LATE GLACIAL
HISTORY, PALEOECOLOGY, AND SEDIMENTATION
IN THE
LAKE NIPIGON BASIN, ONTARIO

A thesis

presented to

The Faculty of Graduate Studies

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Master of Science

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LATE GLACIAL HISTORY, PALEOECOLOGY, AND SEDIMENTATION IN THE LAKE NIPIGON BASIN, ONTARIO

BY

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ABSTRACT

Between 9500 B.P. and 8500 B.P., water overflowed from glacial Lake Agassiz into Lake Nipigon through the Lake Agassiz eastern outlets. The outlets south from the Nipigon basin carried this flow into the northwestern Lake Superior basin. The flow of water through these two outlet systems was regulated by the position of the retreating ice front of the Rainy Lobe.

Former Lake Nipigon levels are recorded by numerous wave-cut terraces found throughout the basin. These reflect both the changing outlets to the Superior basin that were used, as well as erosion of these outlets. Glacial rebound also served as a component in the formation of wave-cut terraces as the level of the land surface rose above a declining and later static lake level.

Deltas formed at the mouths of the eastern outlets as sediment-laden waters from Lake Agassiz spilled into Lake Nipigon. Sand and coarser grained sediments were deposited near the lake shore, while finer sands and silty sediments were deposited on the prodelta slope by underflow and overflow-interflow currents. Finer grained sediments were transported farther out into the basin and deposited, forming rhythmites of clay and silt.

Numerous species of arboreal and non-arboreal pollen present within sediments of the Nipigon-Superior lowlands

infer that upon deglaciation, the Lake Nipigon region became colonized by dense coniferous and deciduous forests interspersed with open meadows and grasslands. Data from fossil shells of 16 species of molluscs, estimated to have lived about 8,800 years ago, suggest that the limnological characteristics of the paleo-Lake Nipigon phases were similar to those of the present lacustrine setting. The radiocarbon age of the bivalve and gastropod shells in the Nipigon basin appear to be too old because of the "hard water effect". All shell dates, therefore, are "corrected" by 500-1,000 years, which brings the history of basin deglaciation into harmony with other wood dates in the region.

I. INTRODUCTION

Between about 9500 B.P. and 8500 B.P., waters which filled the Lake Agassiz basin spilled over into the Lake Nipigon basin through a series of 17 fluvial channels known as the eastern outlets. These channels collectively form five separate systems whose heads form junctions along the continental divide that serve to separate the Hudson Bay (and Lake Agassiz) basin from the Great Lakes-St.Lawrence drainage basins. From south to north the channels form the Kaiashk, Kopka, Pillar, Armstrong, and Pikitigushi outlets (Teller and Thorleifson, 1983).

The flow of Lake Agassiz water through these spillways was regulated by the position of the retreating ice margin of the Rainy Lobe along the continental divide. As ice dams along the divide were breached, channels to Lake Nipigon were activated in sequence from the Kaiashk in the south through to the Pikitigushi system in the north. As the level of Lake Agassiz fell, flow rates waned, and ultimately ceased when the next lower channel became operative.

Large volumes of sediment were deposited into the Lake Nipigon basin as the sediment-laden Lake Agassiz waters emptied into Lake Nipigon. Huge boulders were deposited within the channels themselves, while sands and gravels were deposited close to the Nipigon shoreline. Finer grained sands, silts, and clays were transported farther out into the basin by density currents, forming sequences of rhythmically bedded sediments.

Waters in the Lake Nipigon basin flowed southward into the Lake Superior basin through a system of channels. These seven channels, the Black Sturgeon, Wolf, Wolfpup, Shilabeer, Nipigon, Cash, and Pijitawabik outlets (Teller and Thorleifson, 1983), served to lower the level of Lake Nipigon during the approximately 1,000 year period when glacial Lake Agassiz, Lake Nipigon, and Lake Superior were interconnected.

Numerous species of arboreal and non-arboreal pollen, deposited along with sediments in the Nipigon-Superior lowlands, provide a framework for the reconstruction of the major vegetation types which colonized the newly deglaciated terrain. Radiocarbon datable materials found within sediments of this region are useful in providing relative chronostratigraphic control and a general chronological scheme for the deglaciation of the Nipigon-Superior lowlands.

Former Lake Nipigon levels are well recorded by wave-cut terraces found within the Lake Nipigon basin. As the level of the lake fell in response to changing outlet usage (as the ice margin retreated), outlet erosion, and isostatic rebound, terraces were formed at subsequently lower elevations.

Previous Research and Current Objectives

Steve Zoltai (1965,a) mapped the surficial geology of the Nipigon-Quetico region, and described the glaciogenic sedimentary deposits and their relationship to the movement of glacial ice over this region of Ontario. Tom Schlosser (1983) mapped the surficial deposits of the western Lake Nipigon area in greater detail. He also identified and measured paleomagnetic signatures (depositional remnant magnetism) in the fine grained rhythmically bedded clay and silt deposits of this area. Data from these measurements concluded that marked differences in DRM signatures exists between the varves of the southern basin, and those deposited in more northern locations.

The Lake Agassiz-Lake Superior connection became the focus of a number of research projects at the University of Manitoba under the guidance of Dr. James T. Teller. Grant Miller (1983) produced a number of computer-generated maps of the lithologies of the glacial drift covering the eastern outlets region, and related these deposits to the glacial history of the area. Harvey Thorleifson (1983), in studying the eastern outlets of glacial Lake Agassiz determined the nature, chronology, and the duration of drainage through these outlets. He also related the activity of the eastern outlets to the evolution of Lake Agassiz and the retreat of the Rainy Lobe ice margin. These studies were published in conjunction with the on-going research of J.T. Teller

(Teller and Thorleifson, 1983,1987). Paul Mahnic (in progress) studied in detail the sediments in the northern Lake Superior basin deposited by water flowing through the southern outlets of Lake Nipigon. A synthesis of surface and borehole data from the northwestern Superior basin as far north as the Nipigon basin was published by Teller and Mahnic (1988).

The primary objective of this research program is to develop a sedimentological and chronological model for the Lake Nipigon basin for the period of 9500 B.P. to about 8500 B.P., using stratigraphic data from boreholes and exposures of sediment, ages of radiocarbon datable material, and reconstructed ice margins of the Rainy Lobe. Specifically, this model would delineate the chronology of events that occurred at both the southern Lake Nipigon outlets and the Lake Agassiz eastern outlets, and the response of the level of Lake Nipigon to these events.

A reconstruction of the general paleoecological setting for the region, the depositional processes resulting in the development of deltaic sedimentary packages, and the sedimentological nature of the rhythmically bedded silts and clays exposed within the Lake Nipigon basin also form integral components of this research.

Methods

During the field season of 1985, 18 exposures of sediment along the present Lake Nipigon shoreline were described in detail and sampled. These exposures were made accessible by the use of the Ontario Ministry of Natural Resources, Fisheries Research boat. Forty exposures in areas along provincial highway 527 along the western shore of the lake were also examined and samples of sediment were taken. Numerous secondary (logging) and private roads provided access to additional exposures of sediment. The recent extension of highway 527, east from the town of Armstrong, Ontario, north of Lake Nipigon, allowed for the examination and sampling of additional man-made exposures of sedimentary deposits.

Six boreholes were drilled along the highway out of Armstrong and along highway 527 during the 1986 field season. A total depth of 142 m was drilled using a hollow-stem auger drill. Shelby-tube coring and split-spoon sampling apparatus yielded 37 m of sediment for various analyses, with auger flight samples and borehole circulated sediment providing general supplemental data on the stratigraphy.

Exposures of sediment along the eastern shoreline of the lake, and along provincial highway 11 were also examined, mapped, and sampled. Examination of sediment exposed along the shoreline of Kopka Lake and along the course of the Whitesand River was made possible with the use of a Zodiac inflatable boat.

Through the various means of transportation utilized, a total of 75 sites were examined, their sediments described in detail, and 125 sediment samples were analyzed.

Total carbonate mineral content of the silty and clayey sediments was determined using acid (5:1 water:HCl) digestion techniques. Each sub-sample of sediment was dissagregated in distilled water in order to dissolve any water-soluble components of the sediment. The samples were then placed in a weighed beaker and dried in a drying oven at 85°C,and weighed to two decimal places. Forty milliliters of 5:1 distilled water-hydrochloric acid solution was then added to the weighed sediment samples, resulting in an effervescent reaction. The sediment was then allowed to settle until the solution is clear and free of suspended sediment. The spent acid-water solution was then decanted using a pipette, and fresh solution is added to the sediment. This procedure is repeated a minimum of three times or until any and all reaction ceases. The sediments were then flushed twice with distilled water to remove any acid residue, and allowed to settle. The clear distilled water decanted, the sediments were then dried to desiccation. The dried samples were then weighed and the percentage acid-soluble (carbonate mineral) calculated:

$$\frac{\text{initial dry weight - acid reacted weight}}{\text{initial dry weight}} \times 100$$

As the initial dry weight is the weight of the sediment following the dissolution with distilled water, the difference in weight between the initial dry weight and the acid-reacted dry weight is attributed to calcite and/or dolomite.

Elevations of former Lake Nipigon shoreline features (wave-cut terraces) were measured using an American Paulin model M-1 field altimeter. Elevations of terraces not determined directly in the field were measured using a stereometer and 1:50,000 scale aerial photographs, and applying the parallax equation.

Textural parameters of the silt and clay-sized sediments collected were measured using a Micromeretics Sedigraph particle size analyzer. Sand and coarser grained sediments were analyzed using a Ro-tap automated sieve shaker and Tyler Canadian Standard sieves.

Mineralogy of the finer sediments (silt and clay) was determined by preparing and analyzing powdered sediment samples by X-ray diffractometry using a Phillips Automated Powder Diffractometer System PW1710, utilizing monochromatized Cu radiation. In preparation for XRD analysis, approximately 0.5 grams of dried sediment was ground with a mortar and pestle to a fine powder. The powdered sample was placed on a glass slide and "diced" with a razor blade in order to eliminate any aggregates of powdered sediment. Acetone was added to the sediments creating a slurry and to produce a level "film" of sediment on the slide. Upon evaporation of the acetone, the slide is ready for analysis. The sediment samples were irradiated with Cu-radiation and run at a scanning rate of 2° (2-theta) per minute from 10° to 32°. The general mineralogy of the coarser grained deposits was determined using a Fischer Scientific Stereomaster binocular microscope with 2X and 4X magnification.

Acknowledgements

I owe a great deal of thanks to Dr. James T. Teller of the Department of Geological Sciences, University of Manitoba, for enabling me to become a participant in the Lake Agassiz-Lake Superior connection research. Thanks also must be given to Dr. Teller for acquiring funding fo this research through the National Science and Engineering Research Council Operating Grant number A7835.

Capable assistance in the field was provided by Jamie Bateman (1985) and R. Neal Gray (1986).

While in Thunder Bay, Ontario, facilities for the storage of samples and equipment was made possible by Dave Arthurs of the Ontario Ministry of Culture and Recreation.

Dominion Soils Investigations provided the drilling equipment necessary for obtaining a greater understanding of the stratigraphy of the Lake Nipigon basin.

Particular thanks also must be given to Rick Borecky and the Ontario Ministry of Natural Resources at Macdiarmid, Ontario, for the use of their research vessel, the Ranger IV on Lake Nipigon for 5 days during the 1985 field work.

Dr. Brian Phillips, of the Department of Geography, Lakehead University, Thunder Bay, Ontario, is hereby thanked for providing the field altimeter used for this research.

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Thanks are also given to Dr. Eva Pip, of the Department of Biology, University of Winnipeg, Winnipeg, Manitoba, for the identification of molluscan shells collected, and for her participation in a successful presentation at GAC-MAC '87, in Saskatoon, Saskatchewan.

II. GEOLOGICAL SETTING

Precambrian Geology

The Lake Nipigon basin lies within the Superior Province of the Canadian Shield in northwestern Ontario. The origin of the basin itself may be related to the "failed arm" hypothesis of Franklin and others (1980), which implies that the basin was formed by block-faulting related to Keweenawan rifting in the region about 1,100 million years ago. Green (1983), however, argued that the age of some of the rocks proposed to be related to the rifting episode does not fit the "failed arm" model, rendering this hypothesis unreasonable.

The bedrock of the region is composed of Precambrian rocks of both Archean and Proterozoic age (Fig.1). The basement rocks are composed of late Archean (2716 Ma; Davis and Sutcliffe, 1985) tonalitic gneisses, and metavolcanic-metasedimentary greenstone belt assemblages. These rocks are intruded by Proterozoic alkalic granitic and porphyritic rocks, which outcrop near English Bay on the western shoreline of Lake Nipigon. These intrusive rocks, dated at 1536.7 Ma are equivalent in age to the Sibley Group metasedimentary rocks deposited as a sequence of "red-bed" quartz arenites (Davis and Sutcliffe, 1985). The Sibley Group rocks are intruded by Neohelikian age diabase dikes and sills known as the Logan Sills (Davis and Sutcliffe,

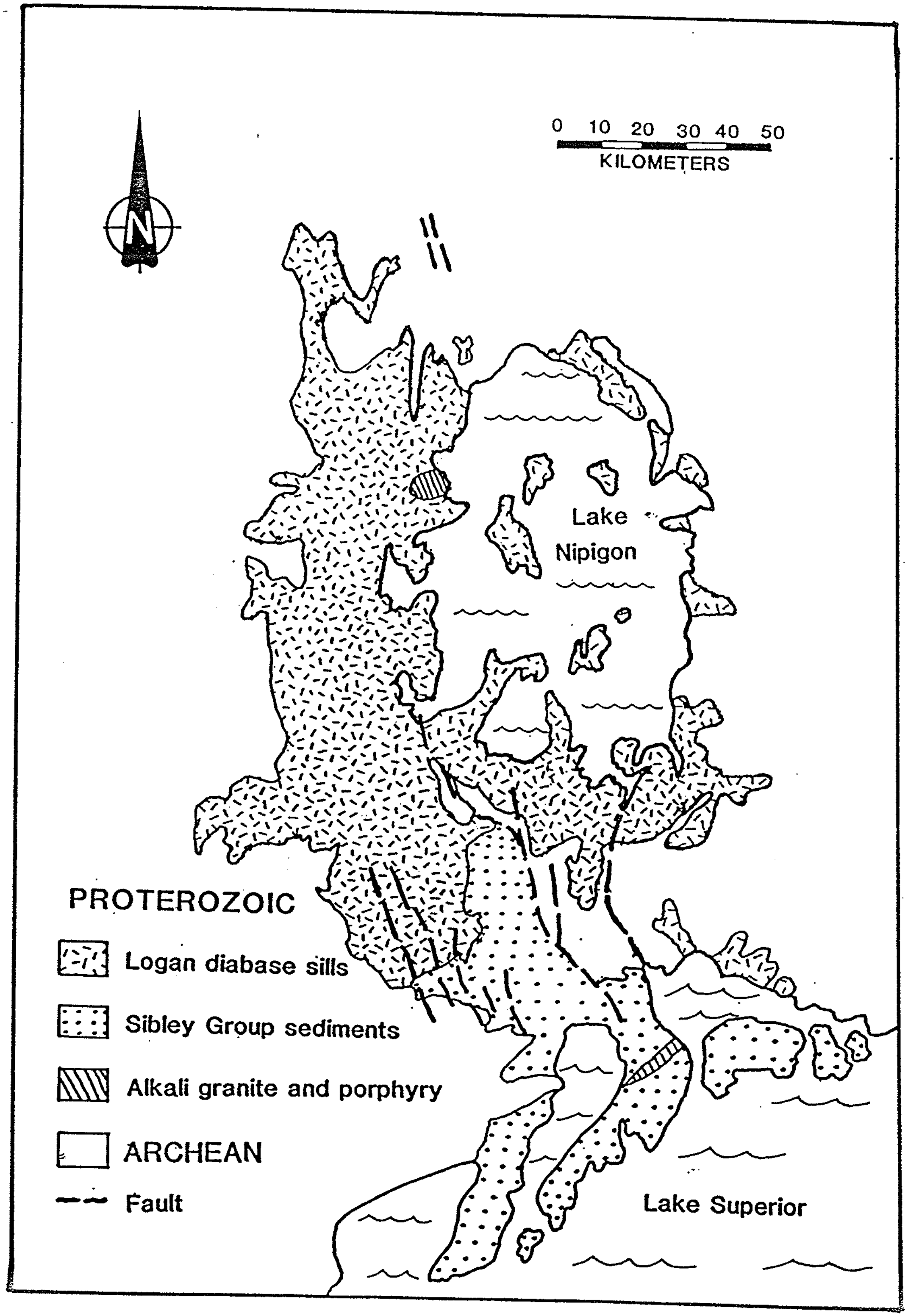

FIGURE 1
Precambrian Geology of the Lake Nipigon Region
(after Davis and Sutcliffe, 1985)

1985). These intrusive rocks form numerous buttes and islands within the Lake Nipigon region.

Localized relief produced by these steep-sided landforms commonly exceeds 100 m, and occasionally exceeds 300 m (Thorleifson, 1983). The general relief of areas underlain by Archean rocks seldom exceeds 30 m.

Multiple advances of Laurentide glacial ice across the region may have served to modify or to scour out the lake basin, along with the Great Lakes basins. The erosive action of the final advance of ice, plus subsequent erosion by early post-glacial runoff, has been largely responsible for the overall morphology of the Lake Nipigon basin.

Quaternary Geology and History

The unconsolidated sediments that cover the Lake Nipigon region are diverse in nature, the result of a complex Quaternary history. These sedimentary deposits can be classified generally into 5 categories: i) non-stratified, poorly sorted, silty and sand sediments deposited by glacial ice (till), ii) glaciofluvial deposits, massive and bedded sand, gravel,including eskers, kames, valley trains, fluvio-deltaic sediments, and ice-marginal outwash complexes, and boulders deposited by flowing water, iii) glaciolacustrine deposits, laminated and bedded clay, silt, and sand deposited in lake waters, iv) eolian deposits, sandy sediments of origins i-iii that have been reworked by wind action, and v) recent organic deposits, primarily peat.

The Quaternary sedimentary deposits of the Lake Nipigon basin region were initially mapped by Zoltai (1965,a). Figure 2 illustrates the distribution of the various types of Quaternary sediments in the region.

The late glacial history of the regions occupied by Lake Agassiz, Lake Nipigon, and Lake Superior during the period between 11,700 B.P. and 8500 B.P. has been divided into 5 separate phases (Clayton and Moran, 1982, Clayton, 1983, Teller and Thorleifson, 1983). During the pre-Moorhead Phase (11,700 B.P.-10,800 B.P.), waters from Lake Agassiz flowed south through the Minnesota River valley (Matsch, 1983) and the Lake Nipigon basin lay covered by Rainy Lobe glacial ice. By approximately 10,800 B.P., the margin of ice had retreated far enough to the north to allow Lake Agassiz waters to flow directly into Lake Superior west of Thunder Bay (Elson, 1967). This event marked the onset of the Moorhead Phase. As the ice front continued to waste to the northeast during the Moorhead Phase, some, or perhaps all of the eastern outlets of Lake Agassiz became ice-free, and directed the overflow of water into the Lake Nipigon basin en-route to Lake Superior (Fig.3). It is uncertain as to which of the eastern outlets were active during the Moorhead Phase which resulted in the decline of the level of Lake Agassiz to the Ojata or the Pas level (Teller and

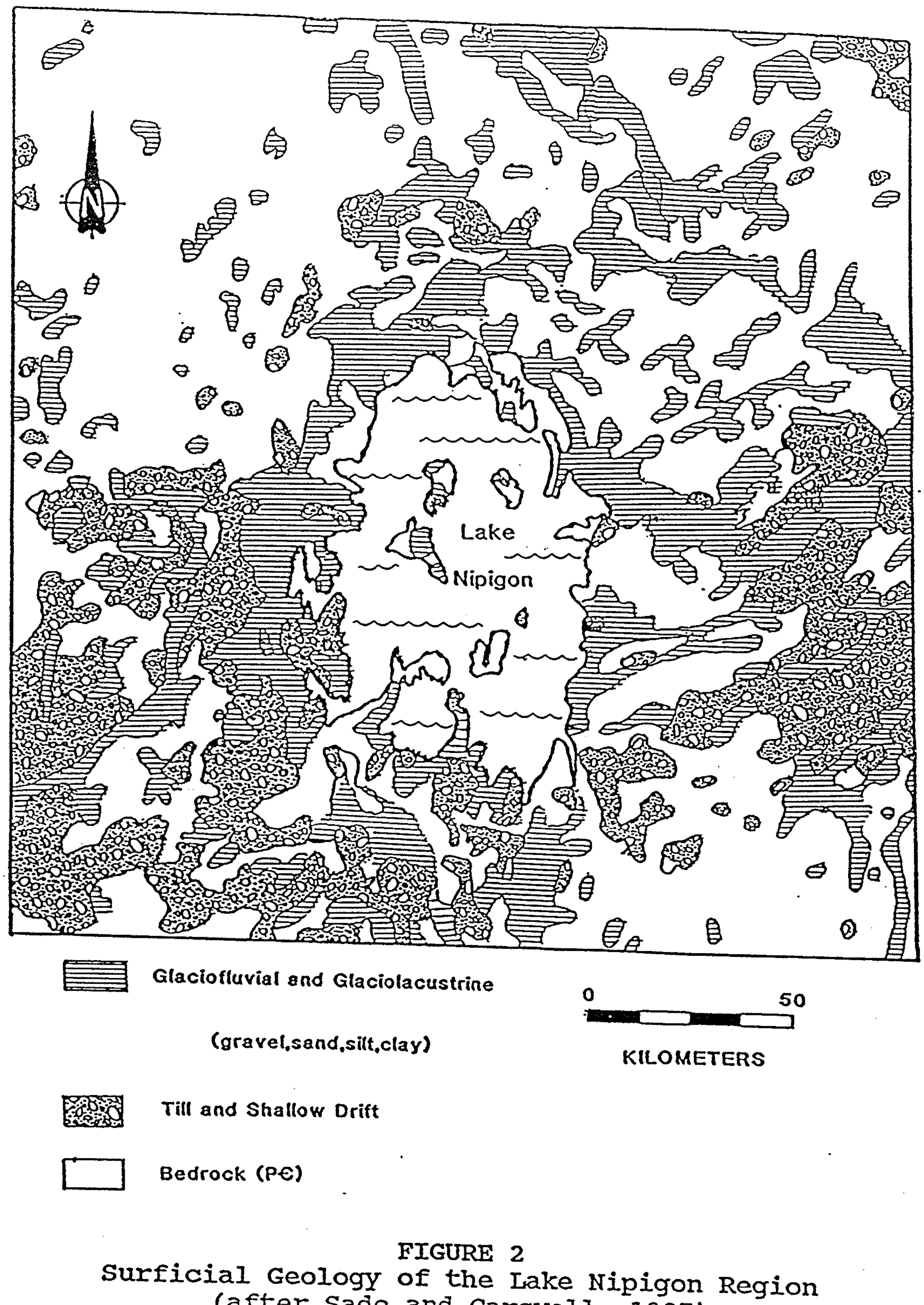

FIGURE 2
Surficial Geology of the Lake Nipigon Region
(after Sado and Carswell, 1987)

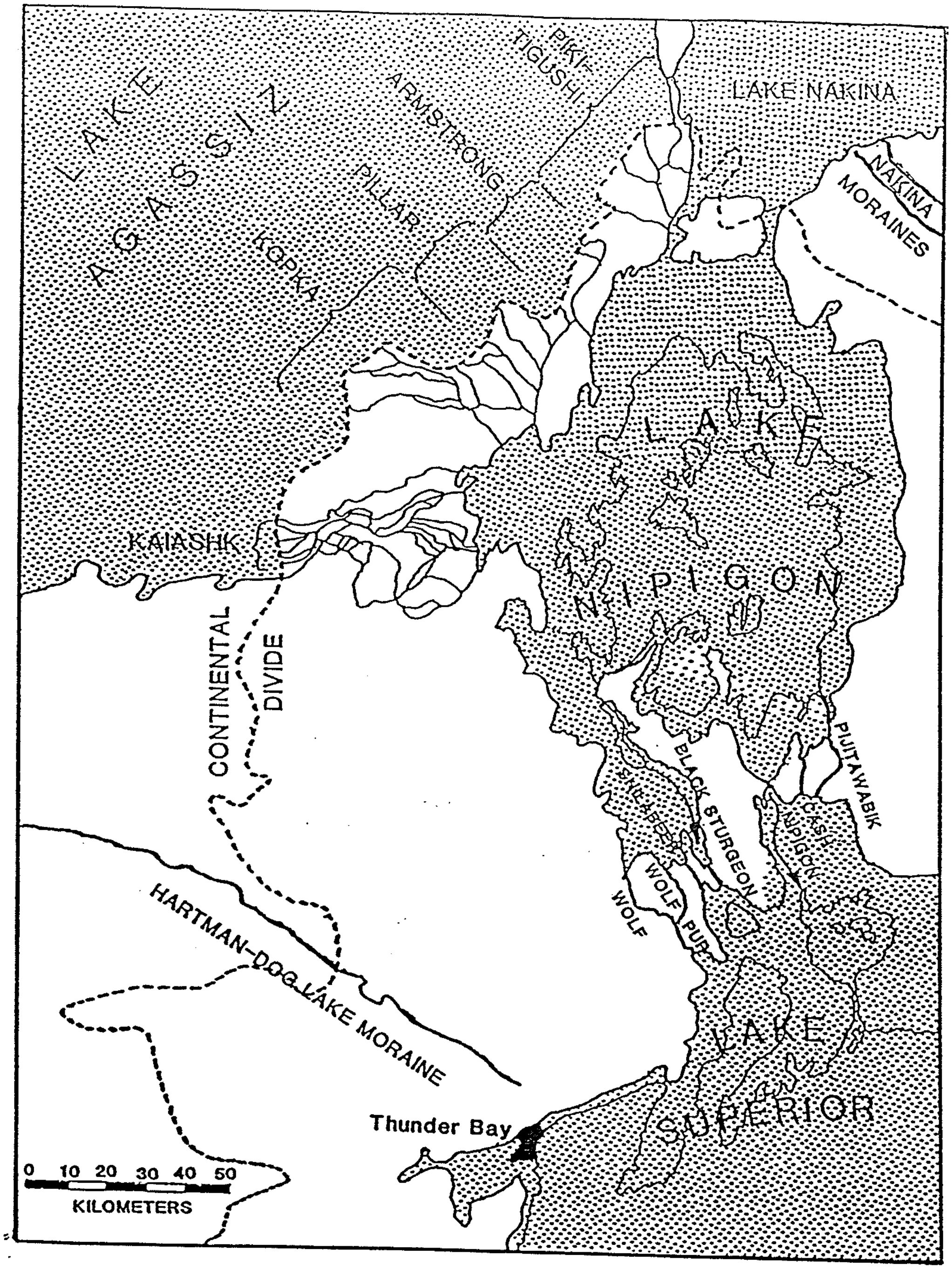

FIGURE 3
Lake Agassiz-Lake Nipigon-Lake Superior
Hydrological System
(after Teller and Thorleifson, 1983)

Thorleifson, 1983). The traditional interpretation of Elson (1967) suggests that Rainy Lobe ice must have retreated far enough to the northeast to allow the flow of water through the northernmost outlet, however Teller and Thorleifson (1983) speculate that the lowest Moorhead Phase level of Lake Agassiz may have been attained as the result of drainage through the higher, more southerly Kaiashk and Kopka outlets (see Fig.3). Ice of the Rainy Lobe readvanced over the region as far as the Hartman and Dog Lake moraines (Fig.3) and southward across the Superior basin to Michigan at about 10,000 B.P., closing the eastern outlets and marking the onset of the Emerson Phase of Lake Agassiz (Teller and Thorleifson, 1983). The margin of Rainy Lobe ice again began to retreat to the northeast, and by about 9500 B.P., water from glacial Lake Agassiz flowed through the Kaiashk outlet at catastrophic discharge rates. This event coincided with the initiation of the Nipigon Phase. Estimates for the discharge through the Kaiashk outlet exceed 100,000 cubic meters per second (Teller and Thorleifson, 1987).

The overflow of water from Lake Agassiz was routed from the Nipigon basin south to the northwestern Lake Superior basin through the Black Sturgeon, Wolf, Wolfpup, and Shillabeer channels (Fig.3). Continued retreat of Rainy Lobe ice served to open the more northerly eastern outlets of Lake Agassiz and the more easterly outlets of the Nipigon basin. At the mouths of each of these channels, large volumes of gravel and sandy sediments were deposited, producing large deltaic sequences. Finer-grained silty and clayey sediments were deposited farther out into the lake basins, forming sequences of silt and clay rhythmites.

By about 8500 B.P., the margin of Rainy Lobe ice lay north of the Nakina moraines (Thorleifson, 1983) (Fig.3). At this time, water no longer flowed into Lake Nipigon, as overflow from Lake Agassiz was directed eastward into Lake Ojibway during the late glacial period known as the Ojibway Phase of glacial Lake Agassiz (Teller and Thorleifson, 1983). This brought to a close the connection of lakes Agassiz, Nipigon, and Superior which persisted during the Nipigon Phase, a period of late glacial history spanning approximately 1,000 years from 9500 B.P. to about 8500 B.P.

III. SEDIMENTS IN THE LAKE NIPIGON BASIN

BOREHOLE SEDIMENTS

Six boreholes were drilled along the western and northern shorelines of Lake Nipigon (Fig.4), and sediment cores were obtained using a hollow-stem auger drill with Shelby-tube and split-spoon sampling apparatus. The borehole locations were chosen in order to obtain data from sediments deposited by the flow of Lake Agassiz water through each of the eastern outlet channels. In most cases, the rhythmites of the Lake Nipigon region are alternating couplets of silt and clay. Some of the rhythmites are triplets, in which case each rhythmite is composed of three distinct sediment types.

LEE Hole

The LEE hole was drilled along the road east of the town of Armstrong, Ontario, 6.0 km east of the Pikitigushi River bridge (887868, NTS map 52-I/7). The total depth of the borehole was 24.0 m with a total cored thickness of 4.0 m. The hole was drilled to refusal at the contact with the bedrock surface.

The upper 21.0 m of the LEE core is composed of massive, fine to medium grained sand (mean grain size $\bar{\emptyset}$=1.60 $\emptyset$) (Fig.5). These sediments are light yellowish brown (10YR 6/4, Munsell, dry), well sorted (σ=0.48 $\emptyset$) and "granitic"

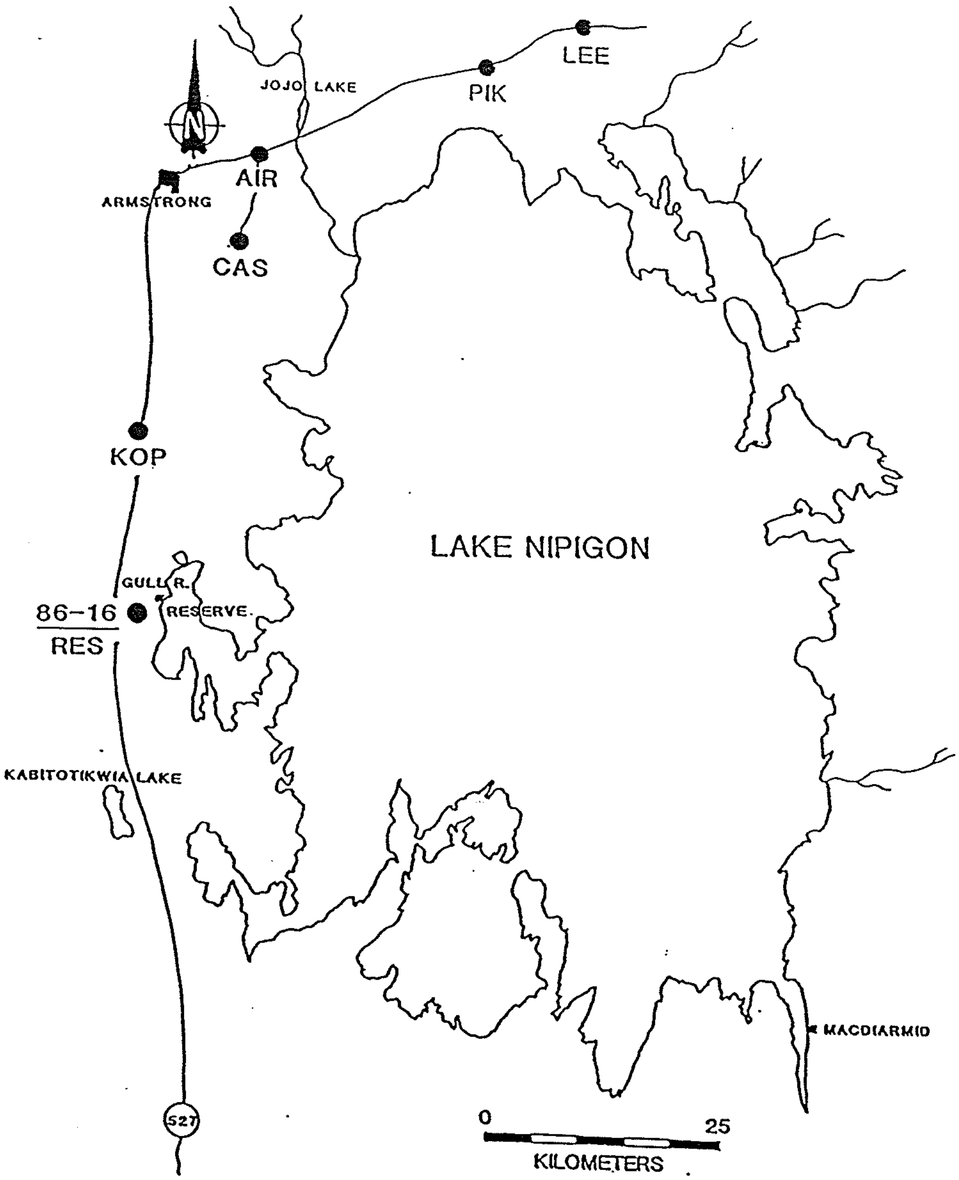

FIGURE 4
Borehole Locations

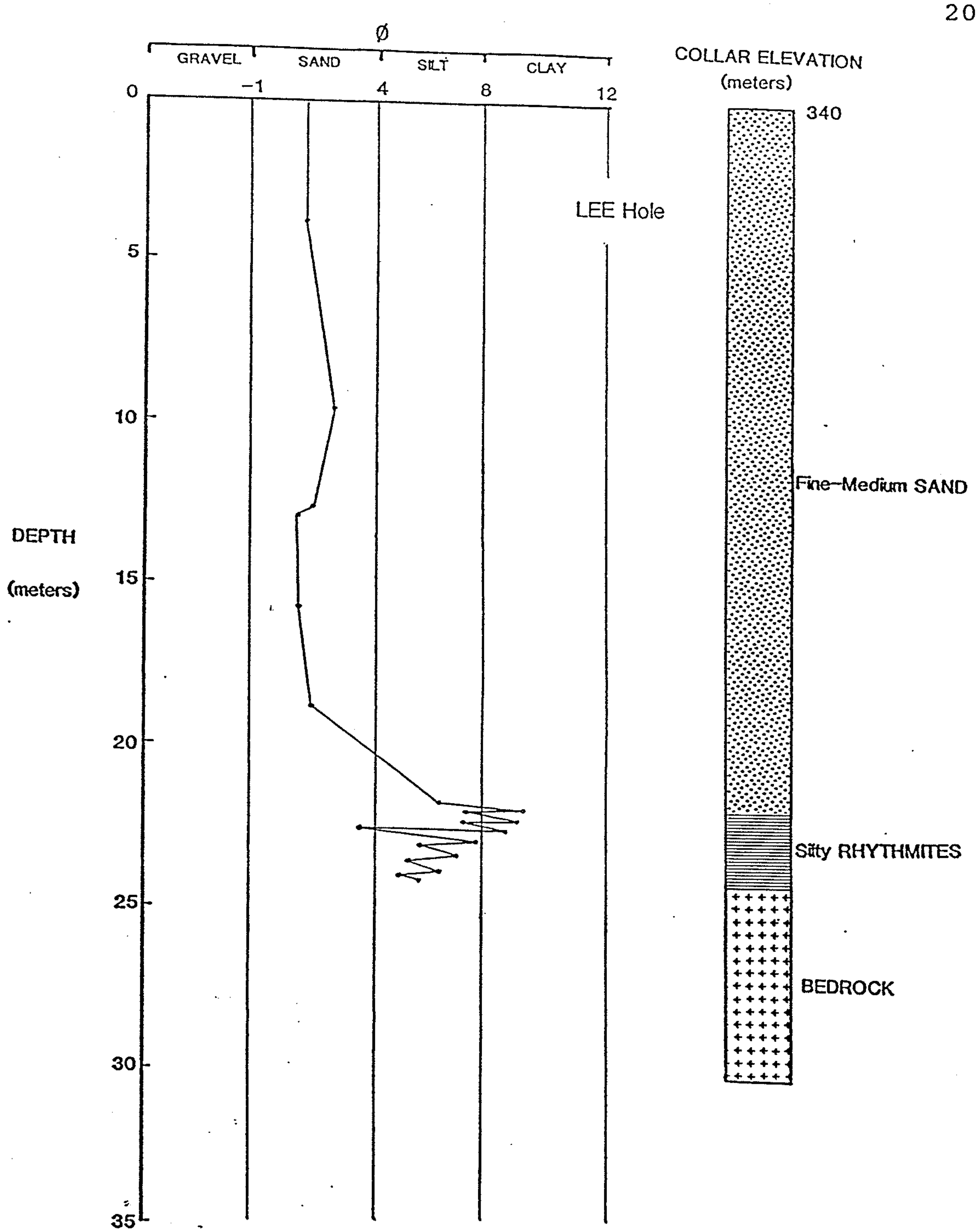

FIGURE 5
Grain Size Trends and Stratigraphy of the LEE Borehole

in composition, containing 84% quartz, 5% orthoclase, 4% biotite, 3% muscovite, 2% hornblende and 2% carbonate clasts. The quartz grains are angular to rounded. Orthoclase grains are generally subangular to subrounded. The minor limestone clasts are well rounded with highly polished surfaces displaying minor abrasion and pitting.

A sharp erosional basal contact indicates that these sandy sediments lay unconformably above the basal 3.0 m of rhythmically bedded couplets of silt and silty sand (Fig.5). Minor distorted clay laminae also are developed within these rhythmically bedded couplets. The silts are medium grained ($\bar{\phi}$=5.60 ϕ), pale olive brown (2.5Y 5/3, Munsell, dry), and poorly sorted (σ=1.43 ϕ). Thin (1-2 mm) laminae occur within these silty sediments. X-ray diffraction analysis indicates that these sediments are composed primarily of quartz, calcite, and dolomite, with minor orthoclase and albite.

The coarser-grained laminae of the rhythmically bedded couplets are fine to very fine grained ($\bar{\phi}$ =3.43 ϕ), olive (5Y 5/2, Munsell, dry) silty sand. These sediments are moderately sorted (σ=0.88 ϕ) and are composed primarily of subangular to subrounded quartz grains. Individual units range in thickness from 3.0-35.0 mm.

The fine grained, distorted laminae developed within the rhythmite sequence are brown (2.5Y 5/2, Munsell, dry) clayey silt ($\bar{\phi}$=7.80 ϕ).

Well rounded quartz pebbles are abundant within the silty sands of the basal 1.0 m of the LEE core sediments. Minor rip-up clasts of clayey silt similar in composition to the brown, distorted laminae are also present within these basal sediments.

The interbedded nature of these rhythmites of silty sand, silt, and clayey silt is inconsistently developed. The silty sand and silt beds show consistent repetition, however the development of the silty clay laminae within the rhythmite triplets is sporadic, with only five laminae observed in a 2.0 m thickness of core. As rip-up clasts of clayey silt are found within the rhythmites, the sporadic distribution of the clayey silt laminae within the sequence may be the result of erosion of these fine grained deposits.

The rhythmites of the LEE core display multiple fining-upward beds, with the silty sands forming the basal sediments of each rhythmite, overlain conformably by the laminated olive brown silts. These laminated sediments grade upward into the thin, distorted, brown laminae of clayey silt.

Figure 5 illustrates the overall coarsening-upward-sequence displayed by the sediments of the LEE core.

PIK Hole

The PIK hole was drilled 4.0 km east of the Pikitigushi River bridge along the northern extension of highway 527

(Fig.4; 875849, NTS map 52-I/7). Total depth of the hole was 31.5 m, with a cored thickness of 8.0 m (Fig.6).

The upper 15.0 m of sediment is composed of rhythmites of clay and silt (Fig.6). Each rhythmite in the uppermost 5.0 m of the rhythmite sequence is a well developed, upward grading triplet of medium to coarse grained sandy silt, fine grained silt, and clay. The clay laminae are dark brown (10YR 3/3, Munsell, dry) with an average grain size of 10.0 ϕ, and are on average 3.0 mm thick. The upper contacts of the clay laminae are sharp, with the lower contacts displaying a gradation into silty sediments. The silts are fine grained ($\bar{\phi}$=7.30 ϕ), pale yellow (2.5Y 7/4, Munsell, dry), poorly sorted (σ= 1.54 ϕ) and finely laminated (less than 1.0 mm). Individual beds have an average thickness of 1.50 cm. Lower contacts show a gradation into the coarser grained sandy silts. These medium to coarse grained sandy silts ($\bar{\phi}$=5.20 ϕ) are light brownish grey (2.5Y 5/2, Munsell, dry), poorly sorted (σ=1.30 ϕ), finely laminated (less than 1.0 mm) and contain minor sand-sized grains of muscovite. These thicker beds of sand ($\bar{x}$=2.50 cm) form the base of the rhythmite triplets, which have an average thickness of 3.50 cm. X-ray diffraction analysis indicates a similar composition for each of the rhythmite members. Quartz is the most abundant mineral component, with calcite, dolomite and minor amounts of orthoclase and albite.

The rhythmites from a depth of 5.0 to 15.0 m are

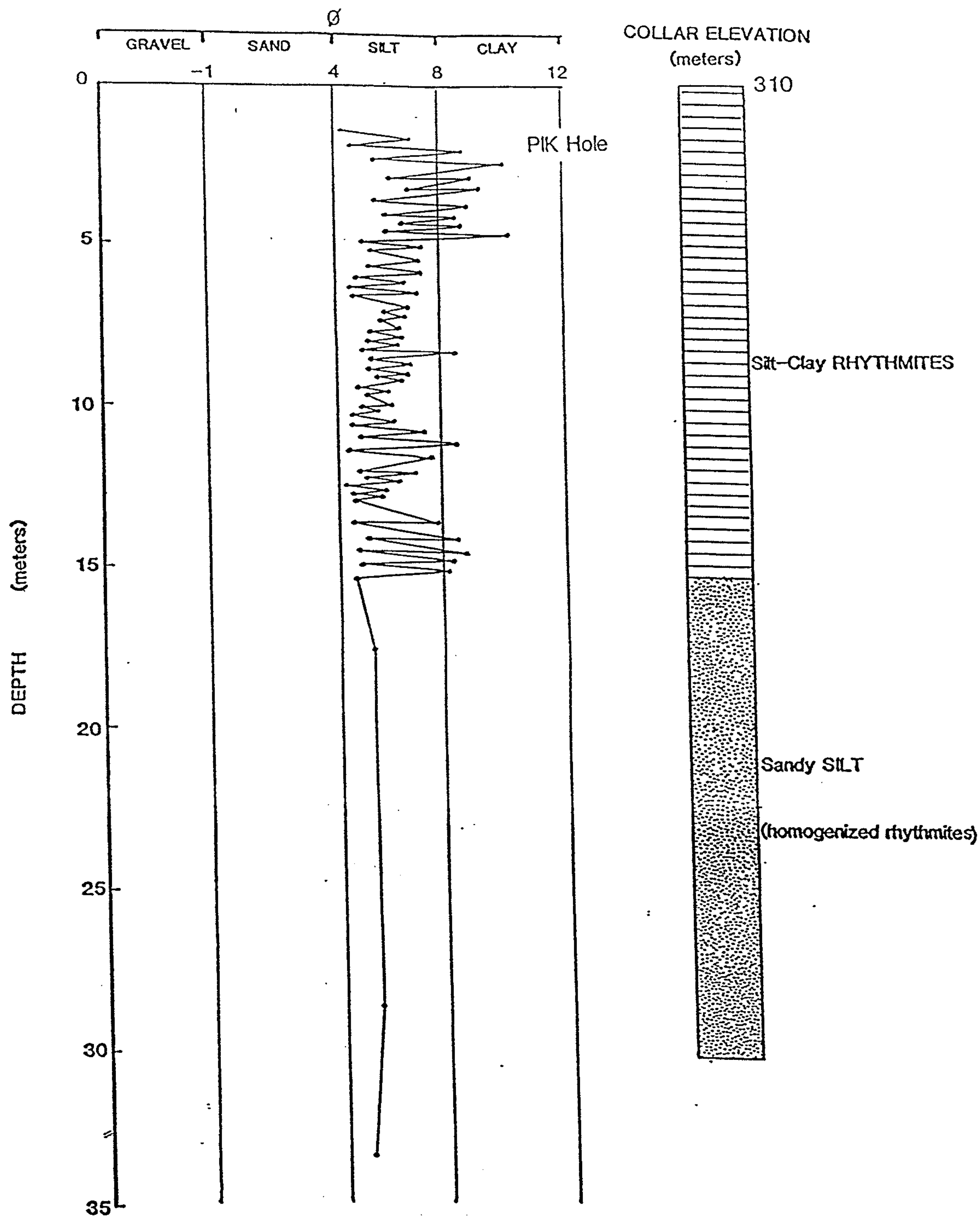

FIGURE 6
Grain Size Trends and Stratigraphy of the PIK Borehole

identical in colour and mineralogy to the overlying rhythmites, although the rhythmically bedded nature of these sediments is not as clearly developed. The fine clay laminae is frequently absent, resulting in a couplet instead of a triplet, and its thickness is highly variable, ranging from 1.0 to 6.0 mm. The average grain size of these clays ($\bar{\phi}$=8.60 ϕ) is coarser than the clays of the overlying rhythmites. Thicknesses of the beds of fine to medium grained silt ($\bar{\phi}$=6.30 ϕ) average 4.0 cm. These silty sediments are finely laminated (less than 1.0 mm) and display minor bioturbation mottling. The basal member of the rhythmites is poorly sorted (σ=1.30 ϕ), sandy medium to coarse grained silts ($\bar{\phi}$=5.0 ϕ). Average thicknesses of these sandy silts is approximately 7.0 mm.

At a depth of 14.0 to 15.0 m, the sediments are composed of thickly bedded ($\bar{x}$=5.0 cm), light grey (5Y 7/1, Munsell, dry) massive and ripple laminated, micaceous fine grained sands ($\bar{\phi}$=2.50 ϕ). Basal contacts of these quartz-rich sands are sharp and erosional as evident by scouring developed within the underlying silty sediments. The upper contacts of the sand beds are also sharp, but do not appear to be erosional.

From 15.0 to 31.5 m, no core was recovered. Split-spoon samples of the sediments in this interval revealed the sediments to be composed of grey (5Y 5/2, Munsell, dry), medium to coarse grained sandy silt ($\bar{\phi}$=5.4 ϕ) that is poorly

poorly sorted (σ=1.60 Ø) and micaceous. Faint laminae are present within these sediments, which are similar to the poorly developed sandy rhythmites at a 14.0 to 15.0 m depth within the PIK core.

The overall grain size for the sediments of the PIK core is fairly uniform (Fig.6). A slight decrease in average grain size for the uppermost 5.0 m of rhythmites is due to the more consistent development of the clay laminae within these rhythmically bedded triplets. The relative absence of the clay laminae within the underlying 26.5 m of the sediments may be the result of erosion, similar to the situation exemplified in the LEE borehole rhythmites.

AIR Hole

The AIR hole was drilled in an open area near the CN railway tracks near the Armstrong airfield (Fig.4; 647726, NTS map 52-I/7). The total depth of the borehole was 25.0 m with a cored interval of only 0.60 m. Samples for the remainder of the borehole were obtained by sampling sediment brought up on the auger flights.

The upper 3.0 m of sediment is composed of massive, brown (10YR 6/3, Munsell, dry) coarse grained, granule-rich sand ($\bar{Ø}$=0.70 Ø) (Fig.7). These sands are well sorted (σ=0.48 Ø) and are composed of 90% quartz, 5% muscovite, 4% biotite, with minor (less than 1%) orthoclase. The granules

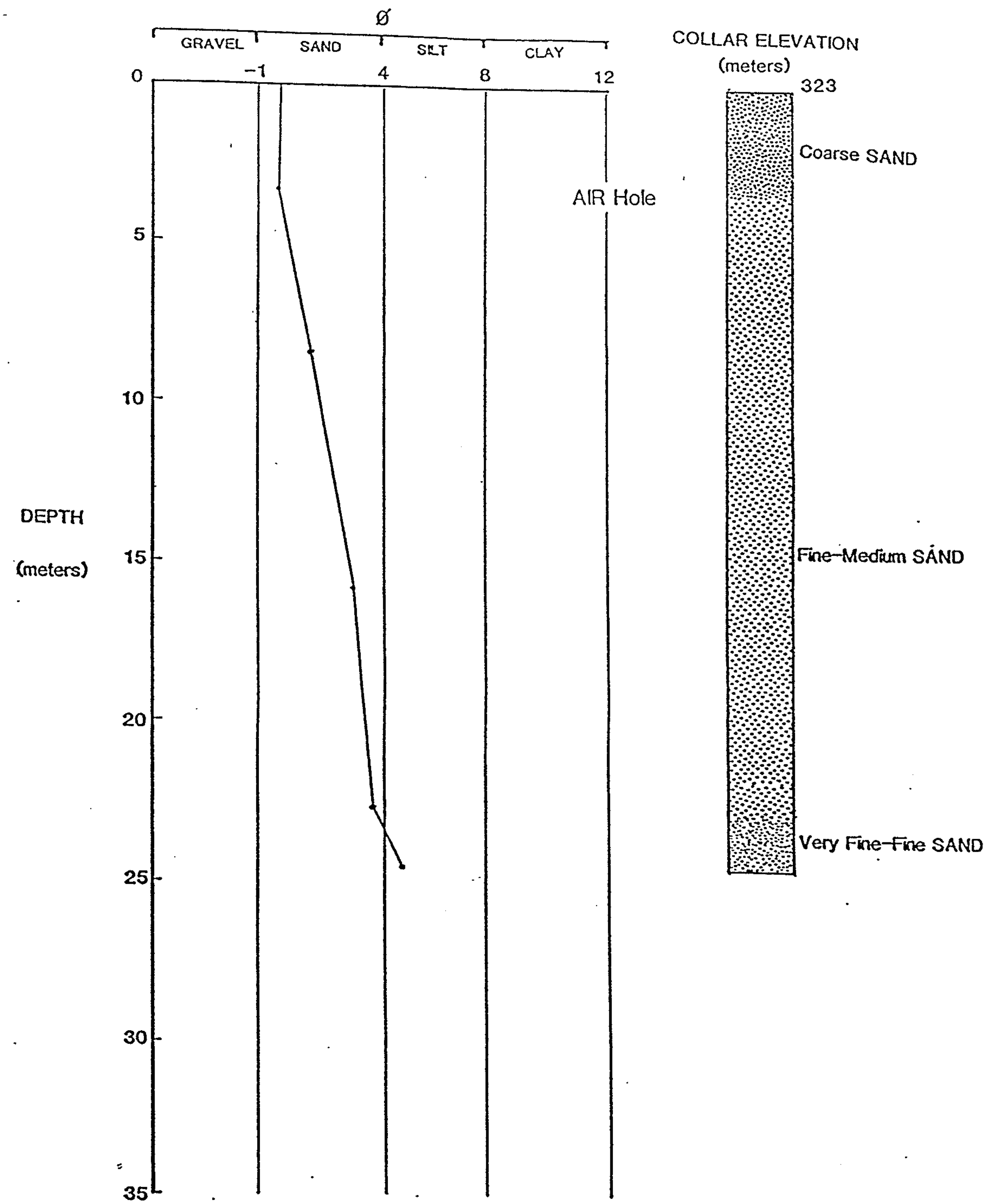

FIGURE 7
Grain Size Trends and Stratigraphy of the AIR Borehole

are well rounded and diabasic in composition.

In the underlying 19.5 m, to a depth of 22.5 m, the sediments are greyish (7.5YR 4.5/, Munsell, dry), fine to medium grained sand ($\bar{\phi}$=2.40 ϕ) that is moderately sorted (σ=0.75 ϕ) and micaceous. These sands are composed of 85% quartz, 4% muscovite, 4% biotite, 3% hornblende, and 2% orthoclase, with minor rounded diabase and quartz granules.

The basal 2.50 m of core is composed of moderately sorted (σ=0.80 ϕ), micaceous, very fine to fine grained sand ($\bar{\phi}$=3.50 ϕ), similar to the overlying 19.5 meters of sediment. Quartz accounts for 85% of these sands, with 5% muscovite, 5% hornblende, 2% orthoclase, and 3% fragments of granite and diabase.

Figure 7 illustrates the overall coarsening-upward-sequence displayed by the sediments of the AIR core.

<u>CAS Hole</u>

The CAS hole was drilled 12.7 km south of the junction of the Castle Lake road and highway 527 (Fig.4; 617607, NTS map 52-I/2). The total depth of the borehole is 30.0 m, with a total cored interval of 12.0 m (Fig.8).

The uppermost 4.0 m of the sediments are rhythmites which can be subdivided into three size members: a basal sandy silt, overlain by medium grained silt and then by fine grained silt. The average thickness of each entire triplet is approximately 4.0 cm.

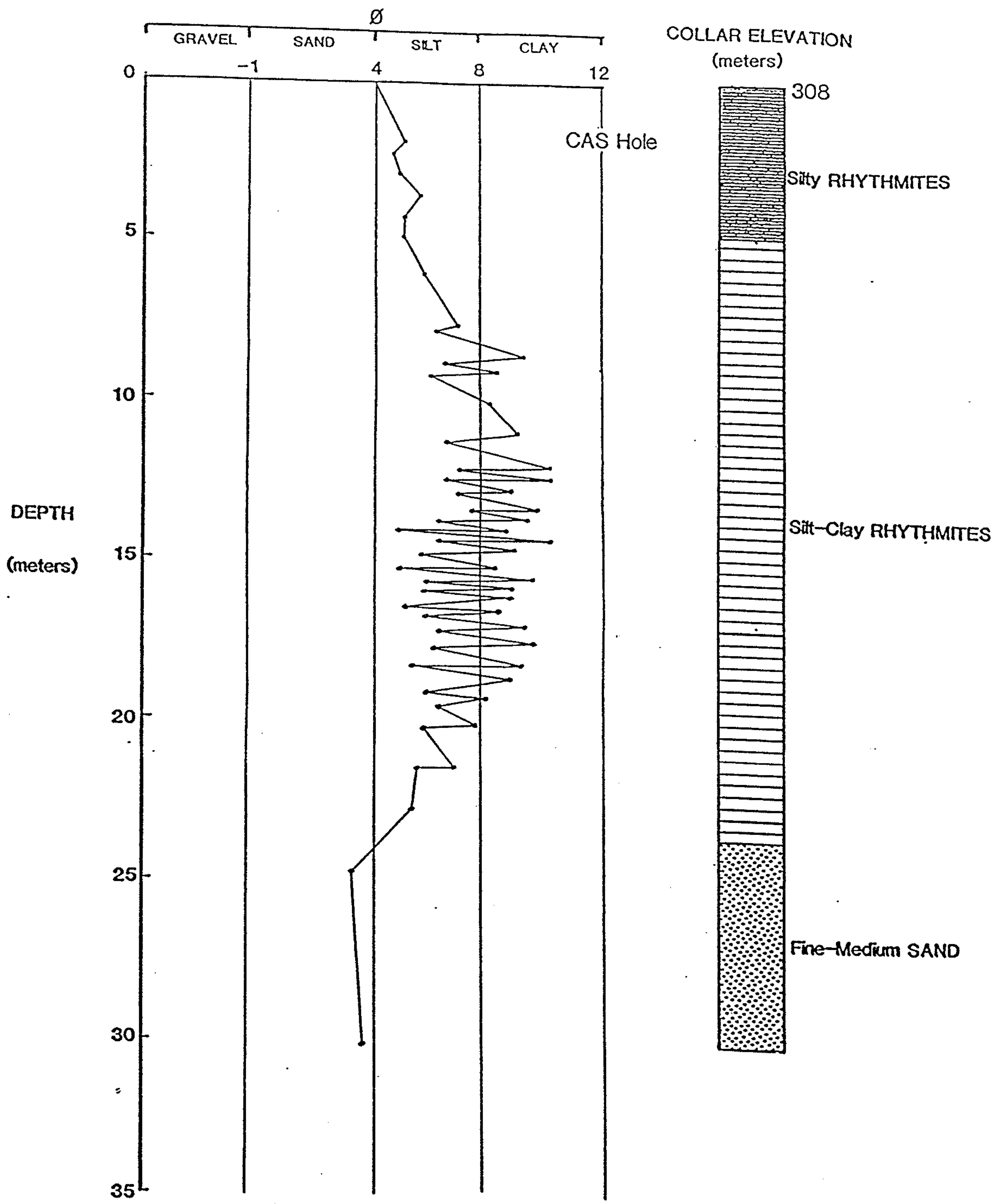

FIGURE 8
Grain Size Trends and Stratigraphy of the CAS Borehole

The sandy sediments of the basal units of these triplets are massive to ripple cross-laminated, olive grey (5Y 5/2, Munsell, dry), moderately sorted (σ=0.70 ϕ), very fine grained ($\bar{\phi}$=4.50 ϕ) sandy silt. Average thickness of the individual beds is approximately 1.5 cm. Lower contacts are erosional and sharp, with upper contacts displaying a gradation from the sandy silts into the overlying more silty sediments.

The sediments forming the middle part of the triplets in the upper 4.0 cm of the section are similar in colour to the underlying part of the rhythmite, but contain little or no sand. These silts are medium grained ($\bar{\phi}$=5.80 ϕ), poorly sorted (σ=1.00 ϕ), finely laminated (less than 1.0 mm) and display bioturbation mottling. The average thickness of this part of the rhythmite is 2.50 cm, and the sediments grade upwards into finer grained silty sediments.

The upper part of the triplets are composed of finely laminated (less than 1.0 mm), light brownish grey (2.5Y 6/2, Munsell, dry), fine to medium grained silt ($\bar{\phi}$=5.20 ϕ). These silty sediments are moderately sorted (σ=0.70 ϕ) and are approximately 1.50 cm thick.

The sandy component of the basal triplet layers is composed entirely of quartz. X-ray diffraction analysis of the silts of the rhythmites indicates that these sediments are composed of quartz, calcite, and dolomite with minor amounts of orthoclase and albite.

From a depth of 4.0 to 23.0 m, the sediments are composed of rhythmically bedded clay, clayey silt, and silt, with rare sandy interbeds. The average thickness of these triplets also increases with depth. At a depth of 4.0-20.0 m, the triplets are 3.50 cm thick. From a depth of 20.0-23.0 m, the average thickness of the triplets increases to 6.00 cm. The basal layers of these rhythmites are finely laminated (less than 1.0 mm), grey (5Y 5/1, Munsell, dry), medium grained silt ($\bar{\emptyset}$=5.40 $\emptyset$), with a variable thickness averaging 2.0 cm and a maximum thickness of 7.0 cm. These silts are moderatley sorted (σ=0.85 $\emptyset$).

The middle part of these rhythmites is composed of finely laminated, grey (5Y 5/1, Munsell, dry) clayey silt ($\bar{\emptyset}$=7.00 $\emptyset$). The less than 1.00 mm thick laminae within these poorly sorted (σ=1.60 $\emptyset$) sediments are distorted as a result of bioturbation. The beds of clayey silt maintain a uniform thickness of approximately 5.00 mm.

Dark grey (5Y 4/1, Munsell, dry) clayey sediments ($\bar{\emptyset}$=9.80 $\emptyset$) form the upper part of the rhythmites. The average thickness of these massive clay beds is 3.0 mm.

Very fine grained ($\bar{\emptyset}$=3.60 $\emptyset$) massive, grey (5Y 5/1, Munsell, dry) beds of quartz-rich sand are developed within some of the rhythmites of clay, clayey silt, and silt. These well sorted (σ=0.40 $\emptyset$) sands are composed primarily of quartz, with minor amounts of muscovite. The average thickness of the sandy beds is 5.0 mm. Basal contacts are sharp and erosional. The distribution of these sandy interbeds is sporadic within the upper part of the rhythmite sequence (4.0-20.0 m). Within the lower 3.0 m (20.0-23.0 m), the thickness and number of sand interbeds appears to increase.

The basal 7.0 m of the CAS hole sediments are composed of light grey (5Y 7/1, dry), finely laminated, moderately sorted (σ=0.73 Ø) quartz-rich, very fine to fine grained sands ($\bar{Ø}$=3.80 Ø). These sediments also contain minor amounts of muscovite and hornblende grains which form the less than 1.00 mm thick laminae. Thin (4.00 mm) sandy interbeds similar to those developed within the rhythmites are also present within these basal sandy sediments.

Figure 8 illustrates the variations in mean grain size of the sediments of the CAS hole.

KOP Hole

The KOP hole was drilled near the junction of highway 527 and the Kopka Lake access road (473375, NTS map 52-H/14). The total depth of the borehole was 19.0 m, with a total cored thickness of 8.5 m (Fig.9).

The upper 3.0 m is composed of rhythmites of clay and silt that average 2.0 cm in thickness. The silty portions form the base of the couplets and are light brownish grey (2.5Y 6/2, Munsell, dry), very fine to fine grained silt ($\bar{Ø}$=7.50 Ø). The sediments are poorly sorted (σ=1.60 Ø),

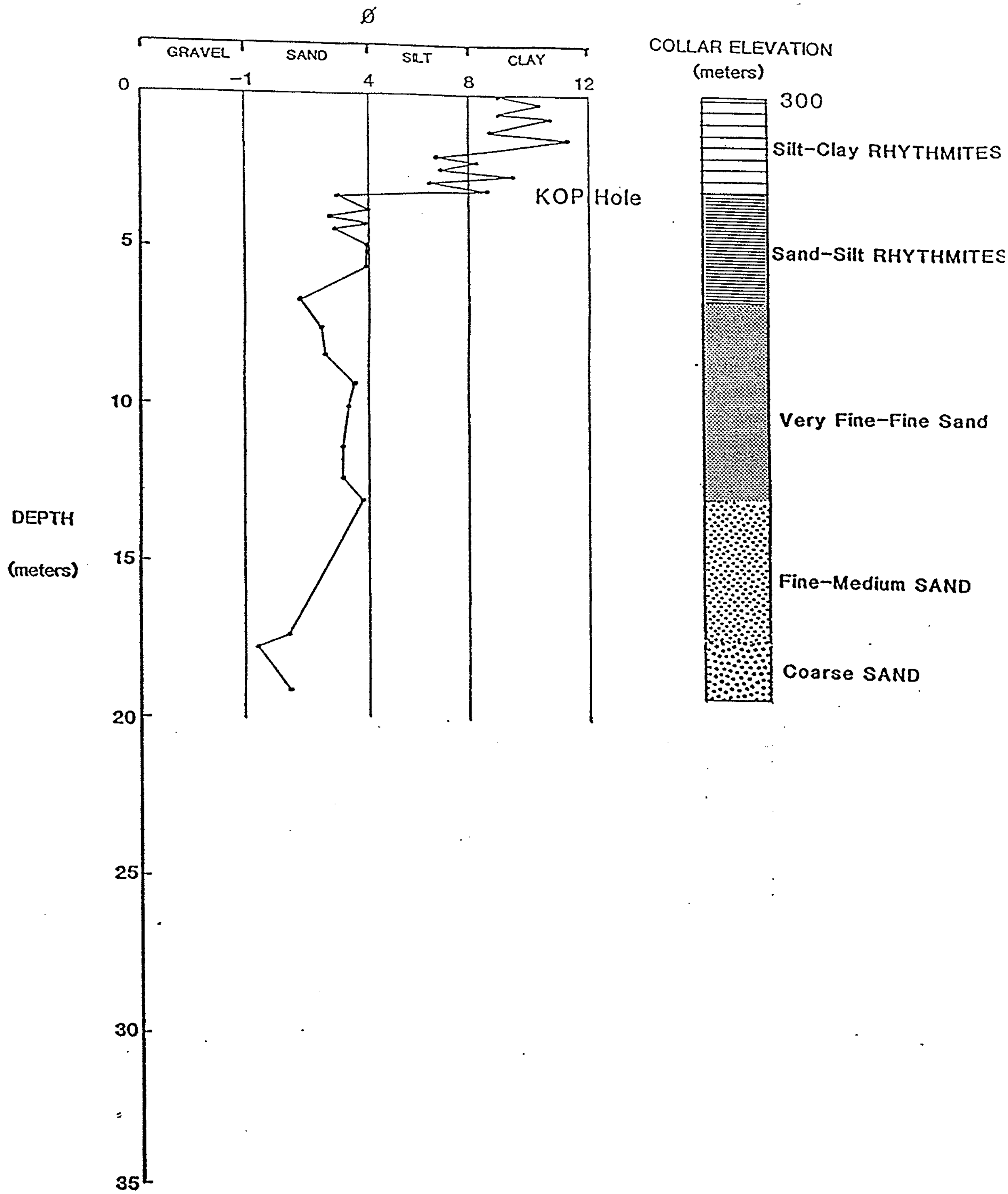

FIGURE 9
Grain Size Trends and Stratigraphy of the KOP Borehole

massive to finely laminated, and have an average thickness of 1.5 cm. Bioturbation is evident within these sediments. The basal contacts of the silty part of the rhythmites are sharp and characterized by thin (less than 1.0 mm) muscovite-rich silty laminae which form parting surfaces between the couplets. Upper contacts show a grading from these silts into the overlying clayey sediments. The finer part of each couplet is composed of dark greyish brown (2.5Y 4/2, Munsell, dry), very poorly sorted (σ=2.40 ϕ) clay ($\bar{\phi}$=8.80 ϕ). The clay laminae have an average thickness of 3.0 mm.

From a depth of 3.0 to 6.5 m, the sediments are sandy and silty rhythmites, with an average thickness of 3.5 cm. The basal members of the couplets are finely laminated, light brownish grey (2.5Y 6/2, Munsell, dry), moderately sorted (σ=0.70 ϕ), very fine to fine grained sand ($\bar{\phi}$=3.00 ϕ). These sandy sediments are composed primarily of quartz, with the fine laminae composed of concentrations of muscovite. Individual beds have an average thickness of 2.0 cm. Basal contacts are fairly sharp with the upper contacts showing a gradation into the finer grained silty sediments of the upper part of the couplet. The upper part of each couplet is composed of finely laminated, olive grey (5Y 5/2, Munsell, dry), well sorted (σ=0.40 ϕ), coarse grained silt ($\bar{\phi}$=4.10 ϕ). Thin (2.00 mm) laminae of micaceous sand, similar to the basal couplet sands are developed within these silty sediments. The average thickness of these silty beds is 2.0 cm.

The underlying 6.0 m (6.5 to 12.5 meter depth) of sediment is composed of laminated, light brownsih grey (2.5Y 6/2, Munsell, dry) sand. These very fine to fine grained sands ($\bar{\phi}$=3.30 ϕ) are moderately sorted (σ=0.63 ϕ), and similar to those sands forming the basal parts of the overlying rhythmite couplets. Quartz accounts for 90% of the sand composition, with 5% muscovite, 3% hornblende, and 2% biotite. The quartz grains are angular to subrounded.

From a depth of 12.5 to 17.0 m, the sediments of the KOP hole are composed of massive, olive brown (2.5Y 4/4, Munsell, dry), fine to medium grained ($\bar{\phi}$=2.10 ϕ), poorly sorted (σ=1.53 ϕ) sand. At the base of this 4.5 m thick sequence of sand, a single rounded diabase pebble (2.0 cm diameter) was found. The sands are composed of 88% quartz, 5% muscovite, 3% hornblende, and 2% biotite, with accessory fragments of grainite and diabase. The basal contact of this unit of massive sand is gradational.

The lowermost 2.0 m of the KOP hole sediments are composed of massive, olive brown sands similar to the overlying sandy sediments. These medium to coarse grained ($\bar{\phi}$=1.26 ϕ) sands are moderately sorted (σ=0.80 ϕ) and appear more "granitic" in composition. Quartz accounts for 90% of the composition of the sands, with 5% muscovite, and 5% orthoclase, with minor biotite grains.

X-ray diffraction analysis of samples of the clays and silts of the KOP core reveals that these finer grained sediments are composed predominantly of quartz, with calcite, dolomite, albite, and minor amounts of orthoclase feldspar.

Figure 9 illustrates the general fining-upward-sequence displayed by the sediments of the KOP hole.

RES Hole

The RES hole was drilled along the road leading into the town of Gull Bay, approximately 1.0 km west of the town site (Fig.4; 474180, NTS map 52-H/14). The depth of the borehole was 12.0 m, with a total cored thickness of 4.0 m. An exposure with a 4.0 m thick sequence (site 86-16) of planar bedded and ripple cross-laminated, light brownsih grey (2.5Y 6/2, Munsell, dry) fine grained sands, lay conformably above the sediments of the RES core (Fig.10).

The upper 11.5 m of the borehole sediments are rhythmites of sand and silty sand which have an average thickness of 4.0 cm. The basal parts of the couplets are massive to ripple cross-laminated, greyish brown (2.5Y 5/2, Munsell, dry), moderately well sorted (σ=0.70 ϕ), very fine grained ($\bar{\phi}$=3.30 ϕ) micaceous sand. Mineralogically, these sediments are composed of 90% quartz, 5% muscovite, 3% hornblende, and 2% orthoclase. The average thickness of the individual sandy beds is 2.0 cm. The basal contacts are

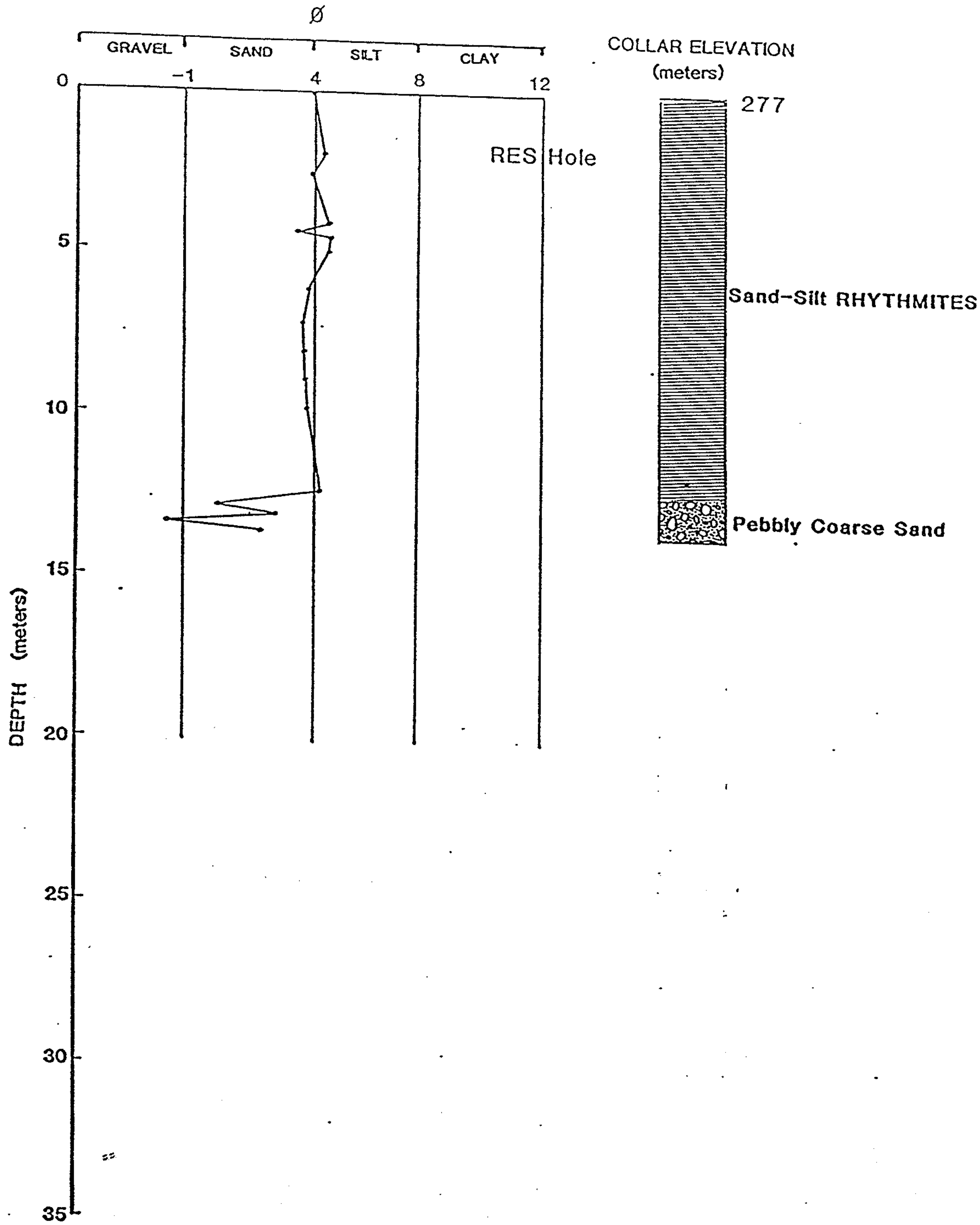

FIGURE 10
Grain Size Trends and Stratigraphy of the RES Borehole

gradational, as are the upper contacts which show a fining of these very fine grained sands into beds of silty sand.

The upper part of each couplet is composed of massive to planar laminated, dark greyish brown (2.5Y 4/2, Munsell, dry), moderately well sorted (σ=0.70 ϕ), silty very fine grained ($\bar{\phi}$=3.90 ϕ) sand. These finer sandy sediments are similar in composition to the underlying basal sands. Thickness of the individual silty sand beds is approximately 2.0 cm.

The lowermost 0.5 m of the RES hole sediments are composed of massive, olive grey (5Y 4/2, Munsell, dry), pebbly, silty coarse grained sand ($\bar{\phi}$=-1.00 ϕ). These sediments are very poorly sorted (σ=3.10 ϕ). Cobble size clasts, too large to be sampled by coring, were encountered at these depths while drilling and suggest an even greater range in sediment sizes than that determined from the samples obtained. The composition of the sand size and coarser grained fraction is 95% diabase, and 5% granitic rock fragments. These sediments are possibly reworked deposits of the Nipigon Moraine, based upon the poorly sorted nature and predominantly diabasic composition of the sediments.

Figure 10 illustrates the general fining-upward-sequence displayed by the sediments of the RES core.

NATURAL AND MAN-MADE EXPOSURES OF SAND AND COARSER GRAINED SEDIMENTS

Seventy samples of near surface sand and coarser grained sediments were collected from exposures of fluvio-lacustrine deposits along highway 527 from Kabitotikwia Lake north to Armstrong and the Jojo Lake area (Fig.11). Sixteen representative samples were selected and analyzed in order to distinguish mineralogical and textural trends in the sediments of the region.

The sediments were deposited at the mouths of the five Lake Agassiz eastern outlet channels (Fig.12). Although some of the sands in this area have been reworked by wind forming the dune fields of the northern Lake Nipigon basin, all analyzed samples show bedding characteristics of either nearshore or fluvial conditions.

Mineralogically, all of the samples contain high percentages of quartz, ranging from 80% to 96%. Grains of hornblende, biotite, and, in smaller percentages, muscovite and carbonate fragments make up the remainder of the sample composition. Percentages of quartz and mafic grains were determined for the 16 samples, and the results plotted (Fig.11). The clustering of the data points suggests a high degree of chemical maturity for the entire sample spectrum. The surfaces of some of the quartz grains are pitted, the result of mechanical abrasion. The individual grains range

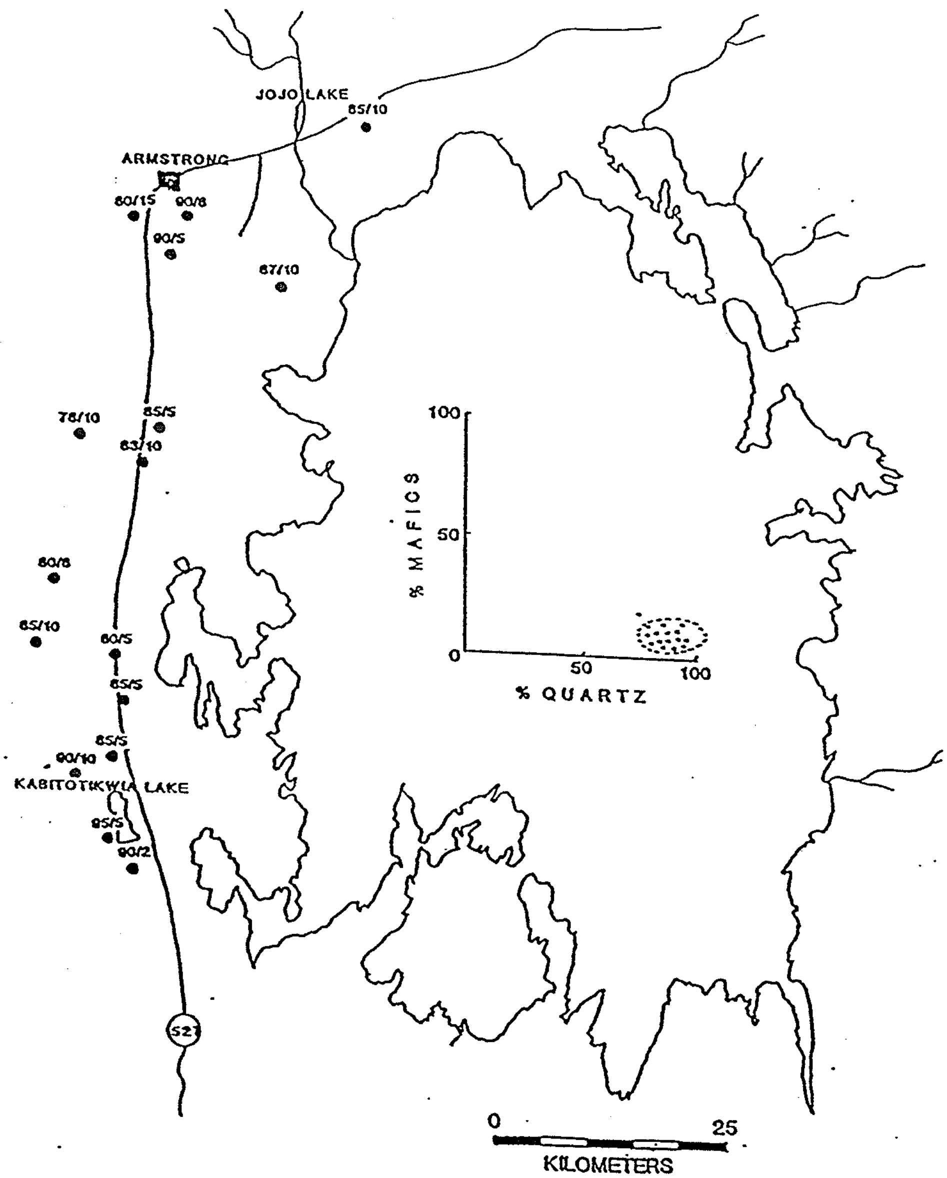

FIGURE 11
Sample Locations and Chemical Maturity of Sandy Sediments Shown by Quartz/Mafic Ratios and Plot

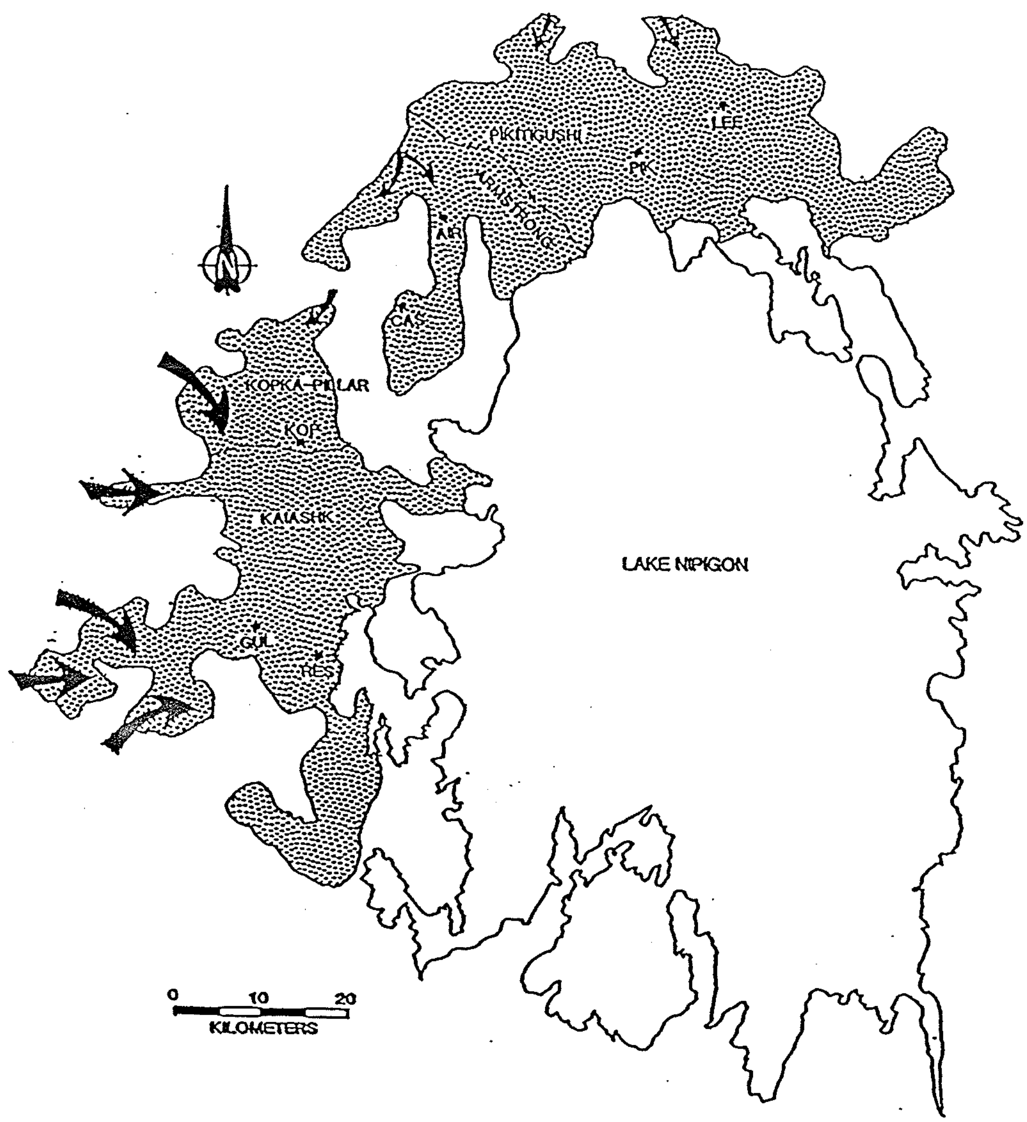

FIGURE 12
Lake Agassiz Eastern Outlet Deltaic Deposits
(arrow sizes proportional to discharge magnitude)
(after Zoltai, 1965a)

from very angular to well rounded. Hornblende grains are generally angular.

DESCRIPTION OF SILT-CLAY RHYTHMITES

Introduction

Samples of rhythmites were obtained from wave-cut outcrops along the western and northwestern shoreline of the lake (Fig.13), as well as from the KOP, CAS, PIK, and LEE cores previously described. The colour of the rhythmites from the Gull Bay, Pike Bay, and English Bay regions are various hues of reddish brown. This probably results from oxidation of iron-bearing minerals (hornblende, biotite) in the silts and clays derived from the bedrock and diabase-rich tills of the southwestern region of the drainage basin (Miller, 1983). The predominantly granitic lithology of the bedrock and glacial deposits of the northern Lake Nipigon and adjacent Lake Agassiz basins results in the greyish colours observed in the rhythmites of the remaining area of the basin.

Gull Bay X-2

The Gull Bay X-2 site reveals a 9.0 m thick sequence of rhythmically bedded triplets of silt, and clayey silt. The basal rhythmite layers are composed of faintly laminated, greyish (5Y 5/1, Munsell, dry), fine grained silt ($\bar{\phi}=6.90\ \phi$) which grades upward into light greyish (5Y 4.5/1, Munsell, dry) slightly clayey, fine grained silt ($\bar{\phi}=7.50\ \phi$) (Fig.14). The uppermost parts of the rhythmite are composed of dark olive grey (5Y 4/2, Munsell, dry) clayey silt ($\bar{\phi}=8.20\ \phi$) which have a greater clay content in comparison

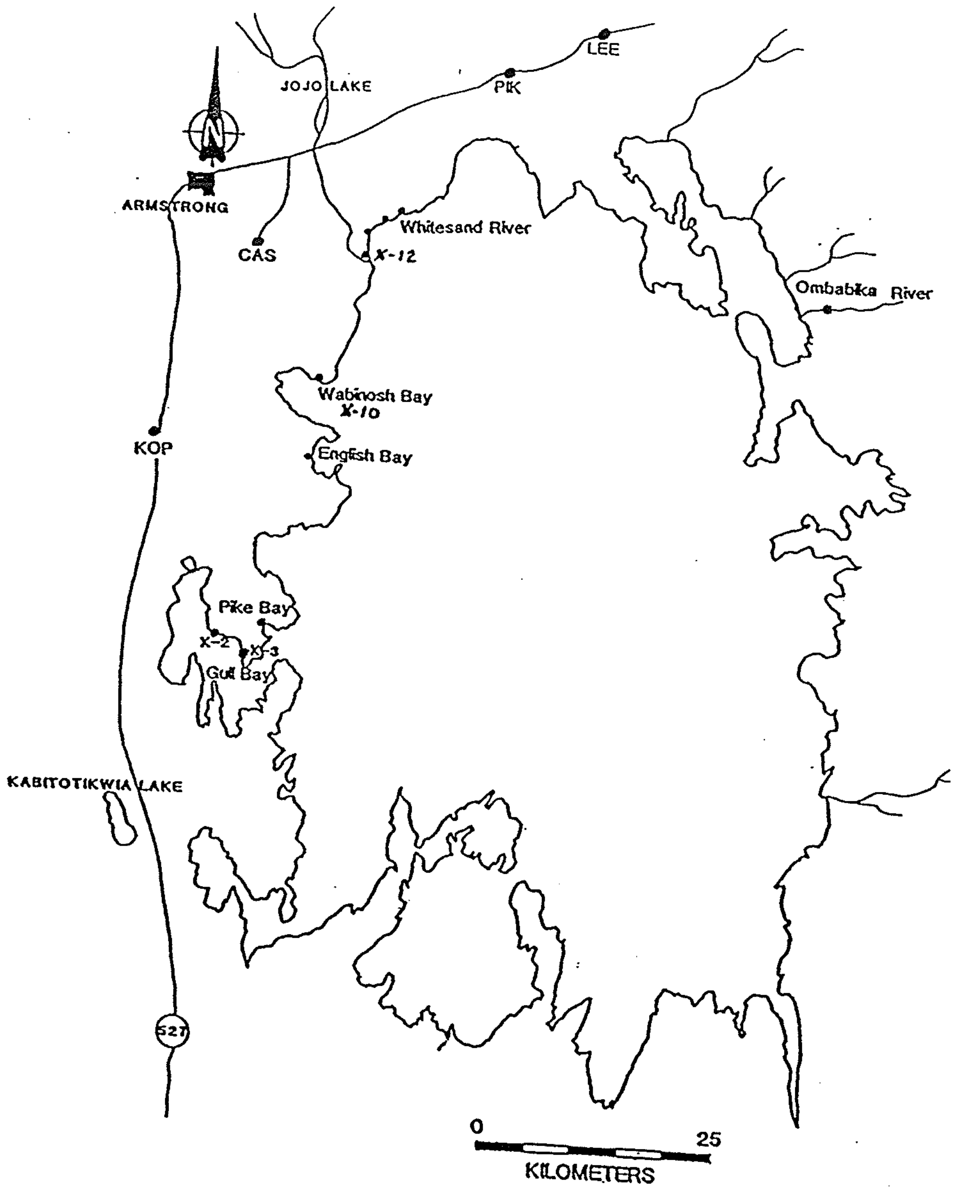

FIGURE 13
Sample Locations of Rhythmite Sediments

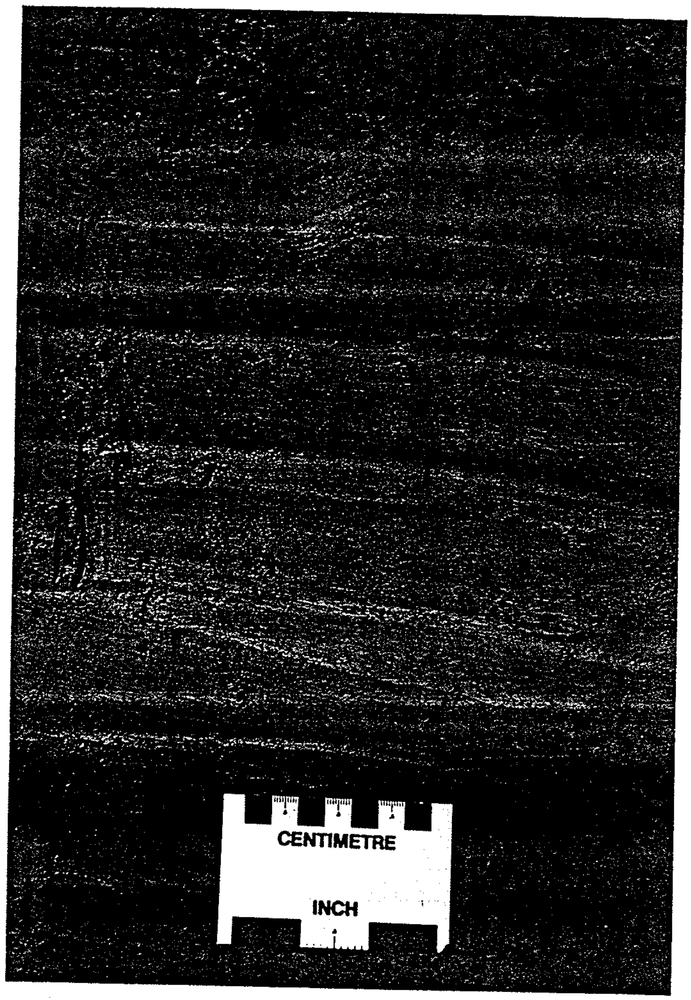

FIGURE 14
Gull Bay X-2 Silt and Clayey Silt Rhythmites
(3.0 meters above lake level)

to the underlying clayey silts. Thicknesses of the individual rhythmite units are variable. The basal fine grained silts form beds with an average thickness of 3.0 cm. The overlying clayey silts form 3.0 mm thick laminae. An average of 30 rhythmites per meter were counted at the exposure of sediment at the Gull Bay X-2 site.

Gull Bay X-3

The sediments of the 6.0 m thick exposure at the Gull Bay X-3 site are similar to the multiple graded silts of the Gull Bay X-2 exposure (Fig.13). The laminated nature of these rhythmites (Gull Bay X-3) is more strongly developed and more readily observable. Thin (0.5 mm) interbedded light grey (5Y 7/2, Munsell, dry), fine grained ($\bar{\phi}=9.60\ \phi$) and medium grained ($\bar{\phi}=6.70\ \phi$) silty laminae form the basal layers which are capped by thin (1.0-2.0 mm), yellowish brown (10YR 5/4, Munsell, dry), silty clay ($\bar{\phi}=10.5\ \phi$) (Fig. 15). The average thickness of the individual rhythmites is approximately 2.5 cm, with 60 rhythmites counted over a 1.0 m thickness. An average of 35 individual laminae were counted within each of the silty rhythmite units. Type A and type B ripple-drift cross-lamination are developed within the rhythmites. These ripple cross-laminated sediments are slightly coarser grained than the planar laminated silts, as evident by a minor sand content. Type A ripple-drift cross-laminae consist of climbing sets of lee-side laminae with no preservation of the stoss-side laminae.

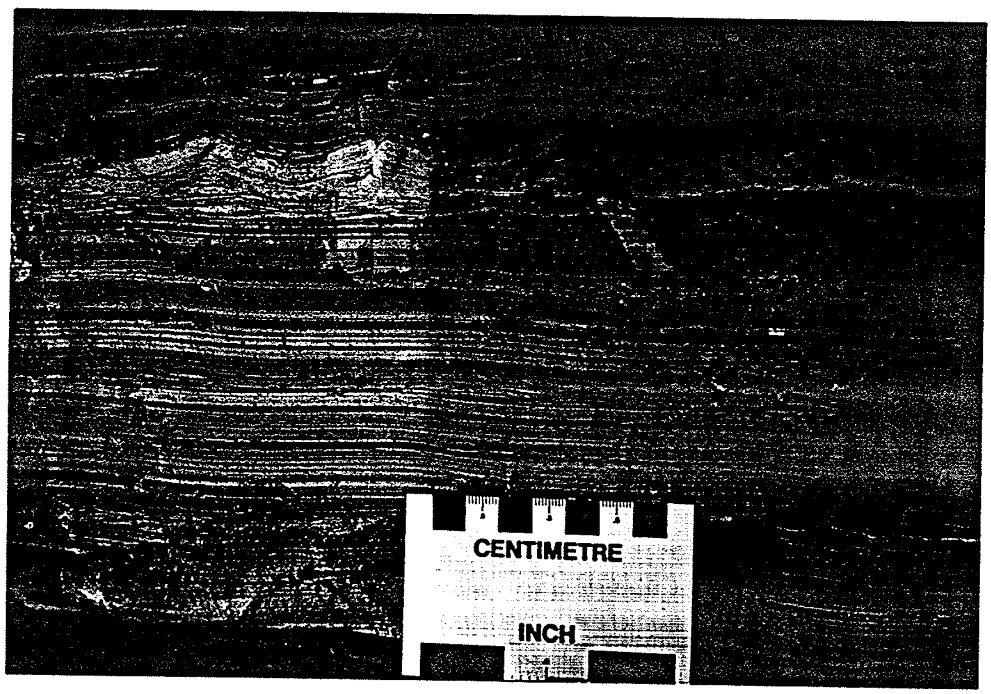

FIGURE 15
Gull Bay X-3 Multilaminated Silty Rhythmites
with Thin Clay Laminae
(5.5 meters above lake level)

The type B classification is applied to ripples exhibiting the preservation of both lee and stoss-side laminae (Jopling and Walker, 1968).

Schlosser (1983) describes varves observed from exposures near the Gull Bay X-2 and X-3 sites as dark brown (10YR 4/2 and 7.5Y 4/4) varves and grey (5Y 4/1 and 5Y 5/1) varves.

Pike Bay

The sediments exposed at the 2.5 m thick Pike Bay site are rhythmically bedded couplets of massive to fine laminated, light greyish brown (10YR 6/2, Munsell, dry) clayey silt ($\bar{\phi}$=9.30 ϕ) and yellowish brown (10YR 5/4, Munsell, dry) slightly silty clay ($\bar{\phi}$=10.9 ϕ) (Fig.16). The clayey silt layers form the basal members of the couplets and have an average thickness of 10.0 mm. Individual laminae within these silty sediments are less than 1.0 mm thick, and are often distorted due to bioturbation of the sediments. The overlying silty clay laminae are in sharp contact with the clayey silts and are thinner in nature with an average thickness of 4.0 mm (Fig.16). These clayey sediments appear massive with no evidence of bioturbation. Ninety rhythmites per meter were counted at the Pike Bay exposure.

English Bay

A 13.0 m thick exposure along the shoreline in English Bay (Fig.13) reveals a sequence of rhythmically bedded

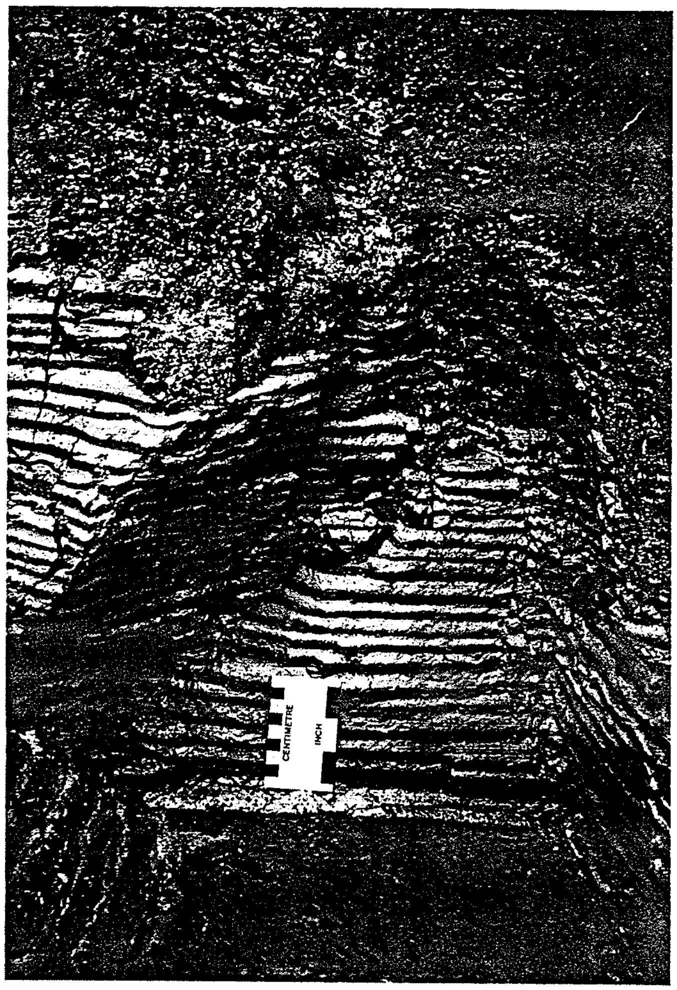

FIGURE 16
Pike Bay Rhythmites
(0.6 meters above lake level)

couplets of clayey silt and slightly silty clay. The basal couplet members are composed of massive to fine laminated, bioturbated, greyish brown (2.5Y 5/2, Munsell, dry), clayey silt ($\bar{\phi}$=8.50 ϕ). These sediments are in sharp contact with the overlying massive dark greyish brown (10YR 4/2, Munsell, dry) slightly silty clay ($\bar{\phi}$=9.95 ϕ). Both couplet members form fairly thin laminae with the basal clayey silt laminae having an average thickness of 7.0 mm, and the overlying silty clay forming laminae 4.0 mm thick. An average of 88 couplets per meter were counted at the English Bay site.

Wabinosh Bay

A wave-cut exposure along the shoreline in Wabinosh Bay, 10.0 km north of English Bay, reveals a 5.0 m thick sequence of rhythmite couplets similar in appearance to the English Bay rhythmites (Fig.17). The basal couplet sediments are intensely bioturbated, greyish brown (2.5Y 5/2, Munsell, dry), clayey silt ($\bar{\phi}$=8.45 ϕ) which form beds with an average thickness of 3.0 cm. These sediments are in sharp contact with the overlying massive, dark greyish brown (10YR 4/2, Munsell, dry) silty clay ($\bar{\phi}$=10.2 ϕ) (Fig.17). The thickness of the silty clay member of the rhythmically bedded couplets is variable, ranging from 4.0 mm to 2.5 cm. Sixty couplets per meter were counted at the Wabinosh Bay site.

Schlosser (1983) described a sequence (site 83 in Schlosser, 1983) of rhythmites in Wabinosh Bay composed of

FIGURE 17
Wabinosh Bay X-10 Rhythmites
(4.0 meters above lake level)

dark brown (10YR 4/3) clay and light brownish grey (2.5Y 6/2) silt.

Whitesand River Cuts

At the mouth of the Whitesand River is a bluff of sediment that extends along the shoreline of Lake Nipigon for approximately 2.0 km (Fig.13). Four different locations were examined along this stretch, and the sediments were analyzed and sampled. The exposure nearest to the mouth of the Whitesand River, site X-12, provides a 23.0 m thick exposure of sediment. The upper 16.0 m of sediments are composed of greyish (5Y 5/1, Munsell, dry) sand.

The basal 7.0 m of the X-12 site reveals a sequence of rhythmically bedded couplets of clayey silt and clay. The basal couplet units are composed of massive, greyish (5Y 5/1, Munsell, dry) clayey silt ($\bar{\phi}$=8.45 ϕ). These sediments grade upward into massive, dark grey (5Y 4/1, Munsell, dry) clay ($\bar{\phi}$=10.8 ϕ). The thickness of the individual couplet members within the X-12 sequence is variable as zones of contorted rhythmites are interbedded with non-deformed rhythmites (Fig.18). The deformed laminae of both the clayey silt and clay have average thicknesses of 3.0 mm. The non-deformed couplets have greater average thicknesses, with the clayey silts forming 1.5 cm thick beds, and the clays forming 7.0 mm thick laminae. An average of forty couplets per meter were counted at the X-12 sequence.

Schlosser (1983) describes a sequence of olive grey

FIGURE 18
Well Developed and Contorted Rhythmites at
Whitesand River X-12 Site
(6.5 meters above lake level)

5Y 5/2) sand overlying rhythmically bedded grey (5YR 6/1) clayey silt and pinkish grey (5YR 6/2) silty clay, exposed along the shoreline of Lake Nipigon (site 81 in Schlosser, 1983) near the X-12 site.

Ombabika River

A 9.0-m-thick sequence of rhythmites lays along the southern bank of the Ombabika River, approximately 3.0 km east of the river mouth at Ombabika Bay (Fig.13). The sediments are rhythmically bedded couplets of massive, light grey (5Y 7/1, Munsell, wet) clay ($\bar{\phi}$=9.80 ϕ) which forms the basal unit, and massive, dark grey (2.5Y N6/, Munsell, wet) clay ($\bar{\phi}$=10.7 ϕ). The contact between the two members, which have uniform thicknesses of 1.5 cm, is sharp.

Thirty couplets per meter were counted within the sequence of rhythmites at the Ombabika River site.

Carbonate and Quartz Content

Both the volume and grain sizes of sediment deposited into the Lake Nipigon basin would have increased during the "summer" period. This resulted from a greater clastic influx to the lake basin via fluvial systems, due to higher precipitation and increased melting rates of ice within the Lake Agassiz and Lake Nipigon drainage basins. Higher wave energy on the unfrozen lake surface would also result in coarser grained silty sediments being deposited within the Lake Nipigon basin during the summer period. In addition, the silt-sized terminal grade for limestone and dolomite, that minimum physical size produced by mechanical abrasion (Dreimanis and Vagners 1971), will cause a greater abundance of carbonate material in the silty sediments as opposed to the clays. Ostrem (1975) suggests that greater amounts of quartz in the coarser grained layers of varved sediments results from a greater influx of detrital sediments to a basin during the "summer" periods. Warmer lake water temperatures with the associated decrease in the solubility of carbonate material, along with the increase in the carbonate material deposited into the lake basin may be reflected in the characteristically higher percentages of calcite and dolomite observed on the diffractograms.

Samples of rhythmites from outcrops and cores were analyzed to determine if any trends in carbonate mineral content exists in the fine or coarse members of the couplets. The samples of the rhythmites were separated into their individual laminae. In analyzing rhythmite triplets of sediment, the clay laminae are regarded as the finer grained members, and the two coarser grained laminae are combined and taken to represent the coarser rhythmite beds. Table 1 lists the results of the carbonate mineral content analyses for the rhythmite sediments of Lake Nipigon basin. The percentage of carbonate material in the sediments at each location is an average value calculated from the number of samples analyzed, with the range of values in the

TABLE 1

Mean Variations of Carbonate Content in the Coarse Grained and Fine Grained Laminae of Lake Nipigon Rhythmites

Location	No. of Samples Analyzed	Carbonate Content Fine (%)	Carbonate Content Coarse (%)
Gull Bay	10	23 (21-28)	40 (35-45)
Pike Bay	5	26 (23-29)	27 (24-31)
Wabinosh Bay	5	33 (29-37)	49 (47-53)
English Bay	4	8 (6-11)	33 (28-36)
KOP	3	30 (9-32)	41 (34-46)
CAS	20	29 (25-37)	38 (30-43)
Whitesand River	10	15 (9-21)	20 (5-26)
LEE	5	59 (53-64)	28 (26-29)
PIK	13	26 (21-30)	39 (35-45)
Ombabika River	6	23 (18-27)	45 (38-51)

sediments shown in parentheses. With the exception of the sediments at Pike Bay, and those from the LEE core, the carbonate mineral content of the coarser members of the rhythmites is consistently greater than that of the finer grained layers. X-ray diffraction analysis of the rhythmites also produces data in regard to the depositional origin of these sediments. Figure 19 illustrates typical diffractograms for the rhythmite units. Of particular interest are the high intensity (Io) peaks for quartz (3.35 Å), calcite (3.04 Å), and dolomite (2.89 Å), indicating that these minerals are relatively the most abundant.

The results of the total carbonate content analysis of the Lake Nipigon rhythmites, and the x-ray diffractograms produced, suggest that these rhythmically bedded silts and clays are varves. Greater calcite, dolomite, and quartz contents are observed for the coarse grained units as opposed to the finer grained clayey sediments. An increased clastic influx to the lake basin during the summer period results in greater amounts of silt, which contains more calcite, dolomite, and quartz, being deposited during this time as opposed to clay.

In a more detailed XRD analysis of the Lake Nipigon rhythmites, Schlosser (1983) obtained similar results. In all of the sediments analyzed, the quartz, calcite, and dolomite contents are consistently greater in the coarser grained members of the rhythmites than in the finer grained

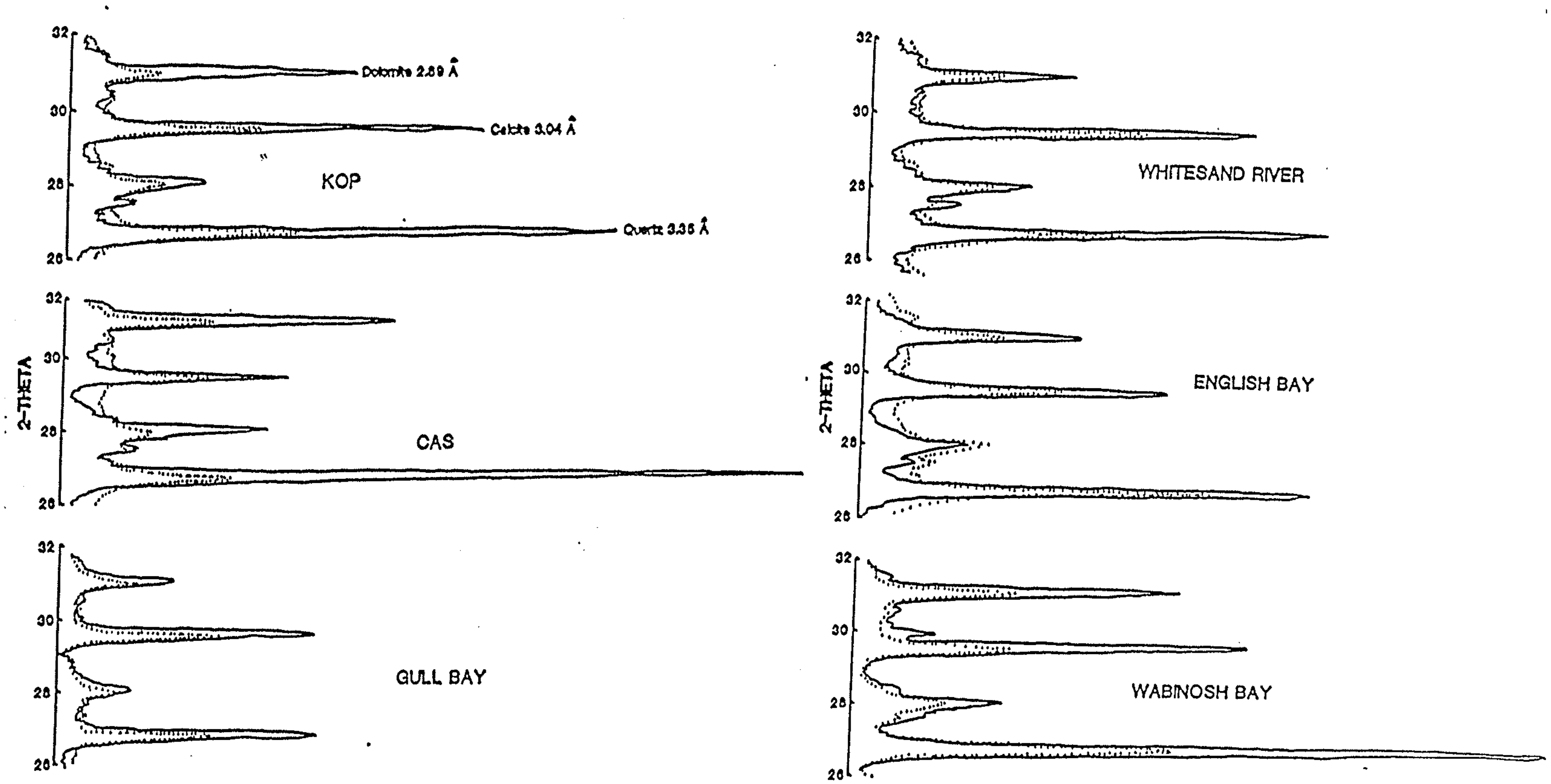

FIGURE 19
Representative X-Ray Diffractograms of Lake Nipigon Rhythmites (solid line refers to coarse grained part, dashed line to fine grained part).

parts.

Statistical Parameters

In studying varved sediments of Glacial Lake Hitchcock, Ashley (1975) concluded that the individual summer and winter varve members form distinct "fields" when the mean grain sizes and the degrees of sorting are plotted against each other (Fig.20 a).

Plotting these two statistical parameters for the rhythmites of the PIK, CAS, KOP, and RES cores, and samples from Gull Bay, Whitesand River, and Ombabika River outcrops, produces similar results (Fig.20 b). Cross-laminated sandy silts, fine to coarse grained silts, and clayey sediments in the Lake Nipigon basin form distinct fields similar to those generated for Glacial Lake Hitchcock. Although the dimensions of the fields are not identical, the general position and trends are similar. The distinct separation between the classical summer and classical winter fields suggests that these two rhythmite units are formed by distinctly different modes of deposition. This consistent repetition of sedimentological processes is best exemplified by the annual climatic cycle rather than by the diurnal cycle or random storms (Ashley, 1975).

Similarily, distinct fields or patterns were obtained when the mean grain sizes were plotted versus skewness for the varves of Glacial Lake Hitchcock (Fig.21 a). In plotting the textural data of the Lake Nipigon rhythmites,

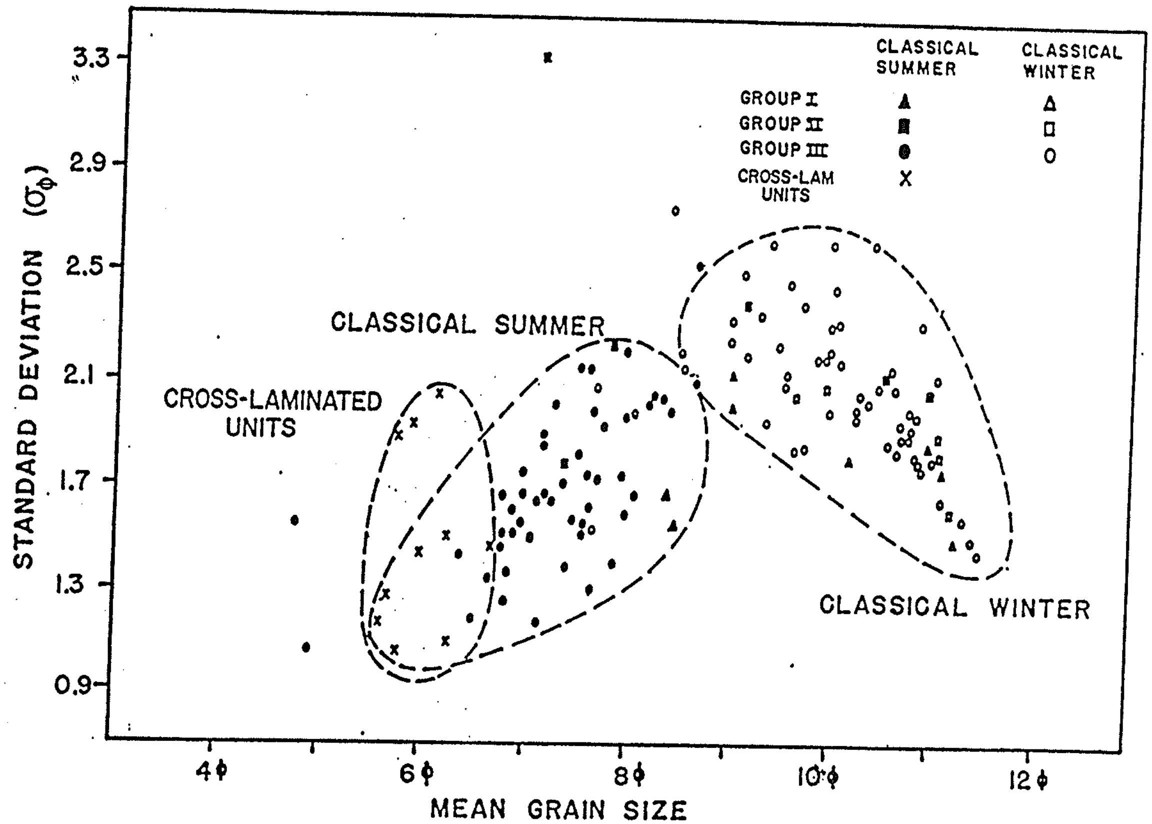

FIGURE 20a
Standard Deviation Versus Mean Grain Size for Glacial Lake Hitchcock Rhythmites
(from Ashley, 1975)

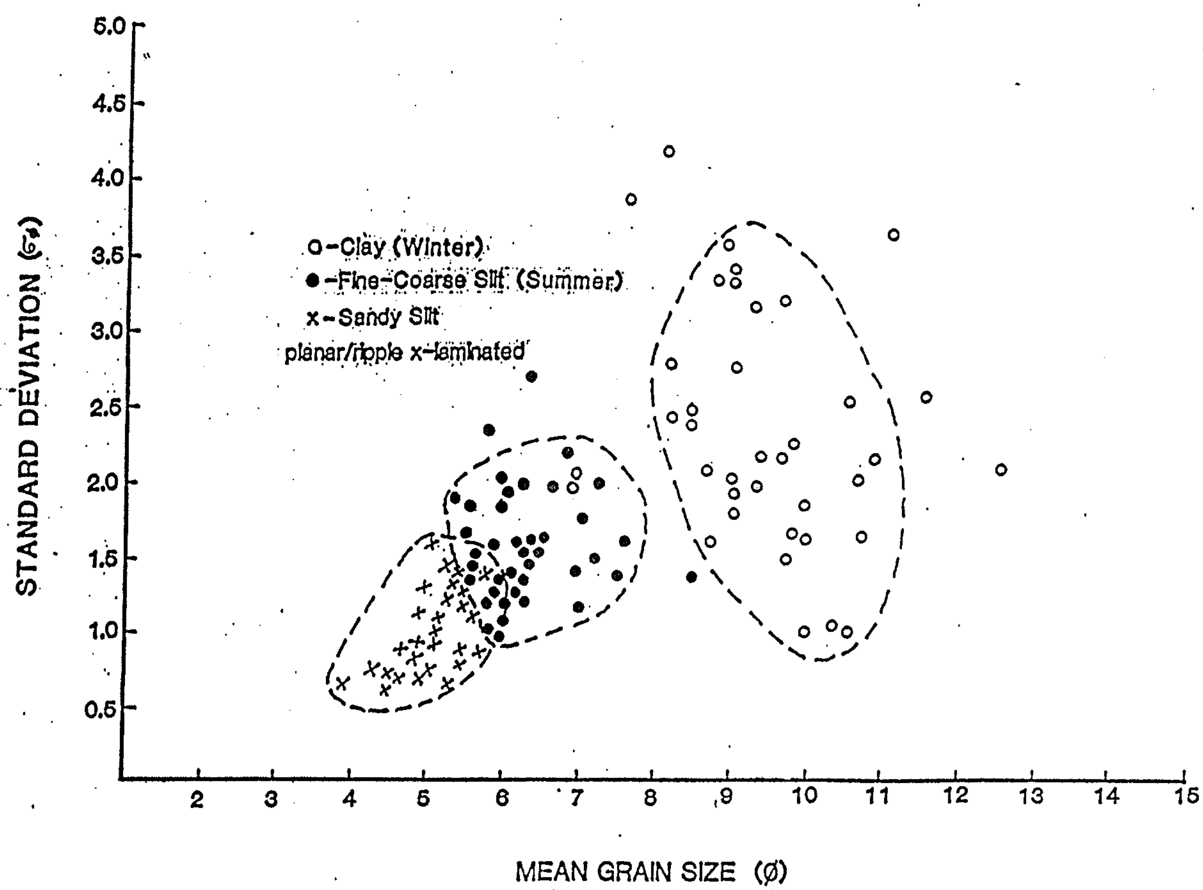

FIGURE 20b
Standard Deviation Versus Mean Grain Size for Lake Nipigon Rhythmites

similar results are obtained (Fig.21 b).

Positive skewness (excess fine grained sediment about the mean) results from the continuous settling of clays interrupted by periodic influxes of coarser grained sediments, or from clay sized sediments contained within turbidity flows deposited along with the coarser sediments (Ashley, 1975). A combination of these two processes can also produce positively skewed sedimentary deposits. Negative skewness (excess coarse grained sediment about the mean) is generally the result of bioturbation (Ashley, 1975).

The position of the "Nipigon line" separating the classical winter and classical summer fields is plotted to the left of that for Glacial Lake Hitchcock. This "shift" of the line results from the generally coarser grained nature of the Lake Nipigon rhythmites in comparison to the varves of Lake Hitchcock. The tight clustering observed for the cross-laminated sandy silts and fine to coarse grained silts (SK=+0.4) and the overlapping of the two rhythmite members suggests a common mode of deposition. The distinct fields created by the finer grained clayey sediments indicates that these deposits were formed in response to separate depositional processes. Some bimodality (mixing) is observed between the classical winter and summer sediments, the result of bioturbation and/or the co-deposition of the finer and coarser grained sediments.

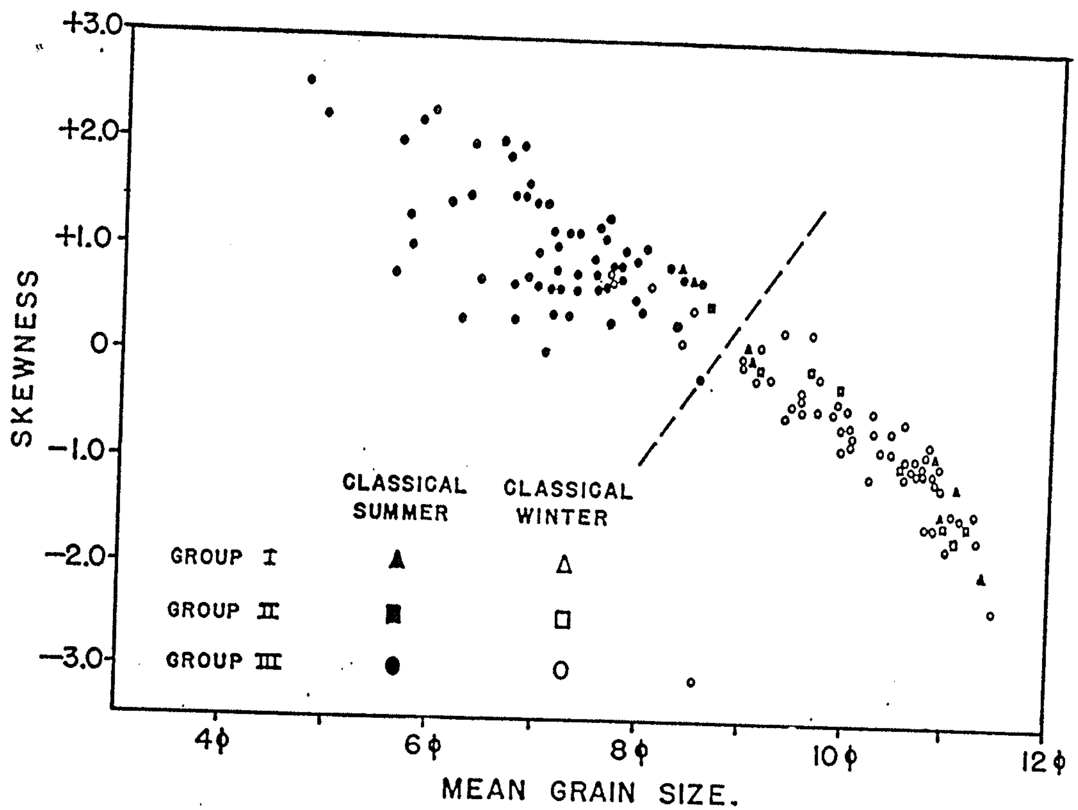

FIGURE 21a
Skewness Versus Mean Grain Size for Glacial Lake Hitchcock Rhythmites
(from Ashley, 1975)

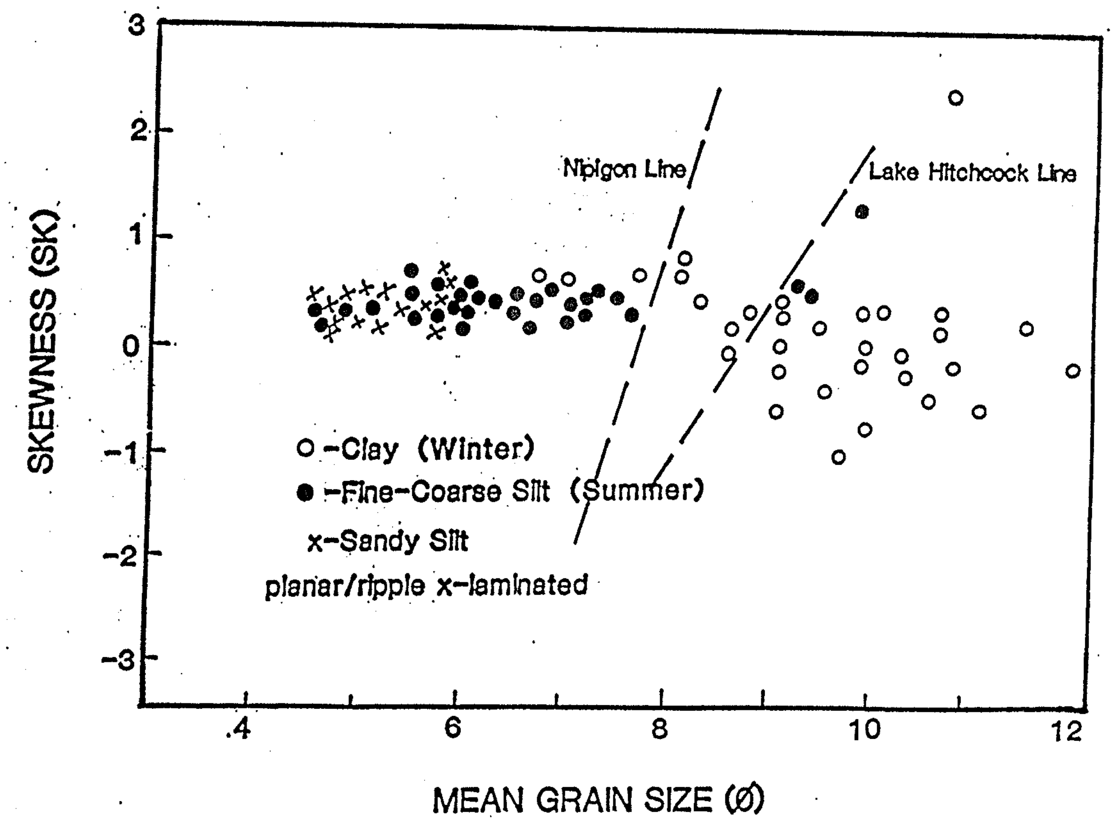

FIGURE 21b
Skewness Versus Mean Grain Size for Lake Nipigon Rhythmites

As observed in the plots of sorting and skewness versus mean grain size, the rhythmites of Lake Nipigon produce results similar to that of the varved sediments of Glacial Lake Hitchcock. The plot of skewness versus mean grain size for the Lake Nipigon rhythmites is predictable, as the skewness values for these sediments are fairly equivalent. The scattering of the data points is due solely to the differences in grain size and is therefore independent of skewness. A similar distribution of the data points for the Lake Nipigon rhythmites would result from the plotting of skewness versus any sediment statistical parameter.

Paleomagnetism

Schlosser (1983) described and sampled sequences of rhythmically bedded silt and clay from exposures located near the outcrops of rhythmites sampled and described in this thesis. In studying the paleomagnetic signatures developed within these sediments, Schlosser determined that the rhythmically bedded silts and clays deposited within the Nipigon basin, recorded the passage of time. These rhythmites, therefore he concluded, are varves, and refers to them as such.

The Gull Bay varves of Schlosser (1983) are located 7.0 km southwest of the Gull Bay X-2 and X-3 rhythmites described earlier. The similarities in colour, thickness, and grain size of these sediments suggest that they may have been deposited concurrently. The Wabinosh Lake exposure of varved sediments described by Schlosser (1983) is located 4.0 km northwest of the Wabinosh Bay rhythmites described earlier in this thesis. The textural similarities between the sediments from these two sites suggests that the deposition of these sediments may also have been contemporaneous. The CAS borehole was drilled at the same location as the Castle Lake Road site of Schlosser (1983), and the varves sampled by Schlosser for DRM analysis may be correlatable in terms of the time of deposition to the rhythmites of the CAS core.

Schlosser (1983) concluded that a measurable depositional remnant magnetism (DRM) exists in the rhythmites deposited at the Kabitotikwia Lake, Gull Bay, Gull River, Wabinosh Lake, and the Castle Lake Road regions. He further concluded that the Kabitotikwia Lake, Gull Bay, and Gull River sediments were all deposited at relatively the same time, followed by the deposition of the Wabinosh Lake and Castle Lake Road rhythmites.

Oriented samples of silt-clay varves were collected from exposures in these five areas, and analyzed to determine if any trends in paleomagnetic intensities, declination, and inclinations exists. Schlosser (1983, p.49), by using curve matching techniques, found that a strong correlation in inclination exists between the 143rd varve of the Kabitotikwia Lake site and the 103rd varve of the Gull River site (Fig.22a, dashed line). At each of these two sites, the inclination values are approximately 70 degrees. Based upon similar observations using curve matching, and similar declination values, another correlation exists between the 43rd varve of the Kabitotikwia Lake site and the 49th varve of the Gull Bay site (Fig.22a, dashed line), however Schlosser (1983) considered this to be only a "possible" correlation. The diagram (Fig.22,a) also appears to show a correlation with the Gull River sequence, although no reference to this is made in his text. If these correlations are valid, then the deposition of the varves at the Kabitotikwia Lake, Gull River, and Gull Bay sites was contemporaneous (Schlosser, 1983). Similarities in magnetic intensities (Fig.22b) and declinations (Fig.22c) between the Kabitotikwia Lake, Gull River, and Gull Bay varves also appear to exist. Time-line correlations were not made because the similarities between these varves were determined to be sedimentological and not from fluctuations in the Earth's magnetic field (Schlosser,1983, p.49).

Although the graphs of intensity, declination, and inclination for the Wabinosh Lake and Castle Lake Road sites display wide fluctuations, they also have an overall increasing or decreasing paleomagnetic trend (Fig.22a,b,c). Schlosser (1983) recognized that such drastic short term shifts in intensity, declination, and inclination were not probable, and concluded that they were the result of factors

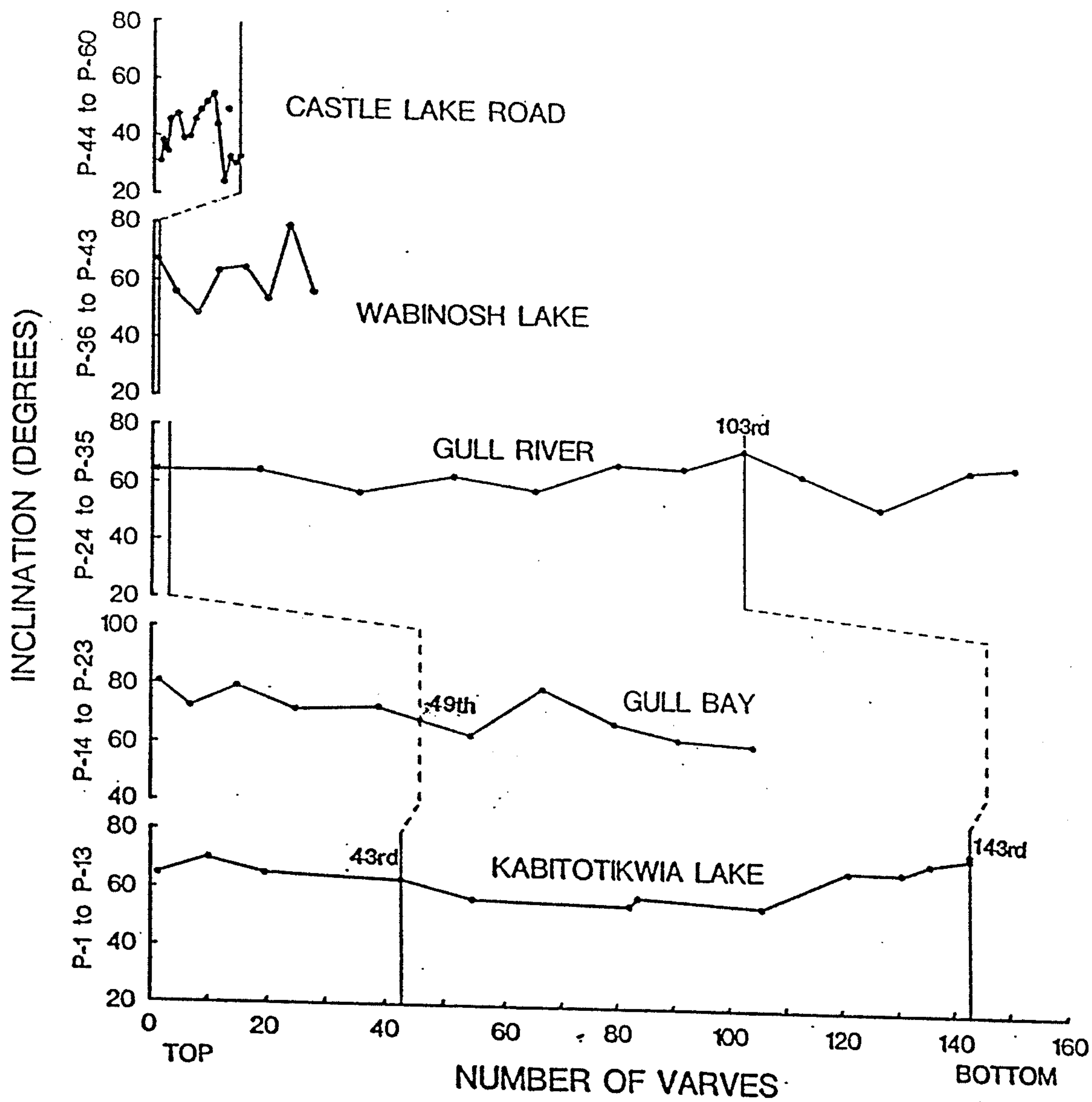

FIGURE 22a
Inclinations of the Depositional Remnant
Magnetism for Lake Nipigon Rhythmites
(after Schlosser, 1983)

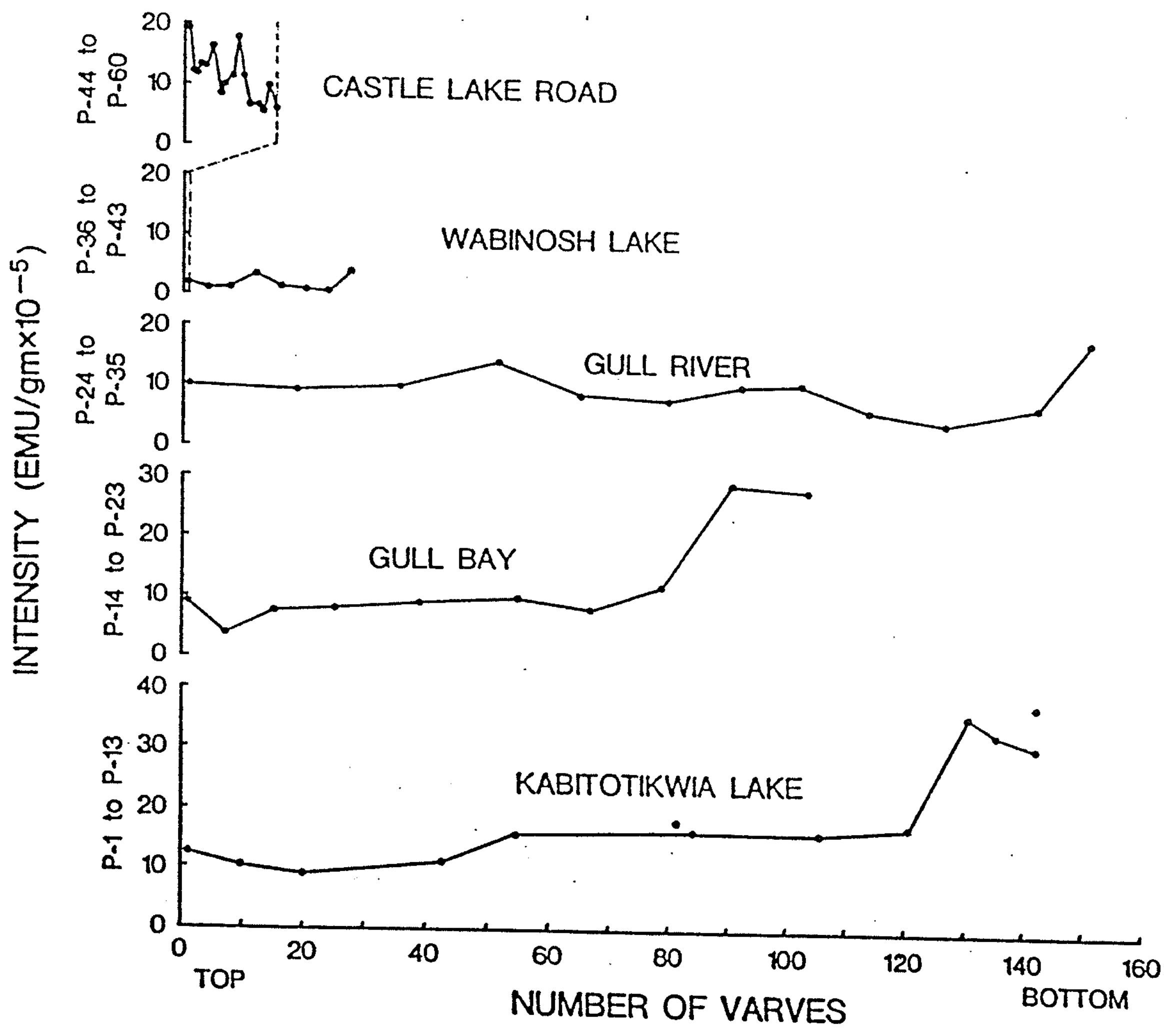

FIGURE 22b
Intensities of the Depositional Remnant Magnetism for Lake Nipigon Rhythmites (after Schlosser, 1983)

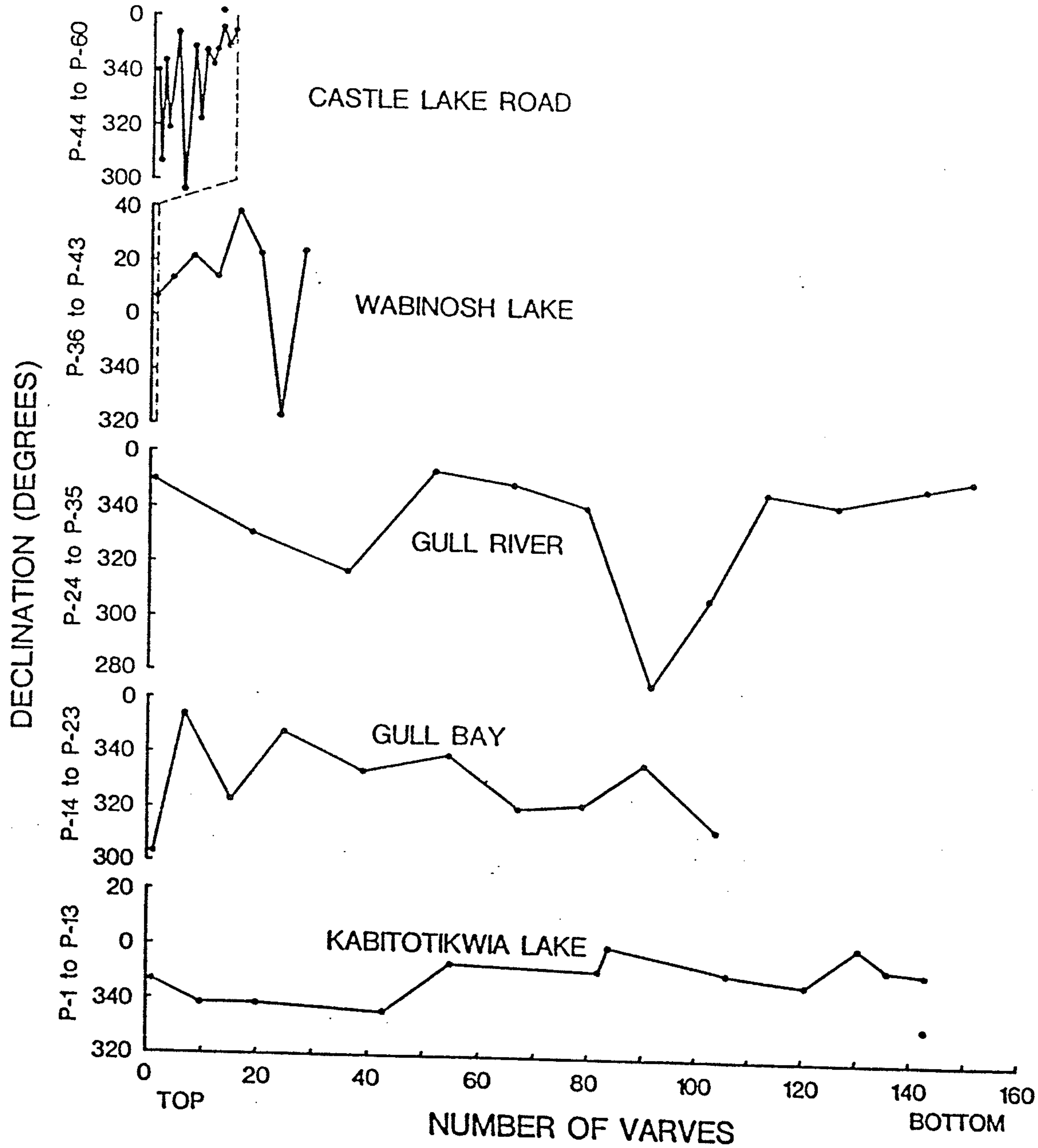

FIGURE 22c
Declinations of the Depositional Remnant
Magnetism for Lake Nipigon Rhythmites
(after Schlosser, 1983)

such as changes in mineralogy, grain size, abundance of magnetic minerals, or oxidation of iron minerals. The sediments in the Wabinosh Lake and Castle Lake Road areas contain very little to no iron-rich minerals, in contrast to the Kabitotikwia Lake, Gull River, and Gull Bay areas, the result of the predominantly granitic composition of the glacial deposits and bedrock of the more northern regions of the Lake Nipigon basin.

The relative lack of iron-rich (magnetic) minerals in the Wabinosh Bay and Castle Lake Road rhythmites renders the results of the DRM analysis of these sediments as suspect. This statement is based upon the fact that in order to be regarded as "good" samples for paleomagnetic analysis, sediments should be strongly magnetized (ie. contain abundant fine grained, magnetic minerals) (Barendregt, 1985). Sediments with relatively greater magnetic mineral content posses a greater susceptibility to the Earth's magnetic field, and therefore, DRM analyses of such sediments will yield more reliable results.

Schlosser, however, does propose that the downward trend of intensity values (from top to bottom) of the Castle Lake Road varves seems to continue with the Wabinosh Lake varves (Fig.22b, dashed line). He also suggests that a correlation between these two sites can be drawn based upon trends observed in the inclination and declination curves (Fig.22a,c, dashed lines). In observing the numerical values for intensities, declinations, and inclinations between the two sites, no readily apparent trend can be seen. If these correlations however, are valid, then deposition of the varves at the Wabinosh Lake site occurred first, followed by the Castle Lake Road deposits (Schlosser, 1983).

Interpretation

Schlosser's conclusions, based upon the DRM signatures of silt-clay varves in the Nipigon basin, pose some questions. The major short-coming is that there is no evidence given to support the conclusion, based upon the results of the DRM analyses, as to why the Wabinosh Lake and Castle Lake Road varves are thought to have been deposited after the Kabitotikwia Lake, Gull Bay, and Gull River varves. The simple change in the patterns of the graphs of intensity, declination, and inclination, from relatively horizontal (Kabitotikwia Lake, Gull Bay, Gull River) to erratic increasing and decreasing patterns (Wabinosh Lake, Castle Lake Road) does suggest that a difference exists between these two groups of rhythmites. This difference in patterns is probably the result of the greater number of samples analyzed from the latter regions as compared to the former, and due to the mineralogical effects discussed previously. I feel that the correlations suggested by Schlosser (1983), drawn between the Wabinosh Lake and Castle Lake Road varves are at best, weak possibilities.

If Schlosser's correlations, however, are regarded as viable, then the rhythmically bedded silts and clays deposited at the Kabitotikwia Lake, Gull River, Gull Bay, Wabinosh Lake, and Castle Lake Road sites, record the passage of time, and are therefore, true varved sediments. The locations of the rhythmites described in this thesis, in proximity to those of Schlosser's research, along with the textural and mineralogical similarities observed between these two groups of sediments, suggest that the rhythmites deposited at the Gull Bay X-2, Gull Bay X-3, Wabinosh Bay, and CAS borehole sites, are possibly varves.

Schlosser's conclusions, in conjunction with the geographic locations of the varves, and the position of the retreating margin of Rainy Lobe ice across the Nipigon basin, suggest that deposition of the Kabitotikwia Lake, Gull River, and Gull Bay varves was concurrent. Schlosser concluded that the Wabinosh Lake varves were deposited following the deposition of the three aforementioned locations, followed by the formation of the Castle Lake Road varves (Schlosser, 1983). This sequence of deposition is similar to the time frame for the sequential opening of the Lake Agassiz eastern outlets. Initially, water flowed into the southwestern Lake Nipigon basin via the Kaiashk outlet. Lake Nipigon at this time would have covered the present areas of the Kabitotikwia Lake, Gull River, and Gull Bay sites, as well as the Gull Bay X-2 and X-3 sites. This resulted in the simultaneous deposition of these rhythmically bedded sediments, a conclusion supported by the similar DRM signatures in the Kabitotikwia Lake, Gull River, and Gull Bay varves. As the margin of ice continued to retreat to the northeast, the more northerly outlets were activated. The flow of sediment-laden water through the more northern Pillar outlet into Lake Nipigon resulted in the deposition of the Wabinosh Lake varves and the Wabinosh Bay rhythmites to the north. Some time later, the still more northerly Castle Lake Road varves and the CAS borehole rhythmites were formed as flow through the Armstrong outlet transported sediments into the Nipigon basin.

VI. PALEONTOLOGY AND PALEOECOLOGY OF SEDIMENTS

Introduction

Trace fossils, fossil mollusc shells, and numerous species of pollen were found within the sediments of the Lake Nipigon basin. Interpretation of data generated from the identification of these various types of fossils provides a framework for the paleoecological reconstruction of the Nipigon basin.

Trace Fossils

Trace fossils are found throughout the sequences of rhythmites at the Gull Bay, Pike Bay, English Bay, Wabinosh Bay, and Whitesand River sites (Fig.13) along the present shoreline of the lake. The rhythmites examined in cores from the PIK, CAS, and KOP boreholes (Fig.13) also showed evidence of bioturbation.

The trace fossils identified at each of these locations are identical. In section, the burrows are semicircular to ovoid, with a mean diameter of 1.2 mm. In plan view, the burrows appear as discontinuous radiating and criss-crossing, curved "feather-like" ridges of variable length (3.0-6.0 mm). The traces are horizontal, with no observable vertical component, and are confined to the silty laminae or located on the bedding plane surfaces of the clay laminae of the rhythmites. Figure 23 shows the appearance

FIGURE 23
Trace Fossils in Pike Bay Rhythmites
Burrows in section view near top of photo
(brown circular patches are oxidized root casts)
(0.6 meters above lake level)

of the trace fossils in section and plan view. The horizontal nature of the burrows infers that these are grazing traces (Repichnia), and that the organisms which produced the traces were motile deposit feeders, and not attached to the substrate.

Numerous workers (Gibbard and Stuart, 1974; Gibbard and Dreimanis, 1978; Duck and McMannus, 1984) have identified trace fossils and the associated aquatic organisms. The majority of the trace fossils found within proglacial lake sediments are crawling or grazing traces attributed to the activities of various types of arthropods. Identification of the organisms that generate the ichnofossils to the species level is difficult, as body fossils are seldom discovered within the sediments. Gibbard and Dreimanis (1978), in studying the trace fossils present in Pleistocene glacial lake sediments in Ontario, identified 9 different varieties of traces. Of this number, only a single crawling trace had the associated organism classified to the genus level (Asellus sp., Arthropoda, Crustacea, Isopoda). Asellus sp., commonly referred to as the water louse, produced trace fossils which were also identified in Pleistocene proglacial lake sediments in England by Gibbard and Stuart (1974); they also identified 6 other types of trace fossils. The remaining tracks, trails, and burrows of these and other studies are concluded to have been formed by organisms which are referred to in a general sense.

Molluscs, nematode worms, water beetles, various crustaceans, chironomid midge larvae, and other "worm-like" organisms are all speculated to have generated the trace fossils commonly found in proglacial lacustrine sediments.

All of the organisms to which the trace fossils in the literature have been assigned feed upon algae and plant detritus (Gibbard and Stuart, 1974, Gibbard and Dreimanis, 1978, Duck and McMannus, 1984). This material, suspended within the lake water eventually settles from suspension onto the sediment surface. The restriction of the trace fossils to the silty laminae of the rhythmites is associated with the influx of detrital food material or to algal blooms. The source of this detrital material flowing into the Nipigon basin may have been the southern Lake Agassiz basin region, which had earlier become ice-free, and had developed forest vegetation. A greater supply of this food material would have occured during the summer season, as the amount and grain sizes of the clastic sediments transported to the lake basin was greater during this period, as opposed to the winter season. Thus the summer season provided more favorable conditions for sustaining the benthonic organisms. The lack of trace fossils within the clay laminae of the rhythmites suggests that the organisms may not have been able to endure the winter conditions, as the supply of detrital food material was cut off, and the clayey sediments being deposited may have formed a substrate which was not favorable to the grazing activities of the organisms. Murawski (1964) and Gibbard (1977) propose that these animals simply may not live on the sediment-water interface throughout an entire year. Insects may undergo metamorphosis from the larval stage which may produce the burrows only during the summer season because the organism vacates the surface of the sediments after a short larval period.

Some aquatic organisms, for example Tubifex worms which are common in Lake Nipigon sediments at the present (Rick Borecky, Lake Nipigon Fisheries Biologist, Personal Communication, 1985), are able to endure the winter periods in lakes (Pennak, 1953). Although these worm-like organisms are sessile in nature (Fig.24), and the trace fossils appear to have been formed by a motile organism, the vigorous waving aeration movement of the organisms may result in the development of radiating patterns of traces on the surface of the sediment.

None of the trace fossils described in the literature which have had the respective organisms identified (or at least speculated upon) appear similar to the trace fossils found within the silty laminae of the Lake Nipigon rhythmites. Banerjee (1973), and Teller and Mahnic (1988) just to the south in the Superior basin, describe and illustrate burrows developed in Pleistocene glacial varves which are virtually identical to those of Lake Nipigon.

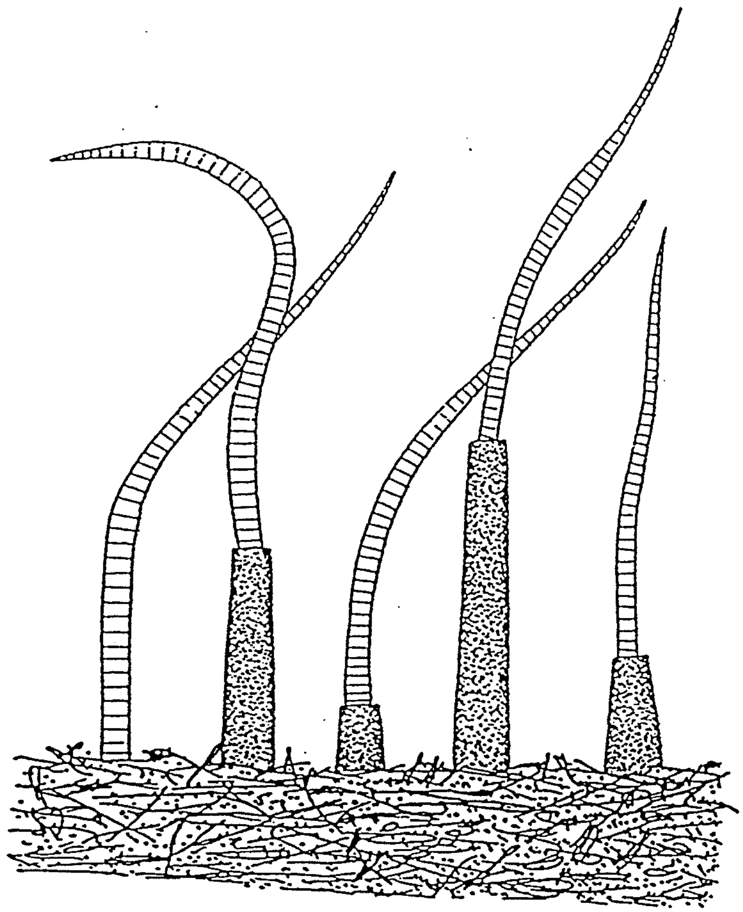

FIGURE 24
Tubifex (x4.5)
(from Pennak, 1953)

However, no discussion or speculation as to the organism(s) responsible for producing the trace fossils is made.

The type of aquatic organism responsible for producing the trace fossils in the silty coarse grained laminae of the rhythmites of Lake Nipigon is unknown. Comparison to tracks, trails, and burrows formed in proglacial lake sediments in the literature suggests that the trace fossils were formed by the activity of aquatic arthropods.

Molluscan Taxonomy

Fossil molluscan assemblages in the Nipigon and adjacent Superior lowlands have been recognized since Coleman (1922), following up on research by R. Bell in 1870 in the Pic River basin in the northern Lake Superior region, discovered fossil gastropods and bivalves in the sediments of that area. Farrand (1960) identified the shell remains of 17 species of freshwater molluscs in the White Otter River basin north of Lake Superior.

In this study, the fossil shells of 16 molluscan species were discovered in an 11.0-m-high bluff of sediments at the mouth of the Namewaminikan River on the eastern shoreline of Lake Nipigon (Fig.25). Zoltai (1965,a) mapped the sediments of this area as lacustrine deltaic sands, deposited by sediment-laden waters of the paleo-Namewaminikan River flowing into Lake Nipigon. Figure 26 shows a stratigraphic section of the sediments of the

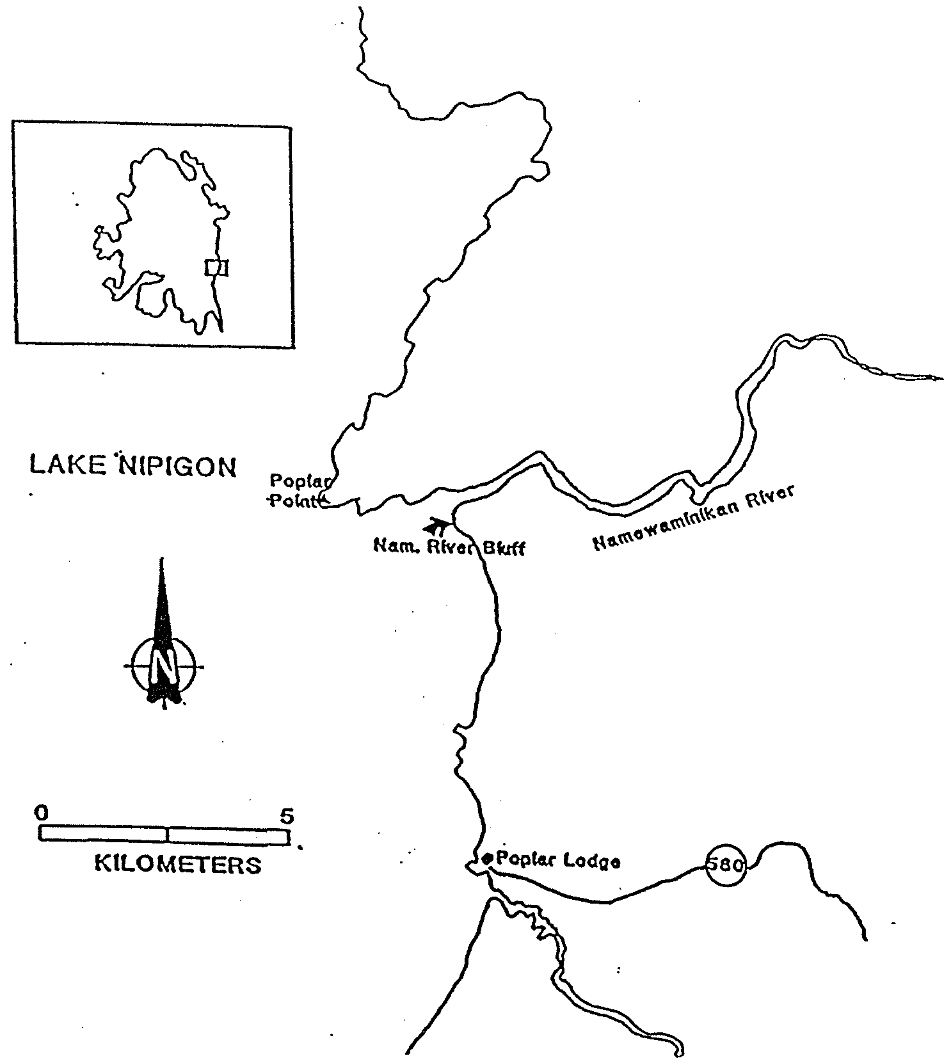

FIGURE 25
Location of Namewaminikan River Fossil Molluscan Assemblage

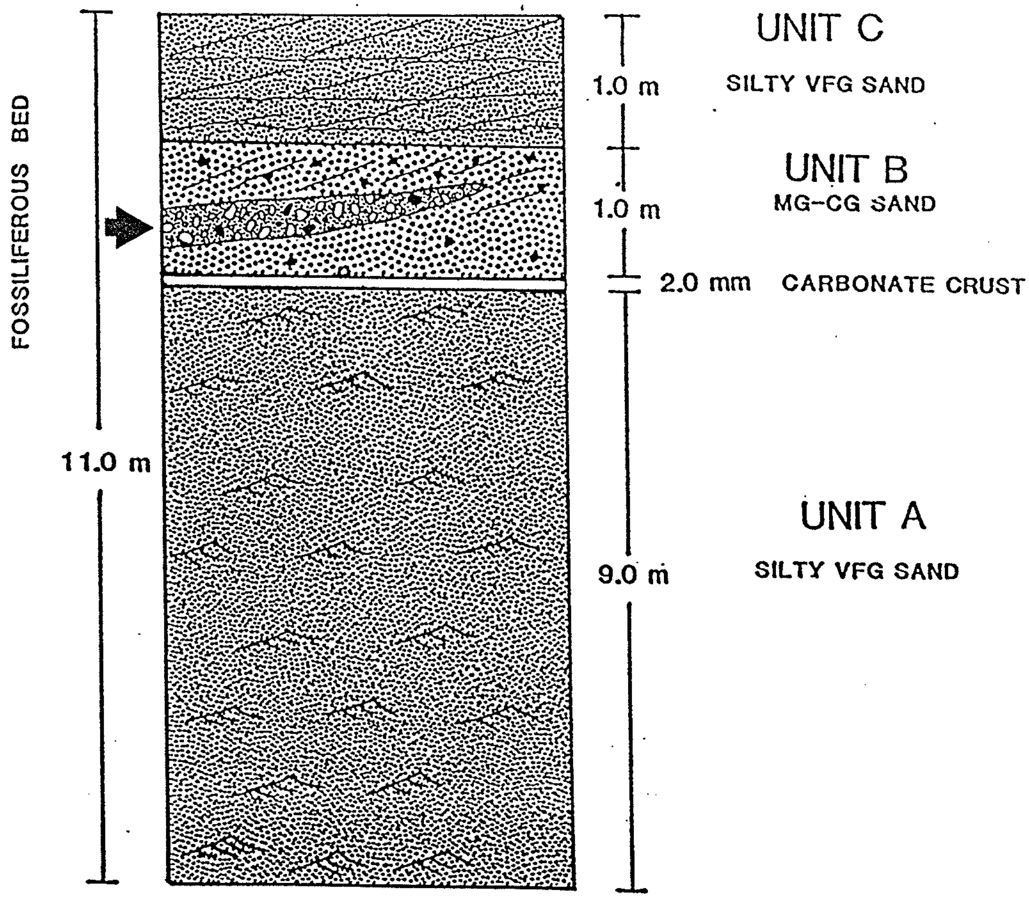

FIGURE 26
Namewaminikan River Bluff Stratigraphic Section
(see text for detailed description)

Namewaminikan River bluff. Unit A is composed of light greyish brown (2.5Y 6/2, Munsell, dry), well sorted, quartz-rich, silty very fine grained sand. The sediments are ripple cross-laminated, with lee-side laminae preservation, and a paleocurrent direction indicative of flow to the southwest.

Unit B is composed of moderately sorted, medium to coarse grained, "granitic" sand (2.5Y 6/4, Munsell, dry). Brownish (2.5Y 4/2, Munsell, dry), granule-sized clay rip-up clasts and granules of granite and diabase are found within these massive sands.

The fossil shells were found within a 10.0 cm thick lens of laminated coarse grained sand and granule-sized sediments within Unit B. These sediments are of similar composition to the sediments of Unit B. The disarticulated bivalve shells were found in a convex-up position. Clay rip-up clasts and granitic and diabasic pebbles are more abundant within this fossiliferous bed.

Unit C is composed of silty very fine grained sand similar to the sediments of Unit A. Large-scale cross-bedding is developed within these quartz-rich sandy sediments.

The contacts between each of the three units are all sharp. A thin calcium carbonate crust is found at the contact between the sediments of Unit A and Unit B. This pale white crust is thought to be a secondary deposit, formed as the result of downward leaching of carbonate material, and precipitation at the top of the permeability change between the coarser grained sands of Unit B and the silty, fine grained sands of Unit A.

Over 200 specimens of freshwater bivalves and gastropods were collected for taxonomic analyses and radiocarbon dating. Dr. Eva Pip (Department of Biology, University of Winnipeg) identified the species present within the Namewaminikan River molluscan assemblage. One hundred seventy-one of the specimens were classified to the species level, with 161 specimens belonging to the Class Bivalvia. The remaining 10 specimens belong to the Class Gastropoda. Sixteen different species in total were identified by Dr. Pip within the assemblage (Table 2).

All of the species identified in the Namewaminikan River molluscan assemblage are common to the Northern Hemisphere (Zoltai and Herrington, 1966). All of the species identified in the Namewaminikan River assemblage, with the exception of Discus macclintocki can be found in the Lake Nipigon basin at the present time, as reported by Adamstone (1923, 1924) from a series of dredgings in Lake Nipigon.

Sphaerium striatinum accounts for 80% (137 specimens) of the assemblage (Fig.27), with S. simile as the second most abundant taxa accounting for 11% (18 specimens) of the assemblage (Fig.28). The remaining bivalve specimens

TABLE 2

Namewaminikan River Molluscan Assemblage

Identified by Dr. E. Pip, University of Winnipeg

BIVALVIA: (5 SPECIES)

Lampsilis radiata L.

Pisidium variable Prime

Sphaerium striatinum Lamarck

Sphaerium simile

Sphaerium transversum Say

GASTROPODA:

a) AQUATIC (8 SPECIES)

Helisoma anceps Menke 1830

Stagnicola palustris Muller 1774

Stagnicola catascopium Say 1817

Gyraulus circumstriatus Tyron 1866

Lymnaea stagnalis Linne 1758

Fossaria dalli F.C. Baker 1907

Valvata tricarinata Say 1817

Promenetus umbilicatellus Cockerell 1887

b) TERRESTRIAL (3 SPECIES)

Succinea avara Say 1824

Nesovitrea electrina Gould 1841

Discus macclintocki F.C. Baker 1928

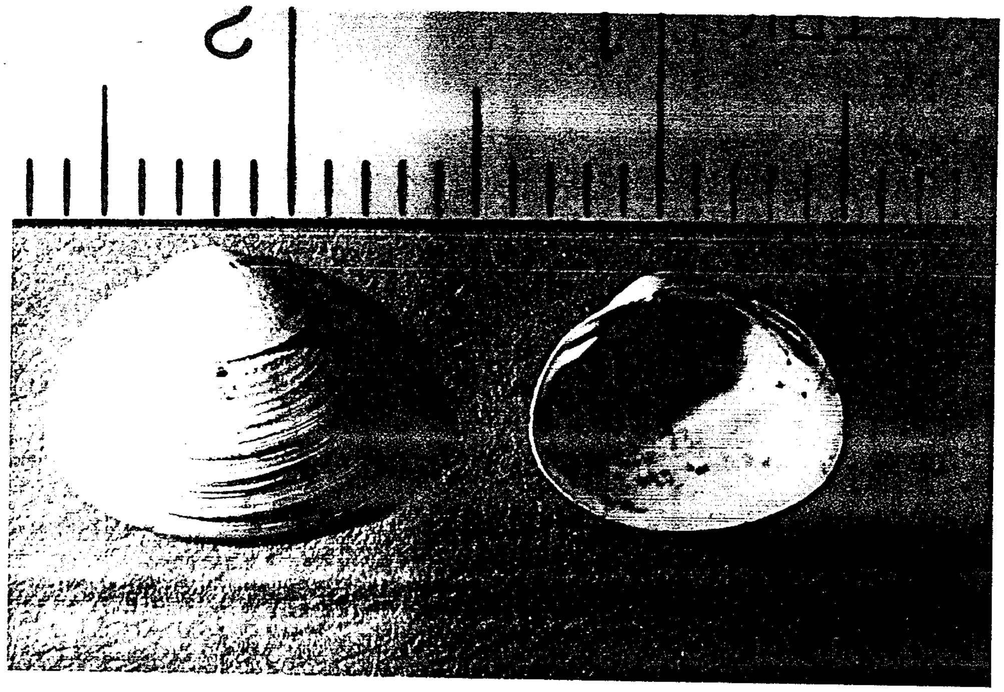

FIGURE 27
Sphaerium striatinum
left valve, exterior view, and right valve, interior view
(scale in millimeters/centimeters)

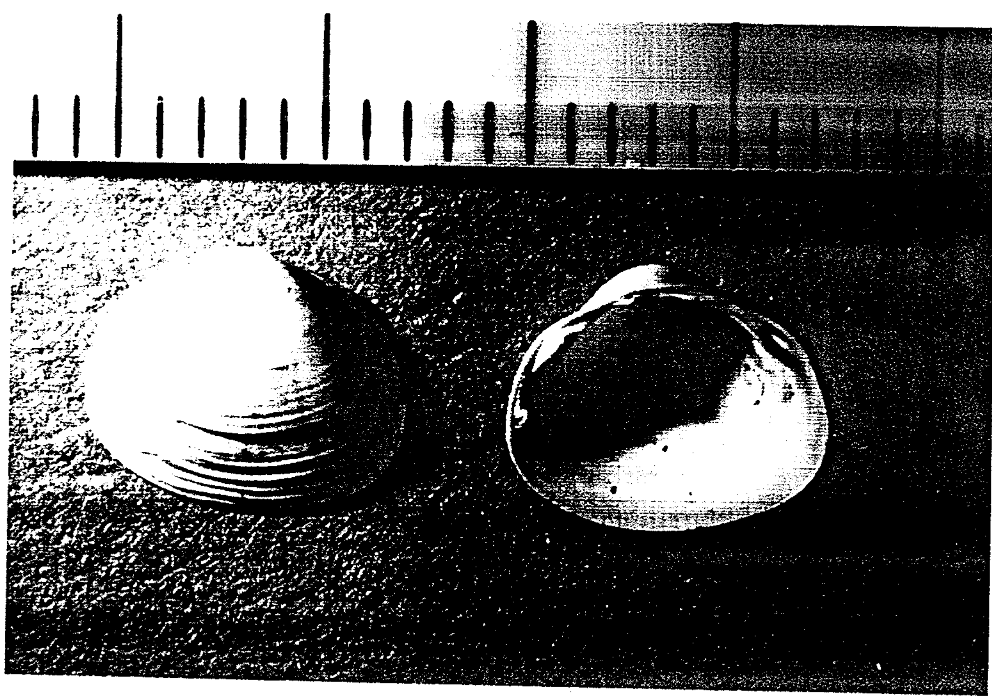

FIGURE 28
Sphaerium simile
left valve, exterior view, and right valve, interior view
(scale in millimeters/centimeters)

account for less than 2% of the total molluscan assemblage.

Valvata tricarinata (Fig.29) is the most abundant species of gastropod, totalling 5 specimens and accounting for 3% of the assemblage. Three specimens of *Helisoma anceps* (Fig.30) (2% of the assemblage) were identified, along with single specimens of *Lymnaea columella* and *L. stagnalis*. The remainder of the gastropod species account for less than 1% of the total assemblage. Of particular interest is the presence of a specimen of *Discus macclintocki* within the Namewaminikan River assemblage. The discovery of this species of terrestrial gastropod marks the first time this species has ever been recorded from Canada (E. Pip, 1987, Personal Communication).

A number of the species identified within the Namewaminikan River molluscan assemblage have been reported in several other studies. Zoltai and Herrington (1966) in a study of late glacial molluscan fauna from numerous locations north of Lake Superior identified 32 species, 8 of which are present in the Namewaminikan River assemblage. Ashworth and Cvancara (1983) in studying the paleoecology of the southern part of the Lake Agassiz basin, identified 84 species of molluscs. Thirteen of the total number of species from the Namewaminikan River assemblage overlap with the taxa of the southern Lake Agassiz basin. Late Quaternary sediments of the Lake Huron basin yielded 61 species of molluscs (Miller et al, 1985), of which 13

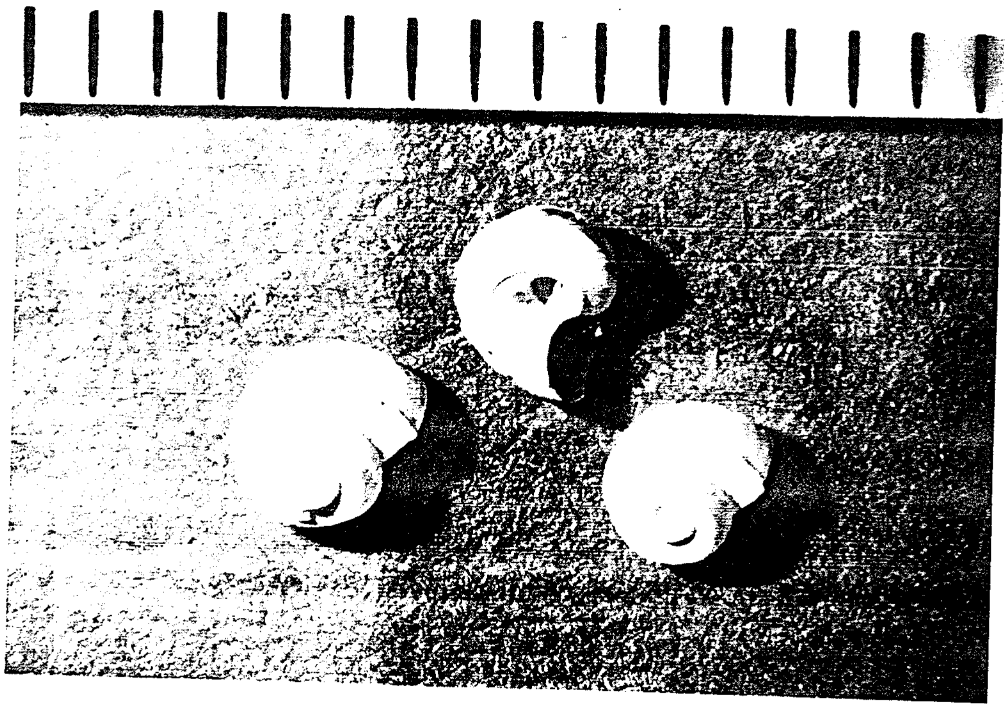

FIGURE 29
Valvata tricarinata
(scale in millimeters)

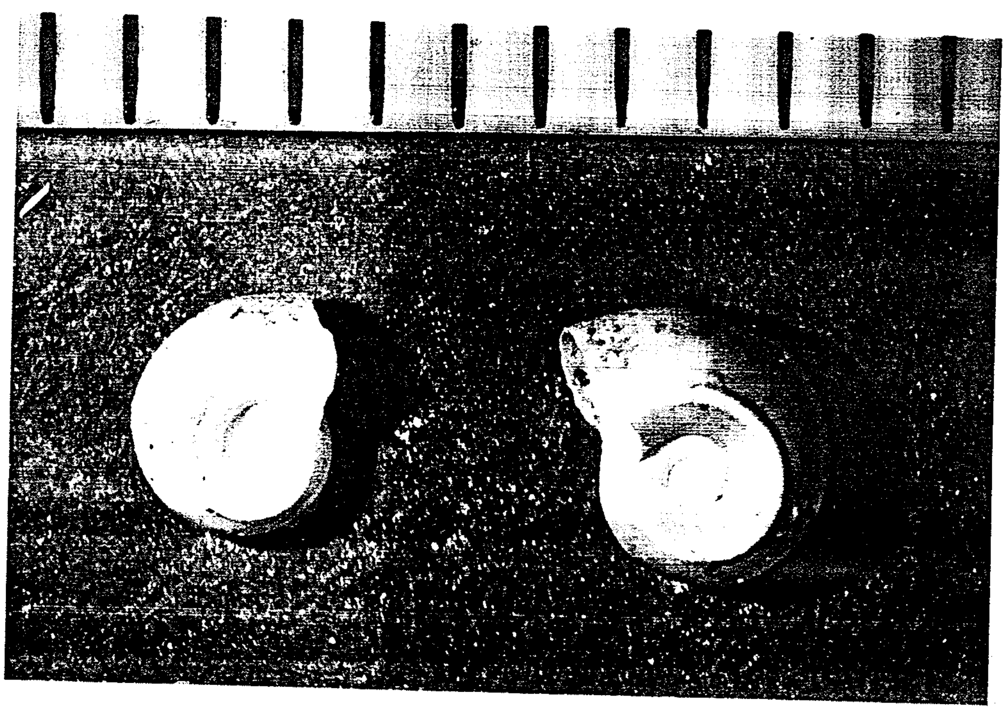

FIGURE 30
Helisoma anceps
(scale in millimeters)

species are common with those of the Namewaminikan River assemblage.

Palynology

Sediment samples from 4 cores obtained from boreholes drilled in the Lake Nipigon-Lake Superior region were submitted to Dr. J.H. McAndrews of the Royal Ontario Museum for palynological analysis. The GUL hole was drilled west of the Nipigon Moraine in the northwest corner of the Gull River Indian Reserve (436240, NTS map 52-H/14). The EVE, EVEN, and DOR holes were drilled within the Superior basin south of Lake Nipigon (Fig.31). The DOR hole is located near the town of Dorion (880089, NTS map 52-A/15), the EVEN hole near the town of Red Rock (022133, NTS map 52-A/16), and the EVE hole 1.5 km north of that (023148, NTS map 52-A/16). Three subsamples were analyzed from each of the GUL and EVEN cores, 10 from the DOR core, and another 12 subsamples from the EVE core. Teller and Mahnic (1988) have described the stratigraphy of the DOR, EVEN, and EVE cores (referred to as sites B,E, and G in Teller and Mahnic).

The total length of core collected from the DOR borehole (B) was 37.7 m. The basal 8.0 m is composed of thin, rhythmically bedded couplets of silt and clay. These thin basal couplets are overlain by thicker couplets of silt and clay which grade upward into coarser sand-silt couplets (Teller and Mahnic, 1988).

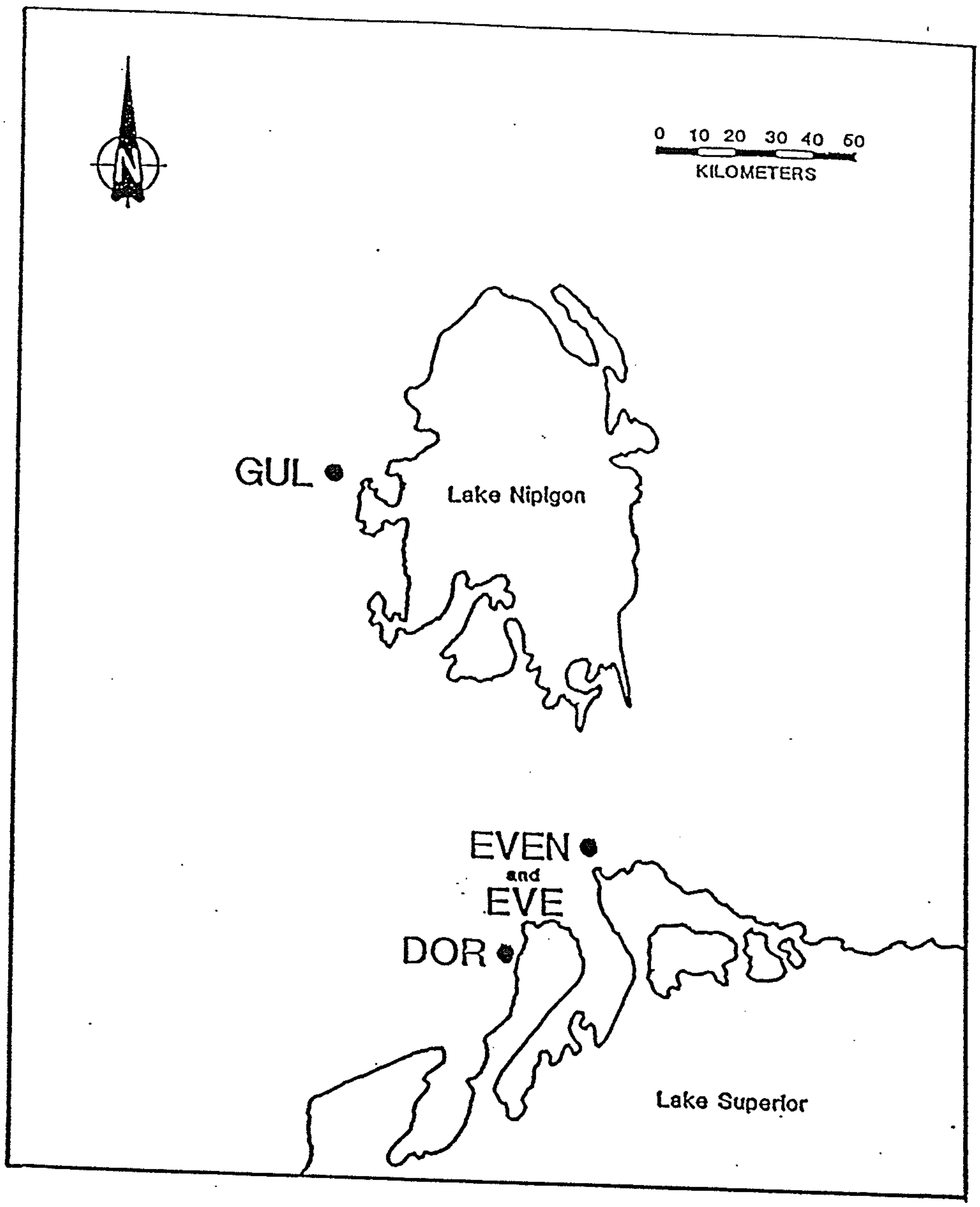

FIGURE 31
Location of Cores Sampled for Palynological Analyses

The EVEN (E) core has a total thickness of 30.0 m. The basal 3.0 m is composed of red till. The overlying 19.0 m is composed of rhythmically bedded couplets of silt and clay, which have variable thicknesses. The upper 8.0 m of core is composed of sand.

The approximately 14 m of core collected from the EVE (G) site reveals a stratigraphy similar to the EVEN (E) site, red till overlain by rhythmites and sand.

The analyses revealed numerous species of both arboreal pollen (AP) and non-arboreal pollen (NAP) present within the sediments (Table 3). The resultant pollen assemblages by and large reflect the floral species which continue to grow in northwestern Ontario at the present time (J.H. McAndrews, 1984, Written Communication to J.T. Teller). _Pinus_ (pine) and _Picea_ (spruce) are the dominant arboreal species. The _Pinus_ is almost exclusively _P.banksiana/resinosa_ (jack pine). Other significant (i.e. greater than 10% content) species of arboreal pollen identified within the sediment samples are: _Abies_ (fir), _Betula_ (birch), _Ulmus_ (elm), and _Alnus_ (alder). Significant non-arboreal pollen species identified are _Graminaea_ (grasses) and _Artemisia_ (sage).

No distinct trends in pollen species content with depth can be drawn from the few palynological results obtained from the four cores, and thus no pattern of forest succession can be interpreted. The entire spectrums of the DOR and EVE assemblages, and the lowermost 2 samples from

TABLE 3

Pollen Content of Sediments
(% of total pollen sample)

	SAMPLE	AP						NAP	
CORE	DEPTH(m)	Picea	Pinus	Abies	Betula	Ulmus	Alnus	Gram	Art
GUL	3.0-3.7	21	45	0	12	2	1	8	0
	4.6-4.9	13	10	36	18	2	11	0	1
	21.5-22.2	15	69	0	2	4	0	2	1
DOR (B)	5.2-5.8	28	53	0	7	1	3	1	2
	6.1-6.7	28	46	0	2	1	2	3	6
	6.7-7.3	31	50	0	4	2	0	5	2
	7.7-8.3	26	56	1	3	3	1	0	2
	8.3-8.9R	32	50	0	3	0	0	0	0
	8.3-8.9G	29	52	0	1	2	0	0	2
	9.8-10.4	18	53	0	6	3	0	2	2
	11.4-12.0	31	38	0	2	3	0	1	7
	13.8-14.4	27	39	0	11	2	0	2	4
	26.1-26.7	19	27	0	14	5	1	7	10
EVEN (E)	1.5-2.1	3	34	0	21	19	6	2	0
	12.3-12.9	12	64	0	7	1	1	7	3
	26.1-26.7	17	45	0	3	0	0	2	18
EVE (G)	3.0-3.7	17	44	0	13	6	0	1	4
	3.7-4.3	10	57	0	8	0	0	3	2
	5.5-6.2	24	31	0	8	1	1	11	5
	6.2-6.8	14	28	0	18	2	3	17	4
	7.1-7.7	18	50	0	5	2	0	6	1
	10.2-10.8	9	39	0	4	6	5	1	9
	10.8-11.4	16	43	0	8	4	3	3	8
	11.4-12.0C	12	55	0	6	7	1	2	4
	11.4-12.0S	19	57	0	5	2	0	7	2
	11.4-12.0s	22	28	0	9	10	2	5	8
	12.0-12.6	3	49	0	7	1	1	3	5
	12.6-13.2	6	51	0	13	7	0	2	3

R- Red G-Grey C-Clay S-Sand s-Silt

the EVEN core reflect a typical _Pinus-Picea_ assemblage. The high _Ulmus_ content at shallow depth in the EVEN core (1.5-2.1 m) suggests that these upper sediments are of Holocene age (J.H. McAndrews, 1984, Written Communication to J.T. Teller).

The GUL 4.6-4.9 m subsample reveals an anomalous palynological assemblage, containing high _Betula_ and _Alnus_ pollen, and one of the highest _Abies_ contents ever recorded by McAndrews (J.H. McAndrews, 1984, Written Communication to J.T. Teller).

Paleoecology of Fauna and Flora

Common molluscan taxa present within the sediments of the Lake Agassiz, Lake Nipigon, Lake Superior, and Lake Huron basins results from the interconnection of these basins during the late glacial period. By 8500 B.P., ice would have retreated far enough to the north, and the four aforementioned basins would have been ice free and interconnected, allowing for the migration of molluscan taxa into the proglacial lakes. The absence of extinct species in the Namewaminikan River molluscan assemblage suggests that the ecological and environmental characteristics of paleo-Lake Nipigon phases can be inferred by direct analogy with those of the present lacustrine setting.

Former shoreline features within the basin suggest that the glacial lake phases of Lake Nipigon covered large areas, greater than the 4582 square km over which the lake now extends. The shorelines of the extinct lakes were rocky with numerous bays and inlets. Temperatures of the lake water would have been similar to that of present day cold temperate region lakes (Zoltai and Herrington, 1966). The aquatic molluscan organisms were able to colonize the shallow depths of the lake, which infers the availability of detrital vegetal matter as a food source for the organisms. The presence of terrestrial gastropod species within the Namewaminikan River assemblage implies that suitable habitats for these organisms had also become established adjacent to the shores of the lake (E. Pip, 1987, Written Communication). By analogy, the paleo-environmental setting of the region at the mouth of the Namewaminikan River would have resembled the present setting. Such an environment would have facilitated the ecological needs for the molluscan organisms identified within the fossil assemblage. Figure 32 illustrates a paleo-environmental reconstruction of the Namewaminikan River region based upon the molluscan species identified, and the sediments within which the fossil shells were discovered. According to Dr. Eva Pip (1987, Personal Communication), the aquatic species suggest a shallow lacustrine setting, with water depths ranging from 3.0 to 10.0 m. The substrate was composed of sand and/or clay, which is reflected in the nature of the sediments of the Namewaminikan River bluff. The clay

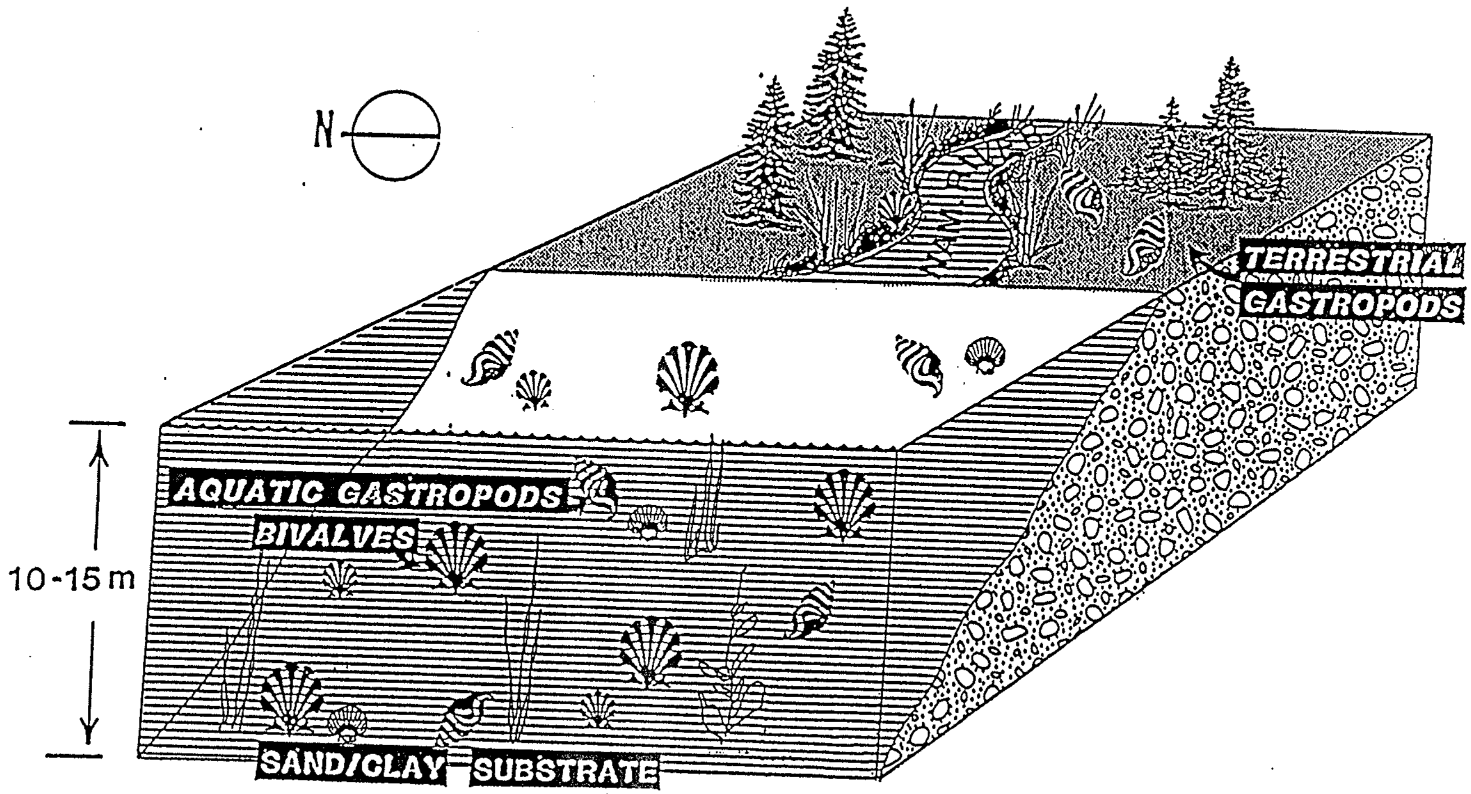

FIGURE 32
Paleoenvironmental Reconstruction
of the
Namewaminikan River Region

present in the paleo-substrate was eroded by wave action and deposited as rip-up clasts along with the coarser grained sediments and mollusc shells.

The sediments of the Namewaminikan River bluff are indicative of a transition from a nearshore deltaic facies (Unit A) to a beach facies (Unit B). The laminated coarse grained sediments of the fossiliferous bed were probably deposited within the high energy swash zone of the beach by breaking waves. The sediments of Unit C are representative of a back beach dune facies as suggested by the similar composition and texture of the sands to those of Unit A, and the development of large-scale eolian cross-bedding within the sediments.

The terrestrial gastropod species infer the presence of a riparian setting in proximity to the shallow lacustrine environment. Vegetation had developed, with abundant aquatic macrophyte species, and a mature coniferous forest with some mixed deciduous woodlands nearby (E. Pip, 1987, Written Communication). Analyses of the pollen found within the sediments of the Lake Nipigon and Lake Superior regions further reflect the presence of dense terrestrial vegetation.

With the exception of the GUL 4.6-4.9 m subsample, the palynological data derived from the sediments of the GUL, DOR, EVE, and EVEN cores reveal _Pinus_-_Picea_-_Betula_ assemblages, with _Ulmus_ and _Alnus_ as secondary components.

These assemblages reflect the typical composition of the forests which covered northwestern Ontario between about 9200 to 6600 B.P. (Bjorck, 1985).

The pollen assemblage derived from the GUL 4.6-4.9 m subsample contains an extremely high Abies and Alnus content in comparison to the remainder of the samples. These two species are generally associated with latter stages of forest succession, and significant Abies and Alnus contents within pollen assemblages of northwestern Ontario are generally found within sediments that are between 7,000 and 3,500 years old (Bjorck, 1985).

As the GUL borehole sediments were probably deposited at about 9500 B.P. when Lake Nipigon waters covered this area, the presence of Abies and Alnus pollen does not fit in well with the accepted chronology for the revegetation of northwestern Ontario (Delcourt and Delcourt, 1981; Bjorck, 1985). The elevated levels of Abies and Alnus pollen within the GUL 4.6-4.9 m subsample may therefore be derived from a highly localized zone of fir and alder growing within the forest of the GUL hole region, or possibly reworked older (Moorehead Phase) orgnaic material. A third possibilty is that the high values may be the result of contamination of the sample by younger sediments during the coring process.

On the whole, the pollen spectra of the GUL, DOR, EVE and EVEN cores indicate that, immediately following deglaciation, the Lake Nipigon-Lake Superior region became colonized by a predominantly spruce and jack-pine, with some mixed coniferous and deciduous forest. Minor amounts of non-arboreal pollen, specifically grasses and sage, suggest that the forested areas were interspersed with open meadows and grasslands.

V. RADIOCARBON DATES

Dates in the Nipigon Basin and Adjacent Area

A number of radiocarbon dates have been generated from organic material discovered in the Nipigon-Superior lowlands (Fig.33). Two samples of wood, conifer cones, and needles were collected from a 10.6 m exposure of clays, silts, and sands along the Kaministikwia River across from Old Fort William, near Thunder Bay, Ontario. The thin (less than 1.0 cm) layer of organic floatsam and jetsam, located near the base of the section can be traced for about 30 m (Gray, 1987). A date of 9640+/-450 B.P. (Old Fort William A, GX-11406) was obtained for one of the samples, while another sample collected along the same stratigraphic horizon yielded a radiocarbon age of 9990+/-360 B.P. (Old Fort William B, GX-11407).

Zoltai (1965,a) collected and dated wood found within the town of Rosslyn near Thunder Bay. The woody debris, found at a contact between sand and an underlying unit of clay, yielded a radiocarbon date of 9380+/-150 B.P. (GSC-287). Organic residue collected at a depth of 7.5 m from a borehole adjacent to the DOR borehole was dated at 9690+/-290 B.P. (Beta-9113; Teller and Mahnic, 1988). A 3.0-m-thick sequence of bedded sand, clayey silt and cross-bedded sand and gravel lies stratigraphically above the borehole site. The cross-bedded sand and gravel contains mollusc

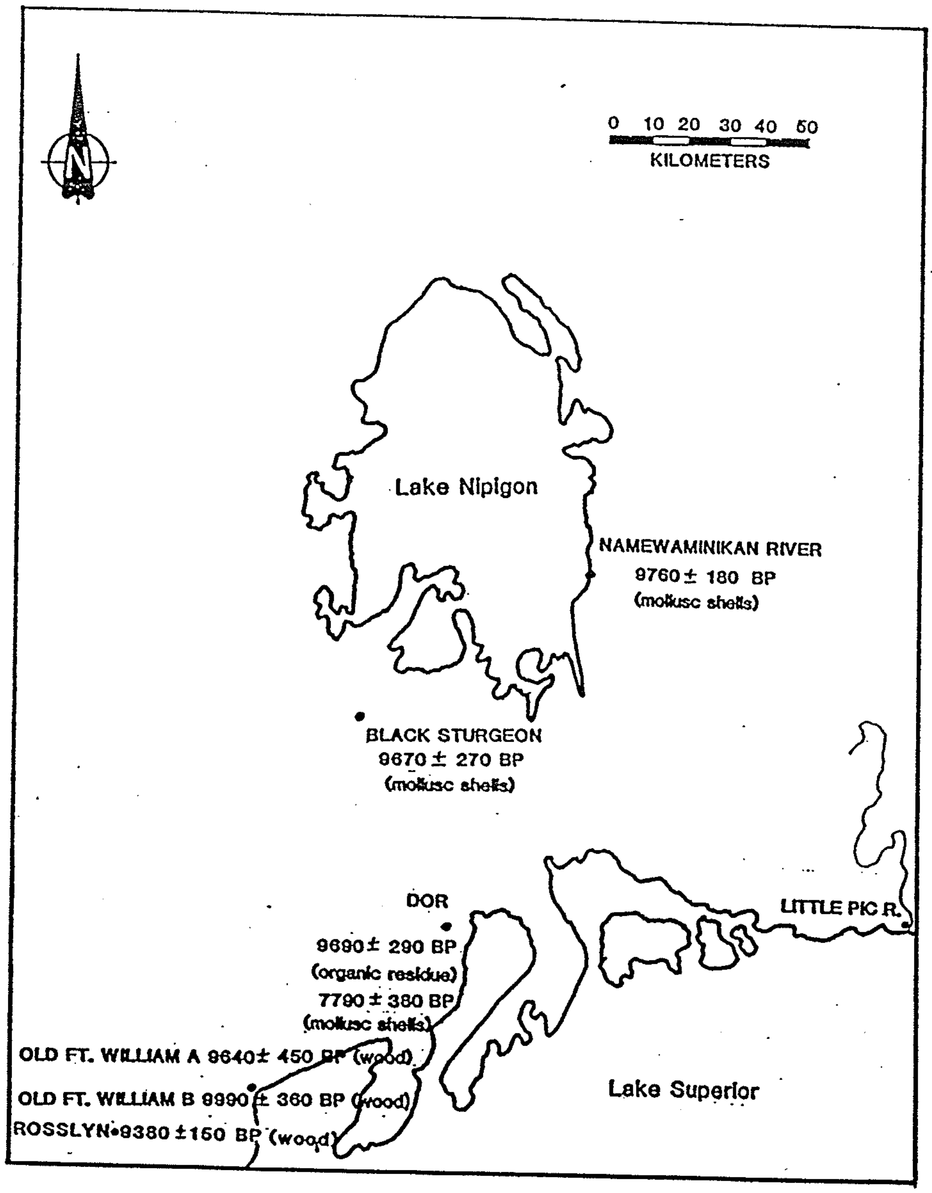

FIGURE 33
Radiocarbon Dated Material
in the
Nipigon-Superior Lowlands

shells which have been dated at 7790+/-380 B.P. (GX-10855; Teller and Mahnic, 1988). A 2.0-m-thick exposure of medium grained sand and rhythmites of clayey silt and silt along the Black Sturgeon River contains mollusc shells which were dated at 9670+/-270 B.P. (GX-10856; Teller and Mahnic, 1988).

Mollusc shells collected from the beach sediments at the Namewaminikan River bluff yielded a radiocarbon date of 9760+/-180 B.P. (BGS-1150).

Discussion of Reliability of Dates on Shells

Sediments containing mollusc shells, exposed at the Little Pic River site were dated at 7060+/-120 B.P. (GSC-91; Zoltai and Herrington, 1966). The section is located near the mouth of the Little Pic River along the northern shoreline of Lake Superior(see Fig.33). The shell date at this location appears anomalous, as the fossil mollusc shells were found "sandwiched" between two horizons containing wood and "charcoal" that was dated much younger. Figure 34 illustrates the position of the mollusc shells with respect to a "charcoal" layer dated at 6100+/-160 B.P. (GSC-285), and two wood samples dated at 5920+/-120 B.P. (GSC-82) and 5960+/-110 B.P. (GSC-103). The observed chronostratigraphic inconsistency suggests that a more plausible date for the mollusc shells would be about 6,000 B.P., approximately 1,000 years younger than the generated

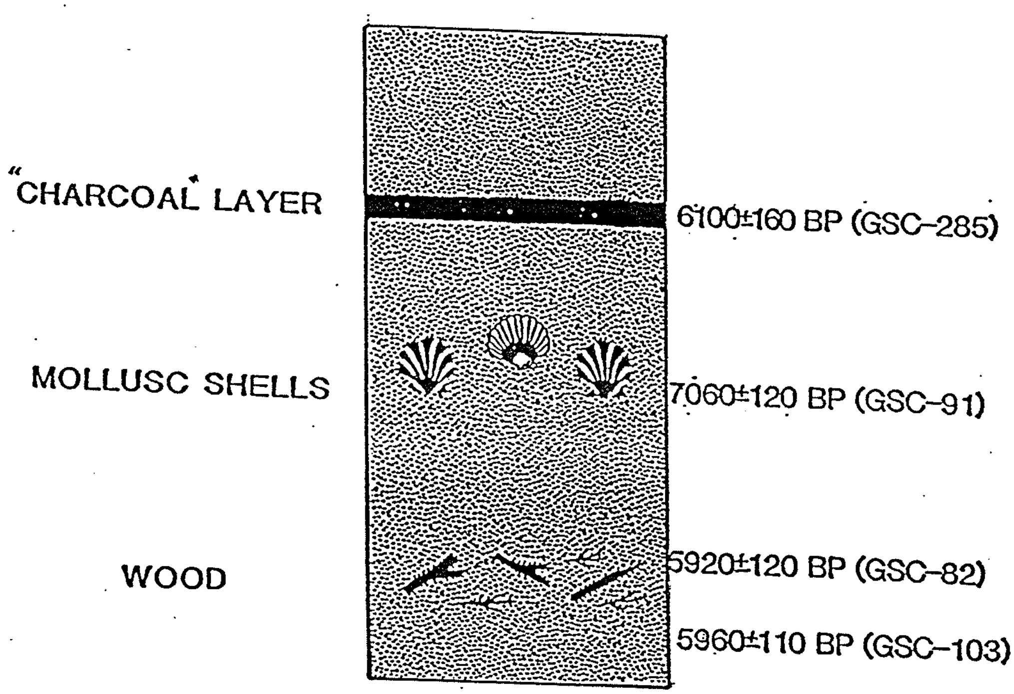

FIGURE 34
Little Pic River Section
(after Zoltai and Herrington, 1966)

date. Because radiocarbon dates obtained from "woody" materials are generally regarded as being more accurate than those obtained from the dating of fossil shell material, and because calcium carbonate shell material is subject to the "old" carbon hard-water-effect, the wood and "charcoal" dates from the Little Pic River site, are considered to be a more reliable indication of the true age of the sediment. The likely source of the non-organic bicarbonate anions in the Lake Nipigon basin and the surrounding watershed are the tills, which contain material derived from the Paleozoic carbonate rocks of the Hudson Bay Lowlands (Karrow and Geddes, 1987). These anions are taken out of solution by the organisms and precipitated with the "zeroed" carbon pool of the atmosphere, forming the calcium carbonate shells. The resultant chemistry of modern, as well as ancient, waters of Lake Nipigon have the potential for generating erroneous radiocarbon dates for shells, (the "hard water effect") because the water may contain Paleozoic bicarbonate anions. The resultant radiocarbon date for the shells would therefore be older than the true age by some value. The Little Pic River section and the associated radiocarbon dates suggest that this error is about 1,000 years.

Errors of up to 2,000 years are cited by Fritz and Poplawski (1974) in dating freshwater mollusc shells from southwestern Ontario. Nielsen and others (1982) cited a 400-year age discrepancy as the result of the incorporation of "old" carbonate carbon into molluscan shell material. In the Nielsen et al. study, a modern shell of the bivalved mollusc Strophitus undulatus was collected in 1941 from Lake Winnipeg, Manitoba, and was submitted for radiocarbon dating. The resultant radiocarbon age of the shell was 440+/-100 B.P. (GSC-3281).

As Karrow and Geddes (1987) have noted, the carbonate material in northern Ontario is probably the result of glacial erosion of Paleozoic rocks in the Hudson Bay Lowlands, so values increase toward the north. They identified a 10% carbonate line (Fig.35), north of which radiocarbon dates would be more likely to be subject to the hard-water-effect. South of this carbonate line, the radiocarbon dates obtained from fossil shells are less likely to be subject to the hard water contamination. On the basis of these studies, I believe the shells in the Nipigon basin are too old. Using the Little Pic River section as a model, where both shells and wood dates occur together, I propose that shell dates in this region are about 1,000 years too old (see Lemoine et al, 1987). As both the Namewaminikan River and the Little Pic River sites lay along the 10% carbonate line, the application of the 1,000 year correction factor to the Namewaminikan River shell date of 9760+/-180 B.P. seems reasonable.

Furthermore, the similar taxonomic composition of the two molluscan assemblages implies that little or no error in

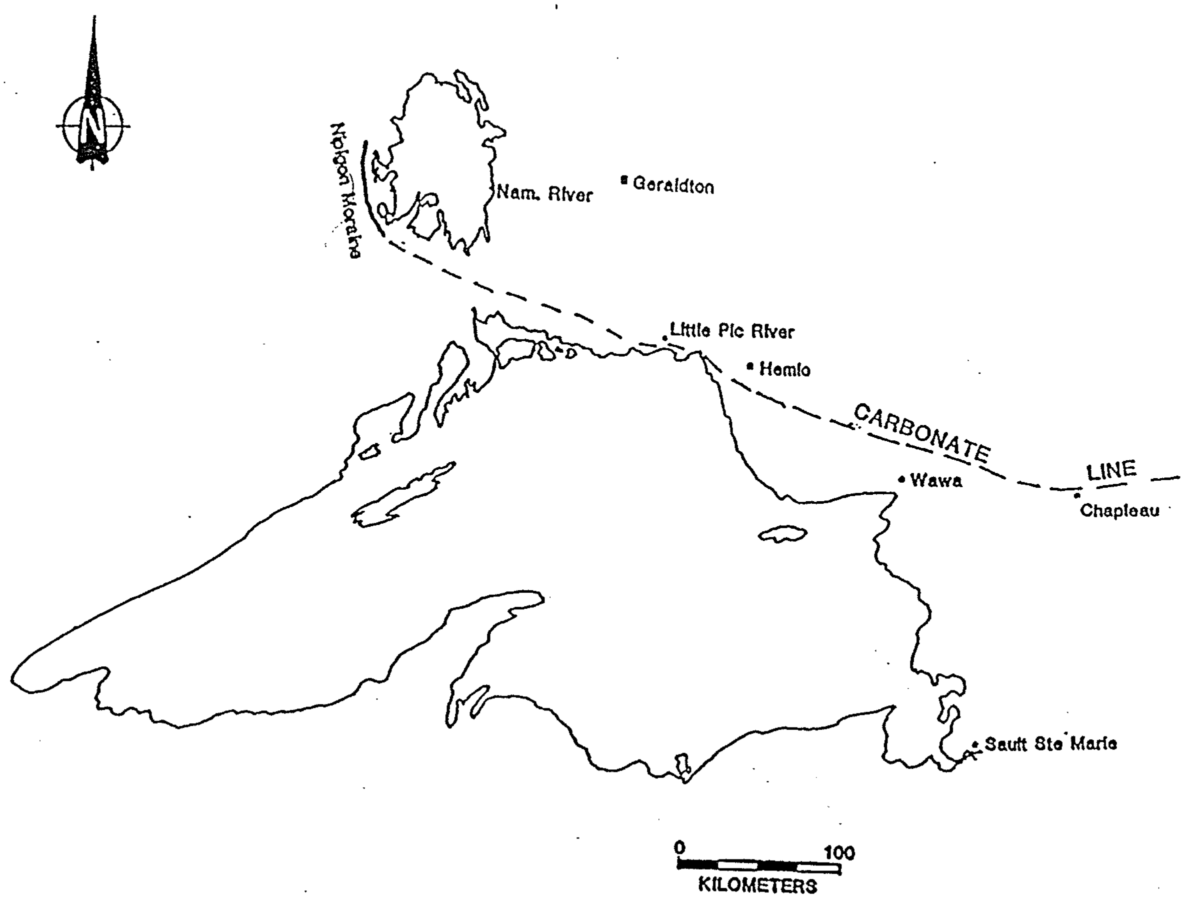

FIGURE 35
Location of Namewaminikan River and Little Pic River Sites and the Carbonate Line
(after Karrow and Geddes, 1987)

the uncorrected age of the shells can be attributed to the variable rates of uptake of the bicarbonate anion by different species. And, as will be discussed later, a corrected age of 8760 B.P. (vs. 9760 B.P.) for the shells at the Namewaminikan River bluff fits well with the deglaciation chronology of the region.

VI. CORRELATION OF MAJOR SEDIMENTARY UNITS

As sediment-laden waters from Lake Agassiz spilled into the Nipigon basin, large volumes of sediment were deposited at the mouths of the eastern outlet channels (Fig.12). The boundaries between the sedimentary packages deposited through the Kaiashk and Kopka-Pillar, and the Armstrong and Pikitigushi systems are drawn arbitrarily. Some coalescence and overlap between these deltaic bodies probably developed as sediment-laden waters from subsequent outlets deposited sediment concurrently with, as well as after their more southerly predecessors.

KAIASHK

Catastrophic flooding through the most southerly eastern outlet (Fig.3), the Kaiashk outlet, deposited sediments over a large area of the western and southwestern Nipigon basin (Fig.12). Sediments of the RES and GUL boreholes, along with five exposures of sediment in the Gull Bay region (Fig.36) are representative of the sediments deposited through the Kaiashk outlet. Figure 37 shows the correlation of the major units in these five sections.

The sands exposed at sites 85-11 and 86-16 are texturally and mineralogically similar, with only a minor difference between the planar-bedded, moderately sorted (σ=0.81 $\emptyset$), fine to medium grained sands ($\bar{\emptyset}$=2.20 $\emptyset$) at site 85-11, which are similar to the sands which overlie the GUL

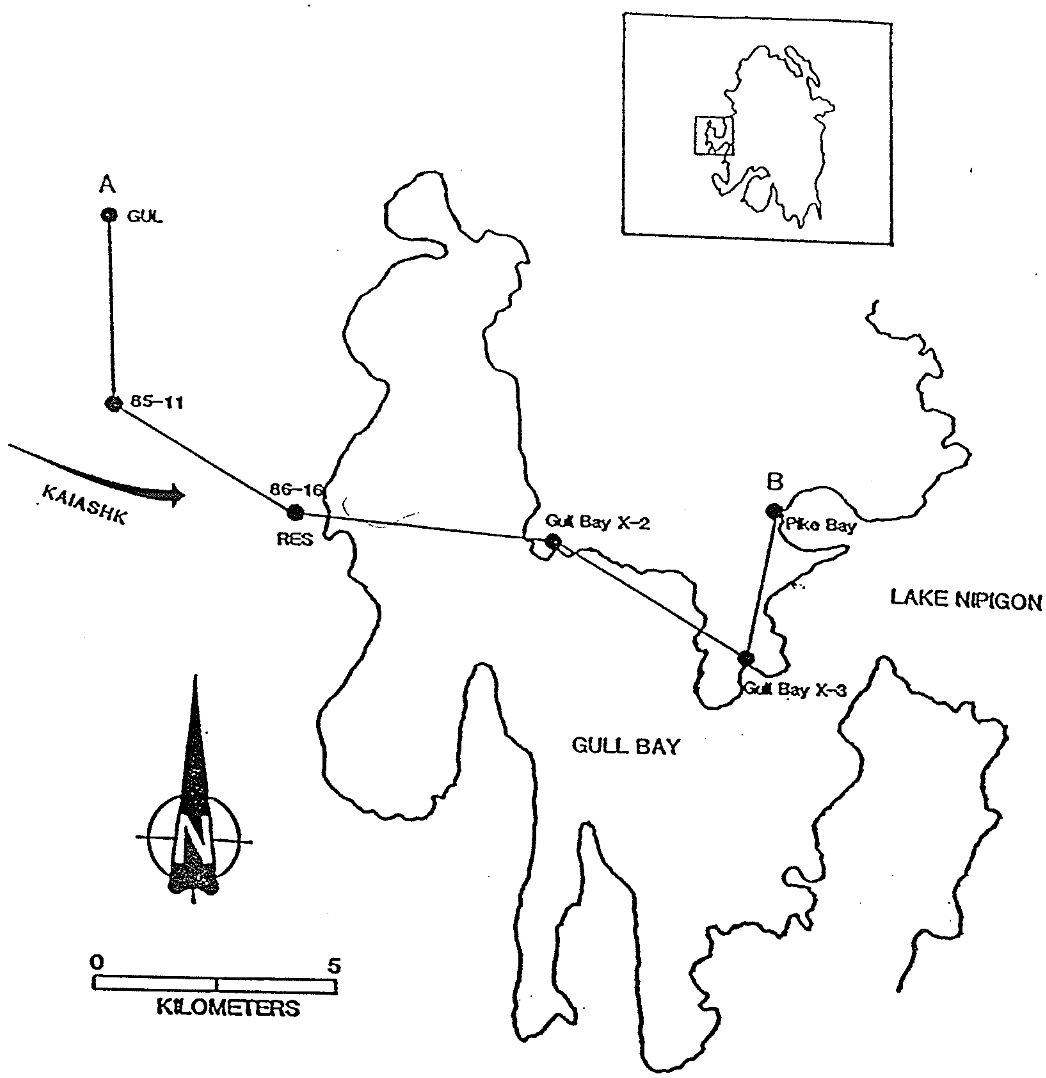

FIGURE 36
Locations of Sedimentary Sections and Boreholes in the Gull Bay Region

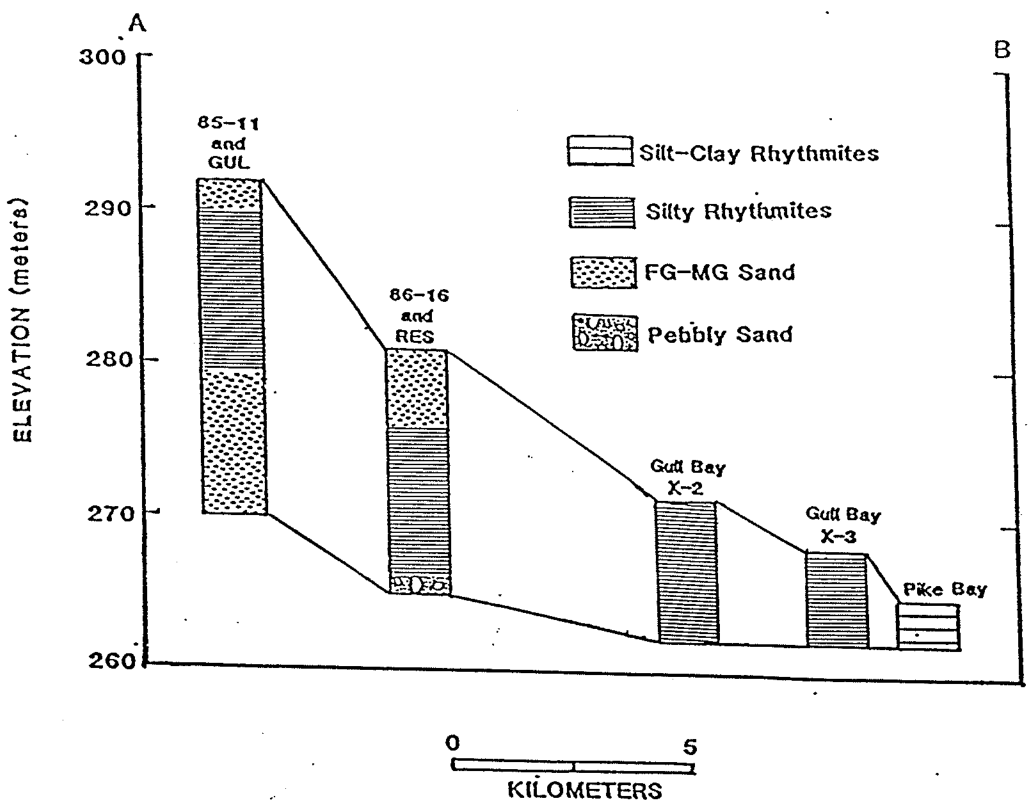

FIGURE 37
Stratigraphy of the Sediments in the Gull Bay Region
(locations of sections in Figure 36)

borehole sediments, and the ripple cross-laminated, moderately sorted (σ=0.64 Ø), fine grained sands ($\bar{Ø}$=3.20 Ø) at site 86-16, which stratigraphically overlie the sediments of the RES borehole. The upper sequences of both the GUL and RES borehole sediments are composed of sandy, silty rhythmites. The basal sequences of both boreholes are composed of coarser grained sandy sediment. The GUL borehole sands are fine to medium grained, whereas the basal RES sediments are very poorly sorted (σ=2.90 Ø), medium to coarse grained sand ($\bar{Ø}$=1.05 Ø) with abundant pebbles and cobbles. The coarser grained nature of these sediments is the result of the proximity of the borehole to the coarse clastic, reworked glacial deposits of the Nipigon Moraine.

The rhythmites exposed at the Gull Bay X-2, X-3, and Pike Bay sites are finer grained than the sandy and silty rhythmites of the GUL and RES cores. The Gull Bay X-2 and X-3 sediments are laminated silty rhythmites, and the Pike Bay rhythmites are still finer, consisting of more distinct couplets of clay and silt.

KOPKA-PILLAR

The five individual channels of the Kopka outlet system and the three channels of the Pillar system (see Fig.3) all deposited their sediment load into a relatively common depocenter. This area is presently situated in the North Obonga Lake region (Fig.38). Initially, sediment would have been deposited in this region as water flowed through the

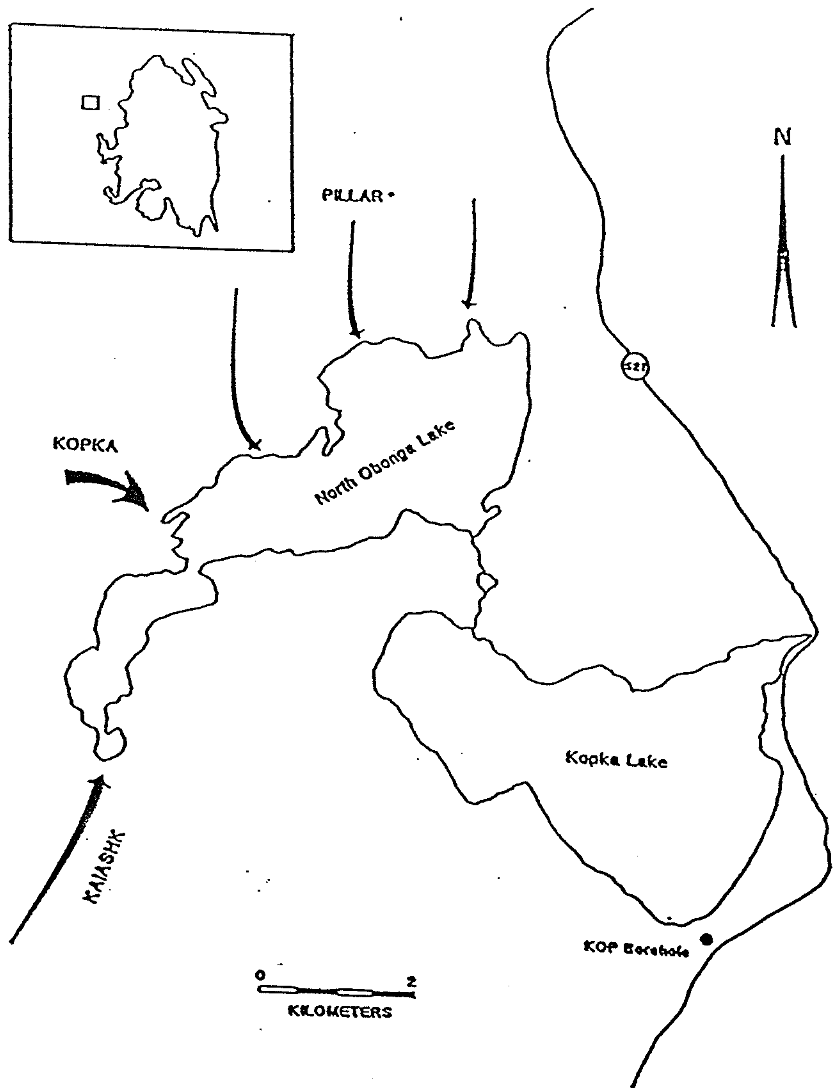

FIGURE 38
Eastern Outlet Sedimentation in the North Obonga Lake Region

Kaiashk system, followed by the Kopka outlet channels into Lake Nipigon. As the flow of sediment-laden water through these channels waned, the Pillar outlet channels became active, resulting in an overlapping sequence of deltaic sediments deposited by the flow of water through the Kaiashk, Kopka, and Pillar outlets. Discharge through the Kopka and Pillar channels may also have eroded some previously deposited sediments.

By the principle of superposition, the sediments exposed on the surface and at shallow depths in the "Kopka-Pillar delta" region were probably deposited by discharge through the northernmost, younger Pillar outlet. These sediments are thinly laminated, interbedded medium and fine grained sand. These sandy deposits are similar in colour and texture to the sands exposed on the surface deposited by the discharge of sediment-laden water through the Kaiashk outlet (85-11, 86-16). As the KOP borehole did not reach the bedrock surface, the sediments recovered (cores) do not reflect the entire complex depositional history of the region.

ARMSTRONG

The discharge of sediment-laden waters through the Armstrong outlet channels resulted in the deposition of a large package of sediment in the northwestern Nipigon basin (Fig.12). Sediments exposed near the mouth and along the course of the Whitesand River, and the sediments of the AIR and CAS boreholes are representative of the sedimentary deposits of this area (Fig.39). Correlation of the major units across this region is shown in Figure 40.

The AIR borehole sediments are quartz-rich, micaceous (muscovite) sands which grade upwards from the very fine grained sands at the base of the 25.0 m thick sequence, to coarse grained, pebbly sands at the surface. Coarser grained gravel deposits are located within the nearby town of Armstrong, and form large aggregate resource deposits. As samples of the AIR borehole sediments were obtained by augering and no core was recovered, it is indeterminable whether these sands are massive or whether they contain sedimentary structures.

The entire 10.0 m thick exposure of sediment at the 86-12 site along the Whitesand River is composed of thinly laminated (less than 1.0 mm), very fine grained silty sand ($\bar{\phi}$=4.00 ϕ). These sands are moderately sorted (σ=0.75 ϕ), quartz-rich and contain accessory muscovite.

The 30.0 m thickness of CAS borehole sediments are composed of a basal unit of sand overlain by rhythmically bedded silty sands. The sands of the basal 7.0 m are thinly laminated (less than 1.0 mm), very fine grained sands similar in composition to the 86-12 sands and the AIR borehole sands.

The upper 16.0 m of sediment exposed at the X-12 site near the mouth of the Whitesand River is composed of well

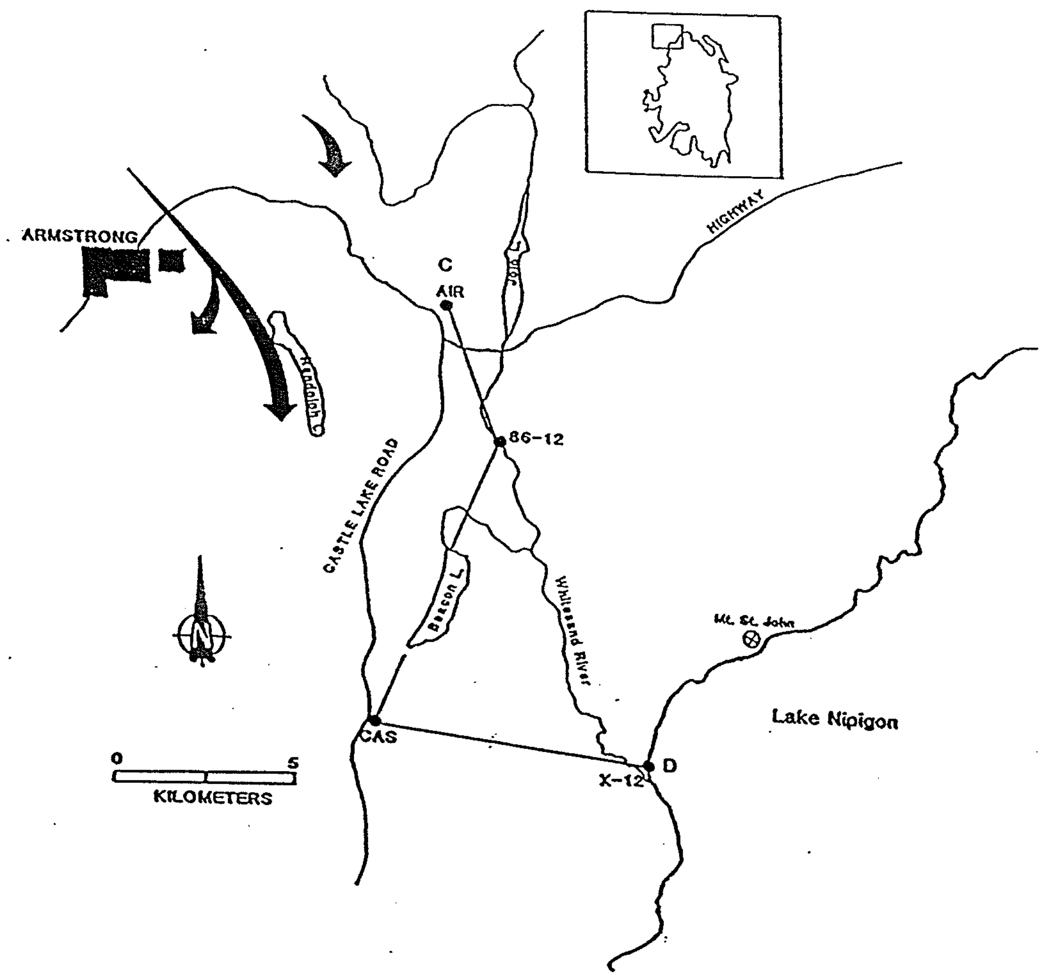

FIGURE 39
Locations of Sedimentary Sections and Boreholes in the Armstrong Delta

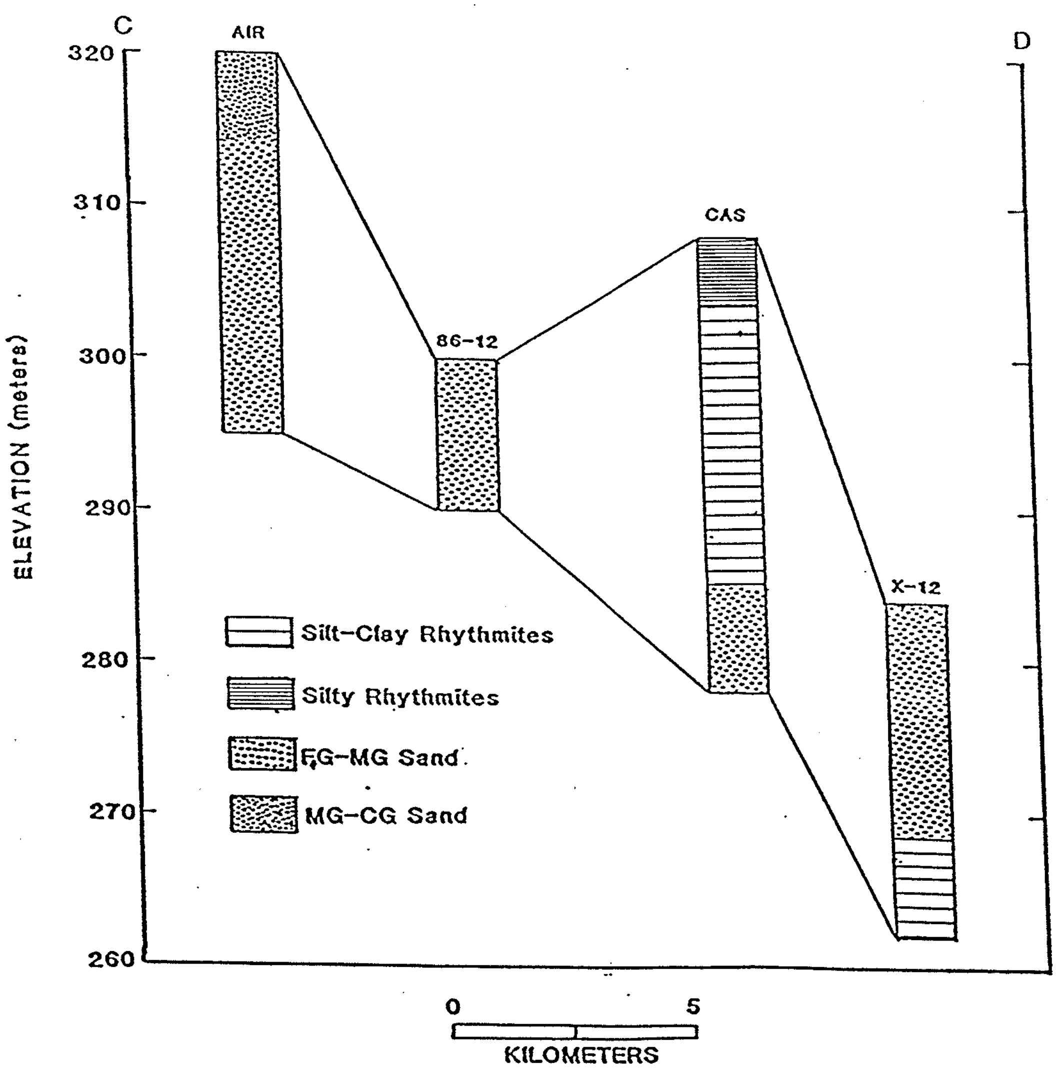

FIGURE 40
Stratigraphy of the Sediments in the Armstrong Delta
(locations of sections in Figure 39)

sorted (σ=0.50 Ø), silty fine grained micaceous sand ($\bar{Ø}$=3.00 Ø). The sands composing the basal 5.0 m of this unit are thinly bedded with some convolute bedding and small-scale faulting developed within the sands. The overlying 5.0 m are more massive sands with minor zones of convolute-bedded sand. The overlying 1.0 m of fine grained micaceous sands are highly deformed bedded sands which grade upwards into a 2.0 m thick unit of planar-bedded, silty fine grained sand. These sediments are overlain sharply by a 10.0 m thick unit of massive silty fine grained sand. The uppermost 2.0 m of the sequence is composed of interbedded, ripple-drift cross-laminated (type A) sands and fine laminated clayey silty sands.

PIKITIGUSHI

The LEE and PIK boreholes are located approximately 25 km northeast of the X-12 site (see Fig.4). Superimposition of the sediments of the LEE borehole onto those of the PIK borehole produces an idealized stratigraphic section of the Pikitigushi delta (Fig.41).

The upper 21.0 m of the LEE borehole sediments is composed of massive fine to medium sands. The basal 3.0 m of poorly developed sandy, silty rhythmites are similar to the basal 16.5 m of PIK borehole rhythmites.

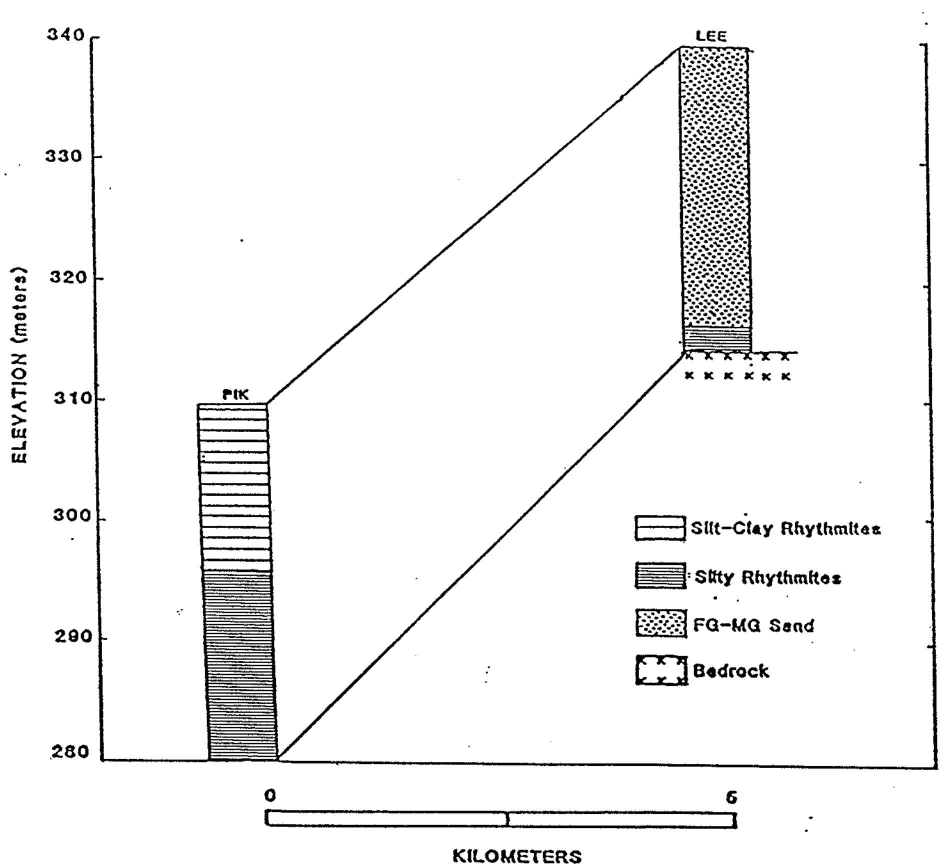

FIGURE 41
Stratigraphy of the Sediments in the Pikitigushi Delta

INTERPRETATION OF DEPOSITIONAL SCENARIO

Kaiashk and Kopka-Pillar Deltas

The lowermost sedimentary units in the western Lake Nipigon basin are composed of fine to coarse grained sand, silty rhythmites, and silt-clay rhythmites deposited by Lake Agassiz flood waters flowing through the Kaiashk and Pillar channels (Fig.42).

The basal unit of the GUL borehole is composed of fine-medium grained sands which were deposited near the mouth of the Kaiashk outlet into Lake Nipigon. The overlying silty rhythmites were deposited into the lake as the discharge of water through the Kaiashk outlet waned.

Farther to the east, silty rhythmites of the RES borehole were deposited over top of reworked glacial deposits of the Nipigon Moraine.

Rhythmites of similar colour and composition to those of the RES borehole rhythmites are exposed at the Gull Bay X-2 and X-3 sites. These silty rhythmites, along with the RES borehole rhythmites were deposited by the discharge of Lake Agassiz waters into the Nipigon basin through the Kaiashk outlet.

The Pike Bay rhythmites, deposited farthest to the east from the mouth of the Kaiashk outlet are finer grained than the GUL, RES, and Gull Bay rhythmites. The transition from silty rhythmites to the rhythmically bedded clays and silts exposed at Pike Bay reflects a decrease in the depositional

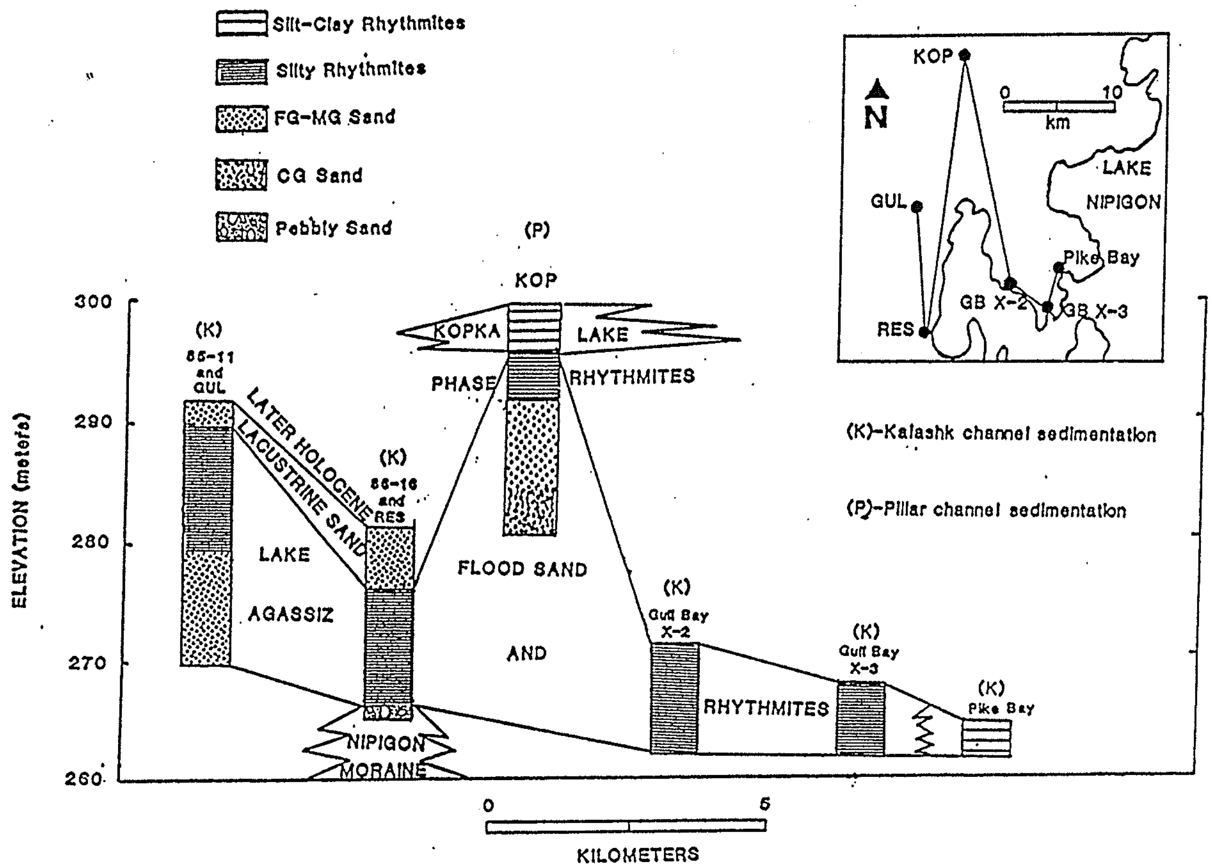

FIGURE 42
Correlation of Sediments Deposited in the
Western Lake Nipigon Region

energy between the Gull Bay X-3 and Pike Bay sites.

As previously discussed, the sediments of the KOP borehole were probably deposited by the discharge of Lake Agassiz waters through the northernmost Pillar outlet into Lake Nipigon. The basal fine to medium, and coarse grained sands of the KOP borehole were deposited by Lake Agassiz floods. The transition from these sands to the overlying silty rhythmites implies a definite decline in the discharge and supply of sediments through the Pillar outlet. The overlying silt-clay rhythmites suggest an even lower energy lacustrine setting and were probably deposited at the bottom of Kopka Lake when this lake stood at a higher elevation than at present, and existed as an individual basin separate from Lake Nipigon. This transition from a "Lake Nipigon" (Lake Agassiz flood) to a "Kopka Lake" phase (Fig.42) occurred as crustal rebound and the flow of water south to Lake Superior served to "lower" the level of Lake Nipigon below the elevation of the former Kopka Lake shoreline.

Lacustrine sands exposed in the Kaiashk delta region (sites 85-11, 86-16) were deposited following the deposition of the Lake Agassiz flood deposits, and may be contemporaneous in age with the Kopka Lake couplets. Crustal rebound of the western Lake Nipigon shoreline region and the lowering of the lake level resulted in the progradation of the mouth of the Kaiashk outlet eastward and the deposition of fine-medium grained sands into a shallow fluvio-lacustrine setting. The lowering of the level of Lake Nipigon probably also resulted in erosion of some of the sediments deposited previously by the flow of water through the Kaiashk outlet into Lake Nipigon.

Armstrong and Pikitigushi Deltas

The basal sedimentary units in the northern Lake Nipigon region were deposited by Lake Agassiz flood waters flowing into Lake Nipigon through the Armstrong and Pikitigushi outlets (Fig.43).

The fine-coarse grained sands of the AIR borehole were deposited nearest to the mouth of the Armstrong outlet. Farther to the south, the Lake Agassiz flood deposits are fine-medium grained sand exposed at the 86-12 site, and within the lowermost 7.0 m of the CAS borehole.

At the X-12 site, near the mouth of the Whitesand River, the sequence of rhythmites at the base of the exposure are representative of distal rhythmites deposited by Lake Agassiz floods. A facies change, specifically a decrease in depositional energy is inferred for the transition from fine-medium grained sand (86-12, CAS) to silt-clay rhythmites (X-12).

The basal 3.0 m of the LEE borehole and the lower 16.5 m of PIK borehole sediments are composed of silty rhythmites of similar colour and composition. These sediments represent distal rhythmites deposited by Lake Agassiz

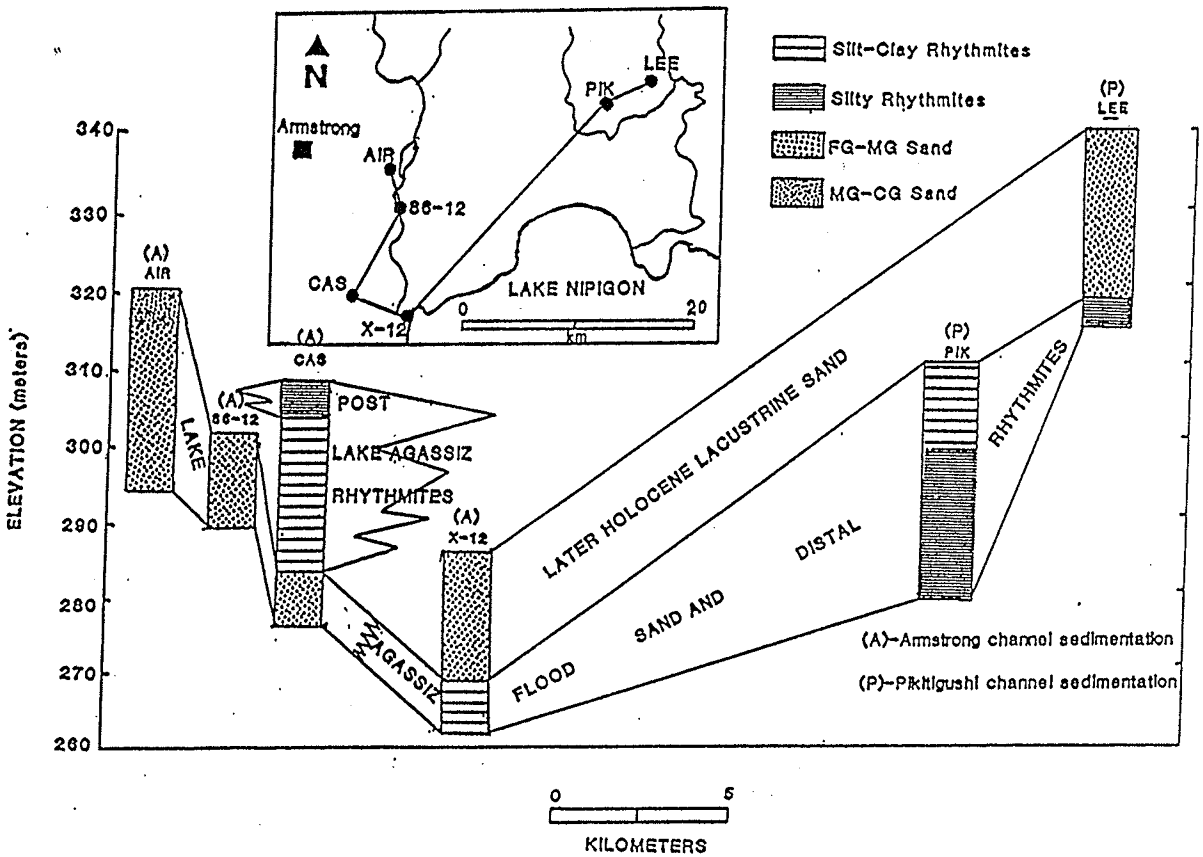

FIGURE 43
Correlation of Sediments Deposited in the
Northern Lake Nipigon Region

flooding through the Pikitigushi outlet. The upper unit of PIK borehole sediments are finer grained rhythmites of silt and clay. The transition from the silty rhythmites to the silt-clay rhythmites in the PIK borehole reflects a decrease in the depositional energy which probably occurred as the result of the waning of the discharge of Lake Agassiz waters through the Pikitigushi outlet.

Following the deposition of the Lake Agassiz flood sands, an estuarine or "back water" environment was probably developed in the area of the CAS borehole. The diabase bedrock of the region forms "buttes" and escarpments approximately 80 m high to the east and west along Castle Lake Road (see Figure 39). This topography would have produced an embayment when Lake Nipigon stood at levels higher than that of the present, and conditions would have been favorable for the deposition of silt-clay rhythmites in the CAS borehole area. As the level of the lake declined and the land surface in the northern Nipigon basin rose in response to crustal rebound, silty rhythmites were deposited in the CAS borehole region as the inflowing source of the sediments prograded towards the south.

Similarly, in response to the southward progradation of Pikitigushi and Armstrong outlet sediments, fine-medium grained sands were deposited over top of the rhythmites of the X-12 site and the LEE borehole. However, these sands may not be related to the Pikitigushi and Armstrong outlet flow, but only to Holocene sands that prograded south as differential crustal rebound raised the northern end up into increasingly shallow water. Erosion of some of the previously deposited Lake Agassiz flood sediments probably occurred concurrently with the deposition of these later Holocene sandy fluvio-lacustrine sediments.

VII. SEDIMENTOLOGY

Introduction

Sediments exposed within the Lake Nipigon basin were deposited by various depositional processes. Till and other glaciogenic sediments, eolian deposits, glaciofluvial, and glaciolacustrine deposits are exposed throughout the entire lake basin region (see Figure 2).

The sediments exposed in sections and boreholes described in the previous chapter, deposited largely as Lake Agassiz flood sediments, are all identified as deltaic on the basis of areal and stratigraphic evidence. Previous studies (eg. Teller and Thorleifson, 1983) refer to some sequences of sediment in the Lake Nipigon basin as having been deposited as underflow fan sequences. Interpretation of sedimentary structures in this study, suggests that underflow, overflow-interflow currents, fluvial, and nearshore processes, were responsible for the deposition of the Lake Nipigon sediments described in this study. The use of the term delta in this thesis represents a complex of sediment types and bedding structures developed at the mouth of former Lake Agassiz overflow channels.

Teller and Thorleifson (1983, p.277) observed cobbly gravel foreset and topset bedding in deltaic sediments deposited by the flow of Lake Agassiz water through the Pillar outlet. Steeply dipping foreset bedded gravel and sand was observed in pits near the town of Armstrong, Ontario, in this study. The presence of these steeply dipping foreset beds of sand and gravel within the Lake Nipigon basin suggests that the deltas formed at the mouths of the Lake Agassiz outlet channels are Gilbertian in nature. Such deltas are representative of non-contact glacial lakes (Smith and Ashley, 1985).

Mineralogical/Textural Interpretations

The high level of mineralogical maturity (see Fig.11) of the sand and coarser grained sediment of the western and northern regions of the Nipigon basin reflects the parent lithological source of the sediments. The high quartz content (80%-96%) is the result of the dominantly granitic bedrock of the Lake Agassiz and western Lake Nipigon basins. Greater muscovite contents are found within the sands of the northwestern basin region. These sediments, deposited by waters flowing through the Armstrong and possibly the Pikitigushi outlets contain as much as 10% muscovite. Precambrian metasedimentary rocks, especially phyllites and mica-schists are common to the northwest of this region (Horwood, 1938) and are probably the source for the muscovite and biotite present within the sediments.

The variable degree of roundness/angularity of the grains is the result of the multiple phases of transport and deposition which the sediments have undergone. The catastrophic discharge of the sediment-laden waters through the eastern outlets would have produced highly angular quartz grains as a result of inter-clast collisions within the fluvial system. Reworking of these sediments by nearshore lacustrine and eolian processes resulted in the increase in the degree of roundness of the grains.

Discussion of the Depositional Nature of Lake Nipigon Rhythmites

Rhythmically bedded sand, silt, and clay observed within the Lake Nipigon basin occur as couplets, triplets, multiple laminated, and graded beds. A couplet refers to a rhythmite composed of two distinct sediment types, typically a basal unit of silt overlain sharply by a unit of clay. Triplets are composed of a coarse grained basal unit of silt or sandy silt which grades upwards into finer grained silty sediment. The contact between these medial silty laminae and overlying clay layers can be gradational, but is more often sharp. The coarser grained units of rhythmite couplets and triplets commonly display multiple internal laminations and graded bedding.

Previous studies (Zoltai, 1965b; Schlosser, 1983) refer to the rhythmically bedded clays and silts of the Nipigon basin specifically as varves. This term infers that these rhythmically bedded sediments were deposited in response to seasonal changes from summer to winter. This commonly results in the deposition of the coarser grained silty sediments during the summer season, and the development of the finer grained clay laminae during the winter period when the surface of the lake is covered by ice and when meltwater and river influx is reduced.

The term varve also implies that these sediments can be applied as a geochronological tool. Numerous criteria have been developed with which to identify the annual nature of varved sediments, however, only two of these criteria are generally accepted as being conclusive. Terasmae (1963) suggests that the presence of pollen and spores within the "summer layers", coupled with the lack of these microfossils in the "winter laminae" implies a seasonally controlled depositional mechanism. A more direct approach as determined by Antevs (1957) involves the general correlation in the difference in age between two radiocarbon dated horizons within a sequence of rhythmites, and the number of "varve years" represented between these two horizons.

As detailed palynological analyses were not undertaken in this study, and because of a lack of radiocarbon datable material within the sediments, the rhythmically bedded silts and clays of the Lake Nipigon basin are referred to as rhythmites and not varves. The possibility of these rhythmites being true varved sediments is evaluated on the basis of the results of the carbonate and quartz content of the rhythmites, the statistical data of sediment textural parameters, the results of paleomagnetic analysis, and the presence of trace fossils within the sediments.

The greater abundance of carbonate and quartz within the coarser grained silty laminae of the rhythmites as determined by acid-digestion and X-ray diffraction implies that the rhythmically bedded sediments of the Lake Nipigon region were deposited in response to seasonal changes. The coarser part of the rhythmite would have been deposited during the open water season (summer-autumn) as sediments were transported into the Lake Nipigon basin by inflowing fluvial systems. The finer grained clay laminae of the rhythmites were developed as the clay grains settled from suspension.

The plotting of the degree of sorting versus mean grain size for samples of Lake Nipigon rhythmites produced results similar to that obtained from varves of Glacial Lake Hitchcock as determined by Ashley (1975). If Ashley's results are representative of varved sediments in general, than the Lake Nipigon rhythmites, based upon the trends of sorting versus grain size observed, could be varves. In sampling rhythmically bedded silts and clays from the western Lake Nipigon region for paleomagnetic analysis, Schlosser (1983) collected samples from the Gull Bay and Wabinosh River areas which were near the sampling sites of the present study. In addition, Schlosser's Castle Lake Road rhythmites were collected from the same location as the

CAS borehole. The results of the depositional remnant magnetism of the sediments by Schlosser (1983) conclude that the Gull Bay rhythmites were deposited first, followed by the formation of the Wabinosh River rhythmites, and later the development of the rhythmically bedded silts and clays of the Castle Lake Road site. Based upon these results, Schlosser (1983) concluded that the rhythmites deposited at these three locations are varves. Because these sediments are correlated with those of the present study in the Gull Bay region, Wabinosh Bay, and the CAS core respectively, it seems likely that the latter rhythmites were also deposited seasonally.

The restriction of the trace fossils to the coarser grained, silty laminae of the rhythmites throughout the Lake Nipigon basin, and the lack of bioturbation within the clayey laminae infers a varved nature for these sediments. Smith and Ashley (1985) concluded that such a restriction of trace fossils within the silty laminae can be used to distinguish varved sediments from non-annually deposited, or surge rhythmites.

Based upon the results of the carbonate and quartz content, sediment textural parameters, paleomagnetic analyses, the presence of trace fossils in the sediments, and the repetative nature and regularity of bed thickness, the Lake Nipigon rhythmites appear to have been deposited seasonally and therefore are probably varves.

Rhythmite Sedimentation and Sediment Dispersal Mechanisms

Rhythmically-bedded sequences of sand, silt, and clay observed within the Lake Nipigon basin were formed in response to cyclical deposition, the signature of ice-contact and distal glacier-fed lake environments (Smith and Ashley, 1985). Rhythmicity is a function of seasonally controlled shifts in sedimentation between a short-term glacial ice-melting season and the remainder of the year. Numerous other causes of cyclical sedimentation do exist, such as pulses in a single underflow (minutes), slump-generated surge currents (minutes), diurnal shifts in sedimentation (hours), or variations in the normal weather patterns (days) (Smith and Ashley, 1985). Such fluctuations can produce small-scale rhythmic bedding, each representative of different temporal scales.

Thermal stratification of the lake water, and sediment stratification form relevant components in the depositional nature of glaciolacustrine rhythmites. Thermal stratification generally develops in most lakes, and sediment stratification will develop in lakes where inflowing waters contain relatively high concentrations of suspended sediment. Each of these limnological factors will affect the inflowing sediments, specifically as to the nature of the dispersion of the sediments.

Generally, inflowing sediments are distributed throughout a lake basin via the dispersal mechanisms of overflow, interflow, underflow, or homopycnal mixing. Homopycnal mixing occurs when the density of the inflowing sediment-laden waters are equivalent to the density of the lake waters. Available data in the literature suggests that homopycnal mixing is uncommon in glacial lakes. Underflow currents generally are generated during the summer or more specifically the open, ice-free periods of a lake. Underflows can occur throughout the winter forming "winter varves", but more commonly stop completely when the clastic influx to the lake basin is retarded by winter ice. Overflow and interflow currents and slump-generated plumes of sediment may occur throughout an entire season, although commonly as varying pulses of dense sediment and water influx.

Underflow currents form as high-density fluvial waters, resulting from relatively high concentrations of suspended sediment, enter lower density lake waters. The resultant turbidity current tends to "hug" the bottom as the flow continues downslope along the delta foreset and bottomset and onto the lake floor (Smith and Ashley, 1985). Underflows in glacial lakes can be generated by either the quasi-continuous discharge of sediment-laden fluvial waters into the lake, or by slump-generated surge-currents triggered by mass movement in unstable deltaic or lake margin sediments. Sediments deposited by underflows are characteristically coarser grained in the area of the sediment-influx point, and become finer grained as the flow continues downslope.

Overflow currents develop when inflowing waters are less dense than the lake waters. Interflow currents form in thermally stratified lakes and tend to flow along the thermocline where the density of the inflowing sediment-laden waters is greater than that of the epilimnetic, but less than that of the hypolimnetic waters. Both overflow and interflow currents transport sediment above the lake floor, and sediments are deposited entirely from suspension (Smith and Ashley, 1985). These two processes are referred to in the literature as a single depositional mechanism, due to the impossibility of distinguishing the two processes by the character of their resultant sedimentary deposits. Characteristically, sedimentation from overflow-interflow plumes in a lake produces rhythmically bedded couplets, as the coarse grains (sand and coarse silt) settle early and fine silt and clay are further held in suspension and transported throughout the lake basin. Commonly, couplets represent the seasonal alternations between sediments transported directly to the depocenter by overflow-interflow plumes during the summer, and finer clays which later settle out during the following winter. These are the classical varves which are well documented throughout the literature of glaciolacustrine sedimentology. Multiple laminations within the basal silty layers reflect shorter-term fluctuations (hours and minutes) in the influx and dispersal mechanisms of sediment.

Overflows and interflows generally contain low concentrations of suspended sediment (5-30 gm/l), and thus annual accumulations of sediment are thin, ranging in thickness from 1 cm for proximal rhythmites to thinner (1-5 mm) rhythmites deposited in more distal areas of a lake basin (Smith and Ashley, 1985).

Sedimentation in Glaciolacustrine Deltaic Environments

Fining-upward sequences of sand and gravel are characteristic of underflow sedimentation in the upper delta. These sediments are generally unstable and usually move downslope by grainflows and avalanches, often triggering surge-currents which continue downslope to the mid-delta and lower delta. Imbricated gravel and larger size clasts are common to the rhythmically bedded sand and gravel deposits of the upper delta.

Sediments deposited on the mid-delta are generally finer grained than those formed in the upper delta regions. Sequences of climbing-ripple laminated sand and silt, and clay draped laminae are commonly developed by underflow sedimentation in mid-delta regions (Jopling and Walker, 1968, Gustavson, 1975, Leckie and McCann, 1982, Smith and Ashley, 1985). Thin clay drapes which overlay sequences of rippled sand and silt are deposited from suspension during the winter period. Clay drapes which appear to interrupt the sequences of rippled sand and silt are deposited from plumes of suspended sediment during quiescent periods following underflow surge-currents (Smith and Ashley, 1985). Due to high sedimentation rates from underflow currents in mid-delta regions, it is difficult to differentiate between rhythmites deposited from quasi-continuous underflows, and those generated by slumping (Smith and Ashley, 1985).

Sedimentation on lower delta forsets is characterized by a combination of overflow-interflow, and underflow sediment dispersal mechanisms. The coarser grained layers of rhythmites deposited by combined flows are composed of ripple laminated and multiple-laminated fine sand and silt. Thin clay interlayers suggest a pause in the influx of sediment (Smith and Ashley, 1985). The contact between the coarser grained units and overlying winter clays is generally sharp. The rippled and multiple-laminated coarse grained summer units of lower delta rhythmites are deposited from underflows, with minor amounts of sediment deposited from overflow-interflow plumes. The finer grained winter layers of silty clay to pure clay are formed as these fine sediments settle from overflow-interflow plumes, and from suspensions generated from underflow currents.

Lake bottom, or glaciolacustrine bottom sediments are deposited at sites far removed (hundreds of meters to kilometers) from the point of sediment influx (Smith and

Ashley, 1985). Rhythmites of silt and clay are deposited in these distal regions by the settling of the fine sediments from overflow-interflow plumes. The coarser grained silty units are massive to finely laminated, and are characterized by a lack of current structures. Rare coarser grained sandy partings and minor sand laminae, which can be found interbedded with the silty sediments, suggest that weak underflow currents may reach these distal depocenters. The clay units which sharply overlay the silty units are generally massive, having been deposited from plumes of clay dispersed throughout the lake basin by overflow-interflow currents. Thin (<1 mm) interlaminated silty clays within these generally massive clay layers are due to the minor influence upon sedimentation by weak underflow-generated plumes of sediment in the immediate area.

Kaiashk Delta Sedimentation

Large volumes of sediment transported through the Kaiashk outlet were deposited into Lake Nipigon forming the Kaiashk delta. Sediments from boreholes and sections exposed in the Gull Bay region (Figs.36,37) are representative of these deltaic deposits, which show a fining sequence from the sandy deposits of the GUL hole and site 85-11 through to the clay-silt rhythmites at Pike Bay. The thickness of the rhythmite units and thus total sedimentation rates decreases from depocenters near the point of sediment influx to more distal regions, with an associated increase in the predominance of sedimentation from suspension (Smith and Ashley, 1985). This can be observed by noting the number of rhythmites per meter developed at each of the exposures of deltaic sediments. This is only a relative measure, however, of total sedimentation rates as each sedimentation system operating in nature is governed by various localized (e.g. the supply of sediment, relief) and geographical factors (e.g. climate). The sandy sediments exposed at sites 85-11 and 86-16 were deposited following the catastrophic discharge of Lake Agassiz floodwaters through the Kaiashk outlet. These sediments, which stratigraphically overlay the GUL and RES borehole sediments respectively, were deposited into a shallow nearshore setting which developed following the flood stage (see Fig.42). The GUL and RES borehole sediments and the sedimentary sequences exposed at Gull Bay and Pike Bay were all deposited during the Lake Agassiz flooding stage as sediment-laden waters flowed eastward into the Lake Nipigon basin.

The 85-11 exposure reveals 1.5 m of planar-bedded fine to medium grained sand (Fig.44). The individual beds are marked by thin planar laminae of medium grained mafic heavy mineral grains which are overlain by medium grained sands. These sands grade upward into the laminated fine grained sands which are capped by heavy mineral laminae. The sands exposed at site 86-16 are similar in composition to the 85-

FIGURE 44
Planar-Bedded Sands at 85-11 Site

11 site sands. These fine grained sands are ripple cross-laminated (Fig.45) with the type A ripple forms accentuated by concentrations of fine grained mafic heavy mineral grains.

Similar sedimentary sequences described by other workers (Gustavson, 1975; Leckie and McCann, 1982) suggest that the sands exposed at sites 85-11 and 86-16 were deposited by the bedload component of density underflow currents flowing down the gently sloping mid-delta slope. The rhythmically bedded nature of the 85-11 sands infers cyclic sedimentation mechanisms which produce multiple pulses of sediment resulting in the formation of fining-upward-beds of medium grained, sand rich in mafic heavy mineral grains, overlain by fine to medium grained sand. Although it is difficult to differentiate the nature of the underflow mechanism (quasi-continuous vs surge-generated), the lack of silt and clay laminae within the 85-11 sedimentary sequence suggests that there were no quiescent periods following the deposition of the bedload sands. This observation tends to rule out the possibility of deposition by surge-generated underflows and favours a quasi-continuous underflow mechanism. The heavy mineral laminae which formed at the base of each rhythmite of sand also infers that sedimentation was occurring at a fairly consistent rate. In contrast to laminations in muds, laminations in sands are generally produced fairly rapidly by various mechanisms

FIGURE 45
Ripple Cross-Laminated Sands at 86-16 Site

including traction of sediment by steady flows (Blatt et al, 1980, p.134). The average thickness (15 cm) of the sandy rhythmites at site 85-11 result in an average of seven rhythmites per meter. This suggests relatively high sedimentation which is characteristic of sedimentation in mid-delta regions.

The 86-16 sands suggest that the volume of sediment in the bedload component of the underflow current was greater, in comparison to the suspended load. This resulted in the erosion of stoss-side ripple laminae and the development of type A ripple cross-laminae. The uniform grain size of the rippled sands throughout the sequence exposed at site 86-16, and the lack of any other bedforms suggests that the sediments were deposited by a fairly consistent depositional mechanism with uniform flow energy. The thin mafic laminae which accentuate the ripple forms result from the migration of the ripples. The erosion and winnowing of more easily transported sediment tends to leave behind the thin lags enriched in heavy mineral grains which mark stoss-side laminae, or accentuate lee-side laminae formed by avalanching (Blatt et al, 1980, p.135).

Leckie and McCann (1982) described graded beds of silt and clayey silt in exposures of glaciolacustrine deltaic sediments in south-central Newfoundland, which are similar in appearance to the Gull Bay X-2 rhythmites (see Fig.14). Textural analyses of the sediments from both locations revealed similar results in terms of the mean grain sizes for the sediments of the individual laminae. Throughout the entire sequence of the Conne River (Newfoundland) deposits, the difference in mean grain size between the coarse and fine rhythmite laminae is approximately one phi unit (Leckie and McCann, 1982). The Gull Bay X-2 rhythmites exhibit a similar numerical difference between the mean grain size of the fine grained silts ($\bar{\varnothing}=6.90\ \varnothing$) and the overlying clayey silts ($\bar{\varnothing}=8.20\ \varnothing$). The silt and clayey silt rhythmites at Gull Bay X-2 were deposited on the slopes of the lower delta by combined sediment dispersal mechanisms of underflow and overflow-interflow currents. The thicker, coarser grained silty units may have been deposited from the suspended load of density underflows, with little or no deposition from the bedload component. This is exemplified by the lack of coarser grained (sandy) sediment, and the lack of cross-bedding within the silty beds. The thin (<1 mm) laminae of clayey silt developed within the coarser grained beds suggest that there were pauses in the underflows, during which time the finer silty clays settled from overflow-interflow, and possibly underflow-generated plumes. The thicker (3 mm) laminae of silty clay represent much longer periods for the settling of these finer grained sediments from overflow-interflow plumes, and represent "winter" laminae.

An average of thirty rhythmites per meter counted at the Gull Bay X-2 site suggest that total sedimentation rates on the lower delta was less than that on the mid-delta (85-11).

The sequence of bedding structures developed within the sediments of the Gull Bay X-3 rhythmites display both type A and type B ripple-drift cross-laminae, and planar, multi-laminated silts (Fig.46). This sequence of bedforms is identical to that observed in glaciolacustrine deltaic sediments deposited on the lower delta by a combination of overflow-interflow and underflow current mechanisms described by Gustavson and others (1975). A transition from the type A ripple-drift cross-laminated sandy silts to the type B silty sediments suggests a decrease in underflow current velocity, and/or an increase in the rate of sedimentation from suspension as opposed to bedload sedimentation. Thin silty laminae deposited directly over the sinusoidal type B ripples tend initially to conform to the troughs and crests of the ripple forms. Subsequently deposited silts tend to form planar laminae. The development of these planar laminations, which are equivalent to the "draped lamination" of Gustavson and others (1975), suggests that deposition from bedload has ceased, the rejuvenation of which is signified by the development of overlying type A cross-laminated sandy silts. The bedform sequence is completed by the formation of the thin (1-2 mm) silty clay laminae which forms above the silty

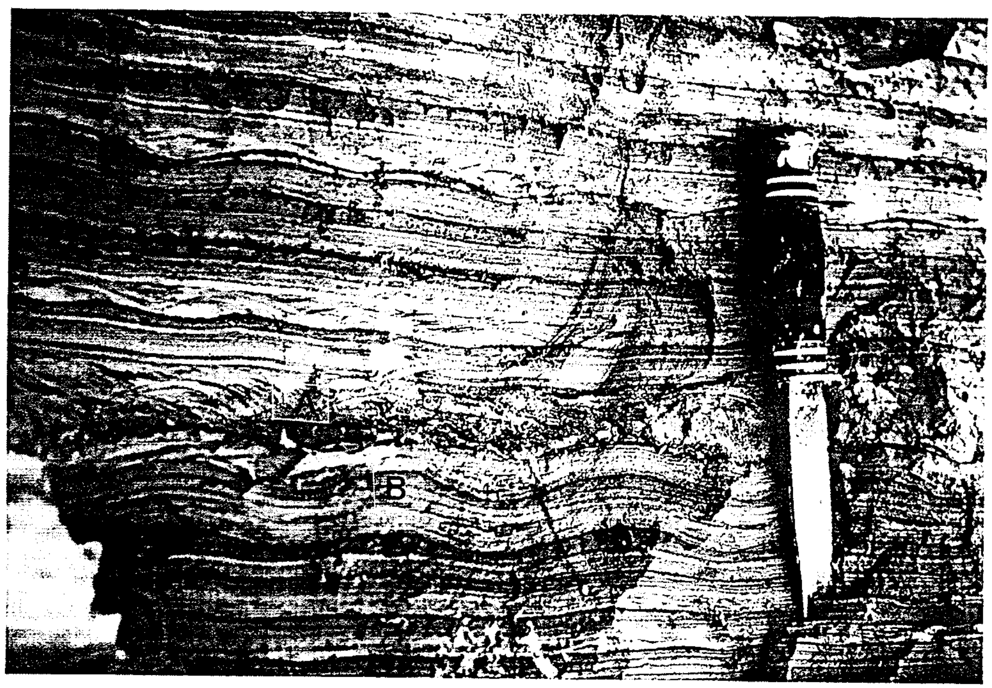

FIGURE 46
Ripple-Drift Cross-Laminated Rhythmites
at Gull Bay X-3 Site
(5.5 meters above lake level; Type A and B ripples)

draped laminations. These clayey laminae are equivalent to "winter clays" deposited as clay grains settle out from suspension and complete a seasonal unit or varve. Thinner (<1 mm) clayey laminae present within the type B rippled and planar draped silty summer units were deposited from suspended plumes during the intermittent quiescent periods following surges of density underflow current sediments. The multi-laminated nature of these summer units (average 35 laminae per coarse rhythmite unit) reflect the highly cyclical nature of deposition from underflow currents, probably resulting from both quasi-continuous and surge-generated mechanisms.

A decrease in the total sedimentation rate on the lower delta region of the Kaiashk delta is noted in comparing the number of rhythmites per meter observed at the Gull Bay X-2 site (30) to an average of sixty rhythmites per meter within the X-3 sequence. Both the rhythmites exposed at the Gull Bay X-2 and X-3 sites are classified as Group I rhythmites in the classification scheme of Ashley (1975). In this category, the thickness of the silty layers is greater than that of the clay laminae, which suggests deposition in a setting relatively proximal to the inflowing sediment source. Ashley's classification scheme, however, is based upon the thicknesses of the individual rhythmite units in relation to each other, and does not take into account the various factors which control sedimentation rates. It should therefore only be regarded as a relative scheme for the classification of variable types of rhythmites developed within a single depositional system, and not used to compare and contrast rhythmites in general.

The Pike Bay rhythmites (see Fig.16) are couplets of thinly laminated clayey silt and massive silty clay. Although trace fossils are present within the rhythmites throughout the entire Lake Nipigon region, the silty laminae of the Pike Bay rhythmites show the highest degree of bioturbation. These rhythmites are also Group I rhythmites (Ashley, 1975), although the average thickness of the clay laminae of the Pike Bay rhythmites is much greater than that of the Gull Bay X-2 and X-3 sequences. It is difficult to distinguish whether the Pike Bay rhythmites were deposited on the more distal region of the lower delta, or as proximal lake bottom rhythmites. The distinction, however, between distal deltaic and proximal lacustrine sediments is arbitrary as the physical processes are similar and facies contacts gradational (Smith and Ashley, 1985).

The thin, fine grained nature of the rhythmites, the lack of current structures, and the sharp contacts between the laminae imply that these rhythmites were developed as sediment settled out from overflow-interflow dominated density currents. Commonly, these types of rhythmites reflect cyclic seasonal sedimentation. The fine laminations present within the clayey silt beds probably reflect fluctuations in sedimentation rates on the order of hours and days (Smith and Ashley, 1985). Such short-term shifts in sedimentation could be generated by the slumping of sediment on the nearby delta front, or by other events such as storms and strong periods of precipitation and runoff in the drainage basin of the lake.

The thin-bedded (ie. thinner than Gull Bay X-2, X-3,) nature and the increased number of rhythmites observed within a one-meter-thickness (90) infers sedimentation from suspension as the predominant mechanism in the formation of the Pike Bay rhythmites.

Kopka-Pillar Delta Sedimentation

In areas outside of the Kopka Lake basin, the uppermost stratigraphic unit of the Kopka-Pillar delta is composed of rhythmically bedded sands similar in composition and texture to the surficial sediments of the Kaiashk delta (Fig.47). The similar sedimentary structures developed within the sediments, and their stratigraphic positions suggest that the sands covering the surface of the Kopka-Pillar delta were also deposited in a shallow deltaic setting. These sands stratigraphically overlay the deposits of the KOP borehole which reflect the transition from an open glaciolacustrine deltaic environment (Fig.48, Units 1,2,3) to a quiet water lacustrine or estuarine setting (Unit 4). The former units were deposited during the Lake Agassiz

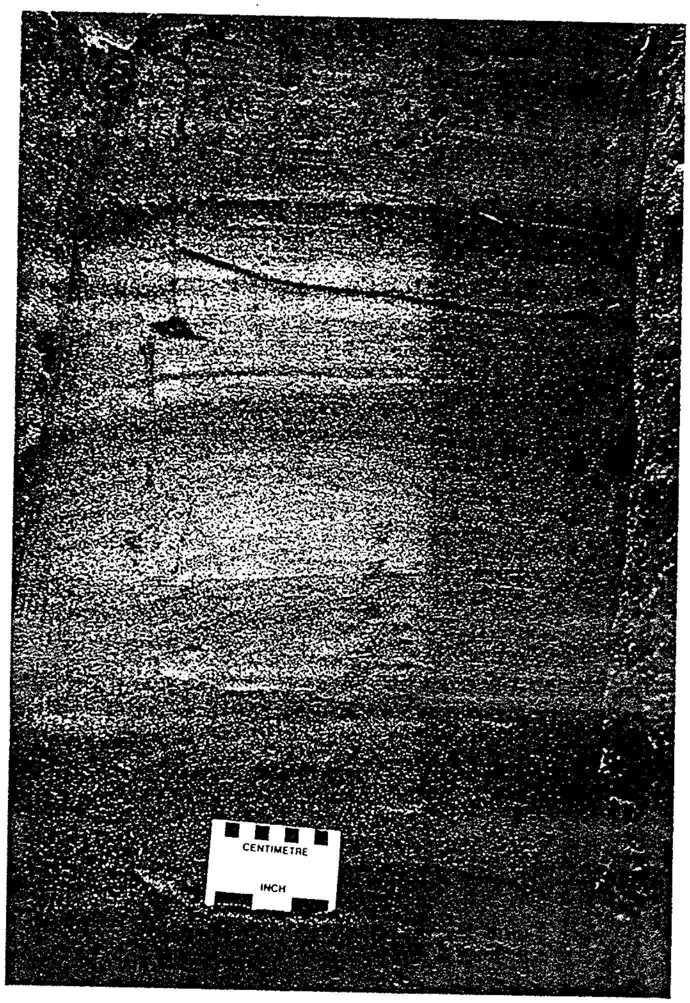

FIGURE 47
Planar-Bedded Sands in the Obonga Lake Region

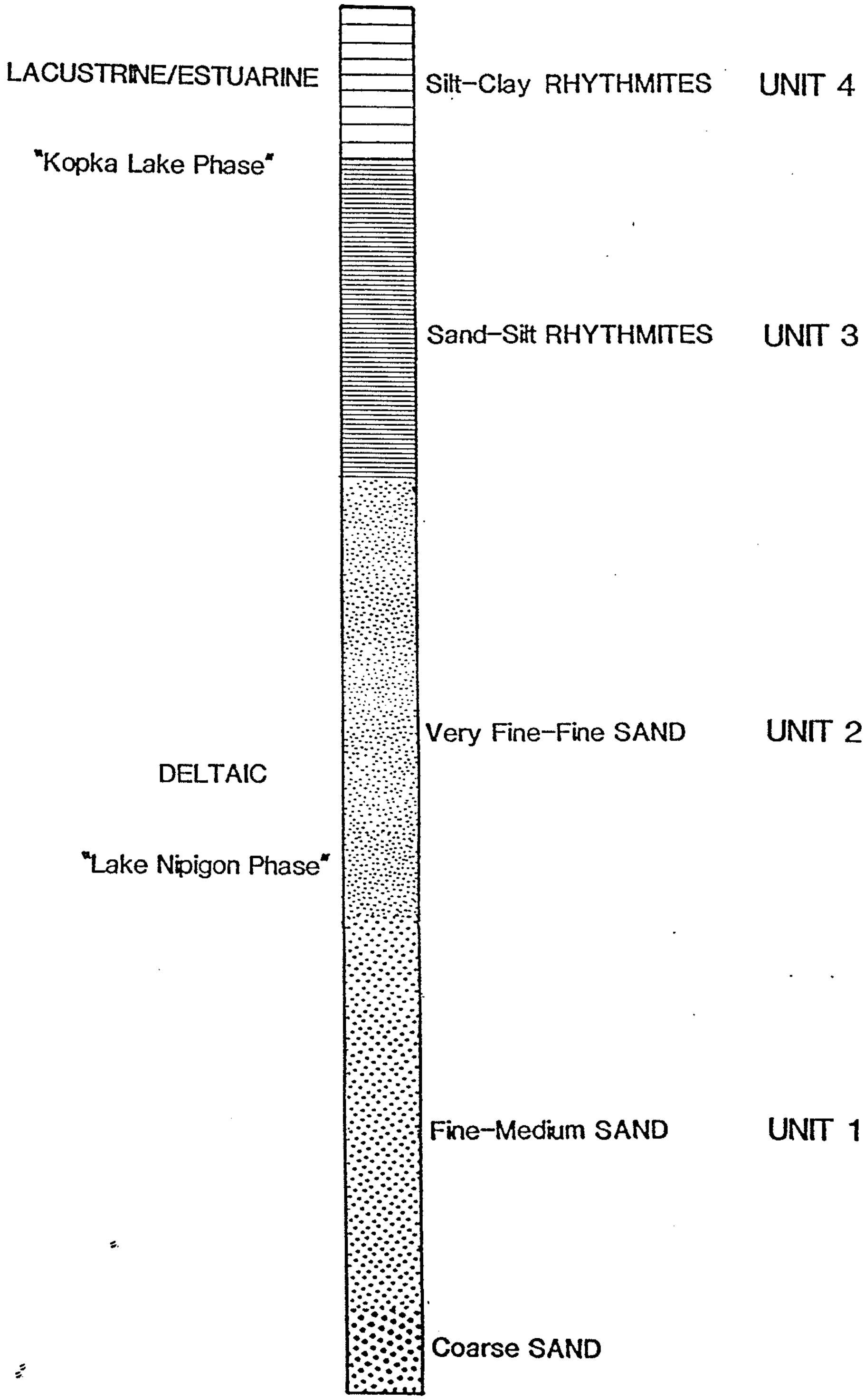

FIGURE 48
Kopka-Pillar Delta Sediments

flooding stage as sediment-laden water flowed into Lake Nipigon. As the discharge of water through the Kopka and Pillar outlets waned and lower depositional energy conditions became prevalent, the former fine grained sediments of Unit 4 were deposited.

Unit 1 is composed of massive, medium to coarse grained sands with rare pebbles. The coarse grained, massive nature of these sediments suggests that they were probably deposited as grainflows or by high energy density underflow currents associated with the discharge of water through the Pillar outlet channels. These coarser sands are overlain by massive fine to medium grained sands of similar composition, which grade upward into laminated very fine to fine grained sands (Unit 2). These laminated sands appear similar in terms of texture and sedimentary structures to sequences of mid-delta deposits in the literature which are formed by bedload sedimentation in density underflow currents. The sediments composing Unit 3 are rhythmically bedded sand and silts which also appear similar to mid-delta rhythmites deposited by underflows.

The fining-upward-sequence displayed by the sediments of Units 1 through 3 reflects the decline in the discharge of water through the Kopka-Pillar outlets during the Lake Agassiz flood stage. In the present region of the Kopka Lake basin, still lower energy, estuarine conditions prevailed following the Lake Agassiz flooding as evident by the development of the Unit 4 rhythmites (Fig.49). These rhythmite couplets, composed of thin clay laminae and relatively thicker very fine to fine grained silt beds, were deposited from suspension of overflow-interflow generated sediment plumes. Rare, thin (<1 mm) silty laminae developed within the coarser grained silty units suggest that there was a minor influence upon sedimentation by weak underflow currents. The silt-clay couplets are similar to rhythmites deposited within the distal deltaic-proximal lake bottom facies transition zone, and were deposited into a shallow estuarine setting.

An average of fifty-eight couplets (varves) per meter are present within the upper KOP core sequence. This reflects a fairly moderate total rate of sedimentation, which is comparable to that of the Gull Bay X-3 rhythmites deposited on the lower delta region of the Kaiashk delta.

Couplets composed of thicker laminae of clay and silt (Fig.50) are exposed near the Kopka River bridge on highway 527. These rhythmites lay stratigraphically above the thinner couplets of the KOP borehole and are composed of approximately equal thicknesses of silt and clay. This would place these rhythmites as Group II rhythmites in Ashley's (1975) categorization scheme, which suggests a more distal position with respect to the sediment source (as compared to Group I rhythmites). These thicker rhythmites were probably deposited at the bottom of Kopka Lake when the

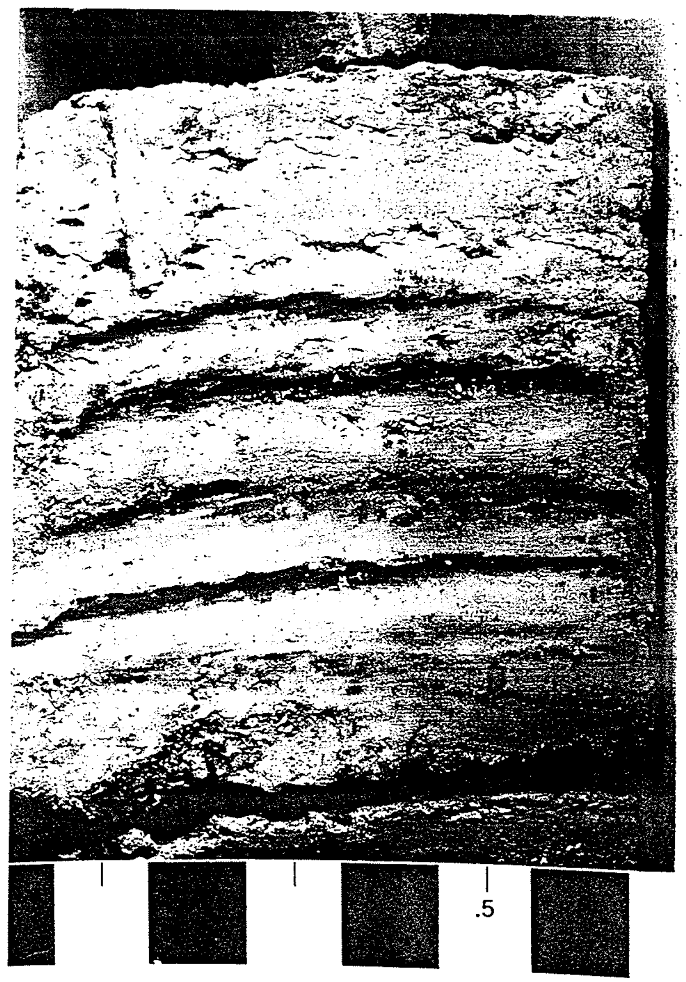

FIGURE 49
Upper KOP Core Clay (dark) and Silt (light) Rhtyhmites
(scale in centimeters)
(from a depth of 1.4 meters)

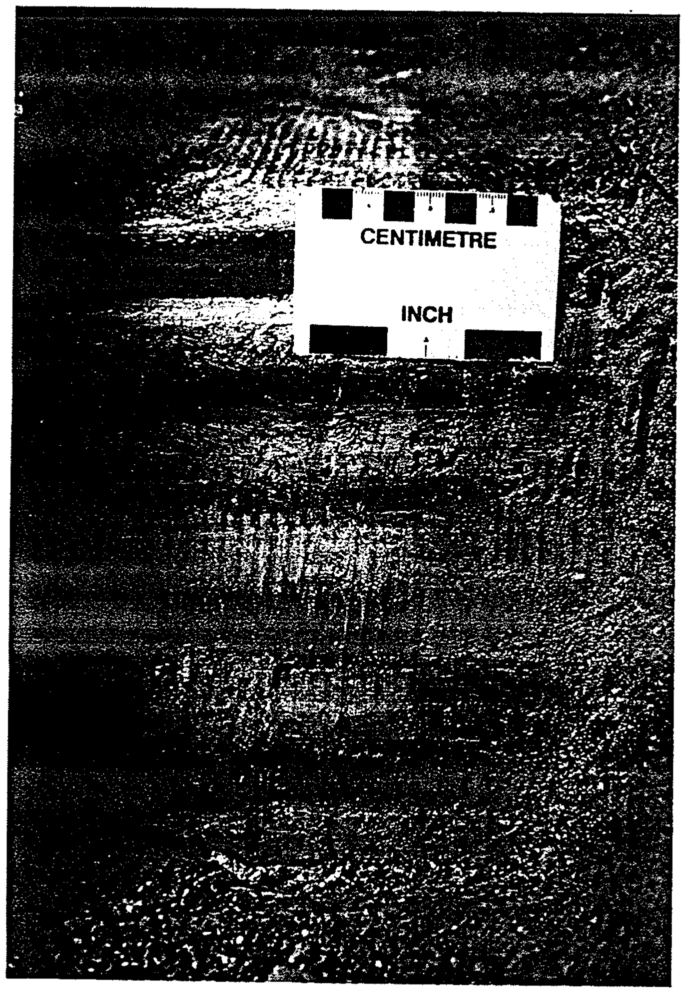

FIGURE 50
Clay (dark) and Silt (light) Rhythmites Exposed
Near the Kopka River Bridge

level of this lake stood at a higher elevation than that of the present, and existed as an individual basin as it does today.

An average of thirty-five couplets per meter were counted at the exposure near the Kopka River bridge. As these rhythmites were deposited within a closed basin, separate from the previously deposited rhythmites of the KOP borehole and those of the Kaiashk delta, inference of the total sedimentation rates by comparison with these latter rhythmites is unsubstantiated. The fewer number of rhythmites per meter developed within the Kopka Lake basin stems from the relatively thicker nature of the couplets. This results from the settling of the fine silts and clays within the smaller (in terms of area of the lake bottom) Kopka Lake basin as compared to that of the open high wave energy lacustrine or estuarine setting.

The transition from a "Lake Nipigon" to a "Kopka Lake" phase (see Fig.48) which is reflected in the sediments of Unit 3 and Unit 4 (and the overlying thicker couplets) would have occurred as discharge through the northern-most Pillar outlet declined. This decrease in the influx of water along with the decline in the level of Lake Nipigon and the uplifting of the land surface, would have resulted in the transition of the Kopka Lake region from an open lacustrine to a shallow estuarine environment and ultimately to a separate closed basin.

Armstrong and Pikitigushi Delta Sedimentation

The sequences of sediments exposed at sites 86-12 and X-12, and within the cores of the AIR and CAS boreholes (see Figs.39,40) were all deposited by the flow of water through the Armstrong outlet forming the Armstrong delta.

The sands of the AIR hole, 86-12, and the basal sequence of the CAS borehole sediments represent a single genetic unit, having been deposited during the Lake Agassiz flooding stage (see Fig.43). The coarser grained nature of the upper AIR hole sands reflect their more proximal position with respect to the inflowing sediment source through the Armstrong outlet system. The lower AIR hole sequence, the 86-12, and basal CAS hole sediments are finely laminated, very fine to medium grained sand.

The presence of the steep foreset bedded sand and gravel deposits at the surface near the town of Armstrong, in close proximity to the AIR borehole site, suggests that the AIR sands were deposited on the upper region of the Armstrong delta. The finer grained, laminated sands (86-12 and CAS) infer deposition farther out on the upper delta. Sedimentation in both regions was likely from grainflows and underflows which are the predominant depositional mechanisms operating in proximal deltaic settings. The coarsening-upward-sequence displayed by the AIR hole sands also reflects a transition from distal, very fine grained sands to more proximal coarse grained, pebbly sand. The uppermost coarser grained units of the AIR hole sequence therefore may represent sediments deposited over top of previously deposited flood sediments resulting from the southward progradation of the shoreline as water levels declined because of crustal rebound, following the Lake Agassiz flooding stage.

The sequence of rhythmites exposed at the base of the X-12 section represent distal facies equivalents to the coarser grained, sandy Lake Agassiz flood sediments to the north. The sequences of clayey silt and clay couplets are interrupted by rare sharp-based beds of ripple-drift cross-laminated (type A) sand (Fig.51). These deposits were formed by sedimentation from combined overflow-interflow and underflow currents. The beds of rippled sand are deposited by bedload sedimentation within underflows, which are probably of the surge-generated variety (as opposed to quasi-continuous) as suggested by the sporadic nature of the sand beds within the rhythmite sequence. The sediments forming the couplets are deposited from plumes of fine silt and clay generated from overflow and interflow currents, and likely also in part from suspended sediments generated by underflow currents. Similar sequences of silt-clay rhythmites with rare sandy interbeds are described by Gustavson and others (1975), and are concluded as being representative of lake bottom sediments. The X-12 sequence was likely deposited in the proximal lake bottom to distal

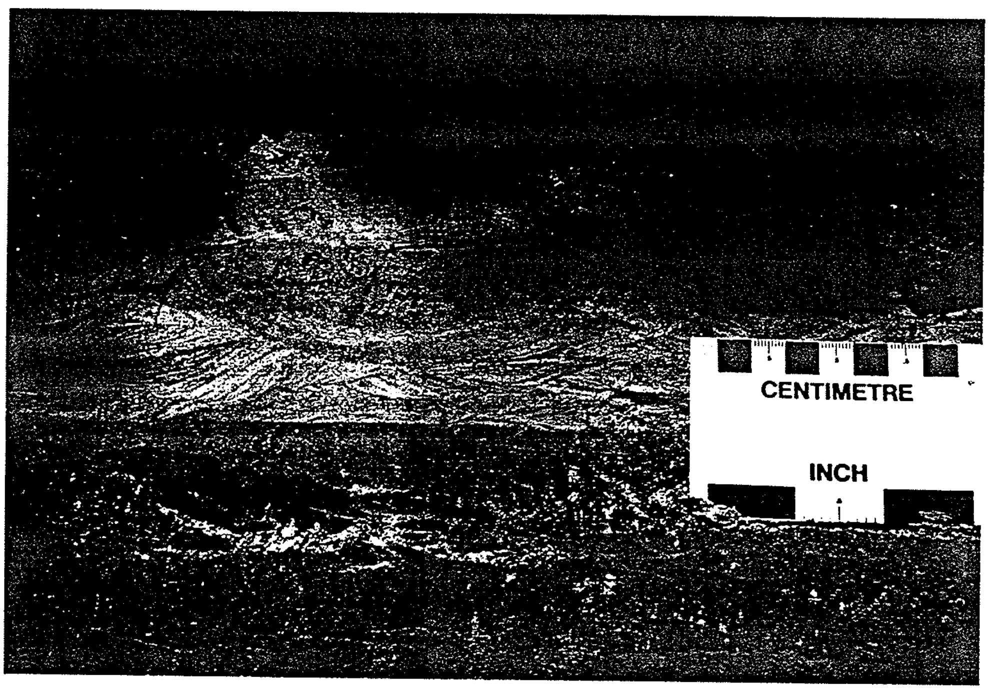

FIGURE 51
Type A Ripple-Drift Cross-Laminated Sands within Clay-Silt Rhythmites Located at the Whitesand River X-12 Site
(5.0 meters above lake level)

deltaic transition zone, as sedimentation from suspension was occasionally interrupted by sandy underflows which were probably caused by slumping on the nearby delta front. Evidence for the occurrence of slumping in the lower delta region is noted in the deformed bedding developed within some of the X-12 rhythmites (see Fig.18). Contorted bedding developed within clay-silt rhythmites in glacio-lacustrine deltaic sequences is commonly the result of slumping of overlying sequences of sediment, although plastic deformation during deposition, or shearing due to overriding turbidity currents can produce such deformational features (Leckie and McCann, 1982). The apparent thinning of these rhythmites is probably the result of compaction of previously thicker laminae in response to the loading by overlying sediments.

Following the Lake Agassiz flooding stage, the northern shoreline of Lake Nipigon migrated to the south. In the region of the present X-12 site, this progradation resulted in the transition from a distal deltaic-proximal lacustrine setting to a nearshore environment. Thick sequences of massive and planar-bedded, fine to medium grained sand (Fig.52) were developed over top of the previously deposited silty clay-clay rhythmites. The sharp-based beds of massive sands are likely grainflow deposits which were deposited by sub-aqueous slumping/avalanching on the upper delta foreset produced by any number of various trigger mechanisms (eg.

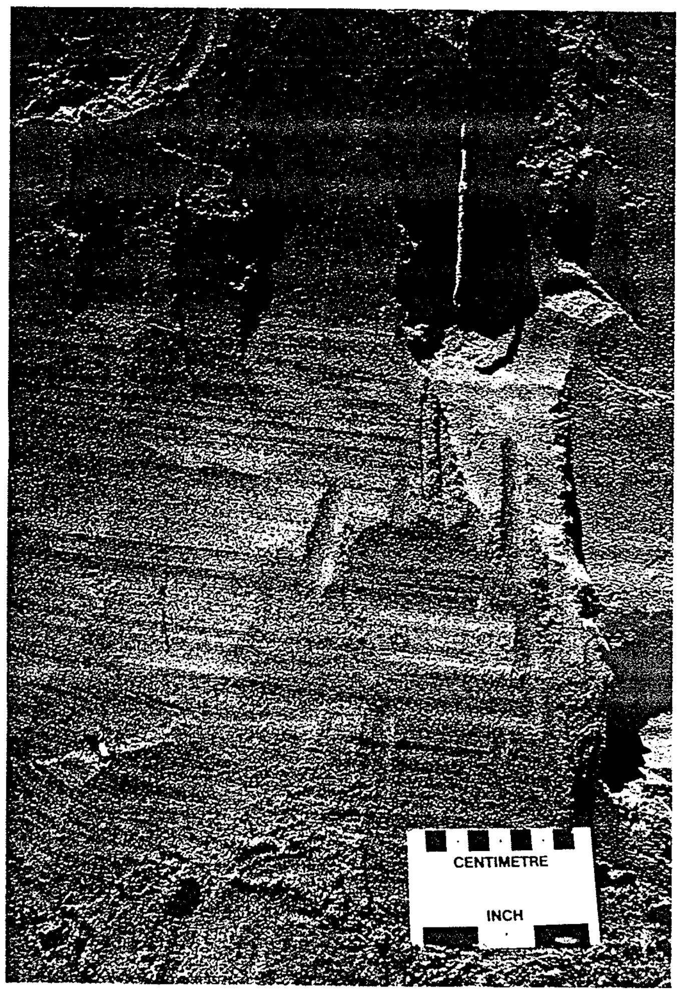

FIGURE 52
Massive and Planar-Bedded Sands Located at the Whitesand River X-12 Site
(19.0 meters above lake level)

storms, increased precipitation and runoff, high water discharge events). Evidence for the occurrence of slumping is observed in the development of convolute bedding (Fig.53) and small-scale faulting (Fig.54) within the X-12 sands.

The planar-bedded sands were deposited as nearshore lacustrine deposits by wave action.

In the region proximal to the CAS borehole site, sedimentation during the post Lake Agassiz flooding stage is recorded by the development of the rhythmites in the upper CAS hole sequence (Fig.55). The "back water" or estuarine setting which developed in this area in response to the localized, high relief produced conditions favourable for the deposition of the fine silt and clay rhythmites over top of the previously deposited deltaic sands. The multi-laminated nature of the silty units and the thin, very fine grained interbedded sandy laminae suggest sedimentation from underflow currents during the summer period. The settling of clays from suspended sediment plumes during the winter period produces the homogenous clayey laminae forming rhythmites similar to those developed on the lower parts in glaciolacustrine deltas. The coarser grained, laminated silty rhythmites which form the upper-most unit of the CAS borehole sequence are similar to mid-delta rhythmites deposited predominantly by underflow currents. The shift to the deposition of these coarser grained sediments resulted from the progradation of the sediment source region in

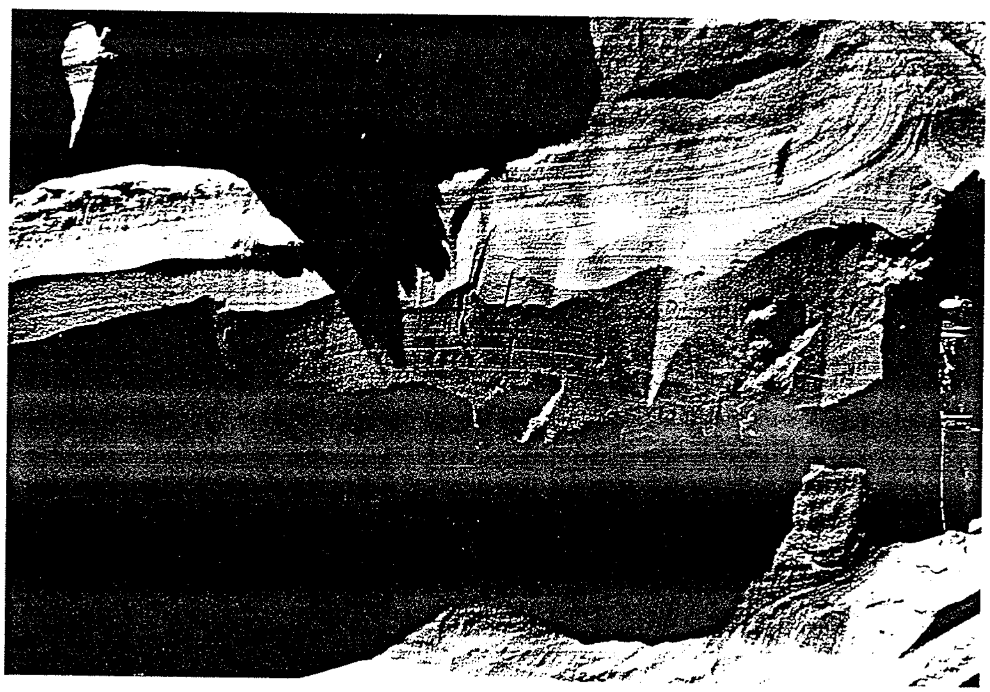

FIGURE 53
Convolute Bedded Sands Located at the Whitesand
River X-12 Site
(15.0 meters above lake level)

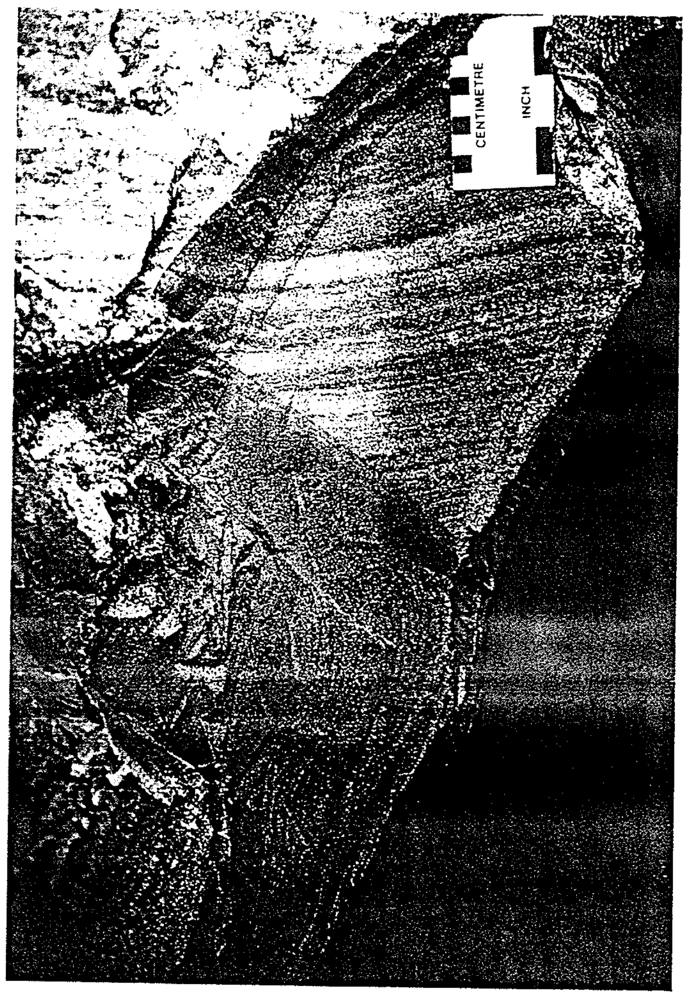

FIGURE 54
Faulting in Bedded Sands Located at the Whitesand River X-12 Site
(7.5 meters above lake level)

FIGURE 55
Upper CAS Core Rhythmites of Clay (dark) and Silt (light) with Thin Sand Laminae
(scale in centimeters)
(from a depth of 6.0 meters)

response to the decline of the level of Lake Nipigon.

The sedimentary sequences forming the Pikitigushi delta were developed under similar depositional conditions as those which prevailed in the formation of the Armstrong delta. The PIK borehole sediments and the rhythmites which form the basal unit of the LEE hole sequence, were all deposited by the discharge of Lake Agassiz flood waters into the Lake Nipigon basin (see Fig.43).

The shift from the coarser grained silty rhythmites of the lower PIK sequence to the overlying silt-clay rhythmites (Fig.56) indicates a decrease in the depositional energy. The upper PIK rhythmites were deposited in the mid-delta region predominantly by underflow currents. Bedload deposition from the underflows formed the basal sandy silt units of these rhythmite triplets, and the thin clay laminae which form the upper part of the triplets were deposited from plumes probably generated by the underflow currents. These clayey laminae are often absent within the rhythmite sequence, the probable result of erosion by the sandy underflows. The contorted, sporadic nature of the clayey laminae is also displayed in the LEE hole sequence of rhythmites. These rhythmite triplets are generally coarser grained (greater sand content) than the upper PIK sediments. Clayey silt rip-up clasts present within the LEE rhythmite sequence provide further evidence as to the erosive nature of the sandy turbidity currents flowing down the mid-delta

FIGURE 56
Upper PIK Core Rhythmites
(scale in centimeters)
(from a depth of 1.8 meters)

slope.

The upper LEE hole sands were deposited during the post-Lake Agassiz flooding stage as the source of the Pikitigushi delta sediments prograded to the south. These massive, fine to medium grained sands probably were deposited as grainflows, as suggested by the thick, relatively well-sorted nature of the unit, and the lack of internal laminae, cross-bedding, or other structures typically formed by the slumping of unstable upper delta deposits which were developed as the post-flood nearshore sediments advanced over top of the more distal, previously deposited deltaic rhythmites.

VIII. DEGLACIATION CHRONOLOGY AND HISTORY OF THE LAKE NIPIGON BASIN

Introduction

Between about 9500 and 8500 B.P. the margin of Rainy Lobe ice retreated across the Nipigon-Superior lowlands. Waters from Lake Agassiz and from melting Rainy Lobe ice filled the Nipigon basin forming the predecessor stages of the modern day Lake Nipigon. The configuration of the late glacial lake stages changed with time as the northern extent of the lake was bounded by the retreating ice front. These paleo-Lake Nipigon lakes were therefore a combination of the presently established classes of glacial lakes, having received meltwater directly from the bounding ice-margin (ice-contact glacial lake) and from the Lake Agassiz basin (distal glacial lake).

By establishing the position of the glacial boundary at 9500 B.P., 8800 B.P., and early post-8500 B.P. using radiocarbon dates obtained from materials within the region, and the locations and relative ages of previously studied end moraines, the history of the Lake Nipigon basin for this 1,000 year period can be outlined. In delineating the positions of the glacial boundary it is also possible to designate which of the eastern and southern outlet channels were actively transporting water and depositing sediment into Lake Nipigon and Lake Superior respectively. The locations and elevations of former shoreline features, with respect to the positions of the ice margin within the Nipigon basin allows for the estimation of previous Lake Nipigon levels. These wave-cut terraces and beaches, in conjunction with the areal extent of lacustrine sediments within the basin region, enables the lateral extent of the paleo-lacustrine settings to be established for each of the three periods in question.

Deglaciation of the Nipigon-Superior Lowlands

By utilizing the radiocarbon ages of dated materials from the Lake Nipigon region (see Fig.33), the relative positions of the retreating Rainy Lobe can be approximated (Fig.57).

At about 9900 B.P. the Rainy Lobe ice front is thought to have been located at the Hartman-Dog Lake Moraine (Teller and Thorleifson, 1983). At this same time the Marks Moraine was formed by a readvance (Marquette Advance) of Superior Lobe ice (Clayton and Moran, 1982). The area along the Kaministikwia River from which the Old Fort William samples of pine needles, cones, and woody fragments were collected would have been covered by ice at this time. This seems to contradict the date of 9990+/-360 B.P. obtained for one of the samples, and suggests that vegetation which had developed in the northwestern Lake Superior region was destroyed as Superior Lobe ice advanced to the Marks Moraine

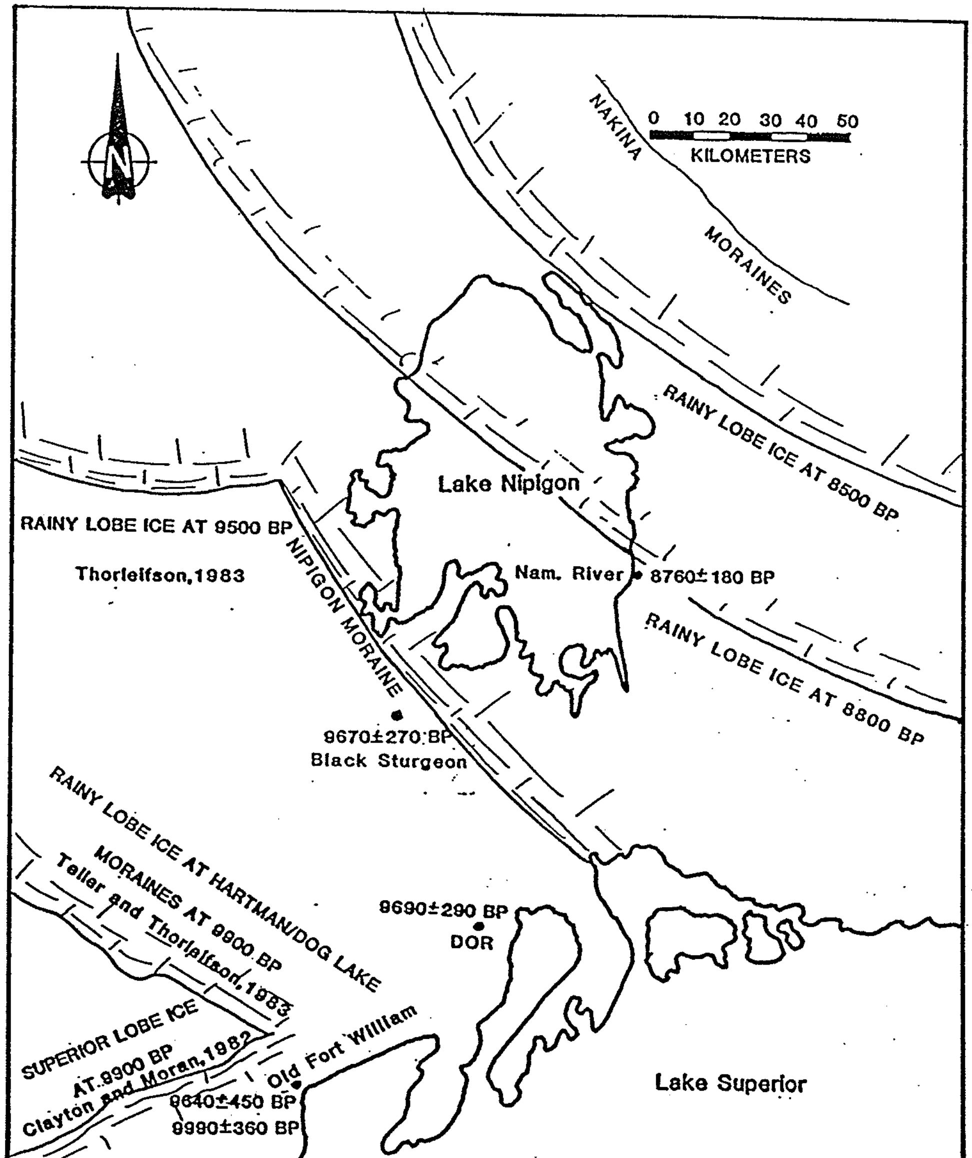

FIGURE 57
Deglaciation of the Nipigon-Superior Lowlands

at about 9900 B.P. The organic material was probably incorporated into till deposits and later reworked and deposited in a lacustrine setting. The date of 9990+/-360 B.P. therefore records the time at which the coniferous forest was destroyed, and does not depict the time at which the organic-rich sediments were deposited.

Thorleifson (1983) suggests that at about 9500 B.P. the Rainy Lobe ice front was located just to the southwest of the present Lake Nipigon shoreline. The radiocarbon dates from the DOR (9690+/-290 B.P.;organic residue) and Black Sturgeon (9760+/-270 B.P.;mollusc shells) sites reflect the retreat of the glacial boundary from the Hartman-Dog Lake Moraine to the position cited by Thorleifson, which roughly coincides with the location and orientation of the Nipigon Moraine. The date obtained from the mollusc shells collected from the Black Sturgeon site however may be subject to the 500-1000 year correction factor applied to the Namewaminikan River shell date. The date of 9760+/-270 B.P. therefore is probably too old, as a result of the hard-water-effect.

The "corrected" date of 8760 B.P. obtained for the mollusc shells from the Namewaminikan River beach deposit suggests that at about 8800 B.P., the southern half of the present Lake Nipigon basin was free of ice. The glacial boundary continued to retreat to the northeast and by about 8500 B.P., the remainder of the basin was uncovered. This is based upon the suggestion made by Teller and Thorleifson (1983) which states that soon after 8500 B.P., the Rainy Lobe ice front stood at or near the Nakina Moraines.

Former Lake Shorelines

As the ice retreated across the Nipigon basin, the level of Lake Nipigon stood at elevations greater than that of the present. Evidence for the existence of higher lake levels takes the form of several levels of wave-cut terraces, which are scattered around the shoreline of the lake. Burwash (1930) noted and measured the elevation of a prominent wave-cut bench north of Windigo Bay. Zoltai (1965 b) calculated the elevations of two wave-cut terraces near the mouth of the Ombabika River along the eastern shoreline of the lake. Schlosser (1983) also measured the elevations of a number of former shoreline features along and inland from the western shoreline of Lake Nipigon. Many of these shorelines documented by Schlosser were also measured as part of this study. Figure 58 shows the locations and present elevations of these shoreline features, as well as new ones identified and measured in the present research.

Elevations of the terraces were measured either directly by altimeter or calculated by parallax using 1:50,000 scale aerial photographs and stereometer. Those elevations determined by the parallax equation were compared to the elevations of the terraces on 1:50,000 scale

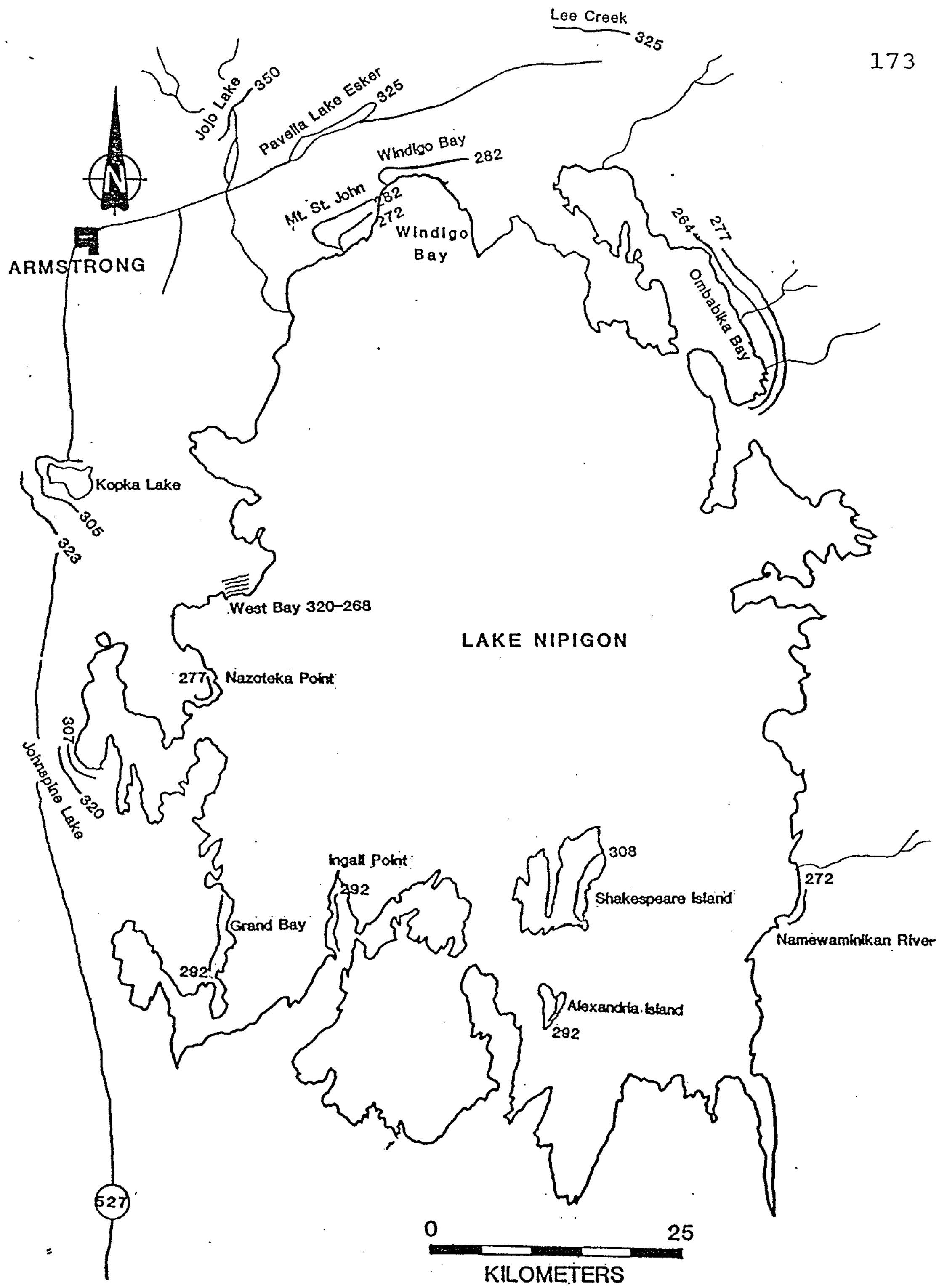

FIGURE 58
Former Shoreline Features with Present Elevations in Meters
(in part after Burwash, 1930, Zoltai, 1965b, Schlosser, 1983)

topographic maps to check the accuracy of the calculated values. In total, 33 former shoreline features were identified and their respective elevations determined.

Most of the shoreline features identified are wave-cut terraces formed by the erosive action of breaking waves upon the sedimentary deposits along the lake shoreline. The upper and lower Johnspine Lake terraces were cut into the deposits of the Kaiashk Interlobate Moraine, west of Gull Bay near Johnspine Lake. The Onaman Interlobate Moraine, which forms the northern shore of West Bay, has a number of benches cut into it. The Pavella Lake esker northwest of Windigo Bay also shows evidence of reworking by wave action. The fossiliferous beach deposit located near the mouth of the Namewaminikan River along the eastern Lake Nipigon shoreline is a former nearshore feature formed by deposition rather than erosion.

Of particular interest is the series of terraces cut into the glacial sediments of the Onaman Moraine at West Bay. At this single location, a large portion of the history of the declining level of Lake Nipigon has been recorded.

The highest lake level on the Onaman Moraine is represented by the relatively flat surface of the moraine, which lies at an elevation of 320 m. Zoltai also recognized a prominent terrace representative of a lower water level at an elevation of 287 m. Thorleifson (1983, Written

Communication) recorded the elevation of 9 terraces between the present lake shore at 262 m, and an elevation of 293 m.

During the field season of 1985, a survey line from the present shoreline was run at a northwest bearing for a horizontal distance of 370 m at West Bay. Eight wave-cut terraces were observed and their elevations measured and recorded. Along with the 320 m terrace, these consecutively lower terraces were developed at elevations of 315 m, 310 m, 305 m, 299 m, 294 m, 288 m, and 275 m.

Each terrace in the West Bay sequence is identified in the field by an abrupt increase in the slope of the land surface. Concentrations of large granitic boulders (1-3 m diameter) occur in proximity to the changes in slope. These "boulder lines" provide further evidence for the representation of former water levels, and similar concentrations of boulders were noted in shallow water depths near Wabinosh Bay (Fig.59). These boulder lines may have formed as the boulders rolled down the slopes of the Onaman Moraine and came to rest in the shallow depths of the lake. Alternatively, the concentrations of boulders may represent boulder lags, produced as finer sediments of the moraine were winnowed out by breaking waves. Both processes would have produced a deposit at the level of the lake at the specific time.

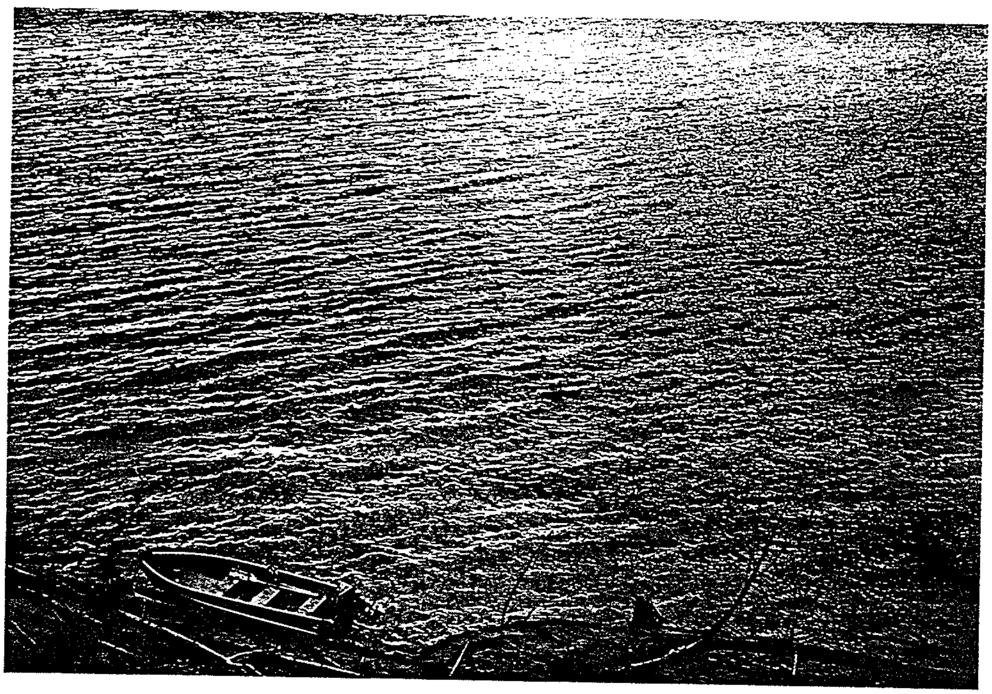

FIGURE 59
Boulder Lines at Present Lake Level in the
Wabinosh Bay Area

9500 B.P. Stage

At about 9500 B.P., the glacial margin of the Rainy Lobe stood near the Kashishibog Lake outlet of the Kaiashk system, a 15 km wide corridor across the continental divide (see Fig.3) (Teller and Thorleifson, 1983). Failure of the ice dam across this channel resulted in catastrophic discharge of water into the Nipigon basin from Lake Agassiz which previously had overflowed southward into the Mississippi River and into the Gulf of Mexico. This marked the beginning of the Nipigon Phase of Lake Agassiz, a period spanning about 1,000 years during which time enormous volumes of water passed through the Nipigon basin en-route to Lake Superior and eventually into the St. Lawrence Valley (Teller and Thorleifson, 1987).

The configuration and location of the glacial boundary at about 9500 B.P. (Fig.60) is similar to that proposed by Thorleifson (1983). This and subsequent reconstructions of the ice margin show a generally smooth and concentric form. In reality the ice front would have been highly irregular, with numerous lobes and bays, the former specifically being developed where the retreating ice was grounded on land. Bays in the ice probably developed in response to rapid calving where the ice was in direct contact with the lake waters. The location of the ice margin at about 9500 B.P. suggests that at least the southwest corner of the Nipigon basin was ice-free at this time, which is in harmony with

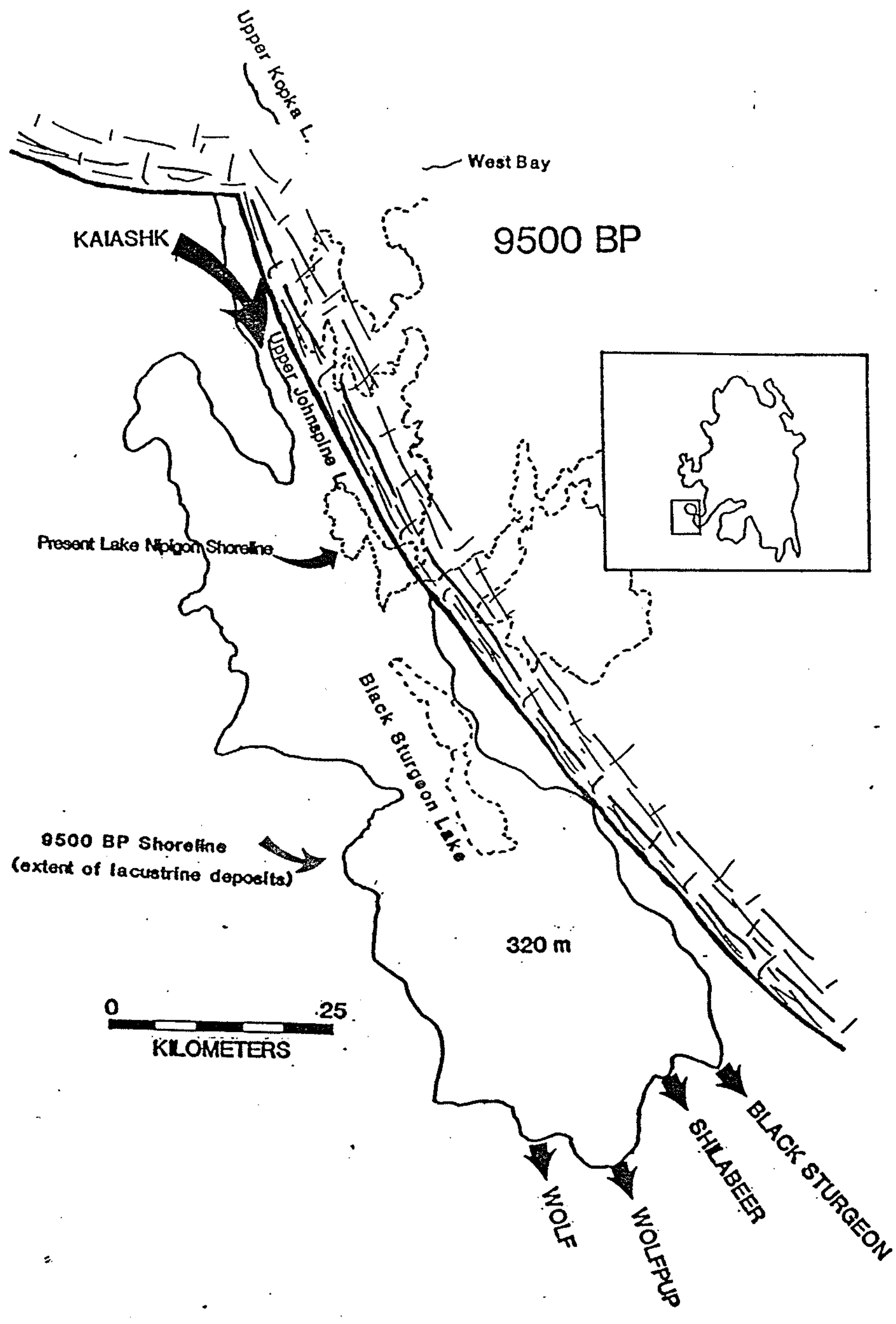

FIGURE 60
9500 B.P. Lake Nipigon Stage

radiocarbon dates obtained from regions farther to the south.

The major routes through which Lake Agassiz water flowed were channels which presently contain the Roaring River, Grim Lake, Pantagruel Creek, Rabelais Creek, Ottertooth Creek, and Paddon Lake (Thorleifson, 1983). Sediments transported through these channels were deposited into Lake Nipigon forming the Kaiashk delta area (see Fig.12). Water entering the Lake Nipigon basin subsequently flowed south into Lake Superior (see Fig.3). The history of drainage through the southern outlets has been suggested by Teller and Mahnic (1988), but is largely speculative. The Wolf, Wolfpup, Shillabeer, and Black Sturgeon channels were probably all ice-free at or soon after 9500 B.P. and capable of transporting overflow from Lake Nipigon at this time.

The areal extent of the 9500 B.P. phase of Lake Nipigon (as shown in Figure 60) is approximated by delineating the extent of lacustrine deposits, as mapped by Zoltai (1965 a), beyond the glacial boundary proposed for this time period. Water within the Nipigon basin probably rose to an elevation of about 320 m as suggested by the elevation of the upper Johnspine Lake wave-cut terrace (320 m). The upper Kopka Lake terrace (323 m) and possibly the uppermost West Bay (320 m, if actually a former shoreline) terrace suggest similar water plane elevations, as these two regions probably became ice-free soon after the upper Johnspine Lake terrace. As these terraces are relatively close together, differential rebound would have little effect on the differences in the respective elevations and thus these terraces are representative of the high level stage of Lake Nipigon which developed at about 9500 B.P.

A major factor controlling the level of Lake Nipigon would have been the flow of water through the southern outlets, and although the Wolf, Wolfpup, Shillabeer, and Black Sturgeon channels were probably all ice-free, the four channels may not have carried water simultaneously. Teller and Mahnic (1988) described sequences of clay-silt rhythmites and turbidite sediments which were deposited near each of the mouths of these channels along the former Minong Level shoreline of Lake Superior, and regarded these deposits as contemporaneous. They also state that the Wolf and Wolfpup channels are and were also in late glacial time, higher in elevation than the Shillabeer and Black Sturgeon channels. Simultaneous flow, therefore, could only have occurred if the level of Lake Nipigon was high enough to supply overflow to all four channels.

Approximations for the elevations of the heads of the southern outlet channels were made by superimposing these locations onto 1:50,000 scale topographic maps of the respective regions. The former spillways are readily identifiable on the topographic maps and therefore the elevation values can be estimated with some degree of accuracy. The elevation of the head of the Wolf channel is about 330 m while that of the Wolfpup channel is approximately 290 m. The heads of the Shillabeer and Black Sturgeon channels form at elevations of about 275 m and 262 m respectively. These estimated elevations suggest that the Wolfpup, Shillabeer, and Black Sturgeon channels probably carried overflow and deposited sediment into Lake Superior when Lake Nipigon stood at its maximum level 320 m. Sediments deposited near the mouth of the higher elevation Wolf channel probably resulted from peak flows related to catastrophic bursts of water through the Kaiashk system as suggested by Teller and Mahnic (1988), or possibly during the short time when the Wolfpup, Shillabeer, and Black Sturgeon channels were still covered by ice.

Although it is difficult to say for certain which of the southern outlets were operating together, and what effect this had on the level of Lake Nipigon, the sediments deposited near the mouths of these channels indicate that each channel did transport overflow from Lake Nipigon to the northwestern Lake Superior basin at about 9500 B.P. The elevations of the upper Johnspine Lake and upper Kopka Lake wave-cut terraces suggest that Lake Nipigon at this time stood at an elevation of about 320 m, and covered an area of approximately 2,250 square kilometers.

8800 B.P. Stage

By about 8800 B.P., the margin of Rainy Lobe ice along the continental divide had retreated to the Pillar outlet region (Teller and Thorleifson, 1983). The corrected date for the Namewaminikan River mollusc shells suggests that this region of the eastern Nipigon basin had also become ice-free (Fig.61).

Overflow from Lake Agassiz was transported through the ancient Chief Lake, Track Lake, and Badwater Lake channels of the Pillar outlet system. Sediment deposited through these channels formed the upper sequences of the Kopka-Pillar delta. According to Teller and Mahnic (1988), the catastrophic discharge of water from Lake Agassiz into Lake Superior via the Nipigon basin would have ended by 9000-8500 B.P., and non-catastrophic flow may have continued through the Black Sturgeon channel.

The three remaining southern outlets, the Nipigon, Cash, and Pijitawabik channels were now uncovered and capable of carrying overflow to Lake Superior. The head of the Cash outlet along the southern Lake Nipigon shoreline stands at an elevation of about 262 meters as estimated from topographic maps. The Nipigon river, a remnant of flow through the Nipigon outlet, continues to carry the flow of water from Lake Nipigon to Lake Superior at the present. The Pijitawabik channel, the most easterly of the southern outlets may or may not have contributed significantly to the

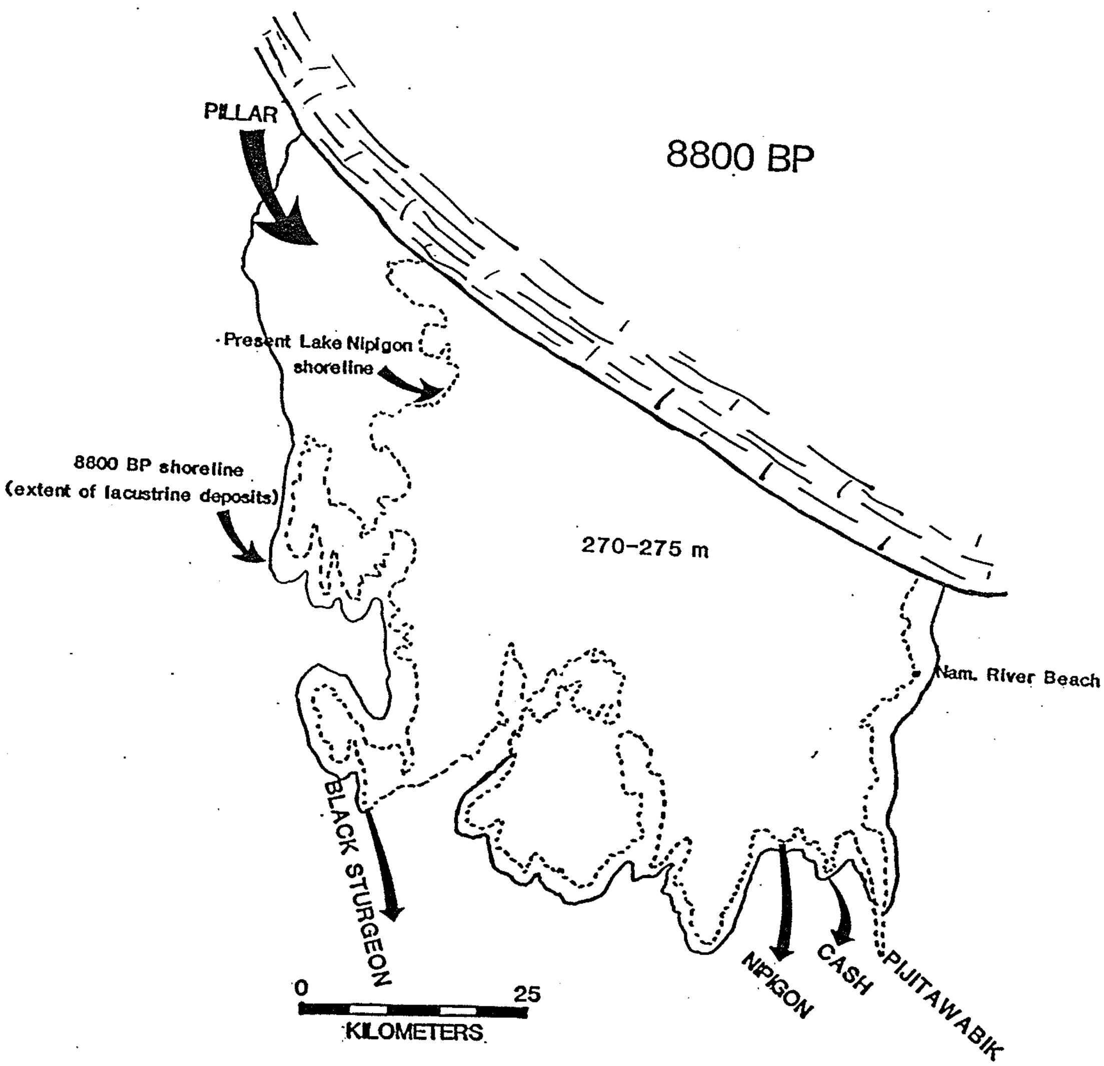

FIGURE 61
8800 B.P. Lake Nipigon Stage

southward flow of Lake Nipigon water, and today the valley is partially filled and blocked by an esker-delta complex (Zoltai, 1965 a) south of Pijitawabik Bay. The collapsed topography within the channel indicates that residual masses of ice covered by fluvial sediments may have blocked the flow of water, as the elevation of the fluvial plain would have been greater than that of the present. By the time the buried ice melted, the level of Lake Nipigon probably had fallen below the elevation of the head of the Pijitawabik outlet, and thus no water could flow through the channel to Lake Superior (J.T. Teller, 1986, Personal Communication).

It is difficult to estimate the elevation of the Lake Nipigon level during the 8800 B.P. stage. The radiocarbon age of the mollusc shells and the elevation of the Namewaminikan River fossiliferous beach deposit suggest that the lake level in this region may have been at approximately 272 meters. The numerous wave-cut terraces in the southern and southwestern regions of the basin which earlier (ie. 9500 B.P.) were covered by ice, had become ice-free. These former shorelines, however, are difficult to correlate across the basin with respect to time due to the effects of differential isostatic rebound, and thus it is not possible to designate which of these features were developed at about 8800 B.P. If, however, overflow continued through the Black Sturgeon channel after 9000-8500 B.P., as suggested by Teller and Mahnic (1988), then the level of Lake Nipigon along the former southern shoreline would have stood at an elevation greater than that of the head of the Black Sturgeon channel, which now is at 262 m, but would have been higher in relation to the Nipigon and Cash channels because of subsequent differential rebound. This scenario, along with the elevation of the Namewaminikan River beach, suggests that at about 8800 B.P., the level of Lake Nipigon stood at an elevation of 270-275 meters. If this was the case, then the Cash and Nipigon channels in addition to the Black Sturgeon outlet carried overflow to Lake Superior.

In the Kopka-Pillar delta region, the areal extent of Lake Nipigon at the 8800 B.P. stage is approximated by the lateral extent of lacustrine sediments in this region as mapped by Zoltai (1965 a). With the lake water-plane standing at an elevation of between 270 and 275 meters, the shoreline along the remainder of the basin probably appeared similar to that of the present Lake Nipigon setting.

Early Post-8500 B.P. Stage

As the glacial boundary continued to retreat to the northeast, the Armstrong and Pikitigushi outlets were opened and the more southerly Lake Agassiz outlets were abandoned. During this period (about 8600 B.P.-8500 B.P.) the Armstrong and Pikitigushi deltas were formed as sediment-laden waters from Lake Agassiz spilled over into the northern Lake Nipigon basin depositing sediment out into this region.

Soon after 8500 B.P. the margin of glacial ice had retreated to the Nakina moraines, and Lake Nakina formed north of the continental divide (Teller and Thorleifson, 1983) (Fig.62). At this time, the northernmost Pikitigushi channel, the Whiteclay Lake channel, probably drained Lake Agassiz water into Lake Nakina rather than directly into Lake Nipigon (Thorleifson, 1983). As a result, deltaic sedimentation within the Lake Nipigon basin declined and sedimentation was dominated by smaller-scale fluvial, and nearshore lacustrine processes.

The outline of the maximum extent of lacustrine sediments in the northern region of the basin coincides with the Lee Creek and Jojo Lake raised shorelines (see Fig.58), which presently stand at elevations of 325 m and 350 m respectively. Because the influx of water from the Lake Agassiz basin had ceased, and the flow of water to Lake Superior continued, possibly along with channel deepening,it is likely that the level of Lake Nipigon continued to decline. The Jojo Lake and Lee Creek shorelines, which today stand well above the modern lake level formed when the northern region of the lake basin was isostatically depressed in relation to the southern outlet by about 80 m (i.e. 350-270 m). Following their formation, these former shorelines were raised to their present elevations.

The overflow of Lake Nipigon water to Lake Superior during the early post-8500 B.P. stage would have continued

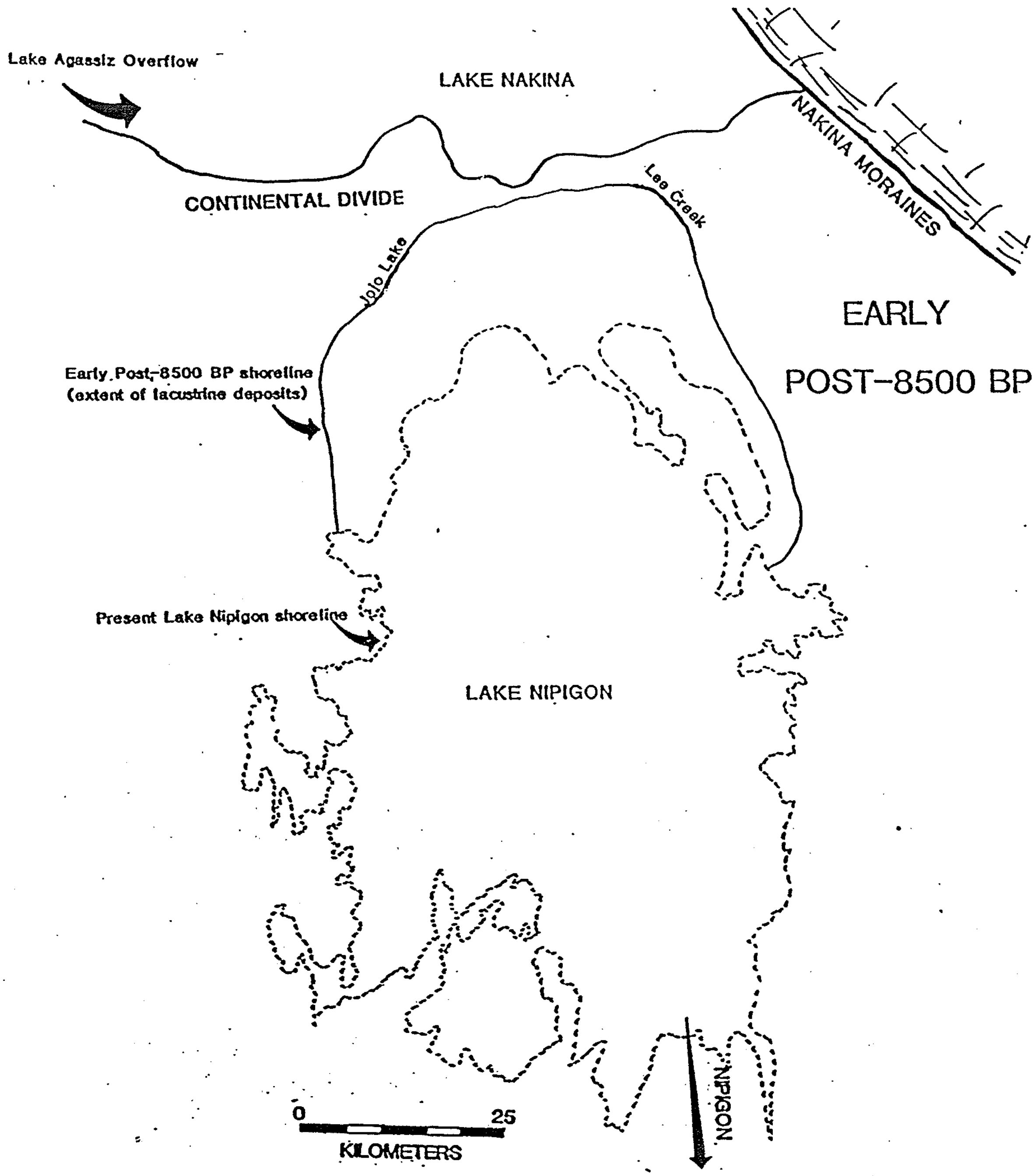

FIGURE 62
Early Post-8500 B.P. Lake Nipigon Stage

through the Nipigon outlet. The Cash and Black Sturgeon channels may have still been operating at this time but were likely abandoned soon afterwards due to the combined effects of crustal rebound and the lowering of the level of Lake Nipigon below the heads of these outlets.

As the surface of the land in the northern basin continued to rise above the level of the lake, successively lower terraces at Mt. St. John, Windigo Bay, and Ombabika Bay were formed (see Fig.58). At this point in time, the configuration of Lake Nipigon would have been almost identical to that of the present setting.

IX. SUMMARY

Between about 9500 B.P. and 8500 B.P., glacial ice of the Rainy Lobe was retreating across the Lake Nipigon basin in northwestern Ontario. As the margin of the ice wasted to the northeast, large volumes of water from glacial Lake Agassiz spilled into the Lake Nipigon basin through the eastern outlets of Lake Agassiz. The flow, often at catastrophic rates, was regulated by the position of the ice margin along the continental divide. Upon entering Lake Nipigon, water subsequently drained southward into Lake Superior through one or more of the Lake Nipigon southern outlet channels.

The initial ponding of water in the southwestern part of the basin at about 9500 B.P. resulted in the development of the highest level of Lake Nipigon, standing at an elevation of about 320 m, as indicated by wave-cut terraces in the western region of the basin. Water flowed through the Black Sturgeon, Wolf, Wolfpup, and Shillabeer channels into the northern basin of Lake Superior, depositing sequences of clay-silt rhythmites and turbidites. By 8800 B.P., the Nipigon, Cash, and probably the Black Sturgeon outlets were also carrying overflow to Lake Superior, as the level of Lake Nipigon had fallen to about 272 m; this is suggested by the elevation of the Namewaminikan River fossiliferous beach deposit and the corrected radiocarbon age of the fossil mollusc shells. As a result, flow through the Wolf, Wolfpup, and Shillabeer channels ceased as the level of Lake Nipigon fell below the elevation of the heads of these outlets. Sediments transported through the eastern outlet channels were deposited, forming large deltas as the floodwaters spilled into the waters of Lake Nipigon. The sandy and coarser grained sediments, composed primarily of quartz with minor amounts of muscovite and mafic mineral grains, were deposited near the lake shore. Finer sandy and silty sediments were deposited on the prodelta slope by underflow and overflow-interflow currents, while finer silts and clays were carried farther out into the basin by overflow-interflow currents forming lacustrine rhythmites. The alternating carbonate mineral content in each couplet, textural parameters, bioturbated silts, and repetative nature of the rhythmically bedded silts and clays suggest that these sediments are varves. Various species of pollen present within the sediments suggest that upon deglaciation, the Lake Nipigon basin was soon covered by a boreal forest, composed primarily of jack-pine and spruce, with some mixed coniferous and deciduous woodlands. Minor amounts of non-arboreal pollen species, specifically grasses and sage imply that the the forested areas were interspersed with open grasslands and meadows. Species of terrestrial and aquatic molluscs found within lacustrine sediments suggest that marsh-type and aquatic macrophyte vegetation also developed around and within the waters of Lake Nipigon.

Lake water temperatures of the paleo-Lake Nipigon stages were similar to those of present day cold temperate region lakes.

Soon after 8500 B.P., the waters of glacial Lake Agassiz spilled eastward into Lake Nakina and then began to by-pass the Nipigon basin altogether. The mechanisms of sedimentation within the Nipigon basin shifted from predominantly deltaic to lesser magnitude fluvial and nearshore lacustrine processes as a result of the decline in the discharge of water through the Lake Agassiz eastern outlets. As Lake Nipigon waters continued to drain into Lake Superior through the Nipigon outlet, the level of Lake Nipigon probably stood at an elevation of between 270 m and 262 m, as the lake level approached hydrological balance.

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APPENDIX

Stratigraphic Sections for Shoreline
Exposures of Sediment

GULL BAY SECTION X-1

Wave cut exposure across Gull Bay east from the town of Gull Bay. Section is within the middle bay in a series of three small bays, approximately 4.5 kilometers south of Tuckaway Lake.

THICKNESS (m)	DESCRIPTION
0.5	Couplets of silt and clayey silt, rhythmically repeated. Coarse member is a pale olive (5Y 6/2) silt, with an average thickness of 2.0 cm. Fine member is a light grey (5Y 7/2) clayey silt, with an average thickness of 8.0 mm. Lower contact is indistinct , but couplets clearly contrast with underlying sediments. Counted twelve (12) couplets in a 0.5 meter thickness. (24 couplets per meter).
5.7	Triplets of slightly clayey silt, clayey silt, and clayey silts with a higher clay content, rhythmically repeated. Coarse member is a pale olive (5Y 6/3) slightly clayey silt with an average thickness of 3.5 cm (SAMPLE: Gull Bay X-1 coarse). These coarser sediments grade upward into a light grey (5Y 7/2) clayey silt, with an average thickness of 4.0 mm (SAMPLE: Gull Bay X-1 light fine). These finer sediments have a sharp upper contact with overlying olive grey (5Y 5/2) clayey silt, which contains a higher clay content than the underlying clayey silts. The average thickness for these darker, clayey silts is 4.0 mm (SAMPLE: Gull Bay X-1 dark fine). Lower 2.7 meters of section is non-oxidized, resulting in a change in colour of the sediments. The coarse member is grey (5Y 5/1); the light fine is olive grey (5Y 5/2); and the dark fine is an olive grey (5Y 4/2).

Level of Lake Nipigon: 853 feet above sea level.

GULL BAY SECTION X-2

Wave cut section located 300 meters west of Gull Bay Section X-1, within small bay approximately 4.5 kilometers south of Tuckaway Lake.

THICKNESS (m)	DESCRIPTION
I.0	Couplets of clayey silt and clay, rhythmically repeated. Coarse member is a whitish (10YR 8/2, dry) clayey silt, with an average thickness of 2.0 mm. Fine member is a dark brown (10YR 4/3) clay, with an average thickness of 2.0 mm. Sediments are blocky and crumble easily. Lower contact is indistinct, but underlying sediments are more thickly interbedded. Thirty (30) couplets per meter counted in 20.0 cm. (150 couplets per meter).
2.2	Couplets of clayey silt and clay, rhythmically repeated. Upper 1.5 meters: coarse member is a light olive brown (2.5Y 5.5/4) clayey silt, with an average thickness of 6.0 mm. The fine member is a dark brown (10YR 4/3) clay, with an average thickness of 2.0 mm. SAMPLE: Gull Bay X-2-1. Sample taken 2.0 meters down-section. Lower 0.7 meters: coarse member are a whitish (10YR 8/2, dry) similar to the upper 1.0 meter of section couplets. The coarse silt members are exclusively bioturbated ("feathery" horizontal trace/burrows). SAMPLE: Gull Bay X-2-2 bioturbated sediments. Sample taken from lower 70 cm of section. Fe-stained "root casts", cylindrical shape, avg. diameter 1.0 cm with maximum diameter of 12.0 cm. Long axis of root casts oriented parallel and oblique to bedding. SAMPLE: Gull Bay X-2-3 root casts. Sample taken 5.0 meters up from lake level. Lower contact of 2.2 meter section is indistinct, but underlying sediments are clearly different from overlying couplets. Counted eighty-two (82) couplets per meter.

3.0	Triplets of slightly clayey silt, clayey silt, and a clayey silt with a higher clay content, rhythmically repeated. These triplets are similar to those of Gull Bay Section X-1. Coarse member is a grey (5Y5/1) slightly clayey silt with an average thickness of 3.0 cm. These coarse sediments grade upward into a light grey (5Y 4.5/1) clayey silt, with an average thickness of 3.0 mm. These sediments have a sharp upper contact with a dark olive grey (5Y 4/2) clayey silt with a higher clay content. These fine members have an average thickness of 3.0 mm. Counted thirty (30) triplets per meter.
3.0	Covered

Level of Lake Nipigon: 853 feet above sea level.

GULL BAY SECTION X-3
Wave cut exposure located 1.0 kilometer southwest of Nazoteka Point.

THICKNESS (m)	DESCRIPTION
6.0	Couplets of slightly silty clay and silt, rhythmically repeated. Upper 2.17 meters: coarse member is light grey (5Y 7/2) silt with an average thickness of 2.0 cm, which are finely laminated (0.5 mm clay lams.).Average of 35 laminae within each 2.5 cm thick coarse member. Fine members are yellowish brown (10YR 5/4) slightly silty clay with an average thickness of 1.0 mm. Within silt members, sediments are symmetrically rippled, with rounded crests. Wavelength: 6.0 cm, amplitude: 0.5 cm. Possibly in-phase climbing ripples. Underlying zone of sediments are parallel bedded silt and clay couplets. Beneath these sediments, zones of eastward-dipping in-drift climbing ripples? with wavelength:5.0 cm, amplitude: 0.5 cm. No obvious lower contact, but at 2.17 meters down-section, ripple laminae dip to the west. Underlying 3.83 meters: couplets of slightly silty clay and silt, same as overlying 2.17 meters. Similar rippled appearence, with in-phase? and in-drift climbing ripples?, and parallel bedded sediments. Sediments are bioturbated. Counted sixty (60) couplets per meter.

Level of Lake Nipigon: 853 feet above sea level.

PIKE BAY SECTION X-6

Wave cut exposure located within Pike Bay, 100 meters North of marsh and mouth of creek.

THICKNESS (m)	DESCRIPTION
2.6	Couplets of slightly silty clay and clayey fine silt, rhythmically repeated. Coarse member is a light brownish grey (2.5Y 6/2) clayey, fine silt, with an average thickness of 7.0 mm. The finer member is a yellowish brown (10YR 5/4) slightly silty clay, with an average thickness of 2.0 mm. Bioturbation is evident in both of the units, but more concentrated in the coarser silt units. The sediments are blocky, and crumble easily. Lower contact of upper 2.0 meters of section is indistinct, but the underlying 0.6 meters of couplets are more thickly bedded. Counted one hundred forty six (146) couplets per meter in the upper 2.0 meters. Couplets in lower 0.6 meters are similar, only coarse member has an average thickness of 2.0 cm , with the fine member averaging 6.0 mm in thickness. Cylindrical, Fe-stained root casts found in lower 0.6 meter zone of couplets. Silt members are bioturbated. Sample of couplets taken (Pike Bay X-6 Couplets). Counted sixty-four (64) couplets per meter.

LEVEL OF LAKE NIPIGON: 853 FEET ABOVE SEA LEVEL

PIKE BAY SECTION X-6.4

Wave cut exposure located across Pike Bay; 1.5 kilometers northeast from Pike Bay Section X-6, and 750 meters due north of Pike Bay Islands.

THICKNESS (m)	DESCRIPTION
6.0	Couplets of slightly silty clay and clayey silt, rhythmically repeated. Upper 4.0 meters: coarse member is a light greyish brown (2.5Y 6/2) clayey silt, with an average thickness of 8.0 mm. The fine member is a yellowish brown (10YR 5/4) slightly silty clay, with an average thickness of 2.0 mm. Counted one hundred sixty-seven (167) couplets per meter in upper 4.0 meters. Lower 2.0 meters: couplets same as above only thicker individual members Clayey silts average a thickness of 1.0 cm, and the slightly silty clays average a thickness of 5.0 mm. Counted ninety-two (92) couplets per meter. Clayey silts are bioturbated throughout the entire section.

Level of Lake Nipigon: 853 feet above sea level.

WABINOSH BAY SECTION X-9•2

Wave cut exposure located on the south shore of Wabinosh Bay, approximately 1.25 kilometers southwest of Inner Barn Island. Diabase bedrock exposed above the section and at the water level.

THICKNESS (m)	DESCRIPTION
0.55	Clayey silt, finely laminated. Interbedded with 4.0 cm beds of very fine grained sand. Laminations in sand are 5.0 mm thick very fine grained sand units. The clayey silts are a pale olive (5Y 5/3) and the very fine grained sands are pale olive (5Y 6/3). Lower contact is gradational. SAMPLE: Wabinosh Bay X-9•2 laminated clayey silt.
7.5	Sand, interbedded clayey silty very fine grained sand and fine to very fine grained sand. Beds of both sands average a thickness of 2.5 cm and are dipping (N 05°E/16°SE). The clayey silty sands are an olive colour (5Y 5/4), and the fg-vfg sands are a pale olive (5Y 6/3). Two rounded pebbles were found at the base of a fg-vfg sand unit at 1.46 meters below the surface of the section. Lenses of fine grained, oxidized sands are found within the interbedded sands, parallel to bedding. Samples of sand units taken 6.0 meters down-section. SAMPLES: Wabinosh Bay X-9•2 clayey silty sand Wabinosh Bay X-9•2 fg-vfg sand.
2.0	Covered

Level of Lake Nipigon: 853 feet above sea level.

WABINOSH BAY SECTION X-10
Wave cut exposure located within large bay 3.0 kilometers north of Inner Barn Island.

THICKNESS (m)	DESCRIPTION
5.0	Couplets of clayey silt and silty clay, rhythmically repeated. The coarse member is a greyish brown (2.5Y 5/2) clayey silt. The fine member is a dark greyish brown (10YR 4/2) silty clay. Thicknesses of the individual units are variable. Within the lower 2.0 meters, the silty clays have an average thickness of 2.5 cm, whereas the clayey silts average a thickness of 3.0 cm. Within the upper 0.5 meters of the section the silty clays average thickness is 4.0 mm, whereas the clayey silts average 2.0 cm thick. Some of the fine members show a grading of the brownish colour to a more greyish colour, due to mixing via bioturbation. Coarse grey clayey silts are bioturbated throughout the section. No counting done.
5.0	Covered

Level of Lake Nipigon: 853 feet above sea level.

WABINOSH BAY SECTION X-10·2
Wave cut exposure located 100 meters west of Wabinosh Bay X-10, in bay north of Inner Barn Island.

THICKNESS (m)	DESCRIPTION
3.7	Couplets of clayey silt and silty clay, rhythmically repeated. Coarse member is a greyish brown (2.5Y 5/2) clayey silt. The fine member is a dark greyish brown (10YR 4/2) silty clay. Thickness of the individual units is variable within the section. In the lower 2.0 meters, the silty clays have an average thickness of 2.0 cm, whereas the coarser clayey silts average 3.0 cm thick. Within the upper 1.0 meter, the silty clays average a thickness of 6.0 mm; the clayey silts average a thickness of 1.5 cm. In the lower 3.0 meters, the number of couplets averages nineteen (19) couplets per meter, while in the upper 1.0 meter there is an average of 60 couplets per meter.
2.0	Covered

Level of Lake Nipigon: 853 feet above sea level.

WABINOSH BAY SECTION X-11

Wave cut exposure located in a large bay 2.8 kilometers west of Wabinosh Bay X-10 site, and 1.5 kilometers northeast of the mouth of the Wabinosh River.

THICKNESS (m)	DESCRIPTION
4.0	Clayey silty very fine grained sand, and slightly silty very fine grained sand, faintly bedded. The clayey silty sands are a light brownish grey (2.5Y 6/2) and have an average thickness of 5.0 mm. The slightly silty very fine grained sand is a pale olive colour (5Y 6/3) and has an average thickness of 3.0 mm. Fe-oxide stained root casts found throughout the section.

Level of Lake Nipigon: 853 feet above sea level.

WABINOSH BAY SECTION X-11·2
Small wave cut exposure located 60 meters east
Wabinosh Bay X-11

THICKNESS (m)	DESCRIPTION
2.0	Covered
0.5	Couplets of clay and silt, rhythmically repeated. Coarse member is a brownish grey (2.5Y 5/2) silt, with an average thickness of 1.5 centimeters. The fine member is a dark greyish brown (10YR 4/2) clay, with an average thickness of 1.0 cm. The silts are exclusivelly bioturbated. Counted fifteen (15) couplets in 45 cm. Thirty-three (33) couplets per meter.

Level of Lake Nipigon: 853 feet above sea level.

WHITESAND RIVER SECTION X-12

Wave cut exposure located 1.0 kilometers north of the mouth of the Whitesand River.

THICKNESS (m)	DESCRIPTION
6.0	Sand, fine grained, micaceous, with faint 1.0 cm thick laminae. Upper 2.0 meters show ripple cross-stratification(poss. in-drift climbing ripples), dipping to the northeast. Cross-bedded sands are an olive colour (5Y 5/4) and are interbedded with 2.0-3.0 cm thick units of massive clayey silty sand and occasional thin (2.0 mm) brown clay laminae. Underlying 2.0 meters is a more massive, fine grained micaceous sand, with a faintly bedded appearence and faint symmetrical ripples. Underlying 1.2 meters is a bedded fine grained, micaceous sand of similar composition to the overlying fine grained sands. The lower 1.0 meter is a zone of convolute bedded fine grained micaceous sand with occasional thin (1.0 cm) beds of an olive (5Y 5/3) silty fine grained sand. Lower contact is gradational. SAMPLE: Whitesand R. X-12 fg mica sand. Sample taken at 5.0 meters down-section.
10.0	Silty sand, fine grained, micaceous and generally massive, with some convolute bedding and faintly laminated zones apparent. Silt content of sand increases down-section. Sand is an olive (5Y 5/3) colour. Upper 1.5 meters is massive, with convolute bedding in the underlying 2.0 meters. These silty sands grade down into a faintly laminated silty sand. Laminae are thin (2.0-3.0 mm) and composed of brown clay. A cave formed by flowing water is found near the base of the 10.0 meter unit, and exposes a fault in the sand showing discordance of bedding. Sharp lower contact with underlying sediments.SAMPLE: Whitesand R. X-12 fg silty sand. Sample taken 15.0 meters down-section.

5.I	Couplets of clayey silt and clay, rhythmically repeated. Coarse member is a grey (5Y 5/1) clayey silt, while the fine member is a dark grey (5Y 4/1) clay. The thicknesses of both members varies throughout the 5.1 meter section. In the basal 2.0 meters, the clayey silt averages al.5 cm thickness; the clays average a thickness of of 1.0 cm. In the upper 0.5 meters, the clays are 3.0 mm thick and the clayey silts also average a 3.0 mm thickness. The couplets are highly contorted in some zones, and poorly developed in others. The number of couplets per meter is variable. The thinner couplets average one hundred thirty (130) couplets per meter; the thicker couplets were counted at forty (40) couplets per meter.
2.3	Covered

Level of Lake Nipigon: 853 feet above sea level.

WHITESAND RIVER SECTION X-13

Wave cut exposure located 75 meters north of WHITESAND RIVER SECTION X-12, and 1.75 kilometers north of the mouth of the Whitesand river.

THICKNESS (m)	DESCRIPTION
0.5	Clayey silty sand, very fine grained, massive. Clay content increases down section. Sand is an olive brown (2.5Y 4/4) colour. Lower contact shows flame structures and loading into the underlying sediments. SAMPLE: Whitesand R. X-13 clayey silty sand.
1.0	Silty clay, blocky habit, contains loads of overlying clayey silty sands. Clay is a yellowish brown (10YR 5/4) color. Loads of sand found only in upper 50.0 cm of unit, five (5) were noted within a 50 cm^2 area, and ranged in diameter from 5.0 to 21.0 cm. Lower contact is gradational as silty clays grade downward into the underlying sediments. SAMPLES: Whitesand R. X-13 silty clay Whitesand R. X-13 clay loads.
3.0	Silt, massive. Greyish brown colour (2.5Y 5/2). Upper 1.0 meter shows contorted lenses (3-5 mm thick) of very fine grained micaceous sand, and occasional thin (1.0 mm thick) laminae of brown clay. Underlying 2.0 meters are distinctly massive, with the lower 50 cm becoming more clayey, with the lower contact gradational. Sample of the silt taken 3.5 meters down section. SAMPLE: Whitesand R. X-13 silt.

0.3	Couplets of sandy silt and clay, rhythmically repeated. Coarse member is a light grey (5Y 7/1) sandy silt with an average thickness of 3.0 mm. The fine member is an olive grey (5Y 4/2) clay with an average thickness of 1.0 cm. The sandy silts show symmetrical ripples with rounded crests. Sample of couplets taken 4.6 meters down section. SAMPLE: Whitesand R. X-13 sandy silt couplets. Counted forty-seven (47) couplets per meter.
3.8	Couplets of clay and silt, rhythmically repeated. Coarse member is a grey (5Y 6/1) silt with an average thickness of 2.0 cm. The fine member is a dark greyish brown (2.5Y 4/2) clay with an average thicknes of 6.0 mm. Counted sixty-six (66) couplets per meter. Lower contact is gradational. SAMPLE: Whitesand R. X-13 Couplets, taken 13 meters up-section.
2.0	Couplets of silty clay and very fine grained sandy silt, rhythmically repeated. The coarse member is a grey 5Y 6/1) very fine grained sandy silt with an average thickness of 4.5 cm. Symmetrical ripples with rounded crests form in the sandy units; avg. wavelength-10.0 cm avg. ht.-5.0 mm. Fine member is an olive gray (5Y 4/2) silty clay, with an average thickness of 2.0 mm. Occasional units of silty very fine grained sand interbedded with the couplets. Sand occurs with ripples similar to those of silts. Sand color is a light grey (5Y 7/1), and the average thickness is 2.5 cm. Counted twenty (20) couplets per meter. SAMPLE: Whitesand R. X-13 couplets, 10 meters up-section.

I.0	Couplets of silty clay and very fine grained sandy silt, repeated. Upper 1.0 cm of coarse sandy silt members are very sandy. Sandy silts are a grey (5Y 6/1) colour with the upper zones being more of a lighter grey (5Y 7/1). Average thicknesses of the units are 4.0 cm. Finer member is a dark grey (5Y 4/1) silty clay with an average thickness of 6.0 mm. Twenty-one (21) couplets per meter counted. SAMPLE: Whitesand R. X-13 couplets 0 meters, taken at base of exposed section, above cover. SAMPLE: Whitesand R. X-13 couplets 4 meters, taken 4.0 meters up section.
2.0	Covered

Level of Lake Nipigon: 853 feet above sea level

WHITE SAND RIVER SECTION X-14
Wave cut exposure located 1.25 kilometers west of Mt. St. John

THICKNESS (m)	DESCRIPTION
13.0	Couplets of clay to clayey silt and silt, rhythmically repeated. Coarse member is a light brownish grey (2.5Y 6/2) silt, averaging a thickness of 4.5 cm. The fine member is a dark brownish grey (2.5Y 4/2) clay to a clayey silt, with an average thickness of 5.0 mm. Coarser, silt members are intensely bioturbated. Counted eighteen (18) couplets per meter.
2.0	Covered

Level of Lake Nipgon: 853 feet above sea level.

WHITESAND RIVER SECTION X-15

Wave cut exposure located 1.2 kilometers southwest along the shoreline from Whitesand R. section X-14.

THICKNESS (m)	DESCRIPTION
11.6	Couplets of silt and silty clay, rhythmically repeated. Coarse member is a light brownish grey (2.5Y 6/2) silt. Fine member is a dark greyish brown (2.5Y 4/2) silty clay. Thicknesses of the individual members are variable within the section. Upper 50.0 cm: coarse silts average a thickness of 1.2 cm. The fine silty clays average a thickness of 4.0 mm. Ninety-four (94) couplets per meter. Underlying 11.0 meters: coarse silts average a thickness of 5.0 cm. The fine silty clays average a thickness of 6.0 mm. Counted sixteen (16) couplets per meter. Lower 1.5 cm of the coarse silt members is more of a slightly sandy silty clay with the sand being very fine grained. Bioturbation is evident throughout the section in both members of the couplets, however more prominent in the coarse silt members.
4.0	Covered

Level of Lake Nipigon: 853 feet above sea level.

NAMEWAMINIKAN RIVER SECTION X-16

Wave cut exposure located at the mouth of the Namewaminikan River, 3.0 kilometers north of Poplar Lodge, and 1.2 kilometers southeast of Poplar Point.

THICKNESS (m)	DESCRIPTION
1.0	Silty sand, very fine grained. Faint bedding (X-bedding?). Upper 50.0 cm is an oxidized yellow colour. Sharp lower contact.
0.9	Sand, medium to coarse grained. Upper 40.0 cm is laminated medium-coarse grained sand with abundant "mud balls" of brown(2.5Y 6/4) silty clay, of granule size. Near upper contact, find a cross-laminated, fossiliferous "trough" of coarse grained sand with granules. Exposed section of trough: 1.0 meter long, 10.0 cm thick, containing pelecypods and gastropods. Occasional rounded pebbles of diabase, granite, quartz, and a few of the Sibley Group. Internal silt laminae (2.0 mm) dip 31° to the north (app. dip). SAMPLE: of samller pelecypods (1.0 cm diameter) and gastropods (1.0 cm long), and fragments of larger pelecypods. Valves of pelecypods found convex-up. SAMPLE: Nam. R. X-16 mg-cg laminated "trough" sediments. Lower 50.0 cm is massive medium to coarse grained sand with occasional granule size silty clay "mud balls" (2.5Y 4/2). Single pelecypod valve found at the base of the unit, convex-up. Sharp lower contact with a 2.0 mm thick whitish coloured crust (carbonate?).
0.05	Clayey silt. Massive. Silts are a light grey (2.5Y 6/2). Gradational lower contact.
3.3	Silty sand, very fine grained. Concentration of mafic grains show sands to be cross-bedded, formed by assymmetrical ripples, which dip to the south. Silty sands are

a light brownish grey (2.5Y 6/2).
SAMPLE: Nam. R. X-16 silty vfg sands.
Sample taken at the base of the unit.

6.0	Covered

Level of Lake Nipigon: 853 feet above sea level.