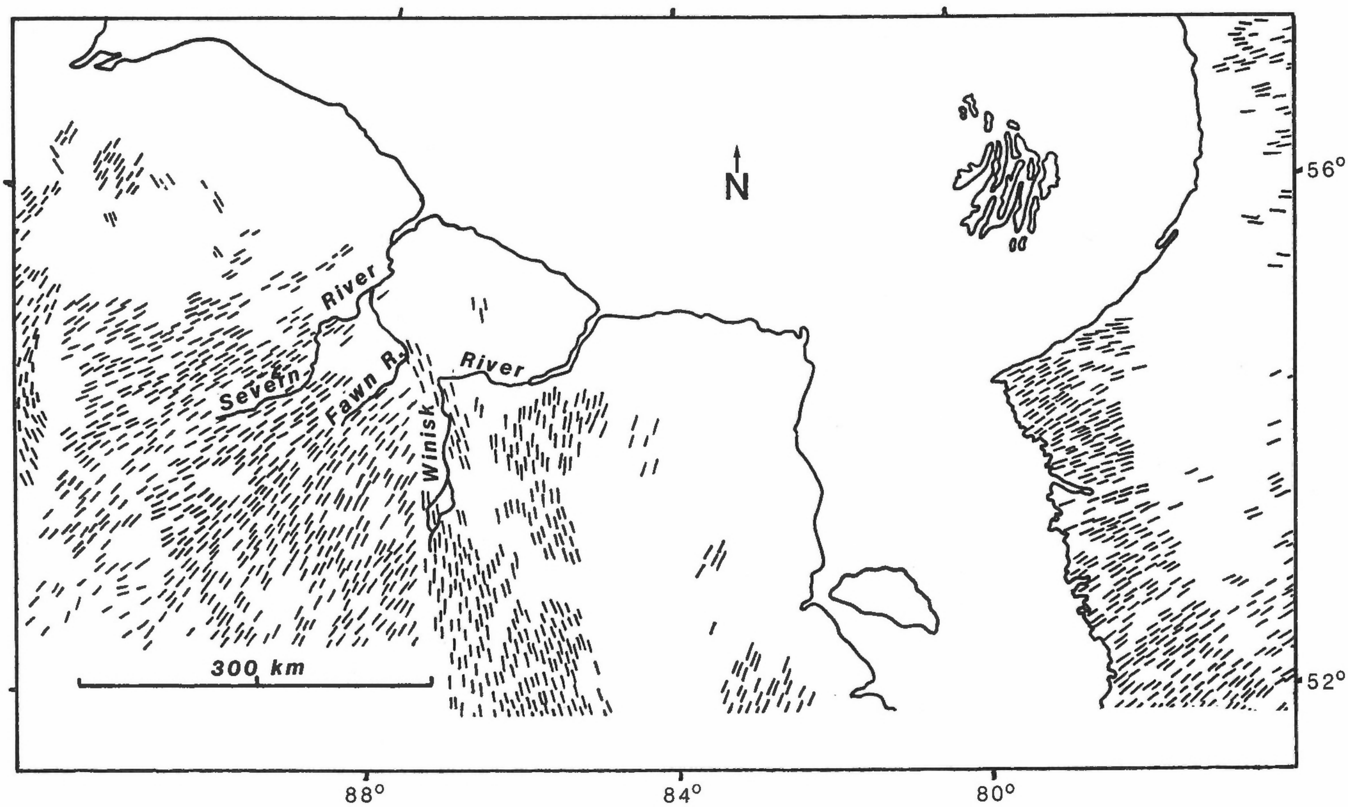


Figure 4. Orientation of flutes (Prest et al., 1968).

Climate and vegetation

The study area has been included in the low subarctic ecoclimatic region by Environment Canada (1989). Summers are cool and four to five months long, with maximum precipitation occurring from July through September. Winters are very cold and snowy.

According to Environment Canada (1989), bog-fen of the area is vegetated by black spruce (*Picea mariana*), Labrador tea (*Ledum groenlandicum*), vaccinium (*Vaccinium* spp.), bog rosemary (*Andromeda polyfolia*) and cloudberry (*Rubus chamaemorus*). Better drained sites are dominated by open stands of black spruce (*Picea mariana*) with understories of dwarf birch (*Betula glandulosa*), Labrador tea (*Ledum groenlandicum*) and lichen (*Cladina* spp.). Drier sites may also include open stands of white spruce (*Picea glauca*) and paper birch (*Betula papyrifera*), with a discontinuous understory of bearberry (*Arctostaphylos uva-ursi*), and bog cranberry (*Vaccinium vitis-idaea*). White spruce (*Picea glauca*), paper birch (*Betula papyrifera*), and trembling aspen (*Populus tremuloides*) also occur on protected, warm sites.

PREVIOUS RESEARCH

The history of study of Hudson Bay Lowland Quaternary geology, along with the ideas that influenced it, can be divided into a series of phases during which major concepts were developed. These include late nineteenth century exploration that led to an understanding of the general nature of continental glaciation in the region, establishment of competing ice sheet models during the first half of the twentieth century, and detailed field work that helped to refine often conflicting hypotheses during the past few decades.

Regional glaciation

Scientific study of the geology of northern Ontario was begun by the Geological Survey of Canada (GSC) in the 1860s (Bell, 1866). Early exploration, mostly by Bell, resulted in acceptance of continental glaciation of the area. Tyrrell (e.g., 1898) subsequently proposed his now defunct concept of multiple ice sheets separated in space and time, but aspects of his model survive in the form of emphasis on multiple domed ice sheet models. Tyrrell (1913, 1914) found evidence for a Patrician ice sheet centred in Ontario south of Hudson Bay. Flint (1943) later restored the concept of a single Laurentide Ice Sheet, but he cited invalid interpretations of isostatic rebound to initiate the presently doubted concept of glaciation centred in Hudson Bay. During reconnaissance of Hudson Bay Lowland Quaternary stratigraphy, McDonald (1969) collected samples that were later used by Shilts (1980) in his revival of multiple centres of glaciation. Amino acid analyses later led to the development of multiple hypotheses for the pre-Holocene nonglacial stratigraphy of the region (Shilts, 1982; Andrews et al., 1983).

Recognition of glaciation

The general character of the glaciation of northern Ontario was first determined by Robert Bell of GSC. Bell (1866, 1870, 1872a, b, 1873, 1876, 1877, 1879a, b, 1880, 1885, 1887) documented striae indicating southwestward ice flow at sites ranging from northern Manitoba, across northern Ontario, to the eastern coast of Hudson Bay. In support of this inferred ice flow direction, Bell (1872a, b, 1877, 1879a, b, 1880, 1887) cited the glacial dispersal of distinctive Proterozoic erratics derived from rocks he had observed along the eastern shore of Hudson Bay. These erratics were found to have been dispersed southward to the Moose River basin, southwestward across northern Ontario, and westward to northern Manitoba. Bell (1887, p. 36G) emphasized as being most distinctive a dark grey granular felsite or greywacke "with round spots, from the size of a pea to that of a cricket ball or larger, of a lighter colour than the rest of the rock, which weather out into pits of the same form." These are the same resistant rocks later correlated to the Omarolluk Formation by Prest and Nielsen (1987) and Prest (1990). These rocks were included in the dark erratics quantified by Shilts (1982). Bell (1887) stated that the rock occurs in situ on Long Island, along the eastern coast of Hudson Bay at the entrance to James Bay; he inferred that the same rock probably continues under the sea northwest of the island. This claim cannot, however, be reconciled with present knowledge. Eade (1966) indicated that Long Island consists of Manitounuck Group rocks. The younger Omarolluk Formation, if present, would presumably lie seaward of the northwest dipping strata of this island. Such an occurrence was not, however, confirmed by Eade. Bell (1872b) also noted the southwestward dispersal of abundant Paleozoic carbonate to the area north of Lake Superior.

Fawn and lower Severn rivers were examined by Low (1886). He reported striae indicating southwestward ice flow along his entire traverse from Lake Winnipeg to Hudson Bay. Low drew attention to the downcutting and resultant exposure of sections along Severn and Fawn rivers for more than 200 miles (320 km) from their mouths. He also reported that the uppermost beds are composed of a light sandy clay containing many boulders of limestone, gneiss, red jasper, and green chloritic and epidotic rocks. Below these sediments, Low reported thin sandy beds containing a large number of small boulders. Low stated that the lowest and thickest beds are made up of a heavy blue clay comparatively free from boulders.

The ice sheet model that was established as a result of exploration carried out prior to 1890 differs little from present views. A single ice mass covering the Canadian Shield and adjacent areas was named Laurentide Glacier by Dawson (1890, p. 162). In part on the basis of information newly acquired in Keewatin by Tyrrell, Chamberlin summarized the nature of this single ice sheet (1895, p. 733-734) as follows:

"Perhaps the most plausible hypothesis at present is that glaciation on the American mainland set in independently in Labrador and in the region northwest of Hudson Bay, perhaps in more than one locality, and that these nuclei grew until their borders coalesced, submerging the Hudson Bay region, and at length developing a great arcuate zone of accumulation along the Laurentian uplands from the coast of Labrador all the way round to the Arctic ocean, embracing at the maximum of glaciation a great reservoir of ice, as Dr. Bell has expressed it, in the Hudson basin. It is possible that the ice over this central basin grew to be a central embossment, but there is no evidence that it was ever so dominant as to cause the ice to push eastward over the Labrador plateau. An arcuate zone of accumulation, in a more restricted sense, has been a favourite conception of some American glacialists; but it is doubtful whether it could have originated as such, and the conception cannot be pushed very far in view of the abundant evidence of transportation from Hudson Bay south-southwesterly across the Laurentian tract, but not in the opposite direction. There seems no present ground for believing that the Laurentian uplands between Hudson Bay and Lake Superior were ever gathering grounds of such dominance as to produce a northerly movement of the ice."

The map of Laurentide Ice Sheet presented by Chamberlin (1895) resembles the major aspects of recent models such as that of Prest (1983).

Multiple centres of glaciation

The concept of the Laurentide Ice Sheet was temporarily dismantled by Tyrrell (1898) who interpreted ice flow from multiple centres as evidence for multiple ice sheets separated in space and time. Tyrrell documented an ice centre located in District of Keewatin and proposed that this ice sheet had been separate from one centred in northern Quebec. Tyrrell considered the "Keewatin glacier" to be older than the "Labradorean glacier", but he was forced to accept contact between them to explain the existence of Lake Agassiz (Tyrrell, 1896).

Tyrrell's views were opposed by Upham (1914), who cited interbedded tills of northeastern and northwestern provenance in Minnesota as well as a contemporaneous ice margin from Atlantic Ocean to the Great Plains. Upham, however, advocated multiple centres of ice dispersal. He calculated the time required to transport Proterozoic erratics from eastern Hudson Bay to North Dakota to be tens of thousands of years (Upham, 1914, p. 520).

At around the same time, Winisk River was examined by McInnes (1909). He considered the Quaternary sediments to be readily divisible into an upper and a lower till. He described the upper till as buff coloured, containing boulders and pebbles of diorite, quartzite, gneiss, red and white sandstone, and jasper, reaching a thickness of 40 feet (12 m), and lacking stratification. The lower till was reported to be an undetermined thickness of extremely tough blue clay with rounded and striated boulders of carbonate, gneiss, quartzite, and conglomerate. The principal departure from earlier observations in the region was the observation on the Winisk River of south-southeastward striations possibly younger than the prevailing southwestward orientation. McInnes acknowledged that these observations could be interpreted as indications of ice flow emanating from Keewatin and added that no evidence of northward ice flow was noticed. He cited the variability about this south-southeastward direction, however, in support of a conclusion that this flow was a result of the deflection of a thinning ice sheet by topography.

Tyrrell (1913) reported that till on the lower Severn contained boulders of red conglomerate similar to Athabasca sandstone and conglomerate that outcrops northwest of Churchill. More recognizable, however, is his reference to fine-grained greenish-brown quartzite or greywacke with readily weathered round calcareous concretions. Tyrrell seemed to be unaware of repeated references to these rocks in the writings of Bell. He speculated that they may be derived from quartzite in the Churchill area, hence transport by Keewatin flow was implied.

Patrician glaciation

As part of a survey of new provincial boundaries for Ontario in 1912, Tyrrell (1913, 1914) ascended the lower Severn and Fawn rivers. This laborious 17 day traverse involved walking the banks of the rivers while boats were hauled with lines. Tyrrell reported the dominance of southwestward striae throughout the area, but he drew particular attention to exceptions. He reported that, along the Limestone Rapids 28 miles (54 km) from Hudson Bay, protected sites revealed striations oriented 5° east of north, which escaped destruction by the later southwestward flow. For 7 miles (11 km) upstream from the rapids, striations oriented 10° west of north (350°) were found on bedrock surfaces. On Fawn River, Tyrrell found striations with the same orientation on a boulder pavement between two tills. Most significant, however, was evidence for northwestward ice flow observed by Tyrrell on sites protected from the younger southwestward flow along the upper Fawn River and at Big Trout Lake.

Tyrrell (1913, 1914) attributed these occurrences of apparent northwestward and northward flow to what he named Patrician Glacier, centred in District of Patricia of northern Ontario. He acknowledged, without reservation, that the bulk of all till throughout the area was deposited by southwestward Labradorean flow, but Tyrrell (1914) concluded that the till sheet consisted of only slightly reworked marine sediments deposited in Patrician time. He cited the presence of marine shell fragments in the till as well as the relationship of its thickness to regional topography. Tyrrell attributed bedrock striations oriented 10° west of north (350°) on Severn River to Patrician flow followed by protection by a layer of Patrician till. He also attributed the upper till on Fawn River to Patrician ice, on the basis of a boulder pavement striated 10° west of north at its lower contact. He therefore attributed the lower till on Fawn River to pre-Patrician time. The striations oriented 5° east of north located at Limestone Rapids on Severn River were also attributed to Patrician flow.

Tyrrell (1913, 1914) made no reference to the southeast striations found on Winisk River by McInnes (1909). These striations have an orientation similar to those found on nearby Fawn River. Rather than incorporating these into his Patrician model, he chose to propose a Patrician dome located southwest of Winisk River.

Tyrrell's earlier views were restated without modification two decades later as part of a symposium on the Patrician centre of glaciation (Tyrrell, 1935). Accompanying his paper were comments by several authors. Leverett (1935) emphasized his belief that the Patrician was a temporary condition affecting a small area. Johnston (1935) referred to southwestward ice flow emanating from northern Ontario as Patrician. In defiance of Tyrrell's preference for ice sheets separated in space and time, both Leverett and Johnston, however, referred to the Patrician as one aspect of a greater Laurentide ice sheet, as named by Dawson (1890).

Later, Prest (1963) reported northwest-trending striae found at several sites in the Red Lake-Lansdowne area of northern Ontario. Prest could only cite weak evidence from one site for northwestward rather than southeastward flow, but he indicated that more conclusive evidence from forms such as roches moutonées had been reported to him by other geologists.

The publication of the 1968 version of the *Glacial Map of Canada* (Prest et al., 1968) presented an opportunity to refine earlier ice flow interpretations. Airphoto interpretation of lineations including flutes and drumlins indicated southwest oriented features in the Severn River area. These flutings were shown to be truncated by a generally southward orientation in the Winisk and lower Fawn River area, where a converging pattern is shown. The western half of this pattern is the area where south-southeastward ice flow orientations were reported by McInnes (1909) and Tyrrell (1913, 1914). The continuity of this ice flow pattern with ice flow arrays farther south shows that these flutings were produced by southward ice flow, not northward as claimed by Tyrrell. Prest (1969) correlated this pattern of south-southeastward to southward ice flow on Winisk River as well as southeastward flow on Fawn River with the late-glacial Cochrane readvance (Hughes, 1965). Hence an important component of Tyrrell's Patrician model, north-northwestward ice flow on Fawn River, was discredited. The other component of Tyrrell's model, striations at Big Trout Lake, were shown as both northwestward and southeastward ice flow.

The outcrops indicating northwestward ice flow have also been examined and discussed by bedrock geologists. Hudec (1960, 1964), who mapped the Big Trout Lake area, acknowledged that the concept of Patrician glaciation had fallen into disfavour; however, he considered evidence for a regional, significantly erosive ice flow toward 320° to be well recorded on widely distributed outcrop surfaces protected from the younger southwestward flow. Evidence of northwestward ice flow in the Big Trout Lake area was also reported by Thurston et al. (1979). After referring to the skeptical reviews of Lee (1968) and McDonald (1969), however, the authors admitted that they were unable to determine whether these striations represented northwestward or southeastward flow.

Shilts (1980, p. 217) attributed southeast-northwest ice flow indicators in Hudson Bay Lowland to Keewatin ice flow, associated with oscillation of the contact between Keewatin and Quebec ice ranging from Seal River of northern Manitoba to the Ontario-Quebec border. Shilts (1985) later elaborated upon this model.

Vincent and Prest (1987, p. 211) acknowledged evidence for at least localized northwestward ice flow. They proposed a lobe of Quebec-derived advancing Early Wisconsinan ice with flow radiating from southwest to northwest as an explanation of these observations.

Ice flow indicators oriented north of west have also been reported for much of northern Ontario on the basis of satellite imagery analysis by Boulton and Clark (1990b), from striated boulder pavements in the Moose River basin by Skinner (1973), and from old striations in Quebec near the Ontario border (Veillette and Pomares, 1991).

Hudson Bay centred glaciation

The concept of a single Laurentide ice sheet (Dawson, 1890) was re-established by Flint (1943). In a comprehensive review, Flint accepted the contemporaneity of a Laurentide ice margin from the Atlantic to the Great Plains (e.g., Upham, 1914) in preference to a model of multiple ice sheets separated in time (Tyrrell, 1898). Regarding the separate issue of the surface geometry of this ice sheet, Flint accepted the Keewatin and Labradorean ice centres (Tyrrell, 1898) but followed Leverett (1935) in attributing them largely to events that occurred in late glacial time, although low domes on the ice sheet surface at these and other centres of outflow were acknowledged. Flint (1943, p. 332-333) cited data pertaining to isostatic rebound in concluding that amongst several domes or centres of outflow, the thickest ice was over Hudson Bay. Most conclusive was the data reported by Stanley (1939), who had conducted two spirit level traverses from sea level to the marine limit in Richmond Gulf, eastern Hudson Bay. Stanley (1939, p. 1936) stated that "if the highest sea level in both places was synchronous, as seems likely, the component of the tilt rate along this line shows a rise of about 3.3 feet per mile westward toward Hudson Bay rather than toward the Labrador peninsula, the last centre of ice movement." The alternative that the western site, where the marine limit was found to be higher, was deglaciated earlier was apparently not considered. The up-dip direction on deformed water planes in Richmond Gulf is now considered to be southward or eastward to a nearby centre of maximum uplift in Quebec (Hillaire-Marcel, 1980; Peltier and Andrews, 1983). Hence it can now be concluded that Stanley's eastern site underwent uplift beneath ice cover after the marine limit was recorded at the western site.

Whereas Flint (1943) concluded that the thickest ice in a multi-domed ice sheet was apparently located over Hudson Bay, the first portrayal of a single-centred ice sheet was verbally presented by Paterson (1972). Paterson cited the pattern of isostatic rebound presented by Walcott (1972) and the likelihood that ice derived from Keewatin and Quebec would coalesce in Hudson Bay to defend his conception of a ridge extending across Hudson Bay. Whether Paterson considered the ridge to be concave or convex along its long axis was not clear. Paterson's model was subsequently cited by CLIMAP (1976), thus forming the basis for ice sheet reconstructions by Denton and Hughes (1981a).

Revival of multiple centres of glaciation

Study of the lithology of erratics in the Hudson Bay region, including till samples collected in Hudson Bay Lowland by McDonald (1969), renewed interest in formulating a model for a multiple domed Laurentide Ice Sheet (Shilts et al., 1979; Shilts, 1980). Shilts reported that distinctive red erratics derived from sources in Keewatin are dispersed offshore from Keewatin and toward Hudson Strait. No Paleozoic carbonates derived from Hudson Bay were found in Keewatin nor were they found to be dispersed eastward into Quebec. South of Hudson Bay, Shilts confirmed Bell's earlier observations of long distance southwestward transport of Proterozoic and Paleozoic erratics. This distance of transport of erratics implied two long-lived major dispersal centres, one east and one west of Hudson Bay. Shilts argued that because a minimum average debris transport rate on the order of 100 m per year seemed unreasonably high, the distance of transport of the erratics indicated that the two dispersal centres persisted throughout the last glaciation and were not simply late glacial features. In addition to Keewatin and Quebec domes, a dome on the Laurentide Ice Sheet within Hudson Bay was proposed by Dyke et al. (1982) and Dyke and Prest (1987) in order to satisfy a perceived requirement for symmetry of ice domes and a source for the Cochrane ice advances.

Doubt regarding our present ability to determine the surface geometry of the Laurentide Ice Sheet at its maximum was raised by Budd and Smith (1987). Their model for resultant trajectories of erratic transport following a glacial cycle that included a single dome over Hudson Bay resembles the pattern reported by Shilts (1980). This was explained by negligible flow beneath the gentle surface slope of the inner portion of the ice sheet combined with vigorous ice flow in near-marginal areas. Hence Budd and Smith (1987) implied that the erratic distribution pattern reported by Shilts (1980) was produced by near-marginal flow during buildup and retreat and that resultant erratic trajectories should not be expected to record the surface geometry of the interior of the ice sheet at its maximum extent.

Analysis of satellite imagery

Regional trends in the orientation of longitudinal glacial landforms earlier mapped using aerial photography by Prest et al. (1968) were re-examined in greater detail by Boulton et al. (1985) using satellite imagery. The generally southwest trend of former ice flow, punctuated with a zone of south-southeast flow extending from Winisk River to Albany River was confirmed. Horsfield (1987) supplemented satellite interpretation with field work in Hudson Bay Lowland. He proposed ice flow from Keewatin, Ungava, and southern Hudson Bay during Early, Middle, and Late Wisconsin time, respectively. Using a combination of additional analysis of satellite imagery and literature review, Boulton and Clark (1990a, b) concluded that the ice flow history of Hudson Bay Lowland involved 1) possibly pre-Wisconsinan southeastward flow, 2) a poorly defined episode of flow from Quebec and possibly Keewatin, 3) west-southwestward Early Wisconsinan flow prior to intra-Wisconsinan deglaciation, 4) a Late Wisconsinan pattern involving southwestward ice flow in adjacent areas but unclear patterns in Hudson Bay Lowland, and 5) Cochrane-equivalent south-southeastward flow extending from the Winisk River area. The second phase, as numbered here, included two major sets of flow-parallel features. Set 18 of Boulton and Clark (1990b) corresponds to the Patrician striations of Tyrrell (1913, 1914) at Big Trout Lake. Occurrences of these north-of-west orientations were reported across northern Ontario and into Quebec, where striations with this orientation have been reported by Veillette and Pomares (1991). Boulton and Clark attributed these west-northwest features across the region to ice flow from Keewatin. The second ice flow pattern of this episode, referred to as pre-C by Boulton and Clark (1990b), is a pattern radiating from extensive southwestward flow in the Lake Superior region to south-southeastward flow on the shield south of James Bay. Boulton and Clark (1990b), presumably seeing something considered to be crosscutting relationships, attributed this latter pattern, which is generally attributed to late glacial time (e.g., Veillette, 1986), to an early or pre-Wisconsinan age.

Hudson Bay Lowland Quaternary stratigraphy

A distinction may be drawn between broad regional and theoretical compilations which led to formulation of ice sheet models and detailed field investigations meant to determine the Quaternary stratigraphy of Hudson Bay Lowland. The first study of sections in this area since the observations of the early explorers was summarized by Terasmae and Hughes (1960). Knowledge of the area greatly increased following reconnaissance study of every major river in the lowland by a group led by McDonald (1969). More detailed work was later carried out by authors such as Skinner (1973), Netterville (1974), and Nielsen et al. (1986).

Missinaibi beds

Organic-bearing deposits underlying till in the Moose River basin, south of James Bay, have drawn the attention of geologists since the late nineteenth century (e.g., Bell, 1904, p. 168). It was McLearn (1927) who finally distinguished Quaternary buried peat from the Mesozoic lignite of the area. Auer (1927) obtained pollen and macrofossil evidence for conditions similar to present from the Quaternary deposits.

The first research on the historical geology of Moose River Basin Quaternary sediments was carried out by Terasmae (1958) and Terasmae and Hughes (1960). They reported two drift units below and one unit above deposits of peat, organic silt, and clay, which they named the Missinaibi beds. Their palynological studies on the Missinaibi beds and postglacial deposits led them to conclude that vegetation in the area at the time of deposition of the sediments was similar to the present. In contrast, a climate warmer than the present was indicated by the interglacial Don Formation in the Toronto area. Because of the lack of evidence that the climate during deposition of the Missinaibi beds was warmer than the present and their conclusion that the time interval was short, an interstadial rank was proposed for the Missinaibi beds. A radiocarbon age of greater than 53 000 years which had been obtained for the interval supported their proposed age of 55 000 to 64 000 years. After a brief period of field work in the area, Prest (1966) subsequently reported marine sediments below till on nearby Abitibi River.

Cochrane readvance

During the field season of 1923, Antevs (1925) carried out a survey of varved glaciolacustrine sediments in the Ottawa Valley, the Huron basin, and the region north of the drainage divide, south of James Bay. It was his intent to assemble a varve chronology for ice retreat across the area. Near Timmins, Ontario, Antevs found varves that thickened upward. At a site near Iroquois Falls the uppermost unit described by Antevs (1925, site 103) was a 10 foot (3 m) unit of stiff, contorted clay. From these observations, Antevs concluded that a major readvance of the ice margin had occurred, a probable correlative of a similar event in Scandinavia. Antevs (1928, p. 154, 210) later reported till overlying the varved sediments of glacial Lake Barlow-Ojibway. The name Cochrane was tentatively used for this event by Bryan and Ray (1940, p. 68). Karlstrom (1956) proposed a Wisconsinan substage rank for the event, but Leighton (1957) referred to the Cochrane as a minor event. The status of the Cochrane was elevated to Formation by Hughes (1965, p. 544), but it was acknowledged that the event was probably one of several ice-margin fluctuations, of local rather than regional significance (Hughes, 1965, p. 564). Prest (1969, 1970), however, elevated the apparent significance of the Cochrane by correlating the apparent overriding of glaciolacustrine sediments in the type area with southward ice flow across the entire eastern half of northern Ontario, including the Fawn and Winisk rivers. Multiple Cochrane events have more recently been indicated by varve thicknesses and crosscutting flutes (e.g., Hardy, 1982; Dredge and Cowan, 1989).

Operation Winisk

In 1967, the GSC carried out a multidisciplinary, helicopter-supported study of lowland geology named Operation Winisk (e.g., Craig and McDonald, 1968). Barrie McDonald, along with Hugh Gwyn, Bruce Craig and their assistants, coordinated the Quaternary component of this program.

McDonald (1969) correlated subtill sediments containing peat or including fluvial sediments with current direction indicators implying flow to Hudson Bay with the Missinaibi beds. McDonald emphasized that subaerial peat deposits associated with the Missinaibi beds occurred at elevations as low as 75 m, thus indicating the absence of a proglacial lake, the surface of which would have been at about 300 m elevation. The presence of subtill stream gravels deposited by streams flowing northward indicated a glacier-free Hudson Bay and drainage northward through Hudson Strait. This conclusion was the primary factor in McDonald's proposal that the Missinaibi beds represented an interglacial rather than an interstadial rank as proposed by Terasmae and Hughes (1960). Specifically, the interglacial rank for the sediments was considered justified by McDonald because 1) they are underlain and overlain by till; 2) they include marine strata, which required that Hudson Bay and Hudson Strait be sufficiently glacier-free to allow the influx of seawater; 3) subaerial environments at low altitudes and streams, also at low altitudes, flowing toward the bay both required that Hudson Bay and Hudson Strait be glacier-free; 4) assuming that the earlier ice sheet developed and shrank in a manner similar to that of the Wisconsinan ice sheet, disappearance of glacier ice in Hudson Bay would indicate sufficient diminution of the ice sheet to merit, in McDonald's opinion, calling the condition interglacial; and 5) the pollen record in the Missinaibi River peats led Terasmae and Hughes (1960, p. 11) to conclude that local vegetation during the nonglacial was "similar to that now present in the region." McDonald also emphasized that the presence of interglacial marine beds in the lowland indicated Hudson Bay was a depression occupied by the sea at least as early as Sangamonian time and that the similarity of the interglacial facies sequence and the postglacial sediments suggested that events during the interglacial were grossly similar to those of the past 8000 years.

McDonald (1969) stated that two tills overlie the interglacial strata on all rivers traversed. Stratified sediments commonly separated the tills in the northwest and southeast parts of the lowland. These sediments were thought to have been deposited in a proglacial lake. He recognized that organic material from this stratigraphic level could provide important age information but found no material suitable for radiocarbon dating. In the central part of the lowland, McDonald considered two tills to be in contact with each other. The contact was reported to be sharp and the tills appeared to be physically distinct; the upper till was found to be generally finer grained, to have a finer blocky structure, and to commonly have a noticeably different colour relative to the lower till. A threefold till stratigraphy was found by McDonald only in the headwaters of the Albany River drainage basin; the uppermost till was said to be identical to the Cochrane till. According to McDonald, bedrock striations, striated boulder pavements, fabric studies, ice-flow features exposed at the surface, and pebble counts indicated ice flow from the northeast, north and northwest. McDonald stated that no acceptable evidence was found to support the contentions of Tyrrell (1913, 1914) that Patrician glaciers flowed northward across the region.

Within the field area for the present study, unpublished GSC field notes filed by the members of Operation Winisk indicate that McDonald examined Fawn, lower Severn, and Shagamu rivers. Gwyn examined the Winisk and Shamattawa. The upper Severn was not examined during Operation Winisk.

In the southeastern and northwestern parts of the lowland, McDonald (1969) reported rhythmically stratified silt and sand of apparent freshwater origin overlying the upper till but underlying fossiliferous marine sediments of Tyrrell Sea. The latter name was assigned to Hudson Bay as it existed during the early Holocene by Lee (1960). In the central part of the lowland, evidence for this postglacial, pre-marine lake phase was not found and interlensed till and shell-bearing sand and gravel implied that the sea was in contact with glacier ice. These lacustrine sediments were correlated with Glacial Lake Agassiz in the northwest and Glacial Lake Barlow-Ojibway in the southeast, although it was recognized that the two may not have been contemporaneous. McDonald also reported the presence of, for several miles along the upper reaches of Fawn River, a 10-12 m unit of evenly stratified clay, silt, and sand overlying fossiliferous marine sediment dated at 7400 ± 140 BP. McDonald considered these sediments evidence for a great influx of freshwater from the west. Attention was drawn to the similarity of the distribution of proglacial lake sediments separating the upper tills and glaciolacustrine sediments during final ice retreat.

In concluding his report, McDonald (1969) named three areas which, based on known exposures, were areas in which stratigraphic study could yield significant results: 1) the Moose River basin, the area later studied by Skinner (1973); 2) Kapiskau River; and 3) Severn River near its confluence with Fawn River.

McDonald (1971) continued to advocate a last interglacial or Sangamonian age for at least the marine sediments of the Missinaibi. He proposed, however, a possible correlation of the Missinaibi peat with the Early Wisconsinan St. Pierre Interstadial. This correlation implied that Early Wisconsinan pre-St. Pierre glaciation did not affect Hudson Bay Lowland. He also proposed correlation of the lacustrine sediments separating the upper two tills with the Middle Wisconsinan Port Talbot Interstadial. He suggested that the central Hudson Bay Lowland had not been deglaciated during this interval.

Moose River Basin stratigraphy

Skinner (1973) reported the results of detailed study of the Quaternary sediments in the Moose River basin south and southwest of James Bay, including the area studied by Terasmae and Hughes (1960). Skinner described 1) three pre-Missinaibi tills and accompanying intertill lacustrine sediments, 2) the Missinaibi sequence, 3) a two till post-Missinaibi sequence separated by a unit he called the Friday Creek sediments, and 4) early Holocene proglacial sediments, including glaciolacustrine, marine, and subaerial sediments. Skinner added much detail to the description of the Missinaibi beds and proposed the name Missinaibi Formation for the marine, terrestrial, and lacustrine sediments. He also proposed the name Bell Sea for the body of water in which the Missinaibi marine sediments had been deposited. Skinner divided the Missinaibi Formation into four members: 1) the Marine member that was deposited in Bell Sea; 2) the Fluvial member that was deposited during stream incision and deposition following retreat of Bell Sea, apparently due to postglacial isostatic rebound; 3) the Forest-peat member that was deposited subaerially; and 4) the Lacustrine member which was deposited in a proglacial lake formed by ice advancing at the beginning of the Wisconsinan. What had been called a till-like deposit within the Missinaibi by Terasmae and Hughes (1960) and a diamicton by McDonald (1969) was shown by Skinner (1973) to be a soil at the base of the Forest-peat member. Skinner found that the lowermost portion of the lacustrine member contained abundant organic material apparently reworked from the underlying forest-peat unit. He showed that Terasmae and Hughes (1960) had based their paleoclimatic inferences on pollen in the base of the lacustrine member that was deposited in a lake dammed by advancing ice, rather than from the soil, which represented most of the interglacial. Skinner reported that if the rhythmically bedded lacustrine member consists of varves, it represents a period of about 600-700 years.

Skinner (1973) reported that two tills overlie the Missinaibi. The upper unit, the Kipling Till, was found to be more calcareous than the lower unit, Adam Till. Typical Chittick values for total carbonate in the matrix of the Kipling are about 30%, whereas a value of 20% is typical for the Adam (Skinner, 1973, p. 34). Skinner's summary of ice flow direction data for the two postMissinaibi tills show considerable scatter, but southwest is the dominant direction for the Kipling, whereas many of the values reported for the Adam are west-southwest.

Skinner (1973) found that the upper portion of the postglacial lacustrine sediments was broken up and redeposited as a clay-pebble gravel. He attributed this redeposition to the action of a density underflow of saline water following the opening of a pathway for drainage of proglacial lake water and influx of marine water through Hudson Bay. This event marked the splitting of the Laurentide Ice Sheet into two separate ice masses. Skinner considered the presence of foraminifera and echinoderm spines in the matrix of the clay-pebble gravel to confirm an origin resulting from the action of marine water.

Evidence supporting an interglacial age for the Missinaibi was reported by Stuiver et al. (1978), who used isotope enrichment techniques on a peat sample from the Forest-peat member to obtain a radiocarbon age of >72 500 BP (QL-197).

The stratigraphic sequence assembled by Skinner (1973) was used by Andrews and Barry (1978) in a review of Wisconsinan glacial stratigraphy that formed the basis of a discussion on glacial inception and disintegration during the last glaciation. In contrast with the correlations made by McDonald (1971), Andrews and Barry correlated the Friday Creek sediments with the St. Pierre Interstadial and concluded that Hudson Bay Lowland had not been deglaciated during the Port Talbot Interstadial. The St. Pierre/Friday Creek interval was correlated with oxygen isotope substage 5a (Shackleton and Opdyke, 1973), which was, according to the isotope data, a time of lesser global ice volume than stage 3, to which the Port Talbot Interstadial was correlated.

Northern Manitoba stratigraphy

Dredge et al. (1986) reported that a three-till sequence overlying oxidized sand and gravel occurs on North Knife River in northern Manitoba. Whereas the youngest till is entirely derived from Paleozoic terrane to the east, the older tills undergo a transition westward to sandy composition indicating the influence of southward flow derived from Keewatin. A fourth till, derived entirely from the east, underlies the oxidized gravel and overlies a second oxidized gravel. The possibility that the two oxidized gravels may be equivalent was mentioned by Dredge et al. (1986), but the interpretation of two nonglacial episodes separated by westward flow was favoured. At Chipewyan Lake, located west of North Knife River, a calcareous till bearing Paleozoic fossils and limestone pebbles is overlain by till emplaced by Keewatin ice.

Nielsen and Dredge (1982) and Nielsen et al. (1986) reported a four till sequence for Nelson River in northern Manitoba. The nonglacial, organic bearing Nelson River sediments resemble the Missinaibi Formation and act as a marker between the upper two and the lower two tills. The sequence was best exposed at the Henday section, prior to its inundation by hydroelectric development. At the base of the sequence is Sundance Till, into which a weathering horizon has formed. This unit yielded fabric and erratic lithology indicating southeastward Keewatin-derived ice flow. The overlying Amery Till contains Proterozoic erratics derived from the east and yielded fabric indicating westward to northwestward flow (Nielsen et al., 1986, their figure 5, sections 416 and 431). At the nearby Sundance section, however, the uppermost till, considered a correlative of the Amery Till at the Henday section, yielded mixed fabric results and overlies a well developed boulder pavement indicating southwestward flow. Above the Nelson River sediments is a till sequence that is divisible on the basis of colour and composition into the lower grey Long Spruce Till and the upper brown Sky Pilot Till. The Long Spruce Till yielded mixed fabric results. Its pebble fraction contains an average of 5% Proterozoic erratics derived from the east, slightly less than the mean of 7% in the Amery Till. Anomalous zones of the Long Spruce Till, possibly a separate unit, yielded up to 23% Proterozoic erratics. Nielsen et al. (1986) attributed the Long Spruce Till to westward ice flow. The overlying brown Sky Pilot Till yielded 5-20% Proterozoic greywacke clasts. Fabrics and its drumlinized surface indicate westerly to southwesterly ice flow.

The Gods River sediments of northeastern Manitoba, reported by Netterville (1974) and Klassen (1986), are an organic-bearing sequence resembling the Nelson River sediments. A till underlying these sediments on Gods River was considered by Klassen (1986) an equivalent of the Amery Till on Nelson River. This unit yielded near-random fabric, with a slight dominance of northeast-southwest orientations (Netterville, 1974, his figure 3). The sequence overlying the organic-bearing horizon, the Wigwam Creek Formation (Klassen, 1986), was divided into two till units, the upper further subdivided at a gradational to sharp brown over grey colour change. Pebble fabrics from the upper three tills of the Wigwam Creek Formation each yielded two directions of preferred orientation that are nearly at right angles (Netterville, 1974, his figure 3). The lower till yielded a north-south component slightly more dominant than east-west. A south-southwest component was preferred in the middle unit; a southwest ice flow direction was indicated for the upper brown till.

Application of amino acid geochronology

The application of amino acid geochronometric techniques to in situ and transported marine shells from Hudson Bay Lowland led to a revised perception of the Quaternary stratigraphy of the area (Shilts, 1982, 1984; Andrews et al., 1983). Their method was based on the principle that L-isoleucine acid (Ile) gradually inverts to its nonprotein diastereoisomer D-alloisoleucine (aIle) by a temperature dependent but temporally consistent reaction (Miller, 1985). The D-alloisoleucine to L-isoleucine ratio (aIle/Ile) is therefore an indicator of relative age. The significant result of the analyses of Hudson Bay Lowland samples was the clustering of values around 0.22, 0.14, 0.07, and 0.03. The first and last values were associated with the Bell Sea and the Holocene Tyrrell Sea deposits, respectively. Using the apparently reasonable assumption that Bell Sea is of early last interglacial age, about 130 000 years, the amino acid data were taken to indicate that marine water invaded Hudson Bay twice during the Wisconsinan, around 75 000 and 35 000 years ago. The alternative interpretation, that the Missinaibi Formation is much greater than 130 000 years old, was not favoured on the basis of thermal history calculations.

The results obtained by Shilts (1982) and Andrews et al. (1983) led to the proposal of a revised stratigraphy for Hudson Bay Lowland. An inferred three-till post-Missinaibi sequence and presence of marine water in Hudson Bay between deposition of the tills conflicted with the conclusions of McDonald (1969) and Skinner (1973), both of whom reported only two post-Missinaibi tills and a lack of postMissinaibi, pre-Tyrrell Sea marine sediments. Both McDonald and Skinner referred to stratigraphic position relative to the Missinaibi as their most important criterion for stratigraphic correlation. Any sub-till marine sediment or organic-bearing unit was therefore attributed to the Missinaibi. For example, the Fawn River gravels overlie a till and are overlain by two tills. McDonald (1969) correlated the gravels with the Missinaibi, but the unit yielded amino acid ratios in the range of the older of the two intermediate clusters. This result implied the possibility of more units, perhaps a three-till post-Bell Sea sequence (Shilts, 1982).

Shilts and Wyatt (1988) and Wyatt (1990) found that marine sediments on Kwataboahegan River, the type section of Bell Sea, predate marine sediments on Abitibi River. The latter deposit was named the Prest Sea sediments by the former authors. Skinner (1973) had, however, correlated all nonglacial deposits underlying till to Bell Sea. It is therefore unclear whether the Missinaibi Formation should be tied to Bell Sea, as advocated by Skinner (1973), or whether some sites may be assigned to the episode which began with Prest Sea. It is furthermore unclear whether the Adam Till pre- or post-dates Prest Sea, or whether an additional till unit should be recognized.

Synthesis

The fact that the study area has been glaciated by generally southwestward ice flow was established by the work of Bell (e.g., 1877) and Low (1886). Speculation regarding more intricate details of the history of glaciation arose with the multiple ice sheet hypothesis of Tyrrell (1898) and the Patrician concept (Tyrrell, 1914). The flawed claim by Flint (1943) that the glacial ice had been thickest over Hudson Bay was apparently universally accepted until work by Shilts et al. (1979) and Shilts (1980) clarified that radial glacial sediment transport from Hudson Bay has not occurred.

The Missinaibi was accepted as the only pre-Holocene nonglacial episode in northern Ontario, and a Sangamonian age was generally considered reasonable, until amino acid data reported by Andrews et al. (1983) indicated the probability of pre-Holocene deposits of more than one age. Hence it was concluded that correlations in existence at the time must be in error.

Thus at the beginning of the present study, knowledge on northern Ontario Quaternary stratigraphy was limited to 1) a general understanding of till compositional trends which tended to indicate southwestward dispersal across northern Ontario; 2) a recognition of multiple tills which lacked detail on actual number of units, differences in composition, ice flow direction, or paleogeographic context; and 3) recognition of at least one interstadial or interglacial episode which postdated the first glaciation of the area and during which climate resembled that of the Holocene.

METHODS

This study was based on field and laboratory study of riverbank sections. Inferences were also made on the basis of published accounts of surface morphological features (Prest et al., 1968). Sites on Sachigo, Severn, Fawn, and Winisk rivers were examined during downriver traverses in inflatable boats. The rivers were reached using float planes chartered at Big Trout Lake, Ontario. Sites on Niskibi, Beaver, and Shagamu rivers were reached by helicopter stationed for the duration of field work at the community of Fort Severn. Field methods included clearing a fresh exposure of the sediment sequence, describing the sediments, collecting field analytical data, and sampling. Sediment samples were subsequently processed in the laboratory for analysis of gravel fraction lithology, matrix carbonate content, and texture. Marine shell fragments from till and whole valves from subtill nonglacial sediments were analyzed for amino acid geochronology. Peat was analyzed for paleoecological data and radiocarbon analysis. Resultant data were interpreted with reference to known aspects of regional geology to assemble an interpretation of regional Quaternary stratigraphy.

Field methods

Although numerous steep cliffs occur along the banks of rivers throughout the study area, most of these faces are obscured by slump blocks and sediments disturbed by present-day processes. Study sites were carefully selected to avoid disturbed sediments and to maximize the vertical extent of sediments available for examination. At each site, a cover of up to 30 cm of disturbed sediment was cleared from a vertical or oblique strip about 2-3 m in width. Compositional changes and contacts were in some cases visible for some distance on either side of the freshly cleared exposure.

Sediment description

Sediments were subdivided into facies (Walker, 1984) on the basis of lithological, structural, and organic aspects detectable in the field. Designation of categories followed the standardized set of glacial facies (Table 1) defined by Eyles et al. (1983). Application of this code to the Severn River sections was discussed by Warman (1987). The facies were considered descriptive designations to be used in subsequent genetic interpretation following consideration of all sources of evidence. Moist sediment colour was determined using a Munsell colour chart.

Fabric

As an aid to interpreting the depositional environment of massive diamicts and, in the case of tills, to determine former ice flow direction, three-dimensional pebble fabric data were collected at several sites on Severn River. Two-dimensional fabrics were obtained on Winisk River.

Fabric data were collected from vertical exposures. About 0.3 m of sediment was cleared from the face to avoid deformed sediment. To prevent a bias in favour of elongate clasts oriented perpendicular to the exposure, two working surfaces oriented 90° to each other were cut into the section. Prolate clasts with a long-to-short axis ratio greater than 3:2 and an intermediate-to-short axis ratio less than 3:2 (Dowdeswell et al., 1985) were selected. Only clasts with a long axis length between 10 and 100 mm were used. An aluminum knitting needle was used to mimic the orientation of all clasts showing elongation while measuring to the nearest millimetre to determine compliance of the clast with shape criteria. A Silva compass, corrected for magnetic declination to the nearest degree and equipped with a clinometer, was used to obtain azimuth and plunge of the knitting needle. Fifty clasts from an area of about 0.5 by 2.0 m were measured at each site.

Table 1. Lithofacies code (Eyles et al., 1983)

Diamict, D	
Dm	matrix supported
D-m	massive
D-s	stratified
Gravel, G	
Gm	massive
Sand, S	
Sr	rippled
Sh	horizontal lamination
Sm	massive
Fine-grained sediment (mud), F	
Fl	laminated
Fm	massive
F-d	with dropstones

Source: Eyles et al., 1983

Orientation and plunge data were plotted on Schmidt equal-area, lower hemisphere projections by computer and contoured according to the method of Kamb (1959) at a contour interval of two sigma. The data were evaluated statistically using the eigenvalue method of Mark (1973). The largest eigenvector V1 was used to indicate the direction of maximum clustering. The significance value S1 was used to indicate the strength of clustering about the mean axis. Strength values were obtained by dividing the eigenvalues by the number of data, *n*. Contoured equal-area projections were checked for eigenvectors falling between modes of bimodal or multimodal data (Woodcock, 1977). The data were tested for randomness using the method of Woodcock and Naylor (1983).

Boulder pavements

Data regarding ice flow direction were obtained from striated boulder pavements. The faceted upper surfaces of such boulders were excavated and the orientation of striations on the facet measured.

Sampling methods

Sediment samples were obtained from vertical exposures. About 30 cm of sediment were cleared from the face to avoid slumped and recently weathered material. Vertical sampling frequencies within a visible lithostratigraphic unit of about 1-3 m were used. In no case did a sampling interval cross a visible compositional break or stratigraphic contact. A 3.5 kg sample meant to be representative of the entire sampling interval was taken. Clasts exceeding about 5 cm in size were discarded.

Marine shell fragments were recovered by breaking apart lumps of sediment excavated from the section. Shell fragments have a colour distinguishable from carbonate rock fragments, so several fragments were usually obtained after a search of several tens of minutes to a few hours. Thermoluminescence (TL) samples were collected in subdued light in lightproof containers.

A block of in situ peat underlying glacial sediments was collected from Beaver River. Varying levels were later subsampled in the laboratory for paleoecological analysis.

Laboratory methods

Drift composition

Diamicts were sampled for later laboratory analysis to determine the bedrock sources of the sediment, to test for the presence and nature of compositional zoning, to assess lateral compositional trends in correlative units, and to assess the nature of processes of erosion and weathering responsible for the present composition of the sediment.

The 2.0-5.6 mm fraction, a portion of the coarse fraction that has been found to be recoverable in sufficient quantity by, for example, Shilts (1980), was examined to identify the lithology of gravel-sized clasts. The carbonate content of the silt plus clay fraction was determined using a gasometric apparatus, and the proportions of sand, silt, and clay in the <2 mm fraction of the sediment were determined. To obtain the 2.0-5.6 mm fraction, a 1.5 kg subsample was wet sieved to remove the >2.0 mm gravel fraction. This fraction was thoroughly washed and dried. The 2.0-5.6 mm fine gravel fraction was then separated for quantitative analysis. The >5.6 mm fraction was retained for nonquantitative analysis. Yield ranged from 20 to 100 grams of 2.0-5.6 mm fine gravel and 10 to 400 grams of >5.6 mm clasts. A sample of about 40 grams of 2.0-5.6 mm fine gravel, consisting of about 1000 clasts, was classified visually under a binocular microscope. The clasts were divided into classes based in part on the earlier work of Shilts (1980) and Wyatt et al. (1986). The clasts in each class were weighed and retained in vials.

Rocks attributed to Paleozoic sources include red carbonate, brown carbonate, brown chert, and evaporites. Carbonates were identified on the basis of colour, surface texture, softness, and effervescence in dilute hydrochloric acid.

Rocks attributed to Proterozoic sources include greywacke, quartzite, mudstone, iron formation, grey chert, volcanics, and sandstone. Black greywacke dominates this group. Some minor clast types may have been derived from Archean greenstone belts east and south of the study area, although these rocks tend to be metamorphosed to grades higher than that typical of the distinctive unfoliated Proterozoic rock types of eastern Hudson Bay.

Rocks attributed to Archean sources include intrusive and high grade metamorphic rocks. Granite is the dominant rock type, but mafic rocks and diabase also occur. Diabase was almost certainly also derived from Proterozoic outcrops on Sutton Ridge, but, because of the infrequent occurrence of diabase in the samples, no attempt was made to separate this rock from other intrusive rock types.

The carbonate content of the <63 μm matrix was analyzed using a technique for the Chittick gasometric apparatus described by Dreimanis (1962). Because of the contrasting reaction rates of calcite and dolomite in hydrochloric acid, two readings of the amount of carbon dioxide produced by these reactions could be taken and the contributions of each of these minerals to total carbonate in the sample determined.

The texture of the <2 mm matrix of diamict samples was determined by GSC staff using methods described by McDonald and Kelly (1968). Three size classes, sand (0.063-2.0 mm), silt (4-63 μm), and clay (<4 μm) were determined. The proportion >2 mm was also determined, but sample size was considered inadequate to obtain reproducible percentages. A 50 g split was used for textural analysis. An additional 10 g sample was tested for moisture content to correct the textural data. The texture sample was disaggregated by freeze-drying and subsequently by treatment with 0.5 *N* sodium hexametaphosphate. The sample was then mechanically mixed, heated to boiling, cooled, stirred, and subjected to an ultrasonic probe for 20 seconds. The sample was then wet sieved through a 230 mesh sieve. The dry weight retained on this sieve was used to determine per cent sand. The material finer than 63 μm was analyzed by pipette analysis to obtain per cent silt and per cent clay.

Geochronology and paleoecology

Isoleucine epimerization determinations on in situ and transported shell fragments from the study area were compiled by Wyatt (1989). Each shell was analyzed at the University of Colorado for its total amino acid assemblage using an automated ion-exchange liquid chromatography amino acid analyzer after acid hydrolysis in purified 6 *N* HCl. In this method, the nonprotein amino acid *D*-alloisoleucine (aIle) is separated from its protein diasteriomer *L*-isoleucine (Ile) and the ratio of the two (aIle/Ile) is used as a measure of the extent of epimerization of isoleucine and hence relative age (Miller and Andrews, 1980; Miller, 1982, 1985). The rate of epimerization is very much a function of temperature as well as time, so an effective diagenetic temperature (EDT) must be chosen or determined using an independent age determination to obtain tentative absolute age determinations. To avoid discrepancies caused by varying rates of epimerization among differing mollusc taxa, only the species *Hiatella arctica* (L), abbreviated Ha, is used here. Data for other species were discussed by Wyatt (1989). Shell morphology was used for identification where possible. The relative concentrations of amino acids (e.g., Miller, 1982) were then used as either a secondary, or primary if morphology was inconclusive, diagnostic procedure for species identification.

Samples of diamicts were analyzed for their content of foraminifera (Warman, 1987) to aid genetic interpretation. Using the techniques of Then and Dougherty (1983), the samples were disaggregated and screened at 2 mm. A 100 g split of <2 mm material was treated in hydrogen peroxide and wet sieved at 0.063 mm. The >0.063 mm material was treated with sodium hydroxide solution and household bleach in an ultrasonic bath. The material was wet sieved at 0.063 mm and dry sieved to obtain the 0.0177-0.710 mm fraction. Using carbon tetrachloride in a separatory funnel, forams were separated by flotation. These laboratory procedures involve several hazardous materials and vigorous reactions. The samples contained from 0 to 74 forams per 100 g, although most contained less than 20.

Peat underlying till on Beaver River was analyzed by R.J. Mott and J.V. Matthews of GSC for pollen, beetles, and plant macrofossils.

EROSIONAL FEATURES ON BEDROCK

Bedrock outcrops along the north shore of Big Trout Lake where Tyrrell (1913, 1914) had obtained evidence for his Patrician glaciation model were reexamined (Fig. 5). Numerous striation sites were encountered along the southern side of a peninsula south of the community of Big Trout Lake. Southwestward ice flow is recorded by striations oriented at an azimuth of 45° to 60°. At sites on south-facing shores and on the southern side of islands that were protected from later glacial erosion, nine occurrences of northwest-southeast orientations were found. These sites include small surfaces a few metres in size, roches moutonées with plucked faces to the northwest, and whaleback forms tens of metres in size. These features range in orientation from 310° to 350° azimuth, but cluster around 320°.

GLACIAL SEDIMENTS

Because sections on Severn River (Fig. 6) provide the greatest vertical exposure in the area, they were examined in the most detail. Sections on Fawn and Winisk rivers (Fig. 7) were examined in somewhat lesser detail. Sites on Niskibi, Beaver, Sachigo, and Shagamu rivers, with the exception of one section on the Shagamu, were sampled and briefly examined.

Description

Exposed sediments on Severn River (Fig. 8) are generally similar to those of Winisk River (Fig. 9) as well as other rivers in the study area (Thorleifson, 1989). The surface of the drift sequences generally has the form of elongate flutes hundreds of metres wide and tens of kilometres long. The sediments were classified by Warman (1987) as diamicts, fine grained sediments, nonfossiliferous sand and gravel, as well as the marine fossiliferous sediments that cap some sections.

Most of the Quaternary sediments encountered underlying this fluted surface consist of generally homogeneous silty massive matrix supported diamicts (Fig. 10) with a significant component of clay, sand, and coarse clasts up to boulder size. Obvious variation is limited to unit thickness and colour. These compact and blocky diamicts contain striated and faceted clasts. The diamicts may be classified as thick and massive, thin and massive, or stratified (Warman, 1987).

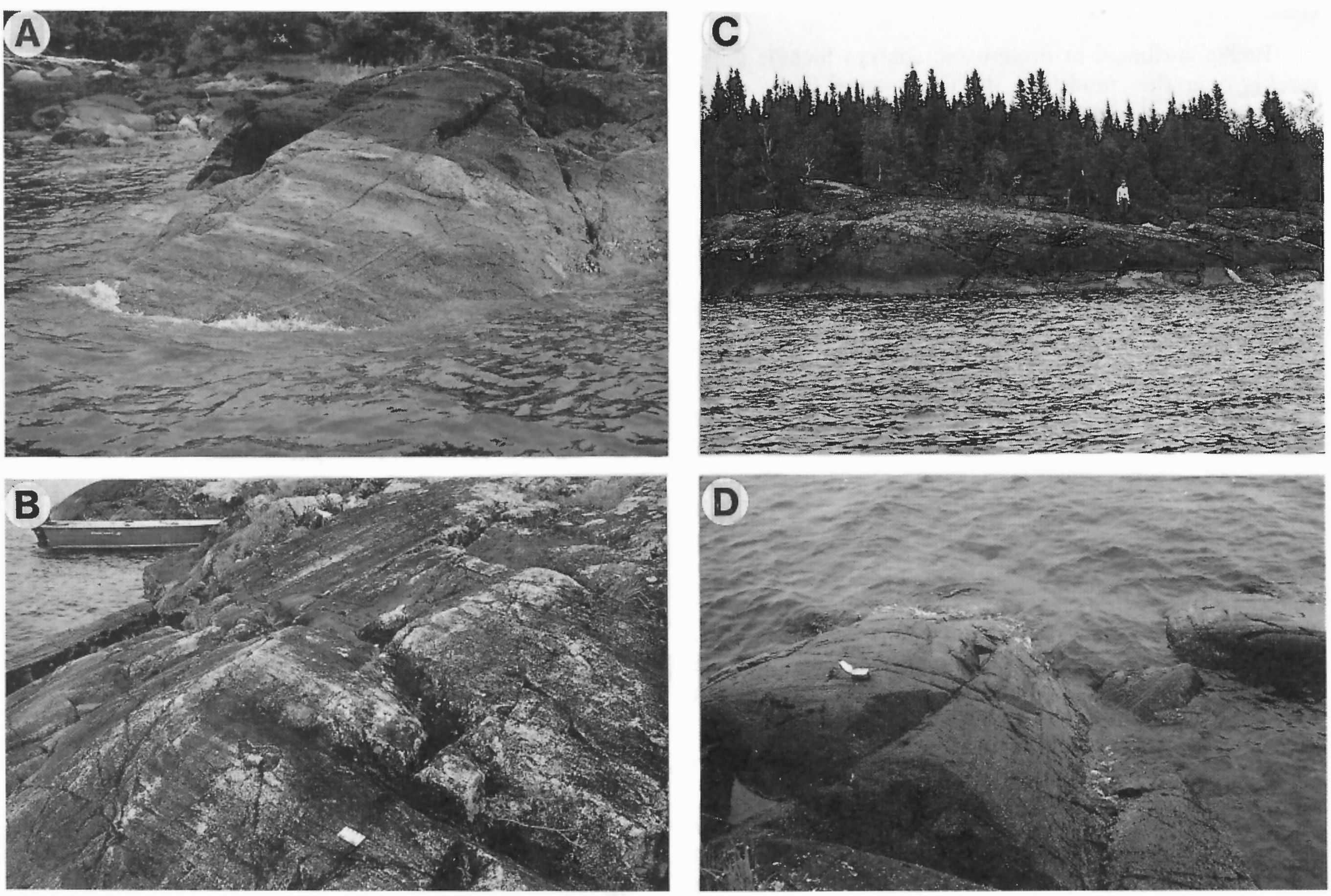


Figure 5. Evidence for northwestward ice flow, Big Trout Lake. **A.** Grooved outcrop, plucked surface on left faces northwest (GSC 203541-Z); **B.** striations oriented 225° in foreground, protected surface striated at 320° between foreground and boat (GSC 202322-G); **C.** large streamlined outcrop oriented northwest-southeast, with gently sloping face toward southeast (GSC 203541-W); **D.** small similarly oriented streamlined outcrop. (GSC 203541-X)

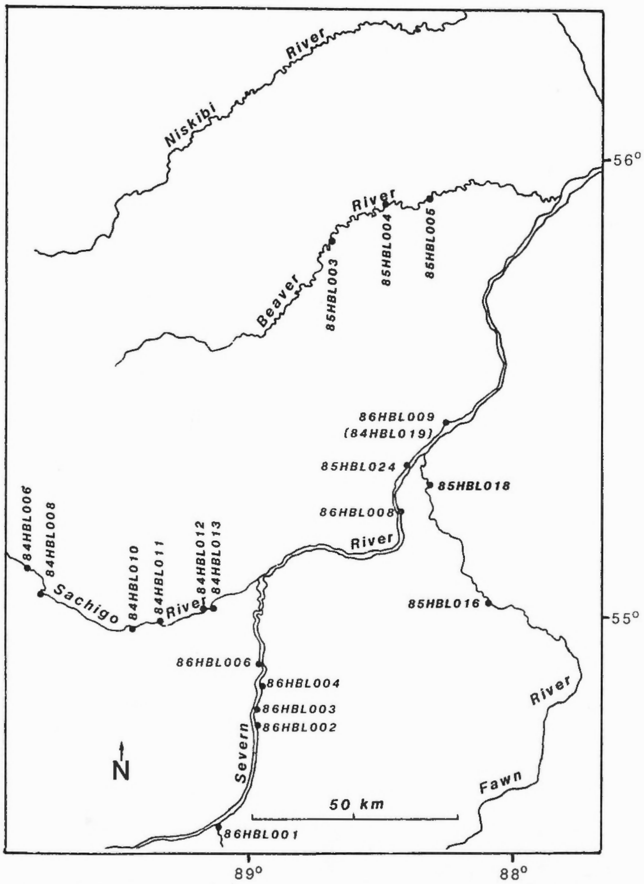


Figure 6. Section locations in the western portion of the study area.

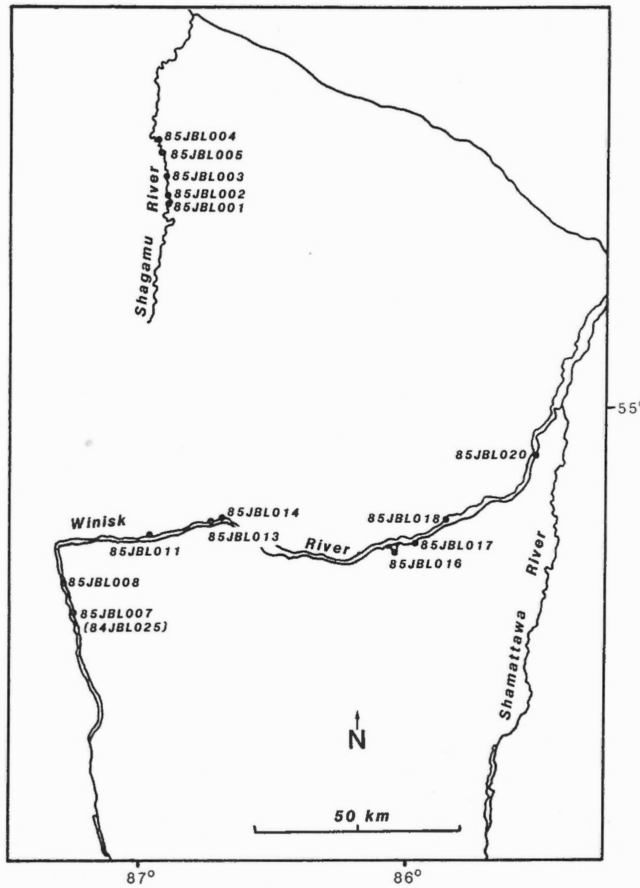


Figure 7. Section locations in the eastern portion of the study area.

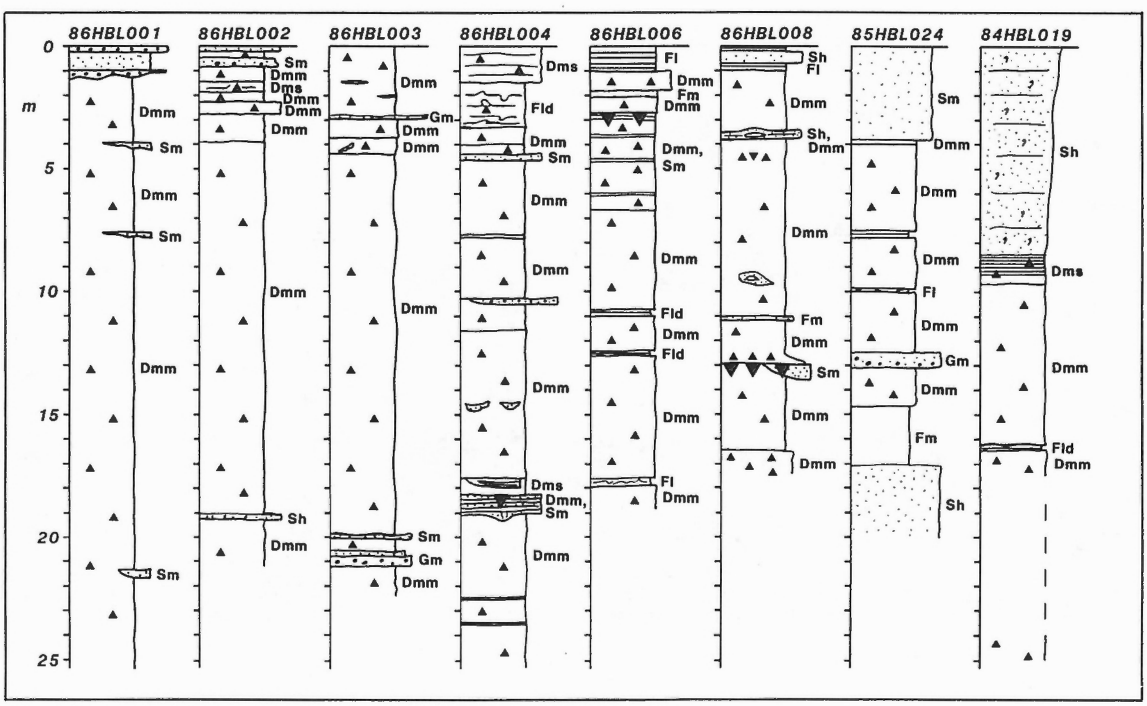


Figure 8. Severn River. Vertical lithofacies profiles. Refer to Table 1 for symbols.

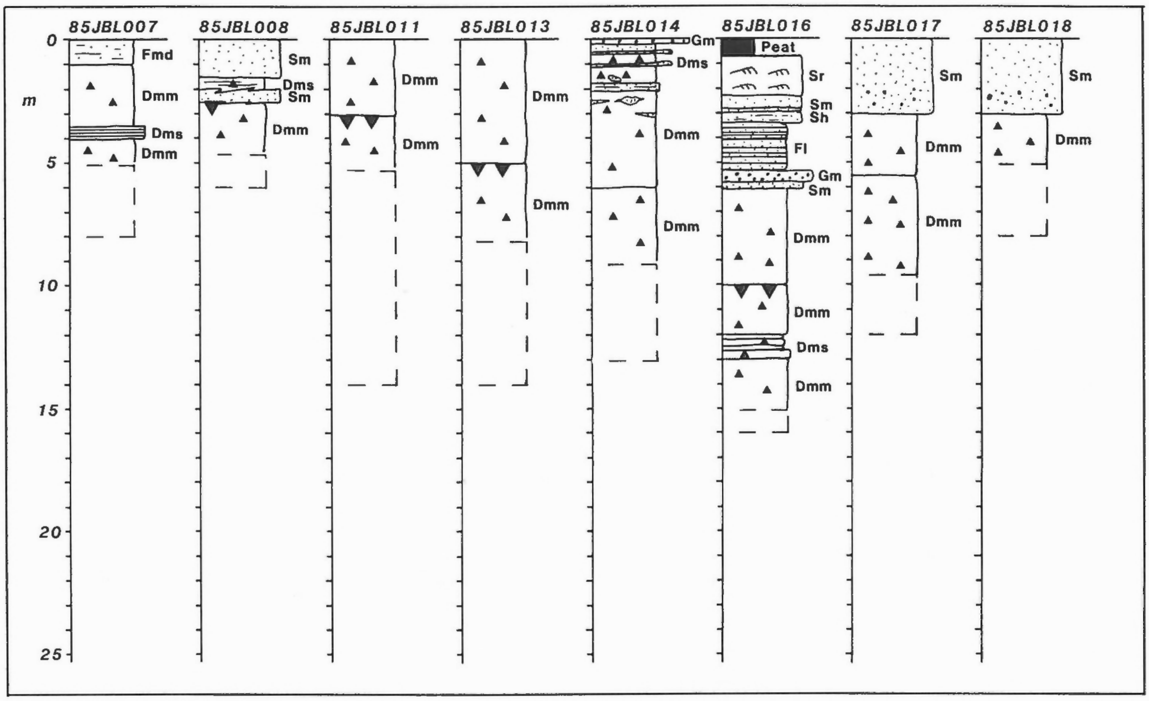


Figure 9. Winisk River. Vertical lithofacies profiles. Refer to Table 1 for symbols.

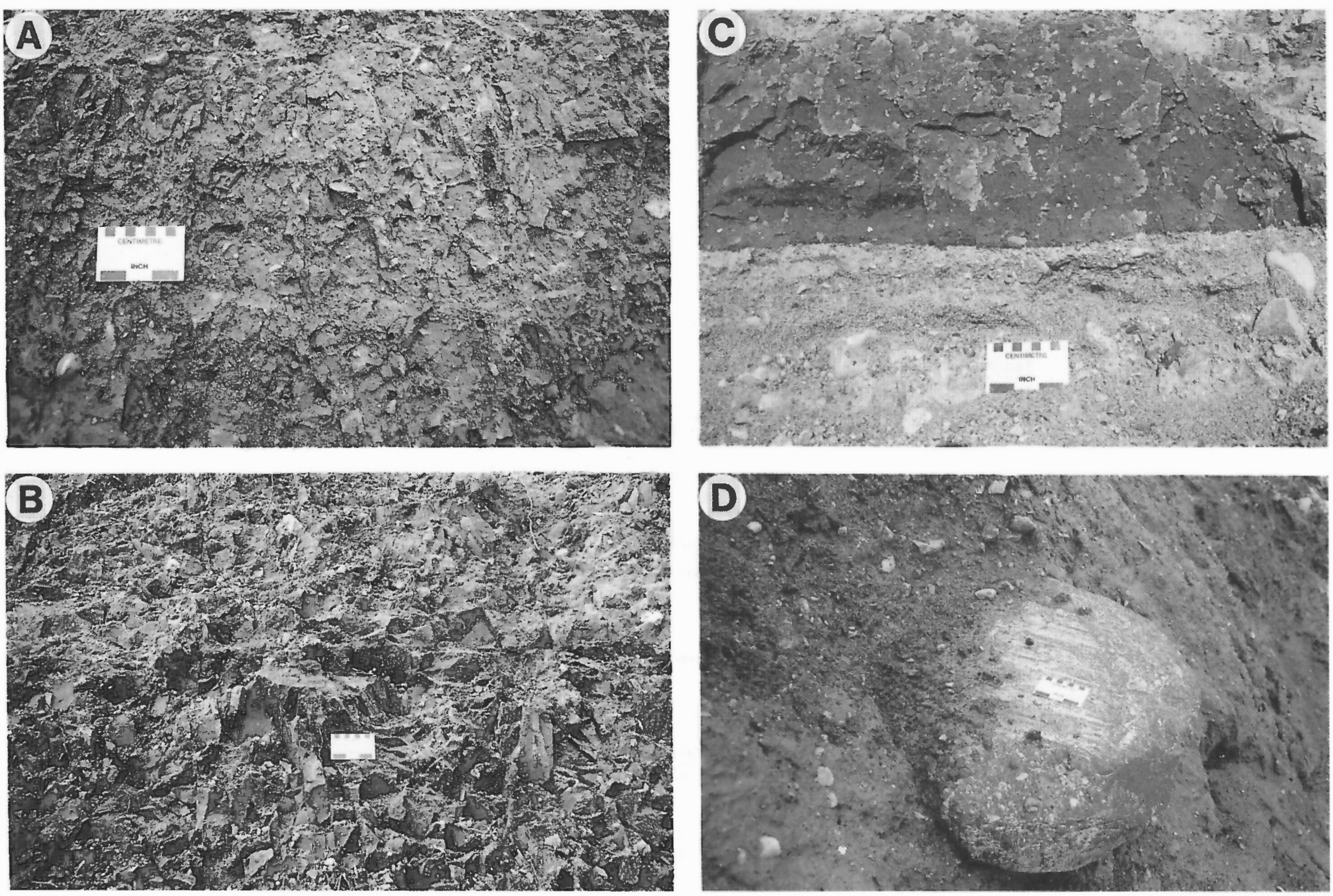


Figure 10. Massive diamicts. **A.** Massive diamict (Severn River, section 86HBL001, GSC 1991-264-C); **B.** Massive diamict; abrupt brown over grey colour change above scale card (Winisk River, section 85JBL014 at 6 m depth, GSC 1991-264-D); **C.** Massive diamict overlying gravelly sand (Severn River, section 86HBL002 at 19 m depth, GSC 1991-264-B); **D.** Faceted and striated boulder at the lower contact of a massive diamict (Severn River, section 86HBL008 at 13 m depth, GSC 1991-264-A).

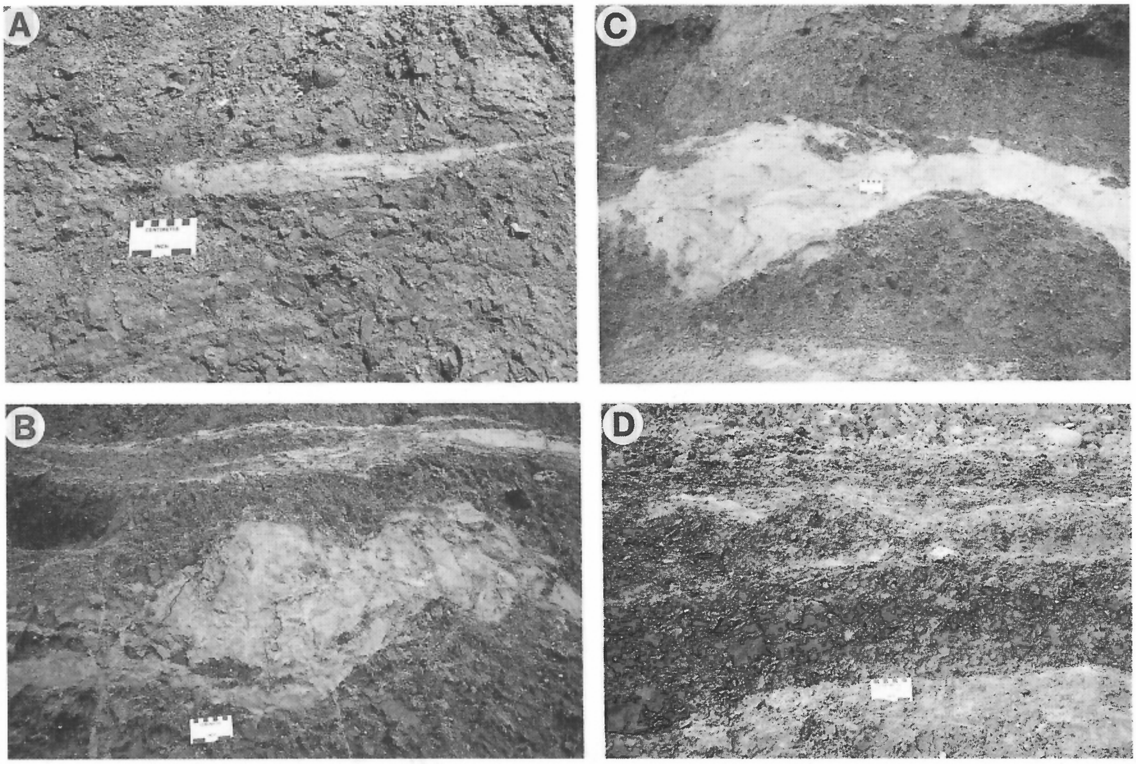


Figure 11. Sorted sediments and stratification in diamicts. **A**. Sand lens with a planar upper contact (Shagamu River, section 85JBL003 at 7 depth, GSC 1991-264-H); **B**. Deformed sand and diamict clasts within massive diamict (Winisk River, section 85JBL014 at 2.5 m depth, GSC 1991264-F); **C**. Deformed sand and diamict clasts within massive diamict (Severn River, section 86HBL008 at 9 m, GSC 1991-264-E); **D**. Stratified diamict (Severn River, section 84HBL019 at 9 m depth, GSC 1991-264-G).

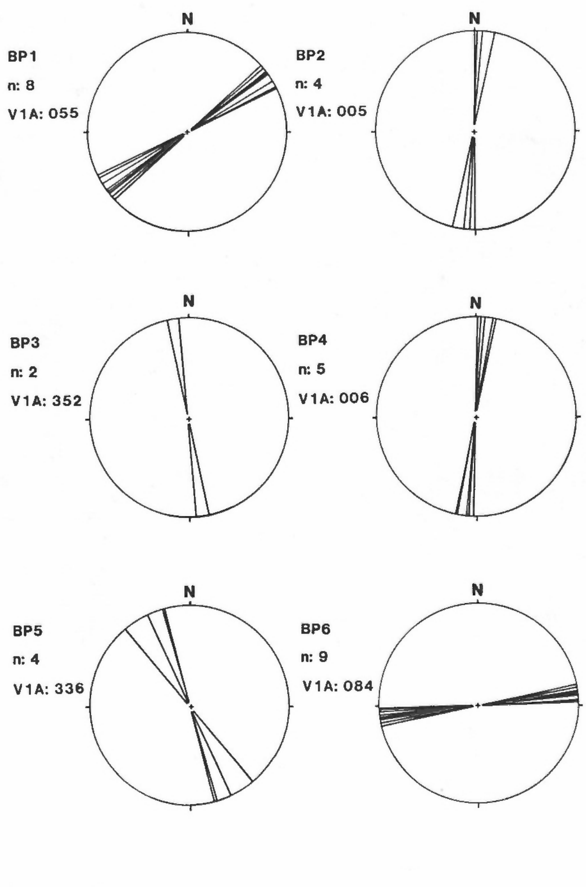


Figure 12. Boulder pavement striation data. n: number of observations; V1A: azimuth of the principal eigenvector.

Thick massive diamict, more than 1.5 m in thickness, in some cases exceeds 25 m in thickness. Thin silt and sand laminae and lenses of sand and gravel, which in some cases have sharp, planar upper contacts (Fig. 11), make up less than 15% of the outcrop area. Also included are deformed masses of sorted sediments (Fig. 11). These diamicts have sharp basal contacts, which in some cases display clearly erosive features such as striated boulder pavements and/or shearing or truncation of the underlying units. With few exceptions, well developed striations on faceted boulders are parallel on successive boulders (Fig. 12).

Unlike thick units, thin massive diamicts (0.2-1.5 m thick), do not display erosive basal contacts. Lower contacts typically are indicated by abrupt changes in texture, structure, or both.

A third major diamict class consists of matrix supported diamicts showing stratification over more than 15% of their outcrop area (Fig. 11) or consisting of massive units each <0.2 m thick. Stratification may either consist of silt beds generally <5 cm thick or alternating bands of diamicts of different colour or texture. Stratified diamicts occur near the top of some sections.

The diamicts contain marine fossils, but only as broken pelecypod fragments (Wyatt, 1989) and low concentrations of forams (Warman, 1987). According to Wyatt (1989), about 75% of the fragments are *Hiatella arctica*; the remainder include the genera *Mya, Macoma, Venus, Astarte,* and *Clinocardium*. Relative abundance of these taxa appears to be related to resistance to breakage. The foram tests recovered by Warman (1987), however, did not show signs of breakage. These forams were dominated by the genus *Elphidium*, but other genera, including *Islandellia* and *Oolinas*, were present. Similar macro- and micro-fossils were recovered from till on Nelson River by Nielsen et al. (1986).

Sand and gravel facies consist of poorly to moderately sorted sediments with well rounded pebbles and cobbles and variable sedimentary structures, unit geometry, and lateral continuity. A channel shaped gravel body low in the sequence at section 86HBL002 exceeds 15 m in width and 4 m in maximum thickness. Gravels are in most cases crudely bedded to massive, whereas sands are more structured, typically showing trough crossbeds 0.5-1.0 m across. The upper contacts of units enclosed by diamict are usually flat and truncated. Sedimentary structures may or may not be apparent immediately below the upper contact. Abrupt contacts are defined by the channel sides and bottoms. Sharply defined diamict beds <0.5 m thick occur within the sand and gravel sequences.

Fine grained facies include both laminated and massive sediments (Fig. 13). These sediments contain varying amounts of admixed sand and granules as well as clots or breccia of material resembling enclosing diamicts. Sharply defined laminations are typically 0.1-1.0 cm thick but may reach 10 cm in thickness. Laminated sequences, including rhythmites, occur within or between massive diamicts. Erosive upper contacts are indicated by truncation of laminations against relief on the contact. Massive clay with few dropstones was encountered at two sites below massive diamicts.

Overlying the diamicts is a thin, discontinuous cover of fossiliferous marine sand, silt, and clay.

Fabric

Most fabric determinations from diamict units (Fig. 14, 15) indicate a preferred orientation of moderate strength for prolate pebbles. As discussed by Warman (1987), the strength of the fabric, however, is low compared to sediments

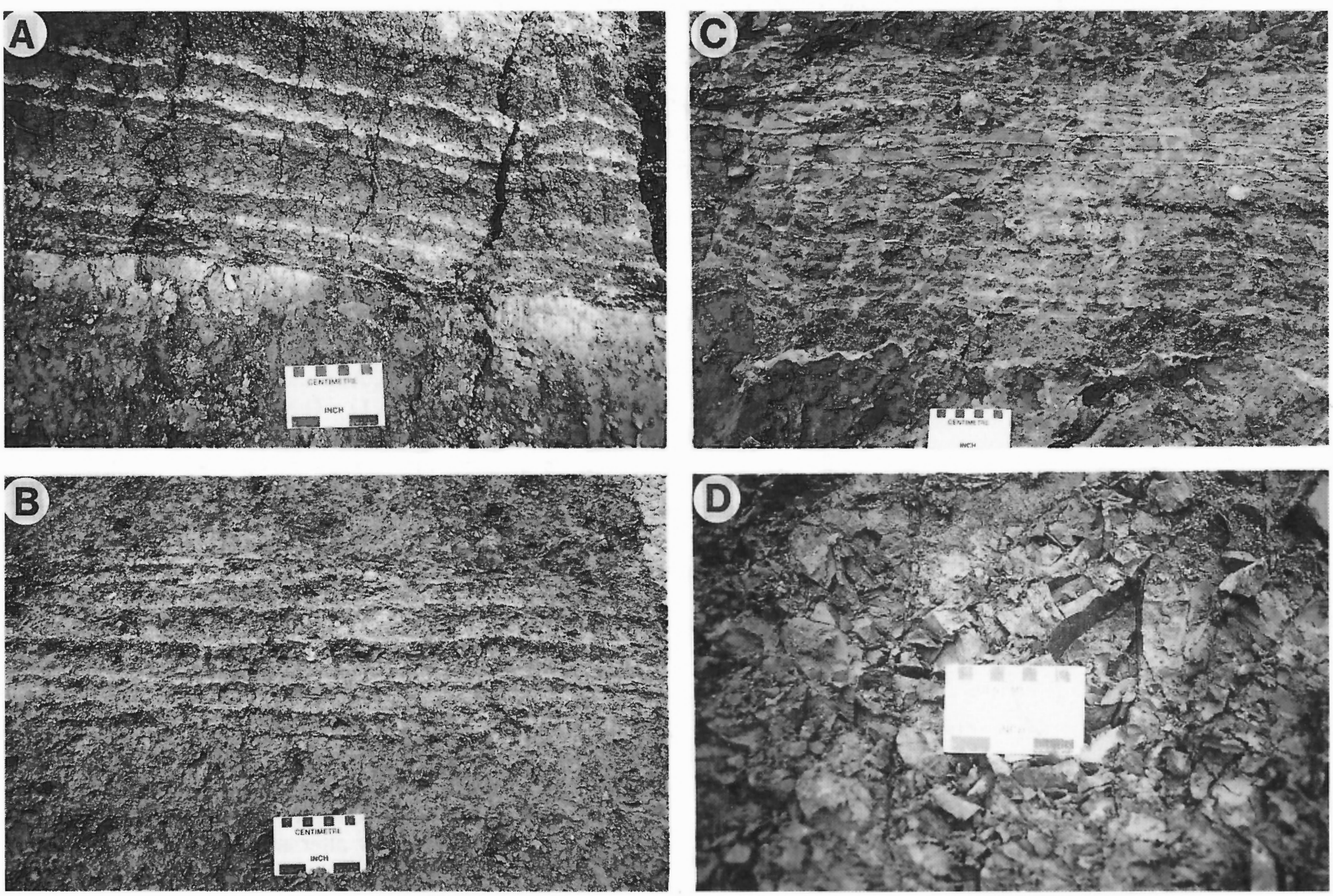


Figure 13. Fine grained sediments. **A.** Rhythmites of proglacial lacustrine or marine origin (Severn River, section 86HBL006 at 0.5 m depth, GSC 1991-264-K); **B.** Rhythmites within a diamict sequence (Severn River, section 86HBL006 at 11 m depth, GSC 1991-264-L); **C.** Rhythmites within a diamict sequence (Severn River, section 84HBL019 at 16.0 - 16.5 m depth, GSC 1991-264-I); **D.** Massive clay containing disseminated organic material (Severn River, section 85HBL024 at 16 m depth, GSC 1991-264-J)

interpreted as till elsewhere. As summarized by Dowdeswell et al. (1985), S1 values for till and debris rich basal ice generally exceed 0.6. S1 values between 0.5 and 0.6 such as those obtained for massive diamicts on Severn River were found to be more typical of sediment flows. These discrepancies may result in part from varying selection criteria for pebble shape in the data compiled by Dowdeswell et al. (1985).

Origin

Facies interpretations were based on lithologic descriptions, morphology, paleontology, fabric, stratigraphic context, and relationship to other facies.

Massive, ungraded matrix-supported diamicts, lenses of stratified sediments with sharp contacts, faceted and striated clasts, striated boulder pavements, preferred pebble orientation, and fluted surfaces indicate subglacial sedimentation. The sequences encountered in the study area closely resemble those described as lodgement till complexes by Eyles et al. (1982), which were considered typical of temperate wet based glaciers by Eyles et al. (1983). Hence the thick massive diamicts typical of the study area are interpreted as basal tills. Thin massive diamicts and stratified diamicts in some cases show a preferred fabric parallel to the fabric of thick, massive units, lack sedimentary structures indicating sediment flow or sedimentation through a water column, and lack an in situ

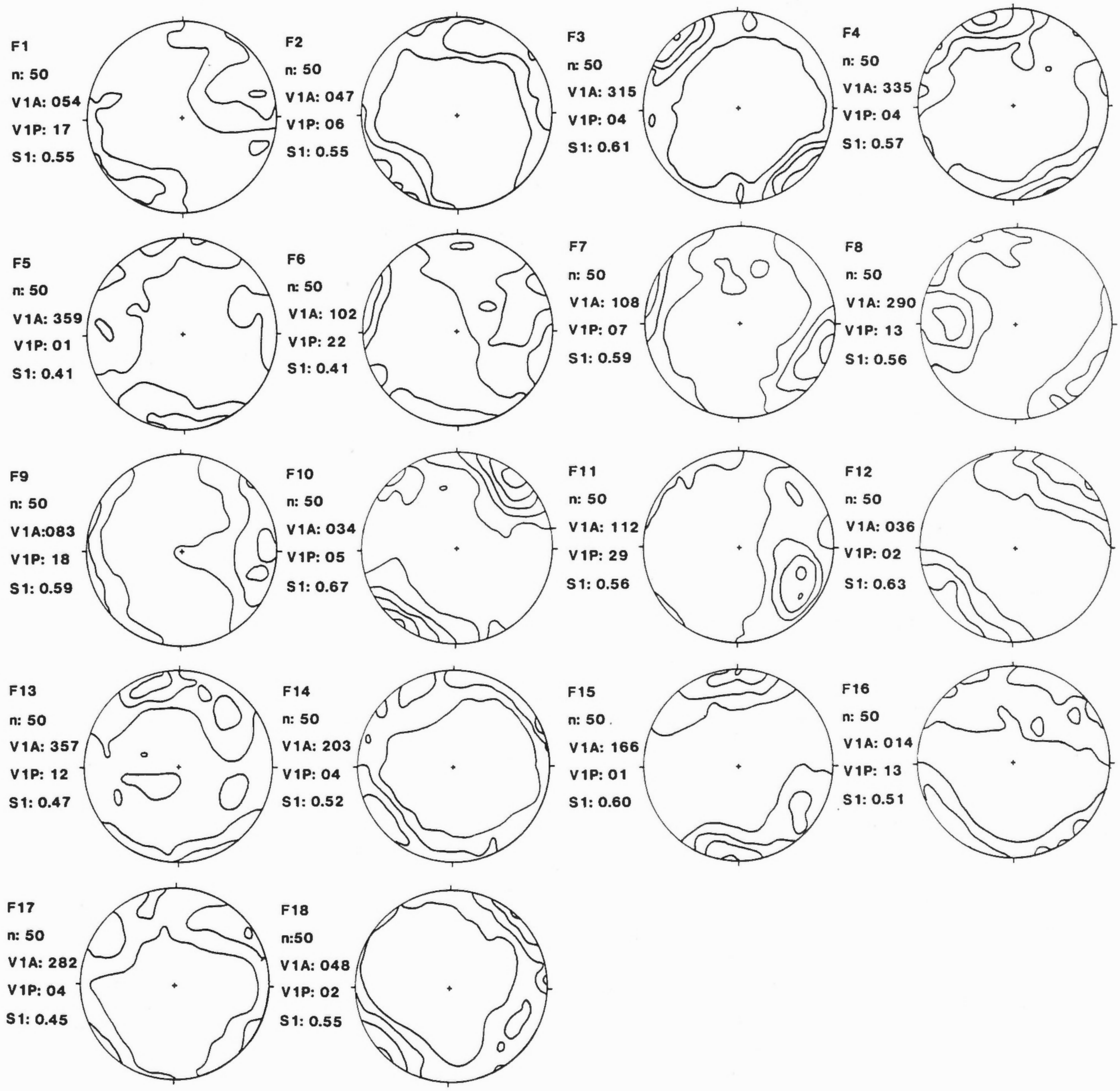


Figure 14. Fabric data, Severn River. Schmidt equal-area nets indicating orientation of prolate-shaped pebbles in diamicts. n: number of observations; V1A: azimuth of the principal eigenvector; V1P: plunge of the principal eigenvector; S1: strength (maximum = 1.0) of the principal eigenvector.

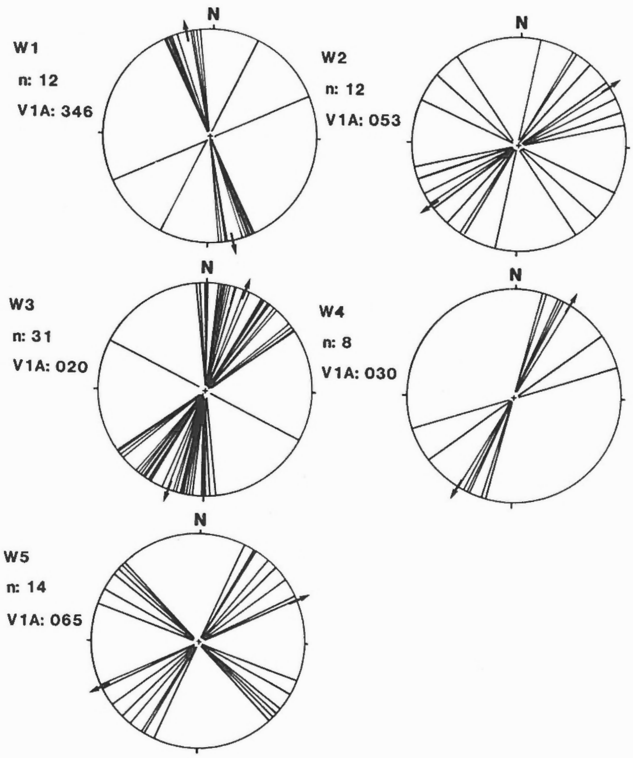


Figure 15. Fabric data, Winisk River. Azimuth of prolate pebbles. n: number of observations; V1A, arrow: azimuth of the principal eigenvector.

fauna. These units therefore are attributed to fluctuating subglacial till sedimentation and the attenuation of heterogeneous debris.

Seismic surveys of the bed of Ice stream B in the West Antarctic have indicated a 10 m thick sediment layer for which the seismically determined shear strength is less than the shear stress exerted by the overriding ice (Alley et al., 1986, 1987a, b). The implication that the sediment must be deforming and hence being transported resulted in analogy with deformation processes reported earlier from Iceland by Boulton and Jones (1979). Processes of deformation transport were further discussed by Boulton (1982, 1987) and Boulton and Hindmarsh (1987). Tills of the study area may therefore never have been entrained by glacial ice, but could instead have been transported by shear. Preservation of deformed masses of sorted sediment, soft clasts, shell fragments, and forams could in this context be attributed to protection by the enclosing fine-grained deforming matrix. Clark (1991) has suggested that striated pavements at the lower contacts of massive sheared diamicts, a common feature of Hudson Bay Lowland, may result from the sinking of boulders in deforming sediment with at least transient very low strength, followed by abrasion of the boulder tops by the deforming sediment. Transportation without entrainment in the ice offers a mechanism for rapid sedimentation. Models involving freezing of debris into the ice, followed by transport and sedimentation as the debris melted out of the ice are constrained by the heat flow requirements of freezing and melting.

Shaw (1985) summarized several diagnostic sedimentary structures, which indicate subglacial sedimentation from ice that is not sliding or deforming internally. The resulting deposit, termed meltout till, is characterized by preserved unlithified clasts, strong fabrics, stratified bands draped over large clasts, stratified sediment lenses with convex upper contacts, and preserved structures in stratified sediment indicating the passive deposition of overlying debris. In the study area, thin stratified diamict at the top of sections on Severn River could have originated by passive meltout from stagnant ice. The alternative interpretation of deposition from sliding ice containing or deforming a heterogeneous debris load is not discounted. The thickness of most diamict units would, however, require high debris concentrations and great thicknesses of debris-rich stagnant ice for a meltout hypothesis to be tenable. The well developed fluted surface of the uppermost till would rule out deposition of a substantial thickness of sediment from stagnant ice, unless the flutes were formed by reactivated ice or if meltout till drapes the flutes.

Hudson Bay Lowland has been the site of deep proglacial lakes as well as extensive marine inundation. Such an area would seem to be a likely site of deposition of ice-rafted diamicts (Eyles and Eyles, 1983). Fluted surfaces, sharp bounding contacts, and striated boulder pavements rule out this origin for most units. Several thick units, such as the lower sediments at sections on Severn River (Fig. 8) are sufficiently buried to be unrelated to observed surface morphology, have unexposed lower contacts, and are not associated with striated boulder pavements. These sediments contain rare marine fossils, but only as broken fragments. According to Warman (1987), the foram content of these sediments is well below values encountered in marine sediments. In the absence of conflicting indications, the massive nature of these diamicts and their preferred pebble fabrics are accepted as sufficient evidence for designation as till.

Sorted sediments with southward paleocurrents and lacking an in situ fauna are attributed to glaciofluvial or glaciolacustrine sedimentation, or both. In the past some degree of deglaciation has been assumed necessary for deposition of these sediments, but maintenance of ice over Hudson Bay is required to prevent marine and subaerial conditions. On Severn River, possible examples of this type of deposit include rhythmites at section 86HBL006 (Fig. 8), at a depth of 11 m. At a depth of 13 m in section 86HBL008 (Fig. 8), sand increases laterally to several m in thickness. On Fawn River, several metres of rippled sand underlie till at section 85HBL018 (Fig. 6). In the latter two cases, a boulder pavement is associated with the lower contact of the overlying till. Nonfossiliferous intertill sorted sediments elsewhere in the lowland include the Friday Creek sediments of Moose River Basin (Skinner, 1973) and the Twin Creek sediments of Gods River (Netterville, 1974; Klassen, 1986). The sediments were attributed by these authors to Middle Wisconsinan partial deglaciation of the region, but Dredge and Nielsen (1985), however, suggested a subglacial origin. This alternative is strongly supported by the work of Eyles et al. (1982), who interpreted such sediment as the deposit of subglacial meltwater flow. Such an origin is easily conceivable for sand, such as the Twin Creek sediments, but rhythmites such as those found on Severn River and within the Friday Creek sediments would require ponding of subglacial meltwater for their deposition. Subglacial lakes have been detected by radio-echo sounding of the Antarctic Ice Sheet (Oswald and Robin, 1973). Shaw (1985) speculated on the probable nature of sediments formed in such subglacial settings, but he acknowledged that deposition in subglacial lakes would be difficult to substantiate.

Sediments underlying till which include in situ flora and fauna or northward paleocurrents are attributed to nonglacial conditions.

Sediments overlying diamicts include fine grained sediment, sand, and gravel. Thickness of these sediments generally increases downstream. Sand at section 84HBL019 (Fig. 8) contains an in situ marine fauna. Hence these sediments are considered estuarine to nearshore marine deposits.

Ice flow directions

Striated boulder pavements yielded several opportunities for the determination of ice flow direction (Fig. 12, 16, 17). In the case of tills showing preferred orientation of prolate pebbles (Fig. 14-17), the azimuth of the principal eigenvector of these data may be of use in determining ice flow direction. Profiles on Severn River include sequences with southwest-northeast fabric overlying sediments with northwest-southeast trends. Indications of intermediate east-west trends are also present at sections 86HBL004 and 86HBL006 on Severn River. Winisk River sections yielded indications of north-south over southwest-northeast trends. A boulder pavement at section 85HBL018 (BP5, Fig. 12), on Fawn River, indicates a southeast-northwest trend at the base of the upper till. On the Shagamu River an east-west trend was obtained from a boulder pavement low in section 85JBL005 (BP6, Fig. 12).

Where fabric within a unit and boulder pavement striations at its lower contact are both available, for example fabric F12 and boulder pavement BP1 (Fig. 16), the two are parallel.

Colour

The most common pattern of diamict colour in the sections of the study area is brown over grey. The colour change is sometimes at a sharp contact, but elsewhere it is a diffuse colour change within a unit.

Munsell colours determined in the field on moist blocks of sediment may by simplified by referring only to their hue. In the study area, slightly reddish brown (7.5YR), brown (10YR), greyish brown (2.5Y), and grey (5Y) were encountered. In sections on the upper Severn River, 86HBL001, 002,

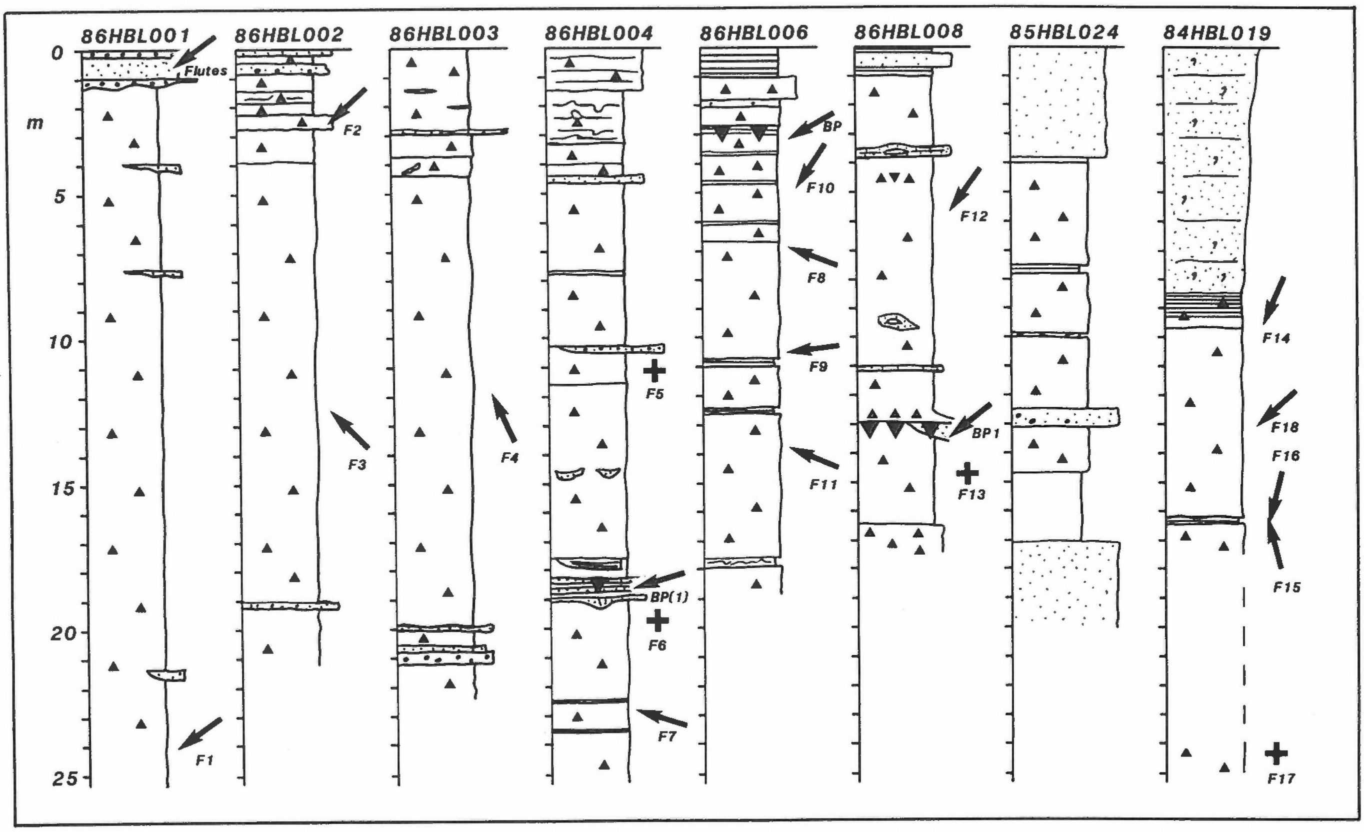


Figure 16. Severn River. Ice flow direction indicators. F numbers indicate fabric numbers from Figure 14. BP numbers indicate boulder pavement numbers from Figure 12. BP(1) indicates a striation measurement from one cobble. Arrows indicate ice flow orientation, with arrowheads arbitrarily directed to the south or west.

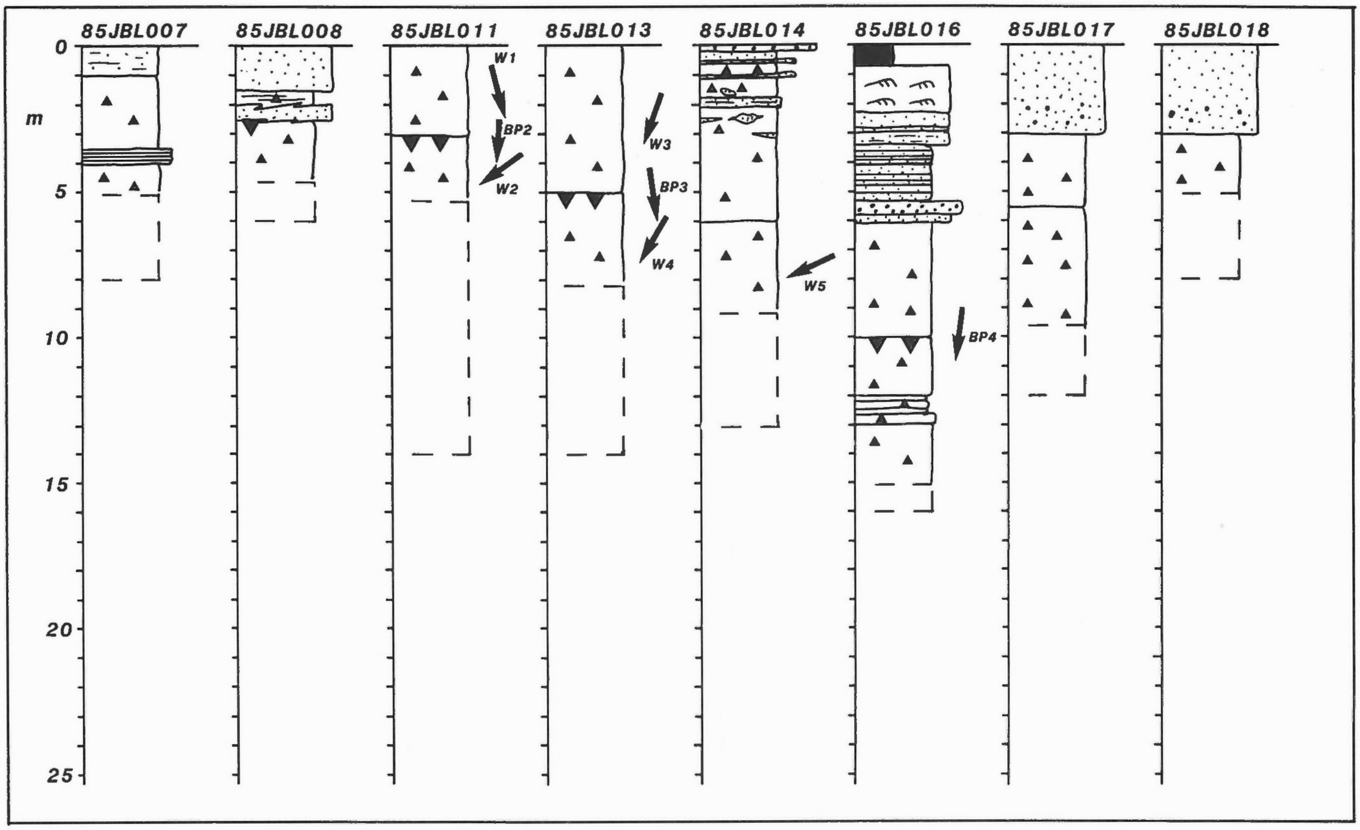


Figure 17. Winisk River. Ice flow direction indicators. W numbers indicate fabric numbers from Figure 15. BP numbers indicate boulder pavement numbers from Figure 12. Arrows indicate ice flow orientation, with arrowheads arbitrarily directed to the south or west.

and 003 (Fig. 18), the thickest till unit oscillates between greyish and brownish colours. In sections 86HBL004 and 006, the middle unit undergoes a transition from reddish downward to greyish, whereas the lower unit is grey. A simpler brown over grey pattern closely linked to lithostratigraphy is apparent on Winisk River (Fig. 19).

A brown over grey colour pattern would in many cases be the product of Holocene oxidation, but, as was discussed in detail by McDonald in his unpublished field notes, this appears not to be the case in the central Hudson Bay Lowland. The brown till is strongly calcareous and hence unleached, thicknesses of brown till reaching 10 m underlie poorly drained soils and are therefore thicker than would be expected for surface oxidation; in places brown till occurs beneath as much as 15 m of unoxidized grey early Holocene marine sediments. Where an oxidation rind was found on blocks of grey diamict, the colour of the weathered sediment was typically the same hue, but higher chroma. For example, an olive grey sediment weathers to olive, not to reddish brown.

Composition

The lithology of the fine gravel fraction from diamicts was classified with four classes for respect to four bedrock sources (Thorleifson, 1989): Paleozoic carbonates; Proterozoic low grade metamorphic supracrustal rocks; Archean intrusive and high grade metamorphic rocks; and a subset of the Paleozoic rocks, red carbonates derived from Devonian rocks of offshore Hudson Bay. Paleozoic rocks underlie all sampling sites, so this fraction can be viewed as the local component. Part of this fraction, such as the red carbonates, may, however, have undergone long distance transport. The Proterozoic rock fragments are an exotic component derived from sources to the east such as Sutton Ridge, Belcher Islands, Richmond Gulf, and the intervening sea floor. Archean rocks are apparently derived from a greater distance away, in Quebec, although outcrops on the southern flank of Sutton Ridge and large areas on the northern Ontario shield south of the study area are also possible sources.

The Paleozoic fraction reflects its nearby derivation by being the most abundant class, making up at least one-third of every sample. Archean rocks, mostly granitic, are a consistent but minor component at about 10%. Proterozoic rocks make up about 25% to at most 50% of the fine gravel. Red carbonate is a distinctive and variable component which ranges from 0 to more than 10%.

The 2-5.6 mm fraction of drift samples from the Hudson Bay region has previously been analyzed by Shilts et al. (1979), Shilts (1980, 1982), and Henderson (1989). Shilts et al. (1979) concentrated on the dispersal of red Proterozoic Dubawnt Group erratics in District of Keewatin, but data for Hudson Bay Lowland and the northern Ontario shield were also reported. Values for Paleozoic content exceeding 90% were reported by Shilts et al. (1979) for the Severn-Winisk area, because

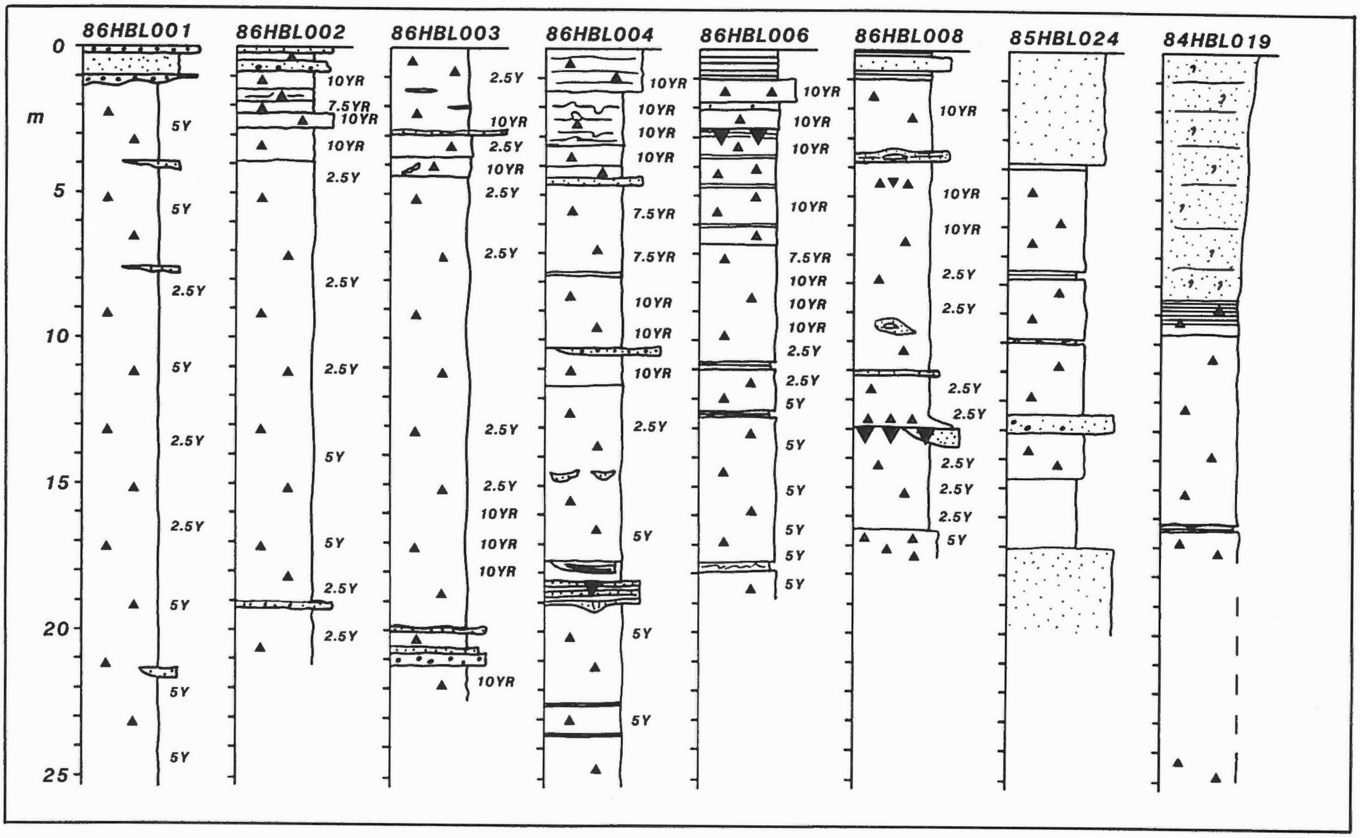


Figure 18. Severn River. Diamict colour.

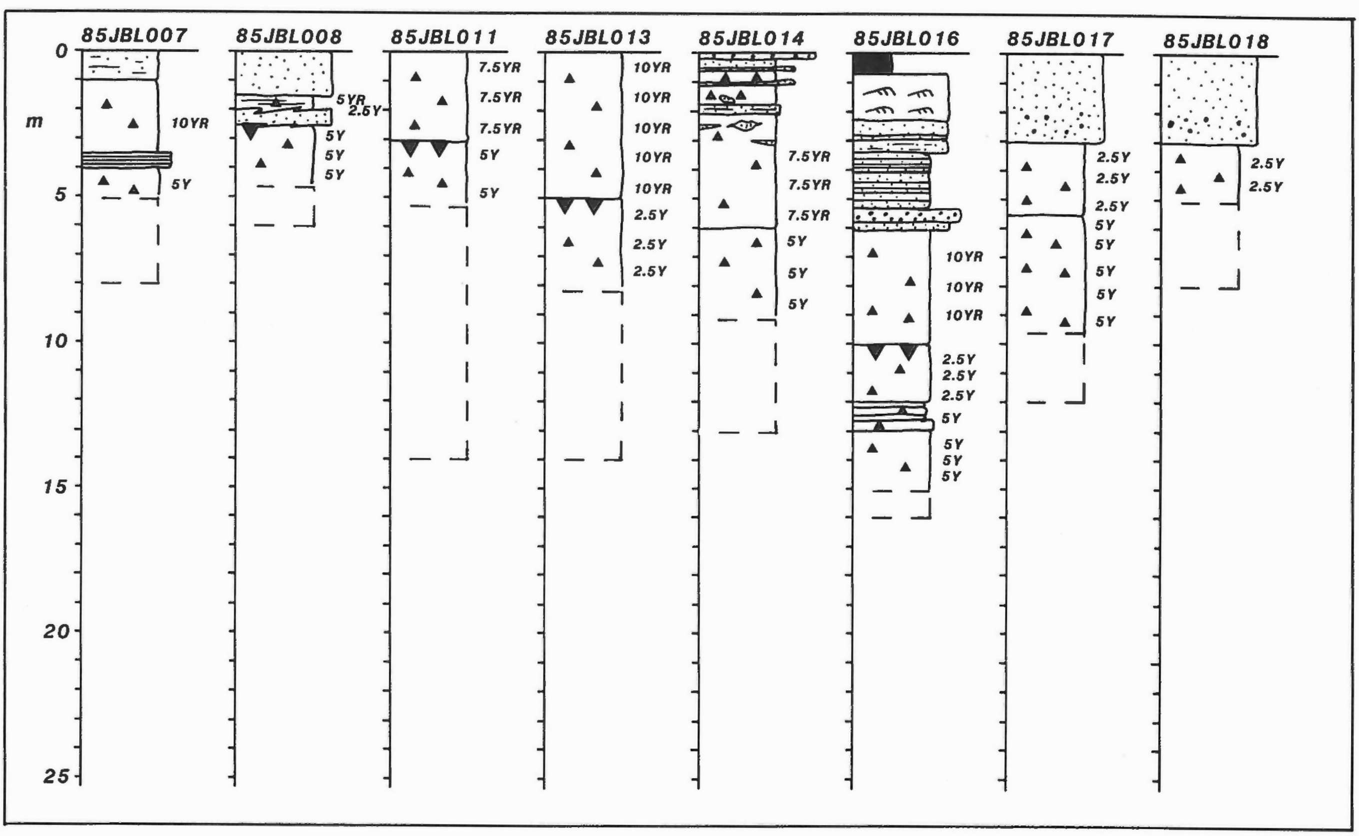


Figure 19. Winisk River. Diamict colour.

black greywacke and other low grade supracrustal rocks were attributed to Paleozoic sources at the time. Shilts (1980) later assigned dark greywacke to Proterozoic sources, although no actual data were presented. Shilts (1982) presented contoured maps indicating regional lithologic trends for this fraction. Henderson (1989) added data for sites on the Hudson Bay seafloor. Values for Paleozoic content between 40 and 80% extend throughout the lowland (Shilts, 1982). Paleozoic rock fragments exceed 80% in northern Hudson Bay, but are suppressed by Precambrian erratics west of the Belcher Islands region and offshore of Keewatin. On the Ontario shield, Paleozoic content diminishes southwestward. The proportion of Archean granitic rocks in Hudson Bay, at about 25% (Henderson, 1989), is more than double the values for Severn-Winisk. These Archean clasts are apparently derived from northern Quebec and Keewatin. Throughout Hudson Bay Lowland (Shilts, 1982), values for Archean rocks are less than 20%, below 5% in the Sutton Ridge area. Shilts (1982) indicated that Proterozoic erratics form a dispersal train extending from eastern Hudson Bay southwestward across Ontario and Manitoba. Values of 50% were reported for the Belcher area. Values for Proterozoic rocks were less than 5% in the northwesternmost part of Hudson Bay Lowland in northern Manitoba and in the southeastern Moose River Basin. In between, values rise to over 20% in the central lowland and the Attawapiskat-Albany area. Values were reported to be depressed below 20% on Winisk River.

Red carbonate content in the samples ranges from zero in many cases up to a maximum of more than 11%, but an association with sediment colour is apparent. Values exceeding 5% occurred in sediment with a Munsell hue of 7.5YR, values of about 3% are associated with hues of 10YR, and greyish material with hues of 2.5Y and 5Y consistently have less than 1% and in many cases zero. These rocks are absent at most sites in the northwestern and eastern portions of Hudson Bay but are generally consistently present in the central and southern areas (Henderson, 1989). Values at most sites in the latter areas are between 1 and 5%. Hence brown till in the Severn-Winisk area is similar in red carbonate content to bottom sediments in southern Hudson Bay. Henderson found values for red carbonate exceeding 40% in central Hudson Bay, over outcrop of the Devonian Williams Island Formation.

The compositional difference in red carbonate content supports brown and grey colours being the result of provenance. The brown matrix colour is probably caused by the fine grained products of crushing of the red carbonates. Pelletier (1969), however, reported that bottom sediments in central Hudson Bay are reddish brown, whereas most of the seafloor, surrounding this central zone, is underlain by olive grey sediments. Hence the brown colour of the matrix of red carbonate-bearing diamicts could conceivably result from the spatial coincidence of reddish brown bottom sediments and Devonian red carbonates. Bottom sediment colour could, in turn, be caused by provenance or may reflect diagenesis.

Red Dubawnt Group erratics derived from Keewatin have been reported by Shilts (1982) and Henderson (1989) at sites on the Hudson Bay seafloor as far southeast as the vicinity of the Manitoba-Ontario border. No Dubawnt erratics were encountered in the Severn-Winisk region.

Carbonate consistently makes up more than one-third of the less than 63 µm matrix of diamicts, with calcite being about 50% more abundant than dolomite. Occasional samples, such as carbonate rich till resting on bedrock at section 86HBL008, have calcite-to-dolomite ratios of about 3:1. In general, the carbonate content of the 63 µm fraction is correlated to the Paleozoic carbonate content of the 2.0-5.6 mm fraction (Fig. 20). Paleozoic content between 60 and 80% in the fine gravel is, however, slightly negatively correlated with Chittick values.

The less the 2 mm matrix of the till samples is dominated by silt. Although silt percentages commonly exceed 40%, sand and clay each make up typically less than 30%. A few clay-rich and sand-poor samples were obtained from stratified units.

Analytical data were plotted on vertical profiles by Thorleifson (1989). Inspection of the data indicated that the most useful variables for stratigraphic differentiation are the Paleozoic-to-Proterozoic ratio, or more simply the percentage of either, in the fine gravel and red carbonate in the same fraction (Fig. 21, 22).

Lithostratigraphy

Severn River

The exposed sequences of Severn River (Fig. 8) do not lend themselves to unambiguous stratigraphic correlation through reference to lithofacies alone. Diamict matrix colour offers

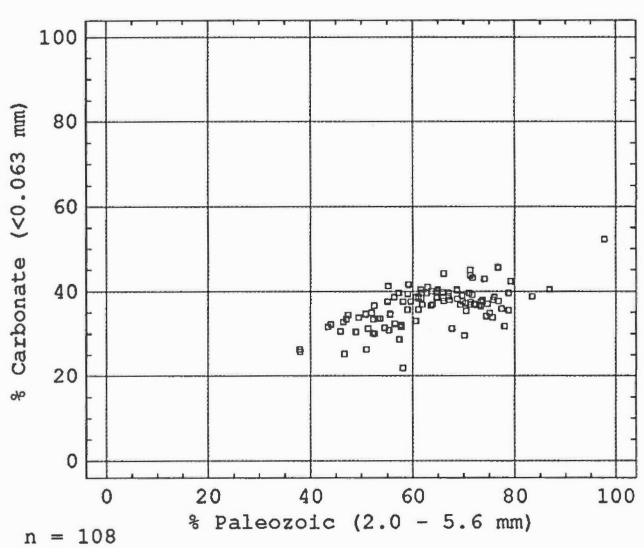
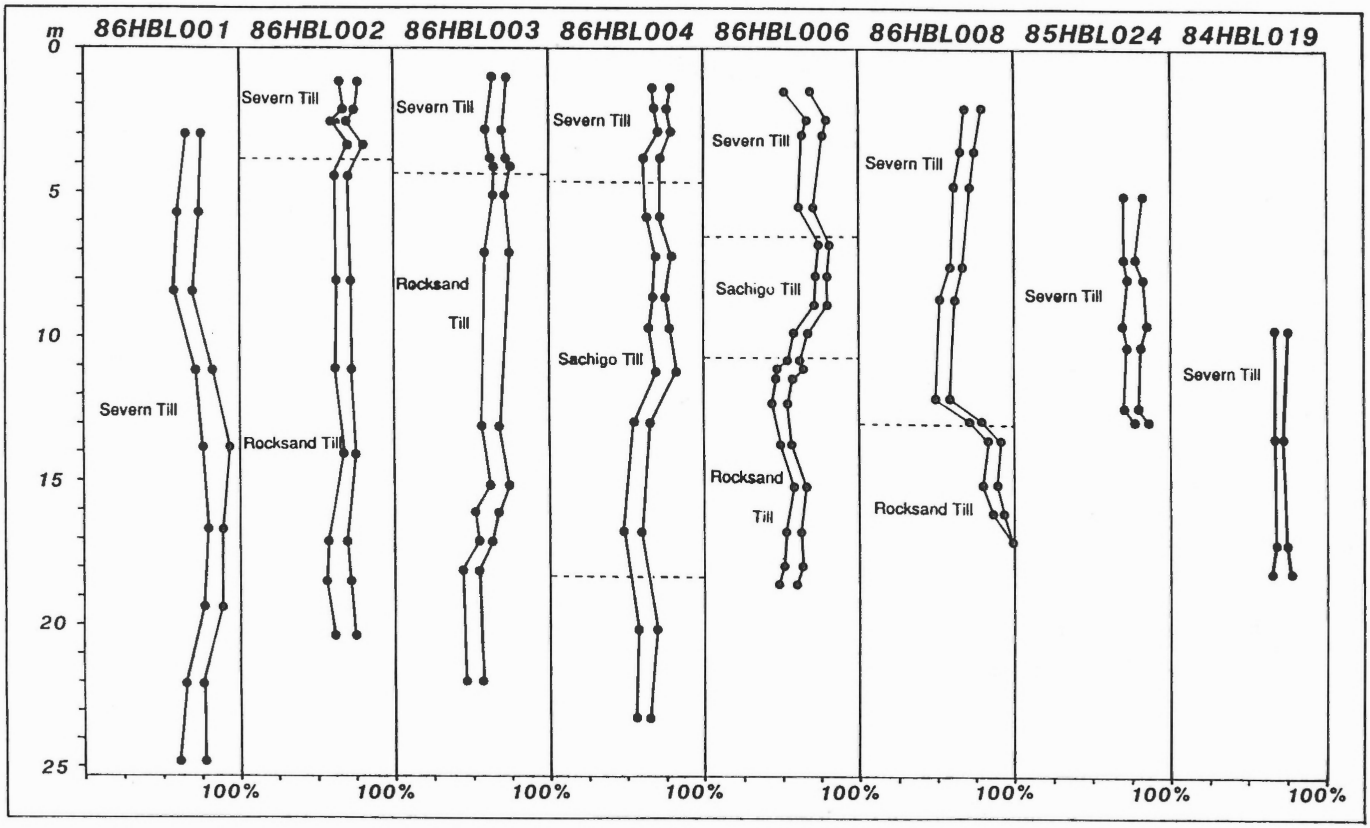


Figure 20. Comparison of Chittick and fine gravel carbonate.



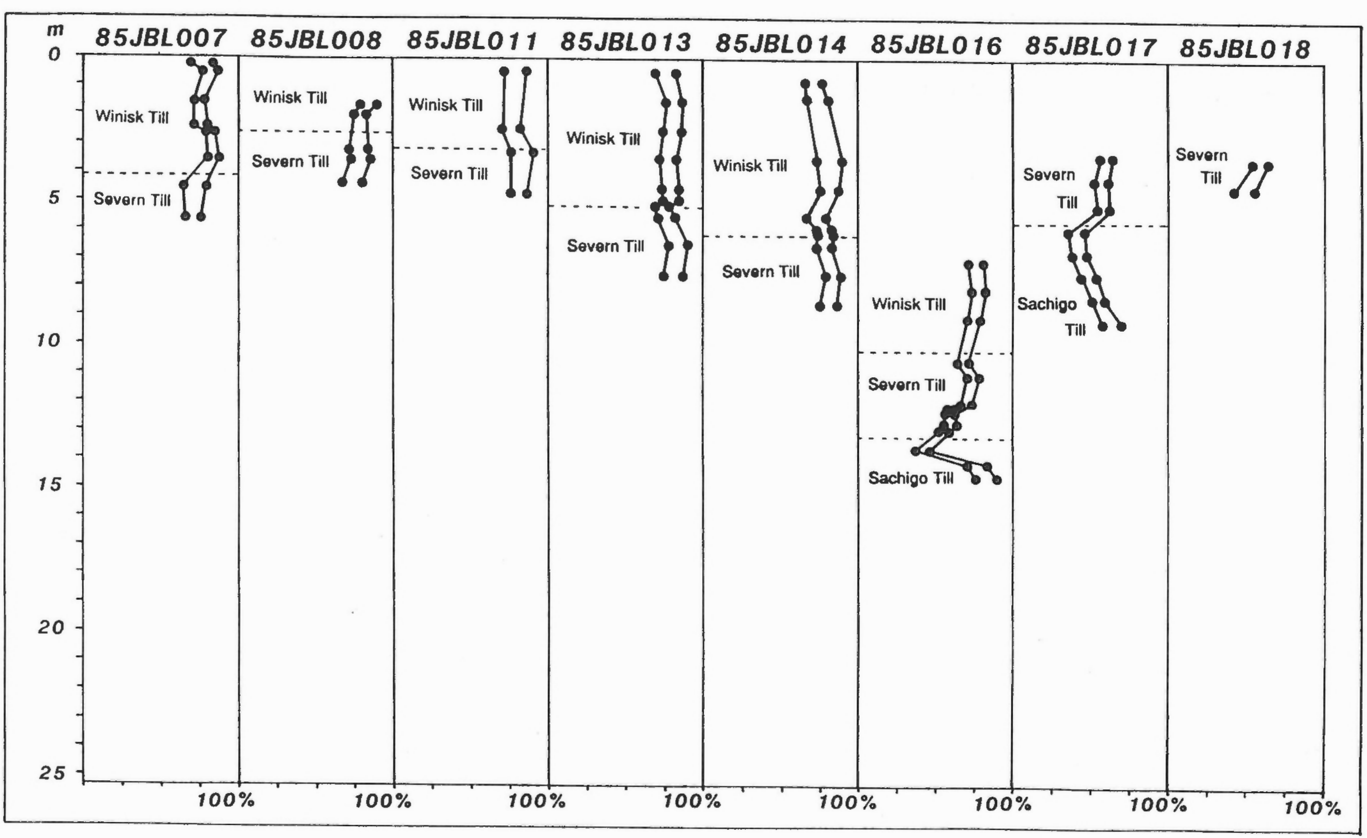


Figure 21. Lithology of the fine gravel fraction (Paleozoic + Archean + Proterozoic = 100%).

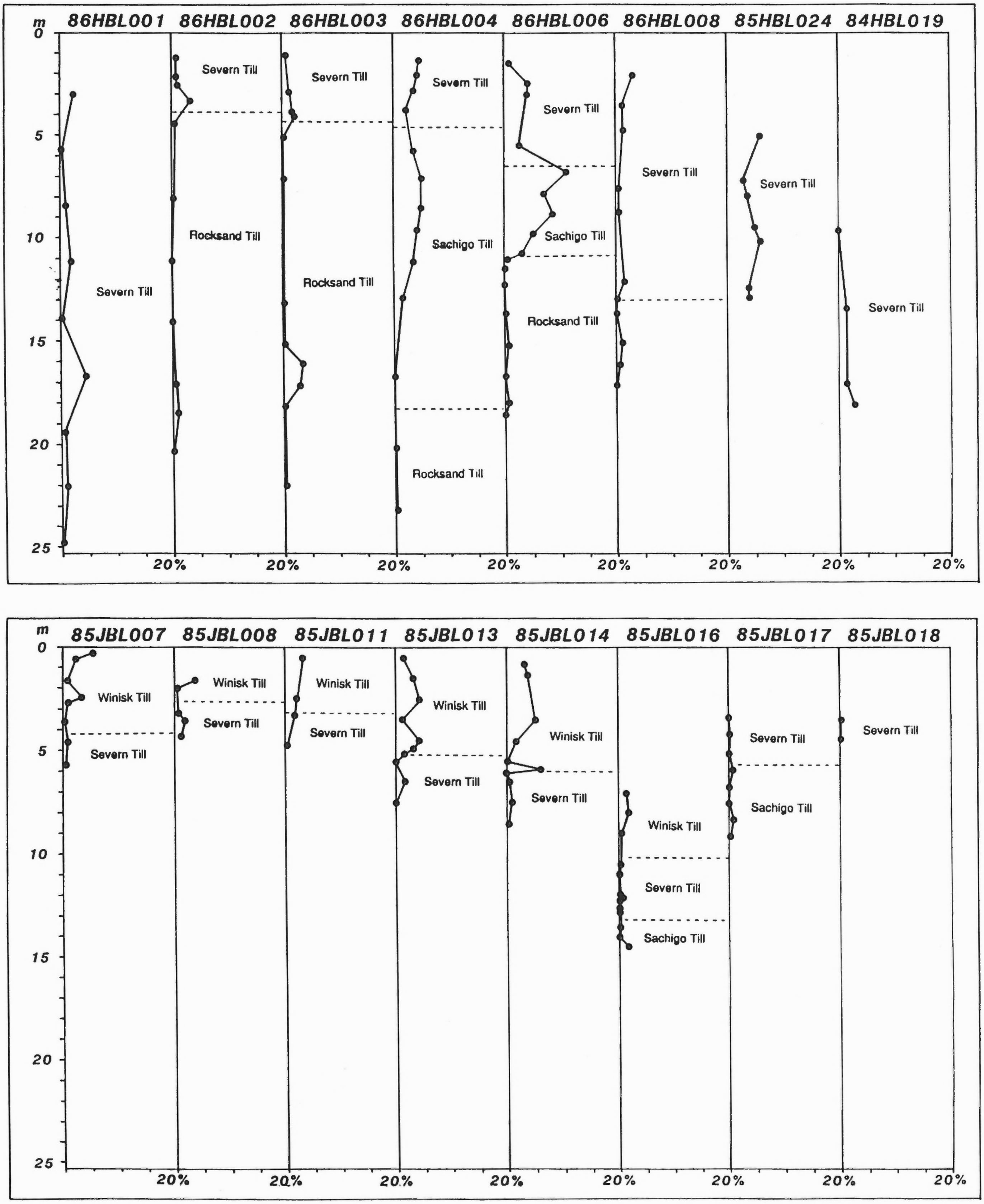


Figure 22. Red carbonate content of the fine gravel fraction.

the possibility of correlation by colour, brown till over grey till, but several complications such as grey till over brown till and brown till over a reddish-to-grey transition over grey till confound any such attempt. The sediments may, however, be subdivided into till units separated by sharp contacts by referring to compositional and ice flow direction data.

The uppermost till deposits on Severn River underlie a surface that is everywhere molded into northeast-southwest flutes (Fig. 4). The carbonate-rich, granite-poor composition of the till indicate that this is southwestward, not northeastward ice flow. Fabrics in the uppermost sediments at four sections have northeast-southwest orientations. At section 86HBL001 (Fig. 16), a fabric measured at a depth of 24 m has a preferred northeast-southwest orientation. The lack of any discontinuities in this sequence supports its assignment to one till unit. The upper sediments at section 86HBL008 (Fig. 16) include a southwest-northeast fabric and overlie a boulder pavement striated northeast-southwest. Hence data from this site indicate southwestward ice flow at the base, within, and at the surface of this sequence. The thickness of massive diamicts, that may be attributed to this single phase of southwestward ice flow, ranges from 24 m at section 86HBL001 to only 3 m at section 86HBL002 (Fig. 23). The uppermost diamicts on Severn River have Proterozoic contents below the average, hence elevated Paleozoic values, (Fig. 21) and intermediate red carbonate values (Fig. 22). These upper sediments are therefore correlated as a till unit representing a phase of dominantly southwestward ice flow.

Ice flow directions and composition differing from the overlying upper unit are present at most sections on Severn River (Fig. 16, 21, 22). Two sections, 86HBL004 and 86HBL006 (Fig. 24), include a middle unit with high concentrations of red carbonate, implying southeastward ice flow from Devonian red carbonate outcrops in central Hudson Bay. At section 86HBL006, fabric data, however, as well as a striated cobble at 86HBL004, imply an east-west flow orientation. These two units are correlated as a second till unit, of which the grey lower portion was produced by westward ice flow, but of which the reddish upper portion was produced by southeastward flow.

The lowest sediments at sections 86HBL002, 86HBL003, 86HBL004, and 86HBL006 yielded a northwest-southeast fabric orientation in every case. These grey diamicts are also correlative on the basis of Proterozoic contents in the gravel fraction (Fig. 21) which are consistently slightly elevated and red carbonate values (Fig. 22) which are consistently very low. These deposits are interpreted as a third till unit.

Lithofacies, ice flow direction indicators, and compositional trends therefore indicate three till units for Severn River. These units are well displayed at section 86HBL006 (Fig. 24), so this site is designated as the type section for the three units. Severn Till, Sachigo Till, and Rocksand Till (Fig. 25) are names taken from rivers in this area where few other geographical names are available.

Winisk River

The ice flow direction associated with the upper till on Severn River is well displayed in the pattern of southwest-oriented surface flutes, but this pattern is truncated in the Winisk River area by a different set of flutes. The slightly converging, generally southward, pattern of these flutes (Fig. 4) is paralleled by boulder pavement striations at the lower contact of, and fabrics within, the upper massive diamict unit on Winisk River (Fig. 17). Massive diamicts underlying the surface unit on the Winisk (Fig. 26) are attributed to southwestward ice flow on the basis of fabrics (Fig. 17) and are therefore correlated to Severn Till, the uppermost unit of the Severn sequence. The overlying unit, named Winisk Till, is hence younger than the Severn River sequence. Compositional differences between these upper two tills are not pronounced (Fig. 21, 22), but a sharp difference in colour, brown over grey, is present (Fig. 19). The most clearly displayed compositional variability on Winisk River is an increase in Proterozoic content low in sections 85JBL016 (Fig. 27) and 85JBL017. At the former section, the Proterozoic-rich till unit is separated from overlying Severn Till by nonfossiliferous stratified sediments. Stratigraphic position and probable westward ice flow implied by Proterozoic erratics possibly derived from Sutton Ridge implies correlation of this till with Sachigo Till of the Severn River sequence. A three till sequence results for Winisk River (Fig. 28). The sequence is best displayed at section 85JBL016, which is designated as the type section for Winisk Till. Rocksand Till is not exposed on Winisk River, perhaps because of shallower depths exposed in the sections.

Fawn River

The surface of the lower Fawn River area is part of the array of converging southeastward to southward-oriented flutes (Fig. 4). As originally observed by Tyrrell (1913, 1914), boulder pavement striations at the lower contact of the upper till on this river are oriented south-southeast. The Proterozoic and red carbonate contents of this till are compatible with Winisk Till, so correlation to this unit on the basis of both ice flow direction and composition is acceptable. The lower unit exposed on Fawn River is correlated with Severn Till on the basis of stratigraphic position and compatible composition.

Shagamu River

At section 85JBL005 on Shagamu River (Fig. 7), three diamict units have intermediate Proterozoic fine gravel contents, but the lowest unit, a red diamict, has high red carbonate content. A possible correlation to Winisk, Severn, and Sachigo tills would be supported by high red carbonate contents in Sachigo Till on Severn River. A well developed boulder pavement at the contact between the lower two units at 85JBL005 indicates, however, ice flow westward (BP6, Fig. 12). The middle unit therefore is correlated to Sachigo Till and the upper unit to Severn Till, hence Winisk Till is absent. The lower unit could be correlated with Rocksand Till on the basis of stratigraphic position, but instead red carbonate values as high as 13% are taken as evidence for a separate pre-Rocksand Till unit deposited by southeastward ice flow. The name Shagamu Till, with a type section at 85JBL005, is proposed.

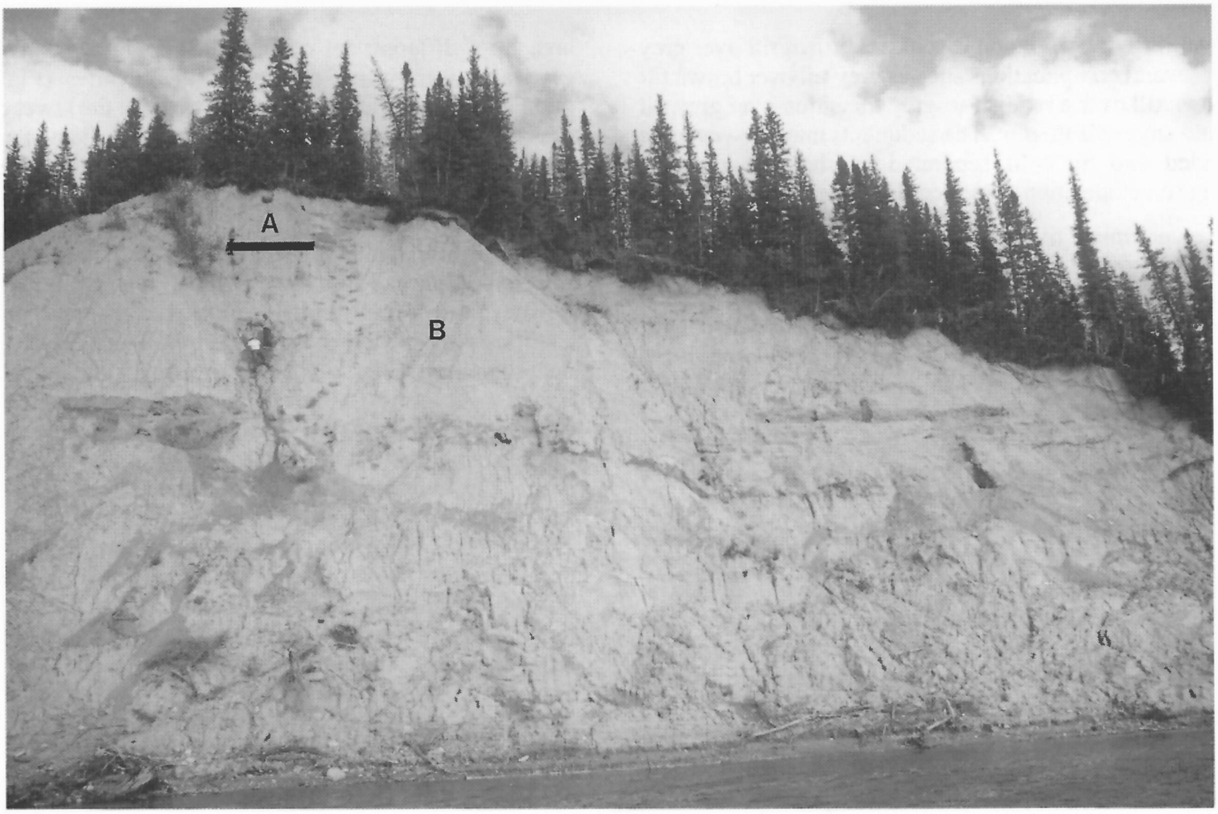


Figure 23. Severn River. Section 86HBL002. This 32 m high section includes 21 m of exposed in situ sediments over an 11 m interval covered by thick slumped material. Severn Till (**A**) overlies Rocksand Till (**B**) at a contact indicated by a line. (GSC 1991-260)

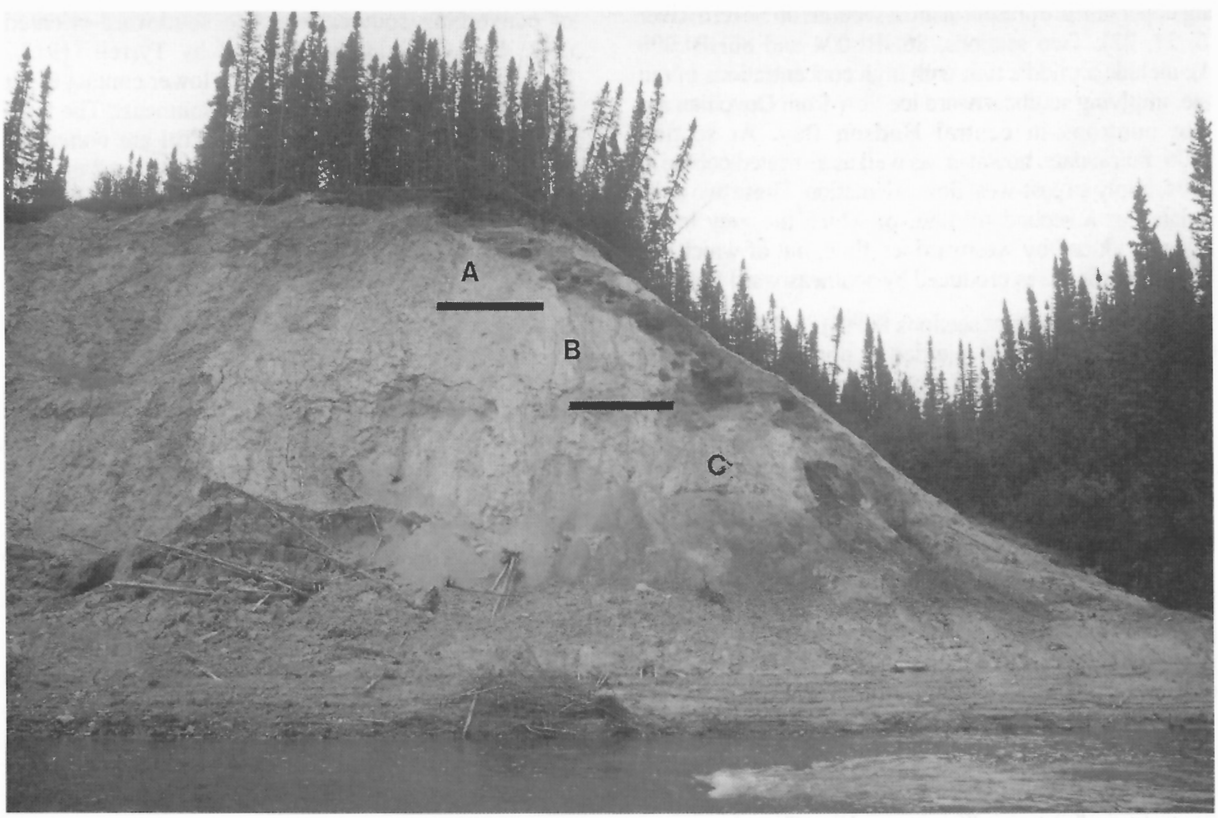


Figure 24. Severn River. Section 86HBL006. This 25 m high section includes in situ sediments that are exposed to river level. Severn Till (**A**) overlies Sachigo Till (**B**) and Rocksand Till (**C**). Contacts are indicated by lines. (GSC 1991-261)

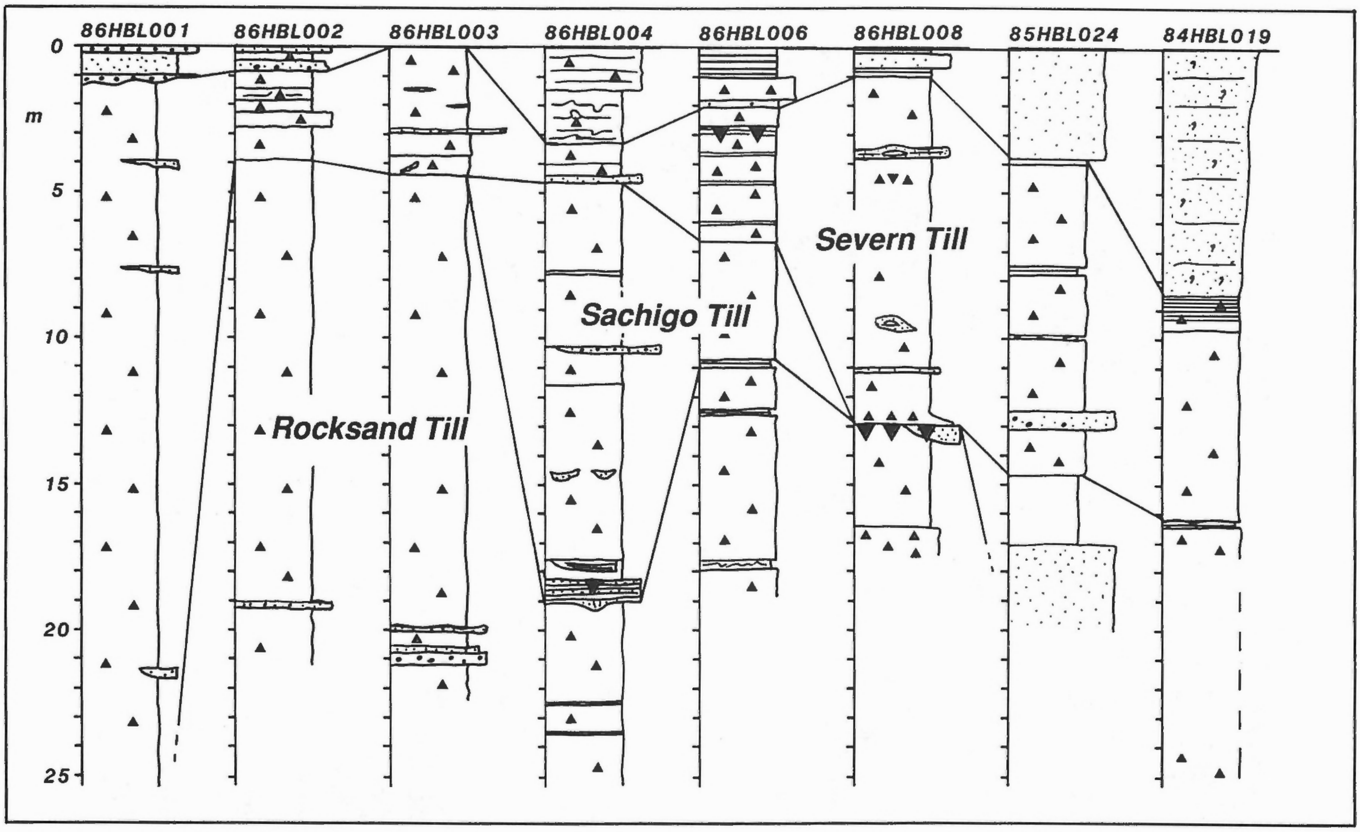


Figure 25. Severn River. Correlation of till units.

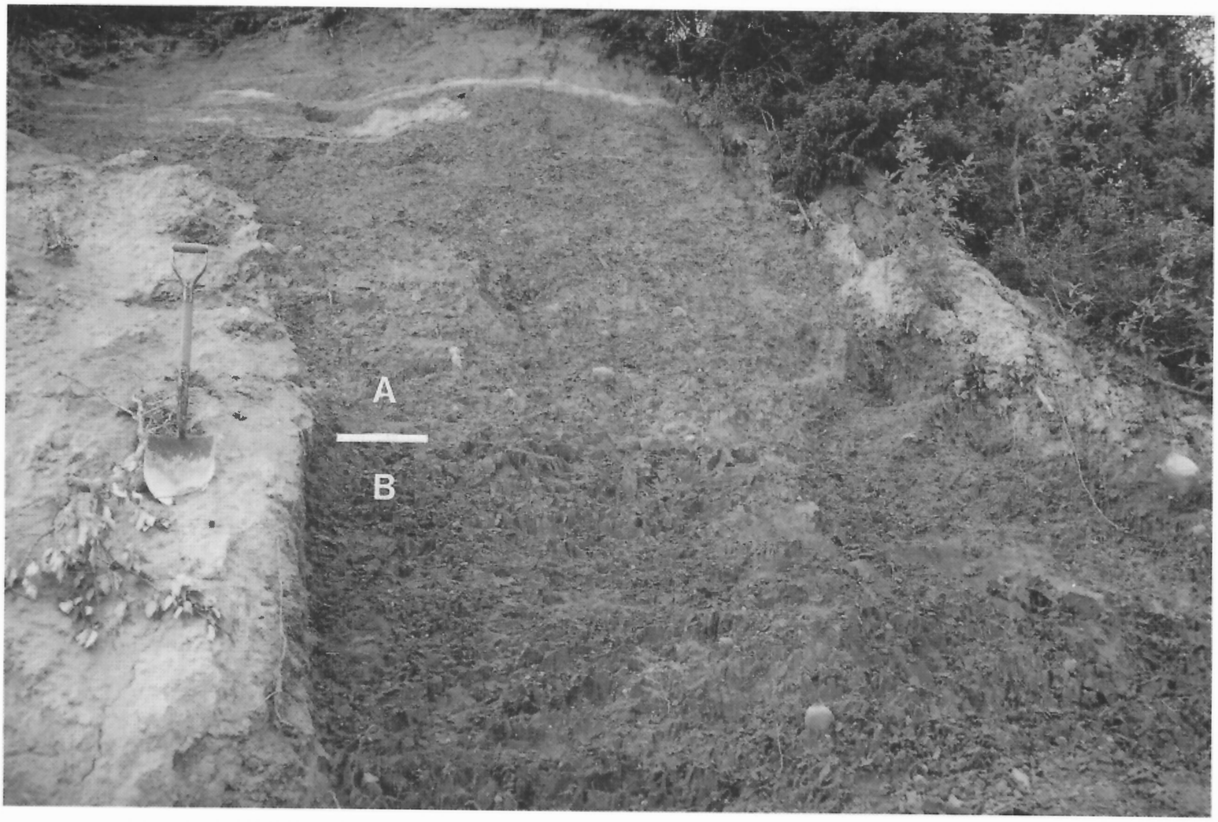


Figure 26. Winisk River. Section 85JBL014. This 13 m high section includes 9 m of exposed in situ sediments over 4 m covered by slumped material. Winisk Till (**A**) overlies Severn Till (**B**) at a contact indicated by a line. (GSC 1991-259)

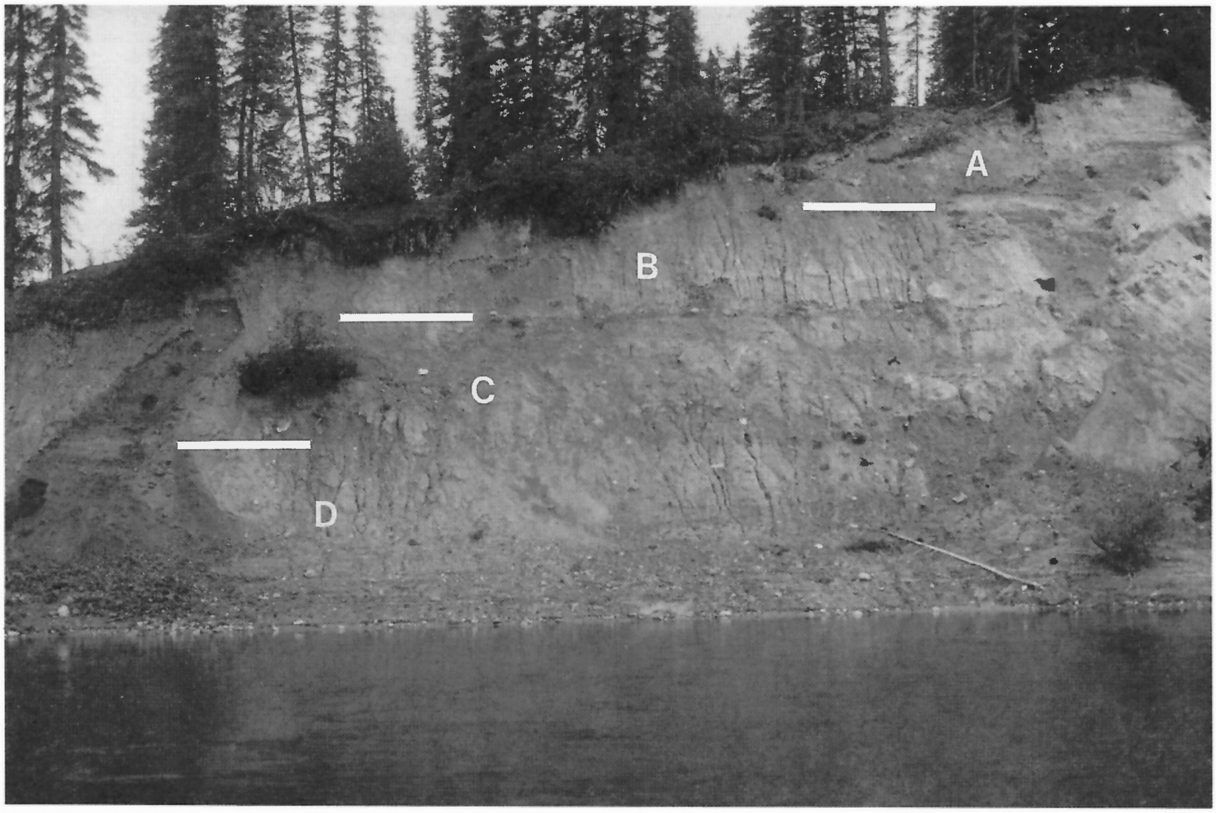


Figure 27. Winisk River. Section 85JBL016. At this 16 m high section, 15 m of in situ sediments were exposed. Postglacial sediments (**A**) overlie Winisk Till (**B**), Severn Till (**C**), and Sachigo Till (**D**). Contacts are indicated by lines. (GSC 1991-262)

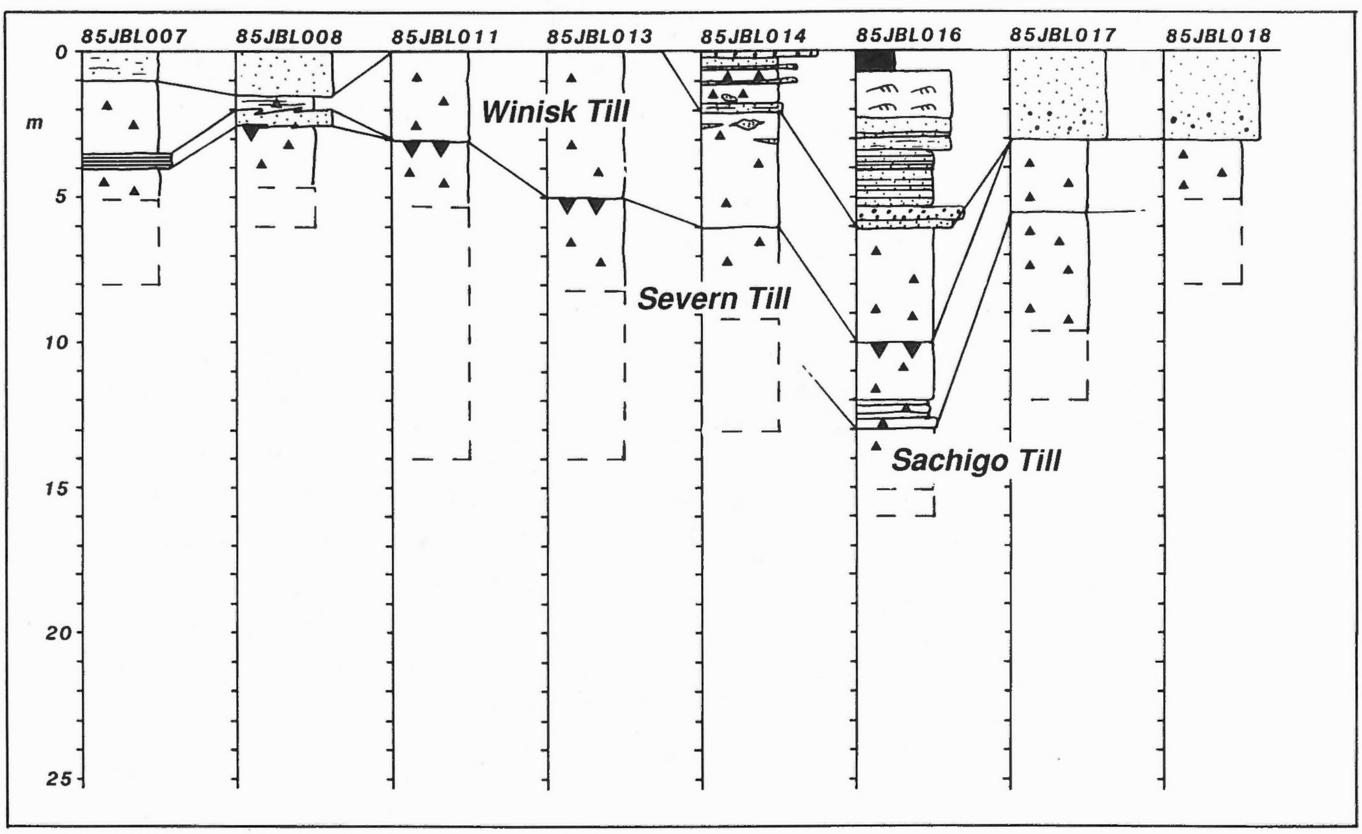


Figure 28. Winisk River. Correlation of till units.

Composition of units

Means of compositional data were compiled for each till unit on the Severn as well as for Winisk River (Table 2). Data for the lithology of the gravel fraction provides useful information regarding provenance and correlation. Chittick carbonate data for matrix carbonate shows some relationship to the fine gravel data, but are of little value in obtaining conclusive information. Grain size data are of virtually no use in distinguishing till units.

Winisk Till on Winisk River contains higher concentrations of Paleozoic debris, more than 70%, than underlying till or till on Severn River. This trend is shown to a lesser degree by the Chittick data and by the grain size data as extra silt. Red carbonate content, at about 2-3%, is consistently higher than underlying till, but not as high as Sachigo and Shagamu tills. Archean rocks show no significant differences between till units. Proterozoic values simply mirror Paleozoic percentages, so low values of under 20% are encountered in Winisk Till. Severn Till on Severn River shows little difference from underlying tills in major erratic types. Red carbonate values are intermediate between those obtained from underlying Sachigo and Rocksand tills. Severn Till on Severn River, however, contains more red carbonate than correlative sediment on Winisk River. More contrast in major rock types is seen on Winisk River, where Severn Till is clearly intermediate between Paleozoic-rich Winisk Till and Proterozoic-rich Sachigo Till. Sachigo Till is distinguished by its high red carbonate content on Severn River and high Proterozoic content on Winisk River. Rocksand Till on Severn River contains slightly elevated values for Proterozoic rocks and consistently lower red carbonate values, relative to overlying till. Shagamu Till on Shagamu River contains as much as 13% red carbonate in the fine gravel.

Till samples obtained on Niskibi and Beaver rivers contain a fine gravel fraction which consists of higher proportions of Paleozoic clasts, including red carbonate, than

Table 2. Drift composition

		All units:			Winisk Till	Severn Till	Sachigo Till	Rocksand Till
Severn River		Min	Max	Mean	Mean	Mean	Mean	Mean
n=		73			0	32	12	29
Fine	%Paleozoic	43.5	97.7	62 ± 10		64 ± 7	64 ± 9	59 ± 13
gravel	%Archean	1.1	17.0	10 ± 3		11 ± 2	9 ± 2	10 ± 3
lithology;	%Proterozoic	1.2	46.8	28 ± 10		25 ± 7	27 ± 8	31 ± 12
weight %	%Red Carbonate	0.0	11.3	1.8 ± 2.2		1.8 ± 1.5	5.0 ± 3.1	0.5 ± 0.8
n=		73			0	32	12	29
<0.063 mm	%Calcite	15.0	40.0	22 ± 4		23 ± 3	22 ± 2	22 ± 5
Chittick	%Dolomite	6.6	20.6	15 ± 2		15 ± 2	13 ± 1	14 ± 2
carbonate;	%Carbonate	25.2	52.2	37 ± 4		38 ± 4	36 ± 2	36 ± 5
weight %	C/D Ratio	1.0	3.3	1.6 ± 0.4		1.5 ± 0.3	1.7 ± 0.2	1.6 ± 0.5
n=		73			0	32	12	29
<2 mm	%Sand	9.1	37.4	29 ± 6		29 ± 6	27 ± 3	29 ± 6
texture;	%Silt	23.2	56.4	43 ± 5		45 ± 4	43 ± 2	40 ± 5
weight %	%Clay	13.3	67.8	29 ± 8		26 ± 6	30 ± 4	31 ± 10
Winisk River								
n=		56			23	25	8	0
Fine	%Paleozoic	35.1	79.9	67 ± 11	73 ± 3	67 ± 9	51 ± 15	
gravel	%Archean	4.9	16.5	10 ± 3	10 ± 3	10 ± 3	11 ± 2	
lithology;	%Proterozoic	9.7	53.6	23 ± 12	16 ± 3	24 ± 10	38 ± 17	
weight %	%Red Carbonate	0.0	6.0	1.3 ± 1.5	2.4 ± 1.7	0.5 ± 0.6	0.4 ± 0.6	
n=		38			17	16	5	0
<0.063 mm	%Calcite	14.2	32.7	23 ± 4	24 ± 2	23 ± 4	19 ± 2	
Chittick	%Dolomite	6.8	19.8	13 ± 3	15 ± 3	12 ± 2	11 ± 3	
carbonate;	%Carbonate	21.9	45.0	36 ± 5	39 ± 3	36 ± 4	30 ± 5	
weight %	C/D Ratio	1.0	3.2	1.9 ± 0.5	1.7 ± 0.4	2.0 ± 0.5	1.9 ± 0.6	
n=		35			16	14	5	0
<2 mm	%Sand	5.3	35.5	26 ± 5	27 ± 4	25 ± 7	28 ± 3	
texture;	%Silt	20.1	48.3	42 ± 5	44 ± 3	40 ± 6	40 ± 1	
weight %	%Clay	20.0	74.7	32 ± 9	29 ± 5	35 ± 13	33 ± 3	

rivers to the south and east. In this area, red carbonate contents of 10% and Paleozoic contents of 80% are typical. These observations are compatible with the location of the sites farther from the source for Proterozoic rocks and closer to the source for red carbonates. An occurrence of red diamict near water level on Niskibi River is correlated to Shagamu Till.

Samples from Sachigo River contain about 2% red carbonate in the fine gravel fraction and a total of about 60% Paleozoic. Hence this is a composition similar to the adjacent Severn River. Similar values, with Paleozoic values elevated to about 65%, were obtained on Fawn and Shagamu rivers.

Warman (1987), on the basis of samples from Severn River, found a mean concentration of 19 forams per 100 grams of the <2 mm fraction in Severn Till, 12 forams per 100 g in Sachigo Till, and 7 forams per 100 g in Rocksand Till. Hence the upper tills appear to be derived to a greater degree from reworked marine sediments. This difference was also apparent in the number of marine pelecypod fragments obtained from the tills (Wyatt, 1989).

Synthesis

Data obtained at sites on Severn, Winisk, Fawn, and Shagamu rivers indicate a multiple till sequence with varying ice flow directions (Fig. 29). The uppermost drift unit, Winisk Till, was deposited by generally southward ice flow on Fawn and Winisk rivers and is divisible from underlying sediments in most cases at a striated boulder pavement and a sharp brown over grey colour change. Severn Till, deposited by southwestward ice flow underlies Winisk Till on the Fawn and Winisk but it is the uppermost unit on Severn River. Severn Till is clearly defined on Severn River, but a lower contact is only tentatively identified at two sites on Winisk River. Sachigo Till is identified at two sites on the Severn on the basis of a distinctive red down to grey transition correlated to red carbonate content. Westward ice flow tentatively indicated on Severn River is correlated to a well developed boulder pavement with east-west striations on Shagamu River. Red carbonates indicate southeastward ice flow for upper Sachigo Till. Rocksand Till occurs as a Proterozoic-rich and red carbonate-poor till below Sachigo or Severn Till at four sites on Severn River. Fabrics at all four sites are oriented northwest-southeast. Elevated Proterozoic content implies generally westward rather than eastward ice flow. This west-northwestward ice flow direction parallels striations at Big Trout Lake (Tyrrell, 1913, 1914; Prest, 1963; Prest et al., 1968). Red carbonate rich Shagamu Till is assigned to a pre-Rocksand Till southeastward ice flow event on the basis of its composition.

Correlation

Sections located across the 1200 km expanse of Hudson Bay Lowland reveal a generally similar lithostratigraphy, but unambiguous section to section correlations are not readily obtained. McDonald (1969) concluded that two tills overlie the Missinaibi Formation throughout the lowland. Skinner (1973) and Nielsen et al. (1986) also determined the presence of two post-Missinaibi tills. In the Severn-Winisk area, however, three tills overlying nonglacial deposits have been found. An attempt at regional till correlation is here made on the basis of 1) stratigraphic position, 2) composition, and 3) ice flow direction inferred from striated boulder pavements at lower contacts, fluted exposed upper contacts, and pebble fabrics.

Winisk Till

A north-south belt of flutes extends from Fawn and Winisk rivers to Albany River to the south (Prest et al., 1968). Hence we infer that the upper till identified in the latter area by McDonald (1969) is a correlative of Winisk Till (Fig. 30). Dyke and Prest (1987) and Dredge and Cowan (1989) attributed surficial ice flow features in this area to many small ice marginal lobations, but their model cannot be reconciled with the presence of a single till unit under a simple pattern of parallel flutes. Furthermore, fabrics from the till and striations on faceted boulders at the lower contact consistently parallel the flutes. Hence Winisk Till and correlative deposits in the Attawapiskat and Albany River area are considered the deposit of a single, simple event.

Prest (1969) attributed these flutes to the western flank of an immense Cochrane Lobe. This scenario must be doubted, however, on the basis of 1) the improbability of ice flow parallel to the postulated Cochrane ice margin, 2) the substantial rise in elevation along the western margin of this belt, and 3) the presence of an esker that trends southward within the belt before it exits the belt and trends parallel to southwest flutes west of the belt (Prest et al., 1968). These three factors, however, can be accommodated by southward ice flow in a belt flanked by comparatively stagnant ice. A feature such as this would be referred to as an ice stream (Flint, 1971). Because evidence of earlier southwestward ice flow is present below Winisk Till and at the surface to the west, this ice stream must have formed late in glaciation. The converging northern portion of the fluted belt is confined by two topographic highs, one on the west in the upper Fawn River area and Sutton Ridge on the east. McInnes (1909) had partially recognized this scenario by suggesting that southeastward ice flow on the Winisk was caused by channeling by topography.

We find it difficult to conceive of a readvance being responsible for Winisk Till. A tongue of ice as narrow as this belt, especially considering the rise in topography from less than 50 m to more than 200 m elevation, is unlikely to have protruded beyond the ice margin without flanking support by slow or stagnant ice. Contemporaneous southward flow in the Fawn-Winisk area and southwestward flow on Severn River we consider unlikely. Southward flow on Fawn River would presumably have beheaded the former southwestward flow on the Severn. We therefore rule out a readvance of the ice front across northern Ontario. Winisk Till therefore was deposited without preceding deglaciation by the surging of an ice stream confined in the north by subglacial topography and on its flanks by stagnant ice.

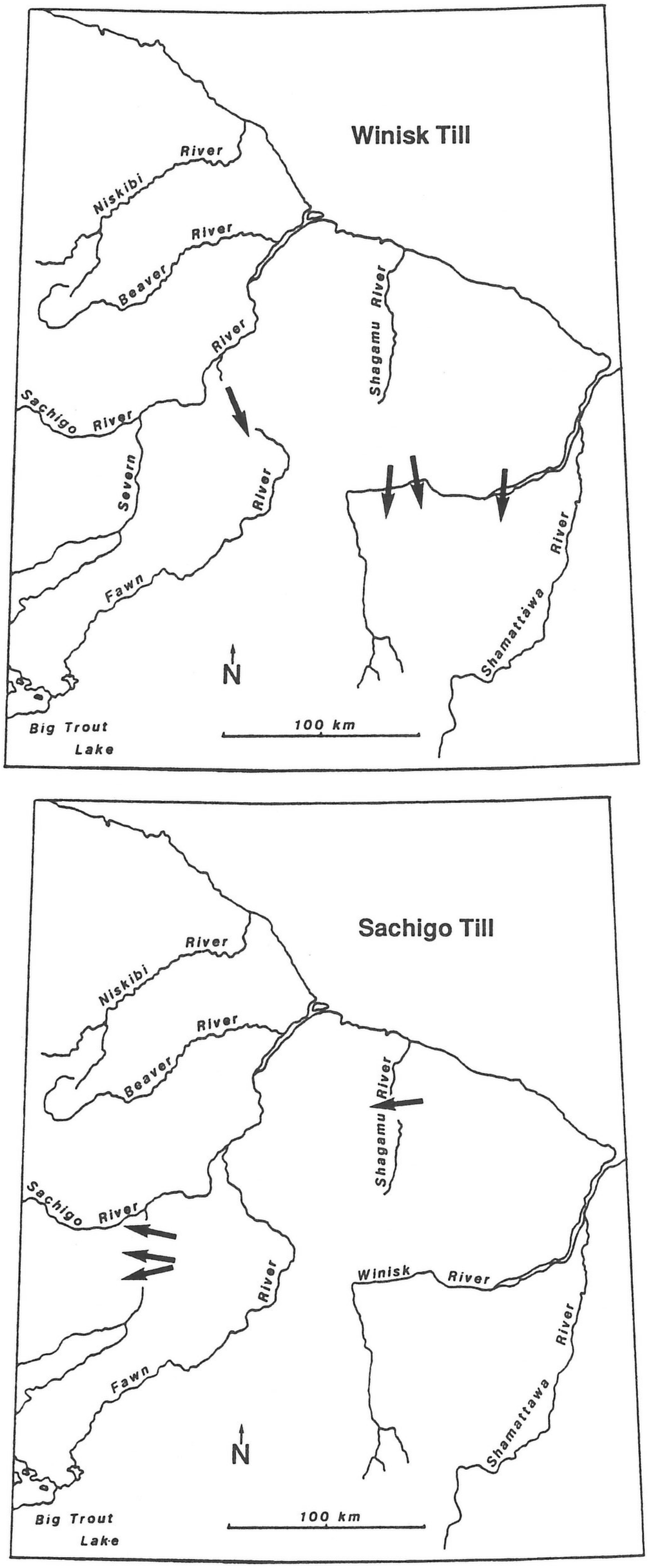


Figure 29. Ice flow direction data for till units.

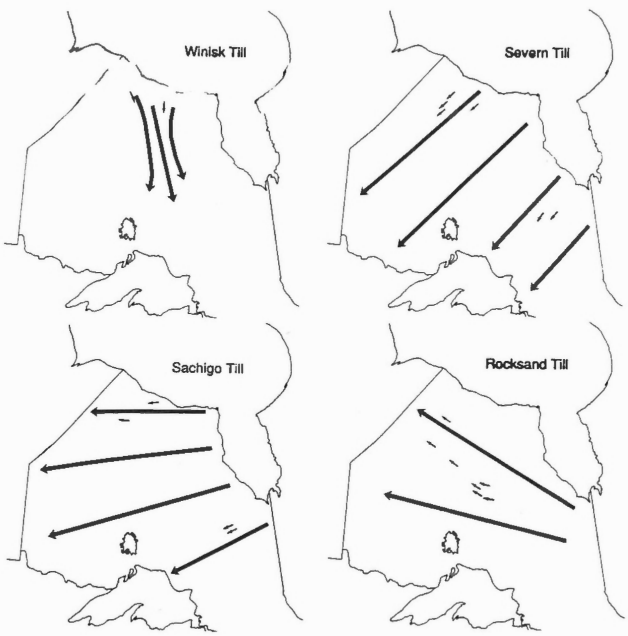


Figure 30. Regional ice flow history.

Severn Till

On Winisk and Fawn rivers, till underlying Winisk Till yields compositional and fabric evidence for southwestward ice flow (Fig. 30). Beyond the limits of Winisk Till, southwestward ice flow is indicated on the *Glacial Map of Canada* (Prest et al., 1968) for the entire Hudson Bay Lowland. At sites in the Severn River area pebble fabrics in Severn Till, composition, and striated boulder pavements at the lower contact of the till indicate that southwestward ice flow was maintained throughout deposition of this unit.

In Manitoba, southwestward ice flow was reported for the uppermost unit, Sky Pilot Till, on Nelson River by Nielsen et al. (1986). On Gods River, the uppermost till unit was defined by Netterville (1974) and Klassen (1986) on the basis of its brown colour and was attributed to southwestward ice flow. This till has a transitional contact with underlying grey till. A similar sequence on Severn River is here considered one till. Fabric in this grey till on Gods River has two modes, south-southwest and west-northwest (Netterville, 1974, p. 9). Netterville chose to attribute this till to flow from the west-northwest, but on the basis of correlation with Nelson and Severn rivers and as was acknowledged by Klassen (1986), southwestward flow is considered more likely. Hence Severn Till of the Severn-Winisk area is correlated with the upper two units of the Gods River sequence (Netterville, 1974; Klassen, 1986) and with Sky Pilot Till of Nelson River (Nielsen et al., 1986).

On the basis of stratigraphic position and dominant ice flow direction (Fig. 30), Severn Till is correlated to Kipling Till of the Moose River basin sequence (Skinner, 1973). Hence Kipling Till is considered the principal Late Wisconsinan deposit of the Moose River basin and not a Cochrane equivalent. Southwestward ice flow was also recorded as the dominant regional ice flow on the shield south of the Moose River basin, preceding locally significant late glacial south-southeastward flow (Veillette, 1986).

Regionally parallel southwestward ice flow recorded across the entire Hudson Bay Lowland indicates an ice divide in the form of an elongate ridge. Lack of ice flow from Hudson Bay into Keewatin or Quebec (Shilts, 1980) indicates this ridge must have been a saddle connecting domes in Keewatin and Quebec (Dyke and Prest, 1987).

Sachigo Till

Correlation of Sachigo Till on the basis of stratigraphic position to Long Spruce Till on Nelson River is supported by high concentrations of Proterozoic greywacke erratics in the latter unit (Nielsen et al., 1986). Till overlying the Gods River sediments is similarly positioned, but Netterville (1974) and Klassen (1986) inferred southward flow. An east-west fabric mode in this till (Netterville, 1974, his fig. 3) was only slightly subordinate to the north-south mode. Their observation may correlate, however, with probable southeastward ice flow, which may have been responsible for red carbonate erratics in upper Sachigo Till.

Correlation by stratigraphic position to the Adam Till of the Moose River basin is supported by the dominantly west-southwestward ice flow determined for this unit by Skinner (1973, his fig. 16). West-southwestward ice flow is also recorded as a rarely observed old event in the striation record on the shield south of the Moose River basin (Veillette, 1986).

Correlation of these observations across the lowland indicates radiation of ice flow from westward in the north to west-southwestward in the south (Fig. 30). In every case, till here attributed to westward flow underlies till revealing evidence of southwestward flow.

Rocksand Till

The Amery Till on Nelson River (Nielsen et al., 1986) is potentially correlative with Rocksand Till on the basis of stratigraphic position. This unit yielded west-northwest fabric at the Henday section, but evidence for southwestward ice flow was obtained from apparently correlative till by Nielsen et al. (1986).

The lowest till of the Gods River sequence, which underlies fossiliferous sediments, is correlative with Rocksand Till on the basis of stratigraphic position. Bimodal fabric from this till was attributed to southwestward ice flow by Netterville (1974) and Klassen (1986).

In the Moose River basin, no till is obviously correlative, but Skinner (1973) did obtain evidence for west-northwest ice flow from striated boulders in till which he correlated to Kipling on the basis of stratigraphic position. These data were obtained on Soweska River just upstream from Missinaibi River (his sites 39, 70, and 71) and on Friday Creek (sites 15 and 16). Striations oriented north of west have been reported for the adjacent shield by Veillette and Pomares (1991).

Shagamu Till

Underlying the Amery Till in Manitoba is the Sundance Till (Nielsen et al., 1986). This unit was deposited by Keewatin-derived southeastward ice flow. This flow could conceivably be represented by the reddish-brown Shagamu Till of Shagamu River and by the second pre-Missinaibi till at section 24M on Missinaibi River, where Skinner (1973, p. 8, his fig. 2B) found evidence for southeastward flow. Southeastward flow predating southwestward flow was also reported for Quebec by Bouchard and Martineau (1985). Correlation of these occurrences would, at this point, be highly speculative.

Synthesis

Five episodes of till sedimentation are recognized for the Severn-Winisk region. These events appear to correlate to sediments elsewhere in the lowland. The youngest event, southward ice flow (Fig. 30), deposited Winisk Till in a belt extending from the Fawn-Winisk area to the Attawapiskat-Albany area in the south. Southwestward flow predates southward flow in Ontario and its deposits, including Severn Till, Sky Pilot Till in Manitoba, and Kipling Till in the Moose River basin, are present across the lowland. This correlation precludes equivalence of Kipling Till and Cochrane Till. Slightly radiating westward flow deposited Sachigo Till, Long Spruce Till in Manitoba, and Adam Till in the Moose River basin. Red carbonate erratics provide evidence for southeastward ice flow for upper Sachigo Till. West-northwestward glacial ice flow which is recorded by striations and roches moutonées in northern Ontario deposited Proterozoic-rich and red carbonate-poor Rocksand Till on the upper Severn River. Rocksand Till probably correlates with Amery Till in Manitoba and equivalents may be present in the Moose River basin. Shagamu Till and Sundance Till in Manitoba record an episode of southeastward ice flow.

PRE-HOLOCENE NONGLACIAL STRATIGRAPHY

The Quaternary stratigraphic sequences exposed at sites across Hudson Bay Lowland are dominated by thick massive diamicts interpreted as tills. Whereas the tills by far dominate in terms of volume, scattered occurrences of thin nonglacial sediments underlying till are equal in stratigraphic significance. These sediments record sequences of events that occurred during episodes of deglaciation. Best known is the Missinaibi Formation of the Moose River basin, which records a progression from marine to fluvial, subaerial, and finally glaciolacustrine environments (Skinner, 1973). Several occurrences of similar deposits were encountered in the Severn-Winisk area.

Occurrences

Sorted sediments underlying till are recognized as being nonglacial in origin based on the presence of in situ organic material or paleocurrents in the same sense as present fluvial trends, or both. Such occurrences are present in the study area at sites on Fawn, Severn (Fig. 31), and Beaver rivers. The clustering of sites in this area may relate in general to deeper exposure of the stratigraphy. The thickness of exposed sediments in this area is greater than, for example, on Winisk River.

Fawn River sites

Sections on the lower Fawn River were examined by B.C. McDonald in 1967. Gravel (Fig. 32) underlying grey till was encountered at three sites, McDonald's sections MR-134, 135, and 141. Crossbedding in the gravel indicated northward paleocurrent, hence free northward drainage and an open Hudson Strait are indicated. These sediments were named the Fawn River gravel by Shilts (1982). Occurrences of these sediments were obscured by slumped sediment during field work for the present study.

At site MR-134, the 2.3 m thick gravel unit underlies 9 m of grey till and overlies a second grey till 4 m thick. Within the gravel, from depths 10.8-11.4 m, is a thin unit described as grey till. The sorted sediments were described as pebble gravel with a maximum clast size of 2.5 cm, with much admixed silt, oxidized to a bright buff orange, strongly calcareous, and lacking shell fragments. McDonald considered the gravel at this site to be a 9 m long lens, which did not necessarily separate two tills, although he considered the lower grey till to be slightly browner than overlying till.

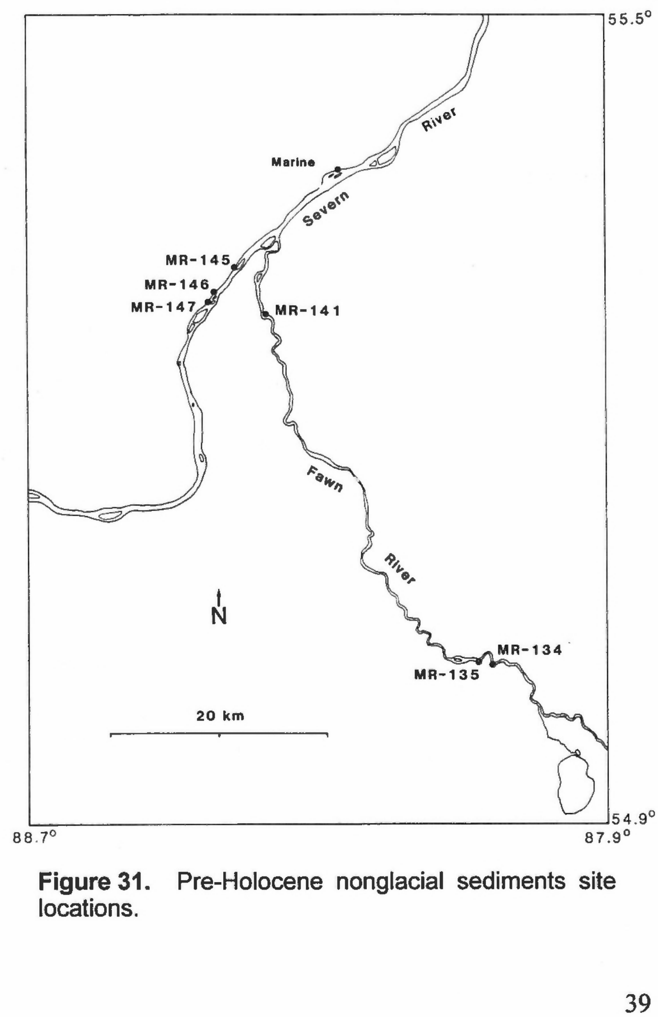


Figure 31. Pre-Holocene nonglacial sediments site locations.

Figure 32.

Fawn River gravel; shovel is 0.5 m long. (Photograph by B.C. McDonald, GSC 138333)

At site MR-135, McDonald found a sharp contact between a 1.8 m thick buff brown till and an underlying 5.8 m grey till, which is separated from a second grey till by a 1.5 m thick well current stratified gravel with northward paleocurrent directions. The gravel was described as being present in lenses on the order of 15 m long and 1.5-2.4 m thick at several places along the exposure but always at the same horizon. The lenses were described as being fairly continuous in places. The gravel lacked shells. Masses of gravel to 0.3 m in diameter were found isolated in the till. The colour and character of the gravel was reported to be the same as in site MR-134. McDonald considered the site to be similar to MR-134 except that the gravel was better exposed, the buff till capped the sequence, and he considered it more likely, after inspecting this site, that the gravel separates two till units.

At site MR-141, only the lower portion of the section was exposed. A 4.5 m thick exposure of grey till was reported by McDonald to be similar to exposures of grey till upriver. A 1.5 m thick gravel unit, below the till and overlying bedrock, was described as rusty orange, well stratified pebble gravel with interbedded sand. McDonald collected what he referred to as shell-like chips, which were common in the gravel. These fragments were later identified as shells of both marine and freshwater taxa (Andrews et al., 1983). At a site 200 m downstream, McDonald was unable during a brief search to find shell fragments in a 6 m thick exposure of the gravel.

The brown till described by McDonald is correlated with Winisk Till. The grey tills of these sections can not, however, be conclusively correlated. In the upper grey till, McDonald obtained measurements from striations on faceted clasts ranging from 215° to 225°, so correlation to Severn Till is reasonable. It is not clear, however, whether Sachigo Till is absent, present at the base of the upper grey till, or whether it is present below the Fawn River gravel. McDonald reported a single striation measurement of 308° in a grey till near river level at site MR-129. This orientation of ice flow is similar to that inferred for Rocksand Till.

Severn River sites

Organic bearing pre-Holocene nonglacial sediments were also located by McDonald on Severn River upstream from the confluence with the Fawn (Fig. 31). McDonald (1969, p. 84) reported clay, sandy silt with peat lenses, sand, and gravel below brown till at sites MR-145, 146, and 147.

At site MR-145, McDonald initially dismissed the clay as a Holocene deposit buried by slumped till. Inspection of sites MR-146 and 147 caused him to reconsider this conclusion.

At site MR-146, only the lower portion of a mostly slumped section was examined. Underlying 1.2 m of brown till, McDonald encountered 1.5 m of clay overlying 0.6 m of sand. He described the clay as blue-grey, unctuous, and generally massive, with the exception of a sandy layer with fine pebbles and some very fine laminations. The upper 0.9 m was found to be leached, although marl laminae 0.6 cm thick in the leached zone effervesced in HCl. The clay was thoroughly jointed throughout and stained with iron oxide along these joint planes. The underlying sand was described as buff to orange, medium grained, partly cemented with iron oxide, strongly calcareous, crudely stratified, and fairly well sorted. The remaining 3 m of section above river level was covered.

At site MR-147, the upper part of the section was slumped, but an excellent exposure of the nonglacial sequence was present at the base of the section. Underlying brown till, the 3 m nonglacial sequence extended to within 3 m of river level. McDonald described the upper 0.9 m of the sequence as thoroughly leached, laminated, blue unctuous clay. Secondary carbonate was precipitated along joints within 3 cm of the contact with overlying till. Joint planes were stained with iron oxide. Another 0.5 m of the clay was present below this material, but at this depth the clay is strongly calcareous. Underlying the clay is a 1.1 m silt unit. The uppermost 0.5 m of this unit was reported by McDonald to be a poorly sorted silt or clayey sand diamicton, possibly sand admixed with the overlying blue clay. This sediment was compact, lacking obvious lamination, and calcareous. The lower 0.6 m of this silt unit contained peaty lenses. A brownish grey hue was attributed by McDonald to disseminated organic matter. Peat bands were a maximum of 0.5 cm thick and 15 cm long. The largest piece of plant material found was 1 cm long. The main layer of plant debris was midway through the unit. Below the organic-rich silt, a sand unit 0.75 m thick was described as oxidized buff orange, well stratified in sedimentary units about 2.5 cm in thickness. The sand was calcareous but lacked shells. Finally, gravel 0.3 m thick and oxidized to a buff orange colour was encountered.

Nonglacial sediments at these sites underlie a multiple unit glacial sequence (Section 85HBL024). This sequence is here correlated with Severn Till on the basis of stratigraphic position and the nature of the sequence at nearby section 86HBL008. Red carbonate values for the till in this section (Fig. 22) are, however, sufficiently high to indicate that Sachigo Till may be present above the organic-bearing deposits. Fabric or other directional data were not collected at the site.

Downstream from the confluence of the Fawn with the Severn, at Limestone Rapids (Fig. 31), are in situ fossiliferous marine sediments underlying till (Forman et al., 1987; Wyatt, 1989). This deposit, at 50 m above sea level, consists of an upward-coarsening silty clay exceeding 1 m in thickness and underlying 18 m of till. Paired valves of *Hiatella arctica* and marine floral remains were recovered from the sediment. The site is located downstream from section 84HBL019. A boulder pavement in the till above the marine sediments indicates southwestward ice flow, hence it is inferred from this observation and from fabrics at section 84HBL019 (Fig. 16) that Severn Till overlies the marine sediment. It is unknown whether other till units overlie this sediment.

Beaver River site

On Beaver River, a tributary of the Severn, (section 85HBL005, Fig. 6) an in situ fibrous peat unit 0.35 m thick underlying till and overlying gravel was encountered. The till overlying the organics is a stratified brown diamict sequence containing abundant red carbonate. Underlying the peat is a 1 m thick unit of horizontally stratified pebble gravel containing shell fragments. Although the peat occupies what appears to have been a channel, the thickness, lateral extent, the lack of clastic sediments mixed with the organic material, and the massive appearance of the fibrous organics indicates that the material accumulated in situ.

Pollen in a 35 cm thick block of the peat was analyzed by R.J. Mott of GSC (Mott, 1988; Wyatt, 1989; Mott and DiLabio, 1990; Fig. 33). According to Mott (1988) the data show little vertical variation, implying that climate did not vary significantly during deposition of the peat. *Sphagnum* sp. spores dominate, but Ericaceae (heath), Gramineae (grass), and Cyperaceae (sedge) pollen values show that these taxa occurred on the wet bog surface as well. Low values for *Alnus* (alder) and *Salix* (willow) attest to the presence of these shrubs in suitable nearby locations. Small amounts of *Artemisia* (sage) and other herbaceous pollen taxa indicate that open, drier upland areas were not locally abundant. *Picea* (spruce) pollen, which ranges between 40 and 50% of the pollen sum, indicates that spruce trees were abundant in the area and probably covered somewhat drier uplands in the region; they may have been present on the bog surface as well. Other tree taxa represented include *Pinus* (pine) at about 20%, *Betula* (birch) at 10% or less, and minor amounts of other tree taxa. These values indicate that pine, if present at all, and birch trees were sparsely represented. According to Mott (1988), northern boreal to forest tundra conditions, with climate as warm or warmer than present, are suggested by the data. The pollen data from the Beaver River site are similar to those obtained from other buried organic deposits in Hudson Bay Lowland (Terasmae and Hughes, 1960; Skinner, 1973; Netterville, 1974; Nielsen et al., 1986; Mott and DiLabio, 1990).

Plant macrofossils in the peat sample were rare and poorly preserved (Matthews, 1988a). Included, however, are macrofossils of the coniferous trees *Picea* (spruce) and *Larix* (larch) (Table 3). This determination supports the presence of trees near the site and hence reduces the likelihood of the spruce-dominated pollen spectrum being the product of long-distance airborne transport. The fossils were considered by Matthews (1988a) to be typical of poorly drained areas within a boreal woodland made up of both spruce and larch.

The small peat sample collected at the Beaver River site contained few insect remains (Table 3). Presence of the bark beetle *Scolytus* sp. supports plant macrofossil evidence that trees probably were growing at the site. Because the site is now near treeline, both plant and insect macrofossils therefore indicate that climate at the time of deposition was probably no colder than at present. The data cannot, however, indicate whether or not climate was warmer than at present. The inferred paleoenvironment has modern analogues at present which extend south from the site into areas with higher temperatures.

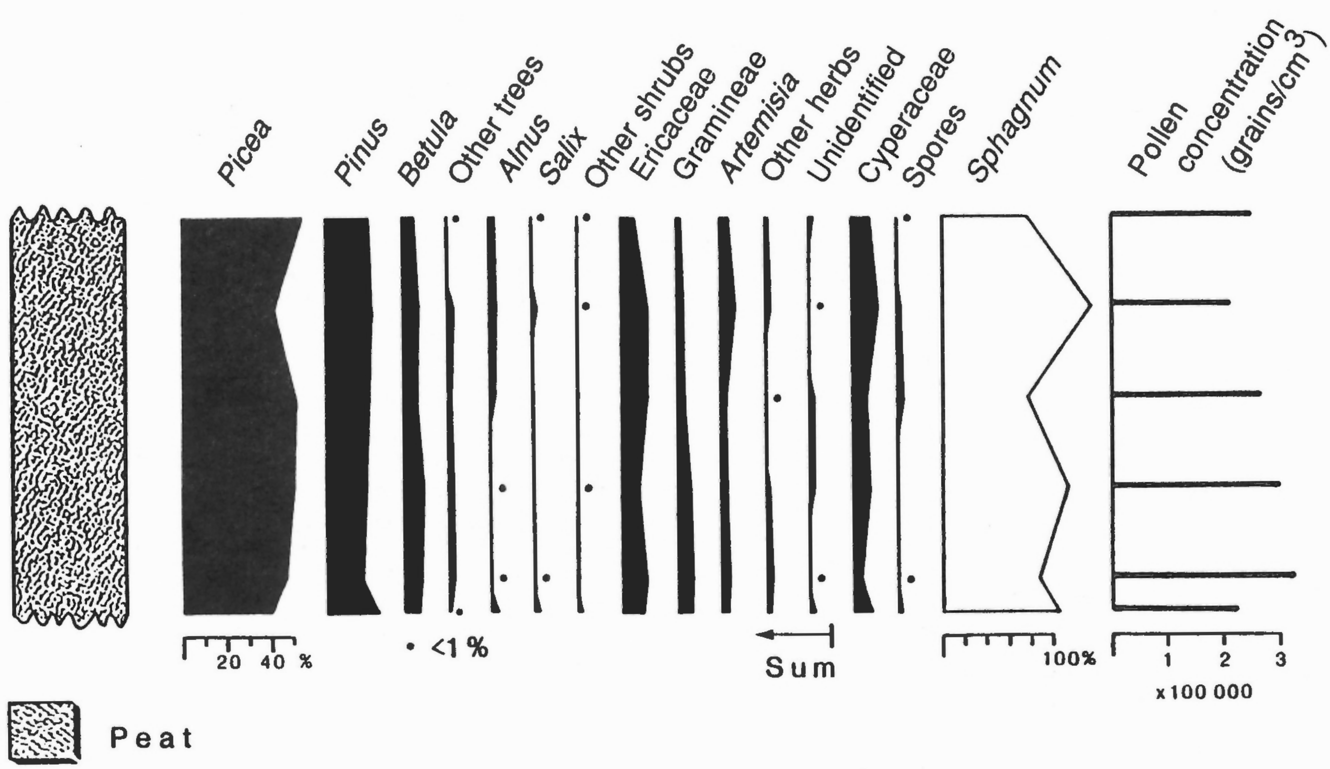


Figure 33. Pollen data from peat on Beaver River.

Synthesis

Occurrences of nonglacial sediments underlying till in the study area provide a record of at least one pre-Holocene nonglacial episode. In the absence of evidence for multiple units, the sediments are named the Fawn River sediments, on the basis of the well known term Fawn River gravel which was introduced by Shilts (1982) and Andrews et al. (1983). A type section at MR-147 on Severn River is proposed. Till underlying the Fawn River gravel indicates that at least this site represents an episode postdating the first Pleistocene glaciation of the area. Reworked shells in the gravel on Fawn and Beaver Rivers indicate marine inundation prior to fluvial sedimentation. The Fawn River sediments contain the remains of species that are present in the area today. Paleoecological inferences from the Beaver River peat indicate climate similar to present. Northward paleocurrent indicators in the Fawn River gravel indicate free drainage to Hudson Bay. Hence these deposits represent at least one episode during the Pleistocene of interglacial or interstadial rank. Little more can be concluded without reference to regional correlation and geochronological data.

Using analogy with the Holocene and comparison to the Missinaibi Formation (Skinner, 1973), a sequence of events may be inferred for the Fawn River sediments. Upon deglaciation at the onset of a pre-Holocene interstadial or interglacial episode, the study area was isostatically depressed below sea level. Marine sediments at Limestone Rapids on Severn River record this interval and indicate conditions and biota similar to present marine conditions. Isostatic recovery led to emergence and initiation of fluvial erosion. Gravel deposits on Fawn and Beaver rivers contain marine shell fragments reworked from emerged marine sediments. Subaerial organic deposits began to accumulate. Plant and insect macro- and micro-fossils from peat over 0.35 m thick on Beaver River indicate conditions similar to the present. At the close of the nonglacial episode, glacial ice advanced, blocking drainage through Hudson Strait. A glacial lake was formed in front of the ice margin. Glaciolacustrine clay and other sediments on Severn River include organic material reworked from the inundated substrate. Leaching of carbonate from silt and clay at sites MR-146 and 147 may, however, indicate a more complex scenario. Finally, the nonglacial deposits were overridden by the advance of ice cover, which later culminated in Late Wisconsinan glaciation.

Correlation

Pre-Holocene nonglacial sediments occur at several sites across Hudson Bay Lowland (McDonald, 1969). The best known occurrences are the Missinaibi Formation of the Moose River basin, and, in northern Manitoba, the Nelson River sediments (Nielsen et al., 1986) and the Gods River sediments (Netterville, 1974; Klassen, 1986). The Kabinakagami sediments of an area west of the Moose River basin were introduced by Shilts (1982) and Andrews et al. (1983).

Table 3. Macrofossils from the Beaver River peat

A. Plant macrofossils (Matthews, 1988a).
Fungal Sclerotia
Bryophytes
Pinaceae - pine family
Larix sp.
Picea sp.
Cyperaceae - sedge family
Carex spp.
Ranunculaceae - crowfoot family
Ranunculus sp.
Rosaceae - rose family
Dryas integrifolia Vahl
Ericaceae - heath family
Andromeda polyfolia L.
Gentianaceae - gentian family
Menyanthes trifoliata L.
B. Arthropod fossils (Matthews, 1988b).
ARTHROPODA
INSECTA
COLEOPTERA - beetles
Carabidae - ground beetles
Dyschirius sp.
Pterostichus sp.
Staphylinidae - rove beetles
Olophrum sp.
Scolytidae - bark beetles
Scolytus sp.
DIPTERA - flies
HYMENOPTERA - wasps and ants
ARACHNIDA
Acari - mites and ticks
Oribatei - oribatid mites

Missinaibi Formation

According to Skinner (1973), the Missinaibi Formation occurs in five discrete areas of the Moose River basin. These sites are located on the upper Missinaibi River and its tributaries, Adam Creek, Abitibi River, Moose River Crossing, and Kwataboahegan River. Shilts and Wyatt (1988), however, have indicated that the Abitibi River site is younger than other sites. The sequence underlies Adam Till, here considered a correlative of Sachigo Till. The upper Missinaibi River sites expose glaciolacustrine sediments, peat, wood, and a weathering horizon. At Adam Creek, silty clay with wood fragments, gastropod shells, marine *Hiatella arctica* shells and fragments, marine foraminifera and ostracoda overlies oxidized gravel, silt, and clay and is overlain by 4 m of glaciolacustrine rhythmites (Skinner, 1973). The Moose River crossing section exposes a subtill sequence of sand, silt and clay with marine *Hiatella arctica* shell fragments overlain by up to 1.5 m of silt-clay rhythmites. Peat and wood fragments are found at the contact between these two units. Fossiliferous marine sediments, later studied by Shilts and Wyatt (1988), underlying till on the Abitibi River were first reported by Prest (1966). Foraminifera from the marine sediment, which are dominated by *Elphidium clavatum*, indicate deposition in cold, low salinity bottom water (Wagner, unpublished 1965 GSC report). The marine sediments underlie oxidized gravel with northward paleocurrent indicators, which is, in turn, overlain by one or more tills (Skinner, 1973). Sections on Kwataboahegan River, just downstream from the confluence with Mistuskwia River, expose subtill marine sediments (Bell, 1904; McDonald, 1969; Skinner, 1973). Pollen analysis of the Missinaibi Formation on Missinaibi, Pivabiska, Soweska, and Opasatika rivers and from the Moose River crossing section all yielded assemblages dominated by spruce and pine, similar to present conditions (Skinner, 1973; Mott and DiLabio, 1990).

The Missinaibi Formation thus strongly resembles the Fawn River sediments, with the exception of the occurrence of more sites, abundant wood, and thicker glaciolacustrine sediments in the Moose River basin. Correlation of overlying till units also favours equivalence of the two sequences. Skinner (1973), however, correlated all Missinaibi Formation sites to the Bell Sea, now known to be older than the Fawn River sediments. It is not known whether the Prest Sea site on Abitibi River is the only occurrence in the Moose River basin that correlates to the Fawn River sediments, or whether other Missinaibi Formation sites are correlative.

Kabinakagami sediments

The Kabinakagami sediments, named by Shilts (1982), outcrop at McDonald's sections MR-46, 47, and 48 on Kabinakagami River, a part of the Albany system located west of the Moose River basin. They underlie either a till with a brown through grey colour transition or two tills and overly grey till. The sediments consist of contorted and faulted laminated and crossbedded sand and silt. Paleocurrent indications are southeastward in sand. Underlying silt yielded a shell fragment.

At site MR-46, McDonald reported an 18 m sequence of sorted sediment underlying 10 m of till. The strongly calcareous till had a light grey buff colour in the uppermost 2.4 m, but below this the colour was consistently medium grey. The underlying sequence consists of sand and a 0.3 m thick silt unit at the base. The sand was described as being pinkish throughout, fairly well sorted, and medium to coarse grained. Crossbedding across entire 3.6-5.5 m horizontal sedimentation units dipped toward 140°. No organics except for minute pieces of coal or wood were observed. Faulting penetrating the lower part of the unit had a strike of 045° and a 65° southeastward dip. The underlying 0.3 m silt unit was described as dark grey, strongly calcareous, compact, and lacking pebbles. Primary lamination in the sediment is highly contorted. A sample from this sediment later yielded a shell fragment (Andrews et al., 1983).

Site MR-47, according to McDonald, is capped by 1.2 m of sand, silt, and clay and a 1.2 m unit described as compact silt till. Half of this sediment consists of clasts, 95% of which are unconsolidated silt. The underlying 4.5 m till unit was described as grey, sandy, and calcareous. At the lower contact of this till, a 1.2 m transition zone included intermixed grey till and strongly contorted buff sand. Below the transition is 3 m of sand described as buff in colour in its upper 2.4 m and grey in the lower 0.6 m, fine to medium grained, and strongly calcareous. Lamination in the sediment is highly contorted. No organics were observed. Below these sediments is 12 m of section, the upper 4.5 m of which exposes strongly calcareous, grey, sandy till.

At site MR-48, a 12 m sequence of grey till includes, from 6.1 to 7.6 m depth, a zone of contorted laminae of grey silt and buff sand mixed with the grey till. Till above the gradational zone is buff grey.

Hence the Kabinakagami sediments lack conclusive indications of subaerial exposure. Southeastward paleocurrents imply glaciofluvial sedimentation. The single shell analyzed by Shilts (1982) and Andrews et al. (1983) may have been reworked. The sediments may correlate to the proglacial or possibly subglacial Friday Creek sediments of the Moose River basin (Skinner, 1973). Equivalence with the Fawn River sediments is therefore highly unlikely.

Gods River sediments

The Gods River sediments (Netterville, 1974; Klassen, 1986; Dredge et al., 1990) consist of silt overlying wood and peat and, at the base of the sequence, sand and gravel. Apparently correlative sediments, which possibly include a basal marine unit, occur on Hayes River (McDonald, 1969, p. 85), Echoing River, and Stupart River (Dredge et al., 1990).

Preliminary analysis of beetles in the Gods River sediments was presented by Netterville (1974). More thorough analysis by Dredge et al. (1990) indicated the presence of bark beetles. Netterville (1974) carried out pollen analysis on a 4 m thick gyttja sequence within the Gods River sediments (Klassen, 1986; Dredge et al., 1990). The data were divisible into three zones based on shifts in tree pollen, primarily changes in *Picea* (spruce). The lower zone was characterized by low but increasing values for spruce and strong representation of *Sphagnum* and Cyperaceae, thus indicating a climate similar to the present tundra regions of northeastern Manitoba and southern Keewatin. The assemblage differed from these tundra sites in their higher content of *Betula* (birch), *Alnus* (alder), and fern spores. The overlying middle zone contains higher values for tree pollen, including a marked inflection in the curves for spruce. This change was interpreted by Netterville as the northward passage of the treeline and establishment of a forest-tundra environment similar to present. The upper pollen zone resembles the lower zone, but shows an upward decrease in spruce and other tree pollen. Hence a cooling climate and southward migration of the treeline were inferred.

The Gods River sediments resemble the Fawn River sediments. Equivalence is also supported by correlation of both overlying and underlying tills. The Gods River sequence overlies till here correlated to Rocksand Till and rests below till which is here correlated to Sachigo Till of the Severn-Winisk area. Further support for correlation is provided by the remains of bark beetles in both sequences.

Nelson River sediments

The nonglacial Nelson River sediments, described by Nielsen et al. (1986), Dredge et al. (1990), and Berger and Nielsen (1990), outcrop on Nelson River in northeastern Manitoba. Total thickness ranges from 2 to 3 m and sediments include gravel, thinly bedded sand, silt, and clay with dropstones at some exposures. Organic material 20 cm thick and composed of woody compressed peat outcrops at two sections. Nelson River sediments underlie Long Spruce till and overlie Amery Till. Beetle remains indicate that the Nelson River sediments were deposited north of the treeline under conditions more severe than those found in the area today. Several taxa now occupying tundra were encountered, whereas taxa characteristic of the boreal forest, such as bark beetles, were absent. Analogous present conditions were suggested to be Eskimo Point, District of Keewatin (Nielsen et al., 1986) or Churchill, Manitoba (Dredge et al., 1990). Beetles from the Limestone section may indicate an open ground assemblage marginally south of the treeline (Dredge et al., 1990). In contrast, pollen from the sediments yielded dominant spruce and pine, suggesting conditions not substantially different from today. A tundra pollen assemblage was recovered from a separate unit at the Sundance section. A woolly mammoth molar found on a bar in Limestone River may have been derived from the Nelson River sediments (Nielsen et al., 1988).

Stratigraphic context, the lithologic sequence, and pollen data support correlation of the Nelson River sediments to the Fawn River sediments. Beetle evidence for a paleoenvironment north of but near treeline contrasts, however, with Severn-Winisk area data. Specifically, the absence of bark beetles and the abundance of the rove beetle *Stenus* sp. in the Nelson River sediments differs from both the Fawn River as well as the Gods River sediments.

Synthesis

Similarity of sequences and context with respect to tills indicates the probable equivalence of Nelson River, Gods River, Fawn River, and Missinaibi Formation sediments. Skinner (1973), however, correlated the Missinaibi Formation to the Bell Sea, which implies an age predating Rocksand Till. The deposits are in every area, however, incomplete, fragmentary records so conclusive comparisons of aspects of the sequences can not be made. Conclusive paleoecological differences have not been recognized, perhaps because of equivalent age or alternatively because of the lack of sensitivity of the northern boreal forest to shifts in climate.

GEOCHRONOLOGY

Besides offering information that may be used in local stratigraphic correlation, geochronological data enable the placement of events into a global chronostratigraphic context. Pre-Holocene nonglacial events in the area may or may be within the reach of radiocarbon dating. Application of the thermoluminescence method has, however, offered useful preliminary data. Amino acid data from marine bivalve shells have provided extremely valuable relative age data which have enabled the placement of marine sediments and till units into a relative time scale, but the data are of limited value in absolute dating.

Radiocarbon

Within the study area, radiocarbon dates from pre-Holocene organics have been obtained at two sites (Table 4). McDonald (1969) obtained an age of >41 000 BP (GSC-1011) for peat lenses in Fawn River sediments on Severn River at MR-147. A finite date of 37 040 BP (WAT-1378) was obtained from the Beaver River peat, but subsequent analyses of the same material yielded infinite ages of >38 000 (GSC-4146), >43 000 (GSC-4154), and >51 000 BP (GSC-4423) (Wyatt, 1989).

Radiocarbon dates have been obtained from organic material underlying till at several other sites across Hudson Bay Lowland (Table 4). Of 30 determinations, 26 have failed to yield counts above background. Marine shells from marine sediments on Abitibi River (Prest Sea) yielded finite dates (Andrews, 1987), but shell material is known for its tendency to acquire young carbon (e.g., Miller, 1985). Skinner (1973), for example, obtained an age of 38 200 BP (GSC-1475) from an unleached shell sample. Following acid treatment to remove the outer portion of the shells, the same collection yielded an infinite date. Hence no pre-Holocene organic material in Hudson Bay Lowland has yet produced a convincing finite age determination.

Beukens (1990) has indicated, however, that infinite GSC dates may require reevaluation. A greater than date indicates that a radiocarbon count is not statistically distinguishable from background. Background is tested by dating pre-Quaternary coal and marble. The recent availability of accelerator mass spectrometry for radiocarbon analysis has

Table 4. Radiocarbon dates from Hudson Bay Lowland pre-Holocene organic material

^{14}C age (years BP)	Lab. no.	Material	River	Reference
33 600	Arizona	shell	Abitibi	Andrews, 1987
37 040	WAT-1378	peat	Beaver	Wyatt, 1989
38 200	GSC-1475	outer shell	Kwataboahegan	Skinner, 1973
>37 000	GSC-1475	inner shell	Kwataboahegan	Skinner, 1973
40 040	TO-125	shell	Abitibi	Andrews, 1987
>19 000	GSC-1535	shell	Abitibi	Skinner, 1973
>29 630	Y-269		Missinaibi	McDonald, 1971
>30 840	Y-270		Missinaibi	McDonald, 1971
>32 000	GSC-3074	wood	Churchill	Dredge et al., 1990
>35 800	GSC-83	wood	Attawapiskat	Dyck and Fyles, 1963
>37 000	GSC-892	wood	Echoing	McDonald, 1969
>37 000	GSC-2481	wood	Stupart	Dredge et al., 1990
>38 000	GSC-4146	peat	Beaver	Wyatt, 1989
>38 000	W-241		Missinaibi	McDonald, 1971
>38 000	W-242		Missinaibi	McDonald, 1971
>41 000	GSC-1736	wood	Gods	Klassen, 1986
>41 000	GSC-1011	peat	Severn	McDonald, 1969
>42 000	Gro-1921	peat		McDonald, 1971
>42 000	Y-1165	peat	Harricana	Stuiver et al., 1963
>42 600	L-396B		Missinaibi	McDonald, 1971
>43 000	GSC-4154	peat	Beaver	Wyatt, 1989
>43 600	GSC-435	wood	Little Abitibi	Lowdon et al., 1967
>49 000	GSC-4420HP	wood	Nelson	Nielsen et al., 1988
>49 000	GSC-4471HP	wood	Gods	Dredge et al., 1990
>50 000	GSC-5071HP	wood	Missinaibi	Morgan, unpublished
>51 000	GSC-4423HP	peat	Beaver	Wyatt, 1989
>51 000	GSC-4444HP	wood	Echoing	Dredge et al., 1990
>53 000	Gro-1435	wood	Missinaibi	McDonald, 1971
>54 000	GSC-1185	peat		McDonald, 1971
>72 500	QL-197	wood	Missinaibi	Stuiver et al., 1978

made possible the determination of radiocarbon content of the background reference materials, so a distinction between background from the sample and preparation contamination in the conventional laboratory may now be made. Tests by Beukens (1990) indicate that the GSC background reference materials have ^{14}C concentrations equivalent to apparent ages of 42 and 45 ka. A GSC date of >50 ka therefore indicates a ^{14}C count not significantly higher (younger) than this age. It can be argued that wood or peat sampled in the field is likely to be contaminated to a degree similar to the pre-Quaternary reference materials. Hence a contaminated reference material is thus required to compensate for expected contamination in the material to be dated. This cautious approach involves assumptions regarding the degree of contamination of the sample and the reference, but it reduces the number of published finite dates resulting from contamination in the environment. The unsettling fact that remains, however, is that a 45 ka old wood sample with negligible contamination, if this is possible, would produce a date of >50 ka. A conservative approach would be to view all infinite age determinations as simply indicating an age of >40 ka.

Thermoluminescence

Thermoluminescence (TL) age determinations were carried out on samples of marine sediments underlying till on Severn River collected specifically for this purpose (Forman et al., 1987). Because the residual TL of a sediment retained at the time of deposition is a function of several aspects of the depositional environment, including subaerial exposure, transport distance, turbidity, and latitude, a sample of Holocene marine sediment was first analyzed. The purpose of this test was to determine an appropriate bleaching procedure to measure a residual TL level from which the TL measured on an unbleached sample is assumed to have begun accumulating. Use of a bleach procedure appropriate for loess yielded a TL age of 13 ka for a sediment known to have a radiocarbon age of about 6 ka. A modified bleaching procedure, which yielded an age of 5.3 ± 0.8 ka for the Holocene sample, was therefore developed. Application of this method yielded ages of 77 and 69 ka, or an average of 73 ± 10 ka for the subtill marine sediment from Severn River. The latter age was in part a function of a value of 30% subjectively chosen for the mean water content for the sediment since deposition. Assumption of much lower or higher water contents would result in age determinations between 65 and 90 ka. Use of a loess bleach, considered inappropriate for this sediment, on the subtill marine sediment would have resulted in an age of roughly 110 ka. We therefore conclude that the Severn River marine unit was deposited on isostatically depressed terrain following deglaciation of the area in late stage 5.

Berger and Nielsen (1990) conducted TL analyses on freshwater silt and silty clay from the Nelson River sediments in northern Manitoba. In contrast with the TL result obtained from Severn River, they obtained age estimates of 32-46 ka from four of five samples. The apparent contradiction with the Severn River result may be because of the age difference to be expected from marine and lacustrine sediments. Marine sediments would have been deposited during the retreat or the advance of the ice mass but are more likely to have been deposited early in the nonglacial episode prior to isostatic recovery. Lacustrine sediments could have been deposited either during ice retreat, hence underlying marine and subaerial deposits, or during the advance when drainage was blocked. Lacustrine sediments, such as those of the Nelson River sections that only underlie till, were likely deposited at the end of the nonglacial episode. An age difference between the Severn River marine sediments and the Nelson River lacustrine sediments sufficient to allow for isostatic recovery and deposition of peat is needed. Hence differing age estimates, about 75 ka for marine sedimentation and 40 ka for lacustrine sedimentation, are not contradictory. Pending confirmation of GSC infinite dates, a contradiction remains with the radiocarbon record, which offers no support for subaerial exposure of the area between 40 and 50 ka. A possible 40% underestimate of age by the TL method, as discussed by Berger and Nielsen (1990), could account for these discrepancies.

Acceptance of the TL age determinations by Berger and Nielsen (1990) would indicate the delay of glacial advance after late stage 5 deglaciation until midstage 3. This would refute the general assumption of probable ice cover during oxygen isotope stage 4.

Amino acid

The results of the first application of amino acid geochronology to Hudson Bay Lowland stratigraphy were summarized by Shilts (1982) and Andrews et al. (1983). Their data were derived from analysis of shells obtained from sites across the lowland by McDonald, Craig, and Gwyn during fieldwork for Operation Winisk in 1967 (McDonald, 1969) as well as by Skinner from the Moose River basin (Skinner, 1973). Andrews et al. (1983) obtained total aIle/Ile (Ha) ratios of 0.03 for early Holocene shells and values of 0.22 for shells of the same species obtained from Bell Sea marine sediments on Kwataboahegan River. Broken, transported shell fragments derived from tills yielded ratios that spanned the range between these two values, but clusters of intermediate values around 0.07 and 0.14 were apparent. The possibility that these clusters were products of differing thermal histories or laboratory procedures (Dyke, 1984) was dismissed by Andrews et al. (1984). The remaining possibility, that the intermediate clusters indicate pre-Holocene, post-Bell Sea marine conditions was favoured by Andrews et al. (1983, 1984).

Data from in situ shells

Wyatt (1989) obtained total aIle/Ile (Ha) ratios averaging 0.14 for the marine sediments on Severn River. This value matches the older of the two intermediate clusters identified by Andrews et al. (1983). Similar values have also been obtained from Prest Sea marine sediments on Abitibi River (Shilts and Wyatt, 1988; Wyatt, 1990). These values are clearly lower than those from the Bell Sea sediments on Kwataboahegan River (Fig. 34).

For the Bell Sea and Prest Sea to be of the same age, 125 ka for example, a temperature history for the Bell Sea 3°C higher than the other sites would be required. If the

Abitibi site is ignored, this scenario is reasonable based on present mean annual temperatures for the Moose River basin, -1°C, and the Severn River, -5°C. Most of the thermal history was controlled, however, by subglacial conditions. Furthermore, the Abitibi and Bell Sea sites are separated by only 75 km, and the Abitibi site is farther south. The Kwataboahegan River Bell Sea site rests at only about 3 m depth, compared to 15 m for the Abitibi site, but both deposits are below the depth of significant annual temperature fluctuation. Temperature history differences can not, therefore, explain the different values.

We therefore conclude that the Severn and Abitibi marine sediments, referred to as the Prest Sea by Shilts and Wyatt, 1988), are correlative. The Bell Sea is significantly older.

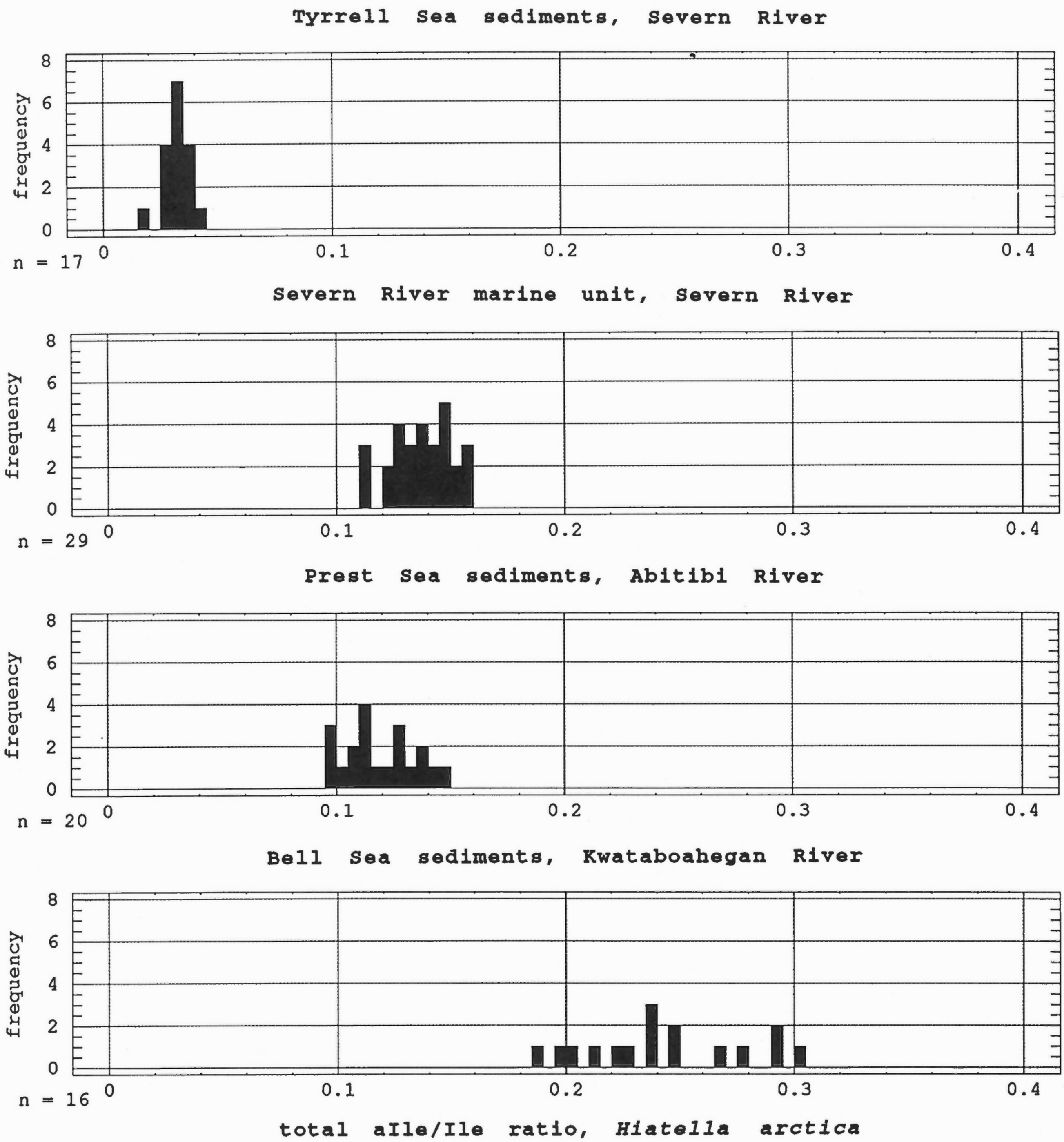


Figure 34. Amino acid data from in situ shells.

The Prest Sea marine sediments mark the retreat of a post-Bell Sea glaciation. The possibility that these sediments were deposited in front of advancing ice at the end of the Bell Sea episode is contradicted by several observations. In the Moose River basin, Skinner (1973) observed glaciolacustrine sediments overlying subaerial deposits of the Missinaibi Formation. In the Severn River area, the shells with Severn River marine unit ratios occur in fluvial gravel on Fawn and Beaver rivers peat, indicating isostatic recovery and subaerial exposure after the Prest Sea episode. Furthermore, lacustrine sediments overlie subaerial deposits on Severn River.

Absolute chronology

Calculation of absolute ages from amino acid ratios requires a knowledge of the thermodynamic parameters governing the reaction for the species in question. Values for the species *Mya truncata* have been obtained by Miller and Hare (1980) and Miller (1985). Isoleucine epimerization in this species proceeds at a rate which is about eight-tenths of the rate for *Hiatella arctica*, so ratios for the latter may be corrected for comparison with the former. Arrhenius parameters derived for *M. truncata*, reported by Miller (1985), are 28.1 kcal per mole for activation energy and 16.45 for the frequency factor. Total isoleucine epimerization ratio at time zero was reported to be 0.011.

Tentative absolute chronologies based on amino acid relative time scales have generally been developed by testing correlations to the oxygen isotope and global sea level records (e.g., Martinson et al., 1987; Bloom et al., 1974). Prior to the development of the present oxygen isotope/sea level paradigm, opinions regarding the age of the last interglacial differed from those of today. Prest (1970), for example, suggested that the Sangamonian extended from 100 000 to over 225 000 years ago. The last interglacial, or the last period of climate similar to the Holocene, is now widely believed to be coincident with oxygen isotope substage 5e, between 115 000 and 125 000 years ago (Martinson et al., 1987).

The tentative absolute chronology for the amino acid-based relative time scale assembled for Hudson Bay Lowland by Andrews et al. (1983) was based on the assumption that the Bell Sea sediments date to oxygen isotope substage 5e. A single value for effective diagenetic temperature (EDT) was then used to interpolate ages for lower ratios. Andrews et al. (1983) obtained a value for EDT of +0.6°C by assuming an age of 130 000 years for Bell Sea ratios of 0.22. A higher value of +2.4°C was obtained using a higher mean ratio, 0.243, based on recently acquired data, an age of 125 000 years, and updated Arrhenius parameters (Miller, 1985). Andrews et al. (1983) discussed what a reasonable value for EDT might be. The value obtained here is rather high on the basis of their discussion. Assignment of the Prest Sea to substage 5e and the Bell Sea to stage 7 gives a temperature of -0.08°C. The temperatures obtained from these two thermal history calculations are, however, within the range of reasonable values, given their sensitivity to the several inputs required. Andrews et al. (1983) acknowledged that a stage 7 age for the Bell Sea cannot be rejected outright. The lack of a convincing conclusion based on thermal history modeling leaves TL dating of Prest Sea sediments as the only avenue for favouring one chronology over the other. Hence a substage 5a age is assigned to the Prest Sea. By extrapolation, Bell Sea ratios, which average 0.243, are assigned to substage 5e.

Data from glacially transported shells

Compilation of amino acid data from individual till units allows placement of ice flow events relative to marine incursions recorded by marine sediments (Fig. 35). The data also indicate a significant degree of reworking of older deposits into younger tills.

Rocksand Till yielded sparse data that span a range of values similar to and slightly lower than those derived from Bell Sea sediments. Old shells could have been incorporated into any till unit younger than the Bell Sea, but the lack of any values younger than the Bell Sea range implies that Rocksand Till was deposited in post-Bell Sea, pre-Prest Sea time. The lack of Prest Sea ratios in Rocksand Till offers further evidence against the deposition of marine sediments in front of advancing Wisconsinan ice.

Sachigo Till yielded both Bell Sea and Prest Sea ratios (Fig. 35). These ratios suggest that this ice advance postdates the Prest Sea but that the older Bell Sea shells were also incorporated.

Severn Till yielded many more shell fragments than underlying till (Fig. 35). On Winisk River, this till contains numerous Prest Sea values as well as what might be called a late Bell Sea cluster around 0.18. On Severn River, Prest Sea and Bell Sea ratios are accompanied by an additional cluster around 0.07, equivalent to the lower of the two intermediate clusters reported by Andrews et al. (1983).

Winisk Till, which is primarily derived from offshore Hudson Bay, yielded values dominated by the 0.07 cluster (Fig. 35).

Values around 0.07 and 0.18 were obtained from shell fragments glacially transported from offshore Hudson Bay. Ratios around 0.07, for example, become progressively more abundant from Sachigo Till, derived primarily from mainland sediment sources, to Severn Till, derived in part from offshore sources, to Winisk Till, derived principally from offshore Hudson Bay. These clusters are interpreted as the younger and colder offshore equivalents of 0.14 and 0.22 values found in onshore deposits (Fig. 36). Prest Sea and Bell Sea sediments at sites now above sea level 1) date to the early part of nonglacial episode and hence are the oldest deposits of the episode, and 2) were subjected to warm subaerial conditions during the interstadial or interglacial, unlike offshore sediments.

The potential significance of onshore and offshore sources of shells was first discussed by Andrews et al. (1984). The difference in age between shells deposited well above present sea level immediately following deglaciation and the final marine sediments deposited below present sea level as Hudson Bay was closed by advancing ice may be as much as tens of thousands of years.

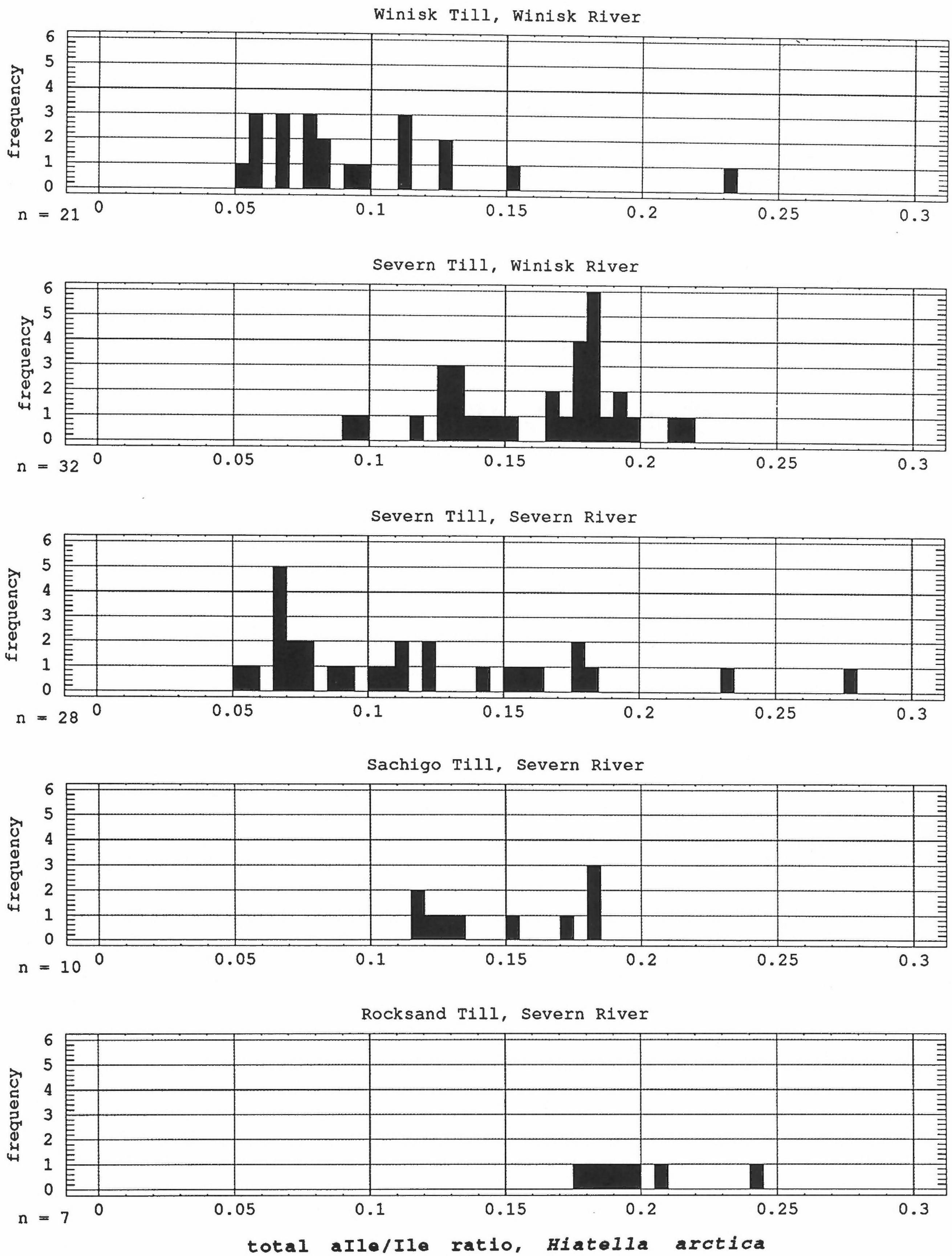


Figure 35. Amino acid data from transported shell fragments.

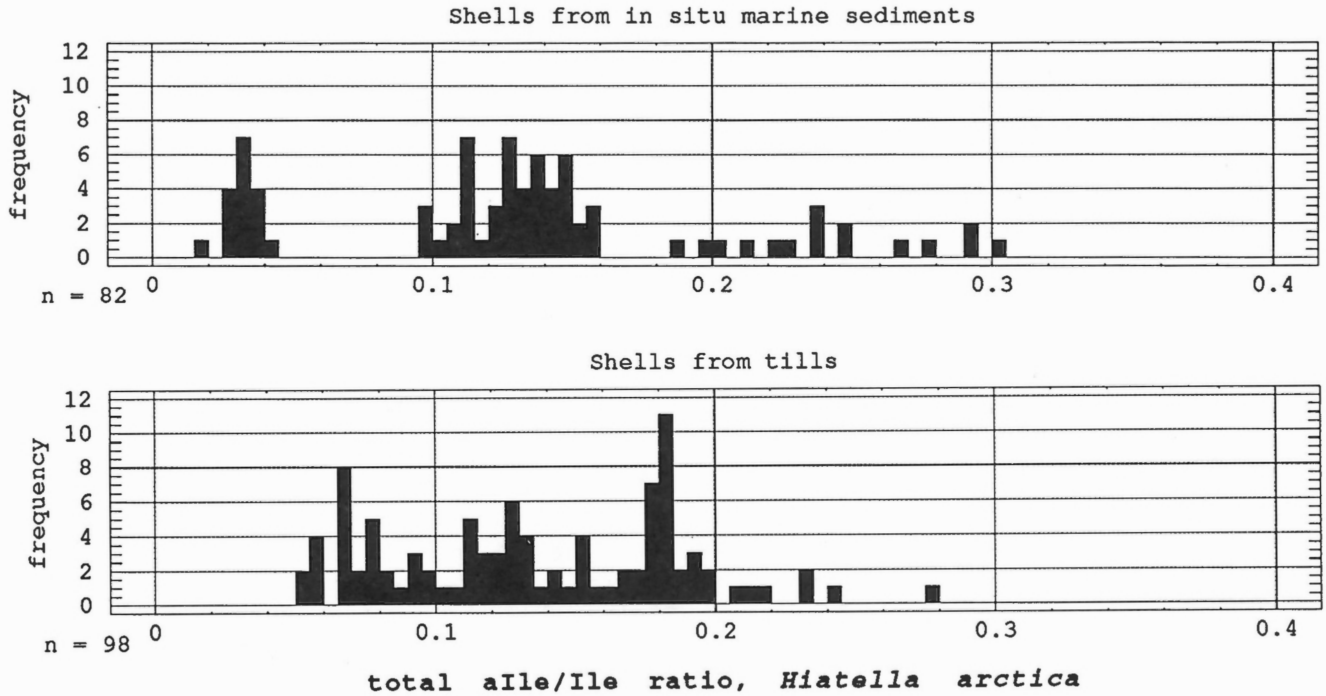


Figure 36. Comparison of data from in situ and transported shells.

Onshore and offshore shells would also have differing thermal histories. Mean annual temperature on land in the lowland ranges from 0 to -7°C, but subsurface temperature is several degrees higher (Brown, 1978; Harris, 1981). Shells about 7000 years old derived from Tyrrell Sea sediments give total aIle/Ile (Ha) ratios of about 0.033, indicating an EDT of 5.5°C. Water at the bottom of Hudson Bay now has a temperature of between 0 and -2°C (Pelletier, 1969; Prinsenberg, 1986). Hence onshore shells would have experienced a warm episode in their thermal histories, which was not experienced by their offshore counterparts. After glacial transport to a site above present sea level, deglaciation, and retreat of sea level, the offshore shells have only been exposed to a few thousand years of warm subaerial conditions.

The combination of age and thermal history offers an explanation for the additional clusters, which is more compatible with known stratigraphy than was the inference of additional glacial and deglacial events, whether by deglaciation of the area (Andrews et al., 1983) or a calving bay only in Hudson Bay (Dredge and Thorleifson, 1987).

Alternative chronology

If TL data are ignored, the Prest and Bell seas may be reassigned to substage 5e and stage 7, respectively. Rocksand Till would be assigned to stage 6 and continuous ice cover would be inferred for some time in stage 5 until the Holocene.

Synthesis

Radiocarbon data from pre-Holocene organics obtained in Hudson Bay Lowland imply that all such deposits are older than 40 000 years. Thermoluminescence data indicate an age of about 75 000 years for marine sediments underlying till on Severn River (Forman et al., 1987). Amino acid data indicate that Prest Sea marine sediments underlying till on Abitibi River are of a similar age, but Bell Sea sediments from Kwataboahegan River are older (Shilts and Wyatt, 1988; Wyatt, 1990). Amino acid data from shells in till (Wyatt, 1989) indicate that Rocksand Till postdates the Bell Sea but probably predates the Prest Sea. Late Bell Sea shells were encountered in Rocksand, Sachigo, and Severn Till. Sachigo and overlying tills yield Prest Sea ratios. Sachigo, Severn, and Winisk tills contain ratios attributed to late Prest Sea in numbers proportional to their degree of provenance in offshore Hudson Bay.

TL data from Nelson River glaciolacustrine sediments (Berger and Nielsen, 1990) indicate that ice cover which culminated in Late Wisconsinan glaciation might not have affected the area until after 40 ka. This age 1) would preclude stage 4 glaciation of the area, 2) has not been confirmed by radiocarbon analysis, and 3) would help to account for total aIle/Ile (Ha) ratios in till as low as 0.05, only slightly higher than Tyrrell Sea ratios of 0.03.

POSTGLACIAL GEOLOGY

McDonald (1969) reported thick postglacial sediments on the upper Fawn River, which he attributed to an influx of fresh water from the west. Elsewhere in the study area, glaciolacustrine sediments were not encountered, thus confirming that the residual glacial ice mass was in contact with seawater at the time of deglaciation.

Spillways in the Sachigo River area (Prest et al., 1968) may be related to the sediments observed by McDonald. Because the channels are located below marine limit, however, their origin must be attributed to 1) a preglacial origin, 2) subglacial origin, 3) scour by a large flood to depths lower than contemporaneous sea level, or 4) marine transgression. Transgression would have been highly unlikely in a context of rapid postglacial isostatic recovery. Eastward drainage of Lake Agassiz is a possible source of water for a major drainage.

Marine pelecypods were collected for paleoecological analysis from a site at Limestone Rapids on Severn River. The collection was examined by A. Aitken of McMaster University. Paired valves of the species *Mya truncata* dominated the collection. Also present were the species *Axinopsida orbiculata, Astarte crenata?, Hiatella arctica, Mytilus edulis, Mya pseudoarenaria, Clinocardium ciliatum, Macoma balthica*, and *Macoma calcarea*. According to Aitken (personal communication, 1987), most of these bivalves inhabit water depths of less than 15 m. Abundant *Mya truncata* along with fragments of *Mytilus edulis* and valves of *Macoma balthica* suggest an intertidal habitat. Most of the *Mya truncata* were found to be greater than 8 years old and many greater than 10 years old. Their small size, however, suggests estuarine conditions. The frequency of small specimens supports an in situ assemblage, although some reworking was indicated by fragmentation of some shells and incorporation of *Astarte* sp., which is generally found at depths greater than 50 m. Paired valves of *Mya truncata* collected from a depth of 2.0-2.3 m in laminated fine sand at this site, section 84HBL019 (= 86HBL009) yielded a date of 6100 ± 70 BP (GSC-4354). This site is located at about 60 m above sea level.

Retreat of sea level in the area was discussed by Craig (1969). Exposures of postglacial marine sediments are not plentiful at sites above about 100 m elevation, where tills and older sediments were examined in detail. Exposures of marine sediment are progressively more frequent at lower

Figure 37. Retrogressive flow slide in postglacial marine sediment, Severn River. (GSC 1991-263)

Table 5. Stratigraphy and correlation

Nelson River	Gods River	Severn-Winisk	Moose River	O18 Record	
Nielsen et al., 1986	Klassen, 1986	This report	Skinner, 1973; Shilts, 1982; Shilts and Wyatt, 1988	TL	Alternative
POSTGLACIAL	POSTGLACIAL	POSTGLACIAL	POSTGLACIAL	1	1
Subaerial	Subaerial	Subaerial	Subaerial		
Fluvial	Fluvial	Fluvial	Fluvial		
Marine	Marine	Marine	Marine		
Glaciolacustrine	Glaciolacustrine	Glaciolacustrine	Glaciolacustrine		
GLACIATION	GLACIATION	GLACIATION	GLACIATION		
		Winisk Till		2	2
Sky Pilot Till	Tills C & D	Severn Till	Kipling Till	2	2
	Twin Creeks sediments		Friday Creek sediments		
Long Spruce Till	Till B	Sachigo Till	Adam Till?	4, 3?	5
NELSON RIVER SEDIMENTS	GODS RIVER SEDIMENTS	FAWN RIVER SEDIMENTS	ABITIBI RIVER SEDIMENTS		
Lacustrine	Lacustrine	Lacustrine		4, 3?	5d
Subaerial	Subaerial	Subaerial			
Fluvial	Fluvial	Fluvial			
		Marine	Marine (Prest Sea)	5a	5e
GLACIATION	GLACIATION	GLACIATION	GLACIATION		
Amery Till	Till A	Rocksand Till	Adam Till?	5	6
			MISSINAIBI FORMATION		
			Lacustrine		
Sundance Soil			Subaerial		
			Fluvial		
			Marine (Bell Sea)	5e	7
GLACIATION					
Sundance Till		GLACIATION			
		Shagamu Till	Pre-Missinaibi Tills	6	8

elevations. Marine silt and clay in the area is vulnerable to slumping, including the formation of retrogressive flow slides (Fig. 37). Well developed shoreline features are present near the present coast.

CONCLUSIONS

Based on the stratigraphy and correlations (Table 5), we infer the following sequence of events for the area.

1. Pre-Bell Sea glaciation

The Bell Sea marine sediments are located well above present sea level on Kwataboahegan River of the Moose River basin (Skinner, 1973). The isostatic depression that enabled deposition of these sediments at this location is attributed to the weight of a preceding ice mass. Sediments predating the Bell Sea are poorly known. Shagamu Till, a red carbonate rich unit found at the base of sections on Shagamu and Niskibi rivers, may be a deposit of the pre-Bell Sea ice mass.

Sundance till of the Nelson River sequence (Nielsen et al., 1986), deposited by southeastward, Keewatin-derived ice flow, underlies Amery Till and a weathering horizon. This till therefore probably predates the Bell Sea. Lack of Keewatin erratics in Ontario indicates that this flow did not extend this far, although transport distance might not have been sufficient to deposit recognizable erratics in Ontario.

The second pre-Missinaibi till of the Moose River basin yielded evidence for southeastward ice flow (Skinner, 1973), but it may be excessively speculative to suggest correlation with Sundance and Shagamu tills on this basis alone. An old southeast ice flow trend is also known on the Quebec shield east and southeast of James Bay (Bouchard and Martineau, 1985; Veillette et al., 1989).

2. Bell Sea

Amino acid data indicate that the Bell Sea marine sediments on Kwataboahegan River (Skinner, 1973) were deposited prior to Prest Sea marine sediments that occur on Abitibi River, which in turn correlate with marine sediments on Severn River. Extrapolation from the TL-dated Severn River marine sediments implies correlation of the Bell Sea to substage 5e, which is generally referred to as the last interglacial. On the basis of a thorough stratigraphic analysis of sites in the Moose River basin, Skinner (1973) concluded that all nonglacial deposits underlying till in the Moose River basin correlate to the episode that began with the Bell Sea.

3. Wisconsinan glacial inception

It is here inferred that glaciation at the close of the last interglacial consisted of generally westward ice flow across northern Ontario. Glacial inception models such as those presented by Flint (1943), Ives (1957), and Vincent and Prest (1987) involving growth of an ice sheet in Quebec are therefore favoured.

The alternative of inception in Hudson Bay by freeze-down of an ice shelf (Denton and Hughes, 1981b) could only be reconciled with available data if it is assumed that Early Wisconsinan ice over the Hudson Bay Lowland was cold-based and hence left no record. Sedimentation by approximately westward flowing wet-based ice would then postdate the growth of an ice sheet frozen to its bed. One would be forced to claim that Quebec ice grew to overwhelm Hudson Bay ice and that basal thermal conditions changed. Freeze-down of an ice shelf in Hudson Bay would have to be reconciled with paleoecological indications from deposits such as the Beaver River peat, which imply climate similar to present in the Hudson Bay area during a time probably coincident with substage 5a. There exists, however, no geological observation that supports inception in Hudson Bay, cold-based glaciation, or Hudson Bay-centred ice flow.

4. Deposition of Rocksand Till

Rocksand Till was recognized at four sections on the upper Severn River on the basis of low red carbonate content, slightly but consistently elevated Proterozoic clast content, and northwest-southeast fabric orientations at every site. Elevated Proterozoic clast content indicates approximately westward rather than eastward glacial transport. Presence of several sites on the shield to the south where striations are oriented northwest-southeast, including roches moutonées with plucked faces on their northwest side, lends credibility to acceptance of the fabrics as being parallel to a regional ice flow pattern directed to the west-northwest. Ice flow with this orientation implies a spreading centre located farther south in Quebec than later domes.

Tyrrell (1913, 1914) combined this pattern of ice flow with what he thought was north-northwesterly ice flow on Fawn River to obtain a model for a Patrician ice centre in northern Ontario. This model is now rejected on the basis of reinterpretation of the ice flow for the upper till on Fawn River as south-southeastward and also because additional striation sites located on the shield (Prest, 1963) indicate an ice source farther east. McDonald (1969) denied the existence of this pattern of ice flow, but the upper Severn was not examined during Operation Winisk, striation sites such as those at Big Trout Lake were not re-examined, and few fabric determinations were made.

Shells obtained from Rocksand Till with total aIle/Ile (Ha) ratios of about 0.20 indicate that this till postdates the Bell Sea. The lack of the lower ratios typical of the Prest Sea marine sediments could be taken as an indication of an inadequate data set but is instead tentatively accepted as evidence that Rocksand Till predates deposition of these younger marine sediments. West-northwestward ice flow is therefore assigned to stage 5.

Correlation to Manitoba on the basis of stratigraphic position implies equivalence of Rocksand and Amery tills (Nielsen et al., 1986; Klassen, 1986). Fabrics obtained by Nielsen et al. (1986) from this till at the Henday section are oriented north of west, but other sites reported by these authors, as well as by Klassen (1986), indicate southwestward ice flow.

Amino acid data indicate that the Prest Sea marine sediments on Abitibi River postdate the Bell Sea marine sediments of Kwataboahegan River. If the Missinaibi sites of the southern Moose River basin correlate with Prest Sea, Rocksand Till would correlate with the uppermost pre-Missinaibi till and hence the till that overlies the Bell Sea sediments. Skinner (1973) reported southwestward ice flow for the former till. If, on the other hand, some southern Moose River basin correlate to Bell Sea, the two-till post-Missinaibi sequence proposed by Skinner (1973) would be open to reinterpretation. Two tills overlie the Abitibi River marine sediments. A third till must exist between the Bell Sea and the Abitibi marine sediments, hence there would be three post-Bell Sea tills in the southern Moose River basin, where Skinner (1973) reported two. Skinner (1973) reported boulder pavements that indicated west-northwestward ice flow. These occurrences were somewhat inconclusively correlated to Kipling Till. The possibility of correlation to west-northwestward ice flow elsewhere in northern Ontario dictates the need for a re-evaluation of these sites.

5. Deposition of Fawn River sediments during a Wisconsinan interstade

An episode of deglaciation, marine inundation, isostatic recovery, and subaerial exposure is indicated by the Fawn River sediments. Although the study area was ice free, extensive ice cover may have persisted over the mainland areas west and east of Hudson Bay. Isostatic depression, presumably by the ice mass under which Rocksand Till was deposited, is indicated by marine sediments on Severn River and the correlative Prest Sea sediments on Abitibi River, now located well above sea level. TL data from the Severn River marine sediments (Forman et al., 1987) indicates correlation to oxygen isotope substage 5a. Isostatic recovery and retreat of the Prest Sea is indicated by fluvial gravel on Beaver and Fawn rivers. Reworked marine shells in these two sites yield amino acid data equivalent to the Severn River marine sediments. Subaerial conditions are indicated peat dated at >51 ka overlying gravel on Beaver River. Paleoecological data from this peat indicate a climate similar to present. Clay underlying till on Severn River is attributed to a glacial lake, which formed in front of the advancing ice mass at the close of the nonglacial interval. Leaching of carbonate from the upper portion of these sediments on Severn River remains, however, enigmatic. TL data from Manitoba (Berger and Nielsen, 1990) indicate that this episode of glaciolacustrine sedimentation dates to about 40 ka, although this age is not supported by infinite radiocarbon dates, which themselves remain contentious (Beukens, 1990).

It is uncertain whether Missinaibi Formation sites (Skinner, 1973), where fluvial, subaerial, or lacustrine sediments underlying till cannot be linked to amino acid data, correlate to the Bell Sea or to the Prest Sea. Stratigraphic position and paleoecological data implies correlation of the Nelson River sediments (Nielsen et al., 1986) and the Gods River sediments (Netterville, 1974; Klassen, 1986), with the Fawn River sediments.

Assignment of the Fawn River sediments to a Wisconsinan interstade is based only on TL data (Forman et al., 1987; Berger and Nielsen, 1990). Alternative age assignments, such as early stage 5, would otherwise be acceptable.

6. Deposition of Sachigo Till

The lowermost till which contains shells with Prest Sea ratios is the Sachigo Till of Severn River. This unit is present at two sections and is characterized by elevated red carbonate content in the upper portion of the till. Westward ice flow is supported by two fabrics at one of these sections and a single striated cobble at the other. The case for westward ice flow is strengthened by a boulder pavement on Shagamu River, where several clasts indicate westward ice flow. Eastward ice flow is contradicted by Proterozoic erratics, which are at levels typical of other deposits in the area. Red carbonates in the upper portion of this till indicate southeastward ice flow late in the episode.

On the basis of stratigraphic position and inferred ice flow direction, with support from composition, Sachigo Till is correlated with Long Spruce Till of Manitoba and Adam Till of the Moose River basin. Southward ice flow inferred for correlative till on Gods River by Netterville (1974) and Klassen (1986) may relate to the flow responsible for red erratics on Severn River.

Sachigo Till is attributed to near marginal ice flow during the growth of the ice sheet which culminated in Late Wisconsinan glaciation. It is unlikely that till sedimentation was active in the area when the ice sheet was at its maximum extent.

7. Subglacial glaciofluvial sedimentation

The upper contact of Sachigo Till on Severn River is a sharp contact with Severn Till. Assuming the correlation of Sachigo Till to Till B of Gods River (Netterville, 1974; Klassen, 1986) and Adam Till of the Moose River basin (Skinner, 1973) is correct, it can be inferred that deposits of stratified sediments on these rivers occur at a level equivalent to the contact between Sachigo and Severn tills. On Gods River, the Twin Creeks sediments consist of massive sand lacking organics. Skinner (1973) reported a similar lack of organics in the Friday Creek sediments, which consist of rippled sand and rhythmically bedded sand, silt, and clay. McDonald (1969), Skinner (1973), and Netterville (1974) considered deglaciation necessary for the deposition of these sediments. A subglacial origin, as advocated by Dredge and Nielsen (1985), is favoured for these sediments. Hence continuous till sedimentation during a period of glacial ice cover is not assumed and some degree of ponding of subglacial meltwater beneath the ice sheet at its maximum extent is claimed. The alternative of proglacial sedimentation would require that Sachigo and Severn tills each be the deposit of a complete cycle of ice cover.

8. Deposition of Severn Till

The upper till of Severn River has a consistent composition of moderate Proterozoic and red carbonate clast content. Southwestward ice flow is indicated by the fluted surface, several fabrics within the till, and striated boulders at the lower contact. Stratigraphic position, ice flow direction, and composition are compatible with correlation to Sky Pilot Till of Nelson River (Nielsen et al., 1986) and Kipling Till of the Moose River basin (Skinner, 1973). The latter correlation precludes the equivalence of Kipling and Cochrane. Parallel southwestward ice flow across northern Ontario and Manitoba indicates an ice centre in the form of an elongate ridge crossing Hudson Bay. Lack of ice flow into Keewatin and Quebec (Shilts, 1980) indicates that this ridge was concave along its long axis, hence a saddle connecting domes in Keewatin and Quebec, as portrayed by Dyke and Prest (1987).

Unlike underlying tills, Severn Till yields marine shell fragments with total aIle/Ile (Ha) ratios of about 0.07, significantly lower than values from shells in Prest Sea marine sediments. Similar data were obtained by Laymon (1991) from the Hudson Strait area. Middle Wisconsinan (Stage 3) deglaciation could therefore be inferred, by interpolation, for the time preceding deposition of Severn Till. Instead, however, continuous ice cover during Stage 3 is concluded on the basis of 1) the lack of deposits indicating marine inundation, subaerial exposure and/or northward drainage, 2) the lack of convincing finite radiocarbon dates, and 3) the probability of deposition of Sachigo Till during the growth and Severn Till during the retreat of the ice sheet. Because of the constraints posed by these considerations, the low ratios are attributed, as discussed by Wyatt (1989), to the combination of 1) a spatial mechanism, the great age difference between shells deposited onshore early in a nonglacial episode and those deposited offshore late in the same episode, and 2) a thermal mechanism, the higher temperatures experienced by shells in subaerial environments during pre-Holocene nonglacial episodes compared to submarine environments offshore. The occurrence of these shells with low ratios in tills derived from offshore Hudson Bay is compatible with both mechanisms.

9. Deposition of Winisk Till

Flute orientations compiled by Prest et al. (1968) indicate a belt of features oriented nearly north-south in the area extending from Winisk River in the north to Albany River in the south. Winisk Till underlies these flutes on Fawn and Winisk rivers and has composition and ice flow data that suggest deposition by the same ice responsible for the flutes. The presence of Severn Till, identified on the basis of ice flow direction and composition, underlying Winisk Till confirms that this ice flow crosscuts former southwesterly ice flow.

Correlation of this ice flow belt with the western flank of a Cochrane lobe (Prest, 1969) is not favoured, as this reconstruction requires ice flow parallel to an ice margin extending up a topographic gradient. Furthermore, an esker oriented parallel to the flutes within the belt exits the belt and continues parallel to southwestward flutes located outside the belt. The ice margin appears to have been at the Agutua – Nakina margin (Prest et al., 1968) at this time. Hence we infer that the belt of ice flow was an ice stream confined by stagnant ice, as well as by slight topographic highs in the north, where a converging ice flow pattern is evident. To the south, no topographic control is present and ice flow diverged slightly. This ice stream is attributed to a late glacial readjustment in a disintegrating ice mass. Drawdown by ice flow such as this would have contributed to the thinning of glacial ice in Hudson Bay, which eventually led to deglaciation of the area by calving (e.g,. Denton and Hughes, 1981b).

10. Deglaciation

Stagnation or at least very rapid disintegration of the ice mass is implied by a lack of disruption of regional surface ice flow trends or ice marginal features of any kind. Lack of glacial marine sediments implies a lack of a significant debris load in the residual ice mass. During isostatic recovery, well developed marine shoreline features were formed.

IMPLICATIONS

Patrician glaciation

The Patrician ice sheet model put forward by Tyrrell (1913, 1914) should now be dismissed. Tyrrell's northwest striation data from the upper Fawn River and Big Trout Lake were confirmed, but his north-northwestward ice flow for the upper till on Fawn River is here shown to be south-southeast. It was the intersection of these two orientations which Tyrrell used to locate a dome in the District of Patricia in northern Ontario. Combination of Tyrrell's striation data with those of Prest (1963) as well as more recent indications of ice flow north of west indicate an ice source in Quebec for northwestward ice flow at Big Trout Lake.

Ice sheet geometry

The ice flow record in the study area indicates the dominance of generally westward followed by southwestward ice flow, along with three less pervasive episodes of southeastward to southward flow. Amino acid data indicate glacial reworking of preexisting sediments. Rates of transport may have been greater than earlier considered possible. The erratic transport trends worked out by Shilts (1980) are therefore resultant vectors, which should not be considered flow lines in an ice sheet. The stratigraphy of the Severn-Winisk region indicates a major ice sheet centred in Quebec and flowing across northern Ontario to Manitoba at the time of deposition of Rocksand and Sachigo tills. For upper Sachigo Till, a rise in relative importance of an ice centre to the northwest, presumably in Keewatin, is indicated by red erratics from Hudson Bay. Severn Till and its correlatives, Sky Pilot and Kipling tills, indicate Late Wisconsinan southwestward flow across the entire Hudson Bay Lowland. This configuration of flow could only have been maintained along a saddle connecting domes west and east of Hudson Bay. Winisk Till is attributed to a topographically controlled ice stream. There is no requirement for a dome in Hudson Bay at any time.

Pre-Holocene deglaciation

The proposal of multiple Pleistocene deglaciations of Hudson Bay Lowland made by Andrews et al. (1983) is here given partial support. Their claim of lithostratigraphic evidence for multiple nonglacial episodes (Andrews et al., 1984), however, lacks justification. Their insistence that Bell Sea dates to substage 5e is also considered to have been unjustified, although extrapolation from TL data now supports this age. Two amino acid clusters reported by Andrews et al. (1983) are attributed to this episode. Values of about 0.22 for total alle/Ile in *Hiatella arctica* seem to represent the early Bell Sea. Values of 0.18 are found in tills and are considered the result of shells living offshore in the final remnant of Bell Sea. Similarly, two clusters are attributed to Prest Sea which is considered equivalent to the Fawn River, Gods River, and Nelson River sediments. Values of 0.14 relate to the early Prest Sea whereas values of about 0.07 are found only in tills and relate to the final remnants of Prest Sea. Ratios from till as low as 0.05, only slightly higher than values of 0.04 from Tyrrell Sea shells, reflect the lack of warm subaerial exposure of offshore Prest Sea shells before the Holocene.

TL data from Severn River (Forman et al., 1987) indicate that the deglaciation, which caused incursion of Prest Sea to sites above present sea level, took place in late stage 5. The end of this episode, which is recorded by glaciolacustrine sedimentation, has been dated in Manitoba at about 40 ka BP (Berger and Nielsen, 1990), although radiocarbon data have not confirmed this age.

If TL data are ignored, the Fawn River sediments and its equivalents could be assigned to early stage 5. The Bell Sea and the Sundance soil would then be assigned to stage 7.

The Cochrane readvance

An area extending from Winisk River to Albany River is fluted in a north-south pattern. This ice flow pattern was attributed to the western flank of a Cochrane lobe by Prest (1969). Dyke and Prest (1987), in contrast, attributed this pattern to multiple minor events. In this report, it is concluded that an ice stream flanked by relatively stagnant ice formed these features. Hence there is no evidence that the Cochrane event, which is reported for the shield south of the Moose River basin, played a role in Hudson Bay Lowland.

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