GEOLOGICAL SURVEY OF CANADA
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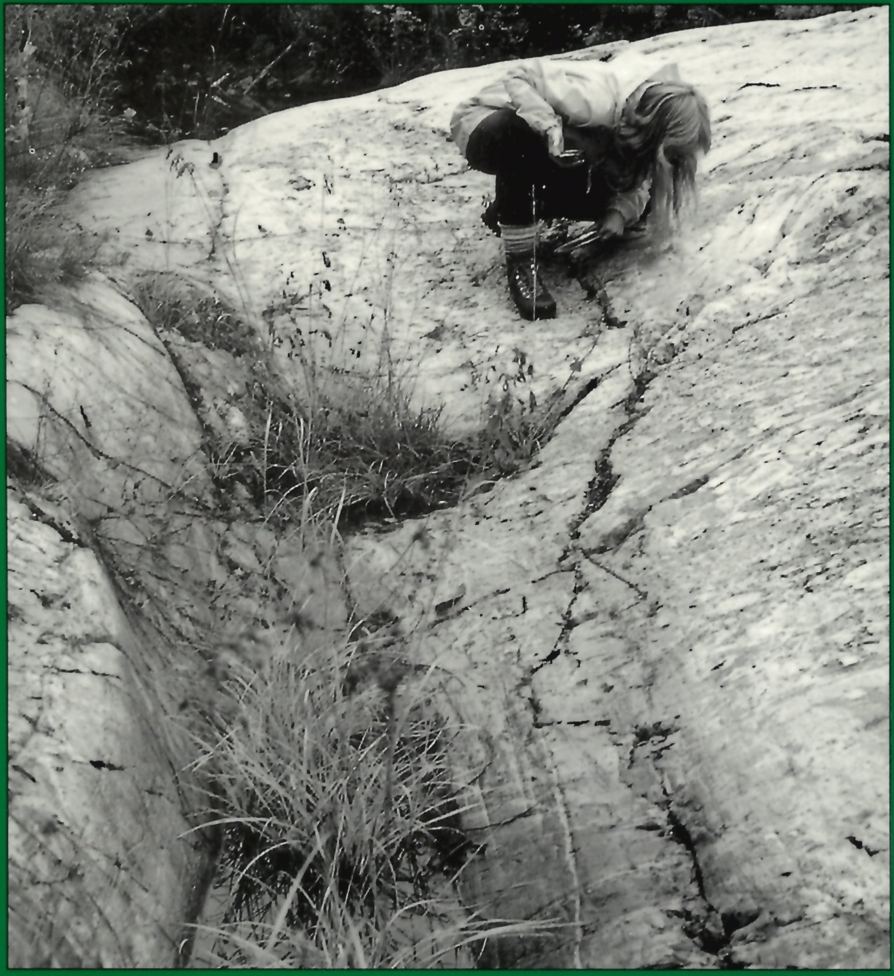
QUATERNARY STRATIGRAPHIC DRILLING TRANSECT, TIMMINS TO THE MOOSE RIVER BASIN, ONTARIO

Sharon L. Smith



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Preface

The Timmins Drilling Transect component of the Canada-Ontario Mineral Development Agreement (1985-1990) has provided a unique opportunity to investigate the sequences and origins of the thick blanket of glacial sediments in this area. Traditional methods of exploration for buried mineralized deposits to the north of Timmins, have been hampered by the thick glacial cover and lack of bedrock or sediment exposure.

This project, through deep drilling coupled with geotechnical methods and geochemical sampling, has provided baseline data that will be useful to both the mineral industry, through enhanced drift prospecting capabilities, and to researchers investigating the glacial history of the region with respect to the Laurentide Ice Sheet. These data may contribute to development of models for deglaciation, which is important to our overall understanding of global climate change in the past.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

La composante de l'Entente Canada-Ontario d'exploitation minérale (1985-1990) qui touche le transect de forage de Timmins a fourni une occasion unique d'étudier les séquences et l'origine de la nappe épaisse de sédiments glaciaires qui couvre la région. La présence d'une couverture épaisse de sédiments glaciaires et l'absence d'affleurements du socle rocheux ou des sédiments ont nuit à la prospection, par des méthodes classiques, des gisements minéralisés enfouis au nord de Timmins.

Grâce au forage à grande profondeur, à l'utilisation de méthodes géotechniques et à l'échantillonnage géochimique, il a été possible de recueillir des données de base qui permettront à l'industrie minérale d'améliorer sa capacité de prospection des sédiments glaciaires, et qui se révéleront utiles aux chercheurs qui étudient l'histoire glaciaire de la région en fonction de l'inlandsis Laurentidien. Ces données pourraient contribuer à l'élaboration de modèles de la déglaciation en vue d'améliorer le niveau de connaissance global des changements climatiques survenus à l'échelle de la planète dans le passé.

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

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Abstract

The composite Quaternary stratigraphy in the region bounded by Timmins to the south and Moose River basin to the north comprises from youngest to oldest: postglacial sediments, Cochrane Formation, Barlow-Ojibway Formation, Matheson Till, three older, unnamed tills, and intertill sediments. Ice flow direction indicators support an early west-southwest ice flow that shifted to the south and then southeast in subsequent glacial episodes. A local, lobate surge toward the east-southeast is the youngest recorded ice flow direction in the study area.

Stratigraphic profiles derived from 70 intact cores to bedrock, suggest the correlation of Kipling with Cochrane and Adam with Matheson tills, and thus provide a link between the Quaternary stratigraphy in the Moose River basin and that of the Timmins vicinity. Pebble lithologies, heavy mineral composition, and geochemistry of silt+clay, clay, and heavy mineral fractions of till indicate that Matheson Till was derived during sustained southwesterly ice flow from a Labradorean centre presumably at the Wisconsinan maximum. The model of Late Wisconsinan configuration of the ice sheet is less clear based on limited information available from this study.

Drift prospecting programs, typically impeded by the thick cover of glaciolacustrine or glacially reworked glaciolacustrine sediments in the region, can be effective if the methodology, including a comprehensive drilling program, is based on a solid framework of stratigraphic information.

Résumé

La stratigraphie composite du Quaternaire dans la région limitée par Timmins au sud et par le bassin de la rivière Moose au nord va des strates les plus jeunes aux strates les plus anciennes: sédiments post-glaciaires, formation de Cochrane, formation de Barlow-Ojibway, till de Matheson, trois tills plus anciens non dénommés, et sédiments d'intertill. Les indicateurs de la direction des glaces confirment l'existence d'un écoulement glaciaire initial dirigé vers l'ouest-sud-ouest, qui a ensuite pris une direction sud puis une direction sud-est au cours des épisodes glaciaires ultérieurs. Une crue glaciaire localisée, de type lobaire, de direction est-sud-est, représente l'écoulement glaciaire le plus récent dont la direction ait été notée dans la région étudiée.

Les profils stratigraphiques déduits de l'étude de 70 carottes intactes recueillies dans des forages allant jusqu'à la roche de fond, suggèrent une corrélation du till de Kipling avec le till de Cochrane et une corrélation du till d'Adam avec le till de Matheson, donc permettent d'établir un lien entre la stratigraphie quaternaire du bassin de la rivière Moose et celle des alentours de Timmins. La lithologie des cailloux, la composition des minéraux lourds, et la géochimie des fractions minérales lourdes du till indiquent que le till de Matheson a eu pour origine, pendant un écoulement glaciaire soutenu de direction sud-ouest, un centre glaciaire situé au Labrador, sans doute pendant le maximum de la glaciation du Wisconsin. Le modèle de configuration de l'inlandsis au Wisconsinien tardif est moins clair, étant donné l'information limitée fournie par cette étude.

Les programmes d'exploration des dépôts glaciaires (drift), le plus souvent interrompus en raison de la présence d'une épaisse couverture de sédiments glaciolacustres ou de sédiments lacustres remaniés par les glaces dans la région de l'étude, peuvent donner des résultats concluants, si les procédés employés, y compris le mode de réalisation d'un programme détaillé de levés, sont fondés sur un solide contexte d'information stratigraphique.

SUMMARY

Quaternary stratigraphy, derived from 70 intact cores drilled to bedrock in the area northeast of Timmins to the Moose River basin, has revealed a sequence of at least four and probably five till units. Composite stratigraphy of the study area, comprises from youngest to oldest: postglacial sediments, Cochrane Formation, Barlow-Ojibway Formation, Matheson Till, and older tills and intertill sediments.

Both glacial dispersal data and limited striation records indicate that the oldest direction of ice flow, toward the southwest (225°-215°), was superceded by a gradual shift in direction southward (180°-165°) and lastly southeastward (155°), the youngest direction of major ice advance. Evidence for an older, westerly ice flow in the study area is very rare and consists of only one bedrock outcrop that exhibited 270° striations. Compositionally, it is virtually impossible to distinguish between a till deposited from ice moving toward the west, and a till deposited by ice advancing in a southwesterly direction, the latter being a well represented event. Even without significant evidence it is impossible to completely discount an early westerly ice flow. A confined zone of ice flow toward 130° recorded southwest of Kapuskasing may be related to a lobe of ice that surged during the final stages of dissipation of the ice front in that area.

The compositional signature in tills derived largely from Paleozoic terrane (from the north and northwest) is distinct from that of crystalline, metamorphic terrane (from the northeast) in the study area. The strength of this contrast decreases with increasing distance from the Phanerozoic source area such that tills close to Timmins are not differentiable on that basis alone, except for Cochrane Till which is extremely carbonate-rich.

The late glacial history of this area, as inferred from provenance of till units in combination with ice flow direction indicators, suggests that strong southwesterly flow (shifting to southerly) was sustained through at least the early part of the Late Wisconsinan prior to diminution of the ice sheet. Compositional evidence for continued tapping of Proterozoic source areas in the Sutton Ridge and possibly as far as the Belcher Islands, into the Cochrane readvance, can not differentiate retreat back to a Keewatin versus a Hudson-based late glacial dispersal centre.

Comparison of core stratigraphy, till composition, and ice flow direction indicators, have allowed some correlations to be made between Quaternary stratigraphy developed in the Timmins area, and that of the Moose River basin to the north. Matheson Till and Adam Till, and Cochrane and Kipling tills are correlated respectively. The ice front active during the Matheson/Adam

SOMMAIRE

La stratigraphie du Quaternaire, déduite de l'examen de 70 carottes de forage prélevées jusqu'à la roche de fond, a révélé l'existence d'une séquence d'au moins quatre et de probablement cinq unités de till. La stratigraphie composite de la région étudiée, allant des strates les plus récentes aux strates les plus anciennes, est la suivante: sédiments post-glaciaires, formation de Cochrane, formation de Barlow-Ojibway, till de Matheson, et tills plus anciens ainsi que sédiments d'intertill.

Les données relatives à la dispersion des glaces et les quelques relevés des striations glaciaires indiquent que l'écoulement glaciaire, initialement dirigé vers le sud-ouest (225° – 215°) a graduellement pris une direction sud (180° – 165°) et finalement une direction sud-est (155°), qui est celle de la dernière grande crue glaciaire. Dans la région étudiée, les indices d'un écoulement glaciaire plus ancien, de direction ouest, sont très rares et représentés par un seul affleurement de la roche de fond portant des striations orientées à 270°. Du point de vue de leur composition, il est pratiquement impos-sible de distinguer un till déposé par des glaces avançant vers l'ouest, d'un till déposé par des glaces avançant vers le sud-ouest; ce dernier épisode est bien représenté. Même en l'absence d'indices substantiels, il est impossible de complètement rejeter l'hypothèse d'un écoulement glaciaire initial vers l'ouest. Une zone confinée d'écoulement glaciaire vers 130° repérée au sud-ouest de Kapuskasing est peut-être associée à la crue d'un lobe glaciaire survenue dans cette région pendant les dernières étapes de disparition du front glaciaire.

La signature compositionnelle des tills provenant largement du terrane d'âge paléozoïque (donc provenant du nord et du nord-ouest) est distincte de celle du terrane métamorphique cristallin (nord-est) dans la région étudiée. Le degré de contraste entre les deux diminue avec la distance de la région d'origine, d'âge paléozoïque, de sorte que les tills proches de Timmins ne se laissent pas différencier sur cette base seule, excepté le till de Cochrane qui est extrêmement riche en carbonates.

L'histoire tardiglaciaire de cette région, telle que déduite à la fois de la provenance des unités de till et des indicateurs de la direction d'écoulement des glaces, suggère qu'un fort écoulement vers le sud-ouest (passant ensuite à une direction sud) s'est maintenu pendant au moins la première partie du Wisconsinien tardif avant la diminution de taille de l'inlandsis. Les indices compositionnels d'un afflux continuel de matériaux à partir de régions d'origine d'âge protérozoïque situées sur la crête de Sutton et peut-être aussi loin que les îles Belcher, dans les glaces de la réavancée de Cochrane, ne permettent pas de différencier le retrait vers un centre de dispersion keewatinien de celui vers un centre de dispersion tardiglaciaire basé dans la région hudsonienne.

Par comparaison de la stratigraphie déduite de l'étude des carottes de forage, de la composition des tills et des indicateurs de la direction d'écoulement, on a pu établir quelques corrélations entre la stratigraphie du Quaternaire de la région de Timmins et celle du bassin de la rivière Moose au nord. Le till de Matheson et le till d'Adam, ainsi que le till de Cochrane et le till de Kipling, ont été corrélés entre eux. Le front glaciaire

glaciation, probably retreated north beyond the Pinard moraine prior to the readvance of Cochrane ice. The Friday Creek sediments are tentatively considered to be a northward extension of the Barlow-Ojibway Formation. No Missinaibi Formation forest-peat member marker horizon was intersected in the cores, although disseminated organic debris was recovered from several stratigraphic levels.

Although there are serious impediments to drift prospecting in this area, a number of steps can be taken to maximize the effectiveness of a sampling program. They are: 1) geophysical surveys to map the subsurface and provide drilling targets; 2) limited stratigraphic drilling with a drill that will recover intact cores, in order to establish the local stratigraphy; and 3) subsequent reverse circulation drilling to provide till samples of the selected strata. This should be followed by identification of anomalous concentrations of elements of interest in selected tills of known ice flow direction by using geochemical or lithological analysis. Anomalies can define dispersal trains that potentially may be traced up-ice to their source.

actif durant la glaciation de Matheson/Adam a probablement reculé au nord au-delà de la moraine de Pinard avant la réavancée des glaces de Cochrane. Les sédiments de Friday Creek sont provisoirement considérés comme un prolongement vers le nord de la formation de Barlow-Ojibway. Aucun horizon repère du membre forestier-tourbeux de la formation de Missinaibi n'a été rencontré dans les carottes de forage, bien que des débris organiques disséminés aient été récupérés à plusieurs niveaux stratigraphiques.

Même si dans cette région, il y a de sérieux obstacles à la prospection des dépôts glaciaires (drift), on peut prendre plusieurs mesures pour maximiser le rendement d'un programme d'échantillonnage. Ce sont: 1) la réalisation de levés géophysiques pour cartographier la subsurface et trouver des cibles de forage; 2) la réalisation de forages stratigraphiques limités, au moyen d'une sonde qui permette de récupérer des carottes intactes, afin que l'on puisse établir la stratigraphie locale; et 3) un forage ultérieur à injection inverse, pour obtenir des échantillons de till dans les strates sélectionnées. Ce travail doit être suivi de l'identification des concentrations inhabituelles d'éléments intéressants dans les tills sélectionnés présentant une direction connue d'écoulement glaciaire, par des méthodes géochimiques ou lithologiques. Les anomalies peuvent aider à définir des traînées de dispersion qui se laisseraient éventuellement retracer en amont jusqu'à leur source.

INTRODUCTION AND BACKGROUND

Objectives

Drift prospecting north of Timmins has been impeded both by the thick cover of glacial sediments, particularly lacustrine sediments deposited in glacial Lake Barlow-Ojibway, and by unresolved Quaternary stratigraphic problems. In this area there is a lack of natural exposures of Quaternary sediments and a deficiency of erosional and depositional information with which to delineate ice flow directions on a regional scale. Some subsurface stratigraphy has been attempted for boreholes drilled by mining companies near Timmins itself, but few natural exposures exist.

The primary objective of this project is to link Quaternary stratigraphy of the area north of Timmins with that established from abundant natural exposures in the Moose River drainage basin, so that these problems can be addressed. Deep continuous coring of unconsolidated sediments was utilized to construct this subsurface link along two roughly north-south oriented transects. In addition, closely spaced drilling was done on the former Kam-Kotia/Jameland mine properties, near Timmins, in order to resolve ice flow directions by studying dispersal from the outcropping orebody. This local-scale study was used to corroborate the regional dispersal patterns.

The depositional and stratigraphic models derived from the drilling will provide a sound base for development of a drift prospecting methodology in this area of thick overburden cover.

Previous work

Although a number of people provided early observations of the Moose River basin (R. Bell, 1877, 1896; Borron, 1891; J.M. Bell, 1904; Keele, 1920; McLearn, 1927), primarily to evaluate economic potential, more recent work has focused specifically on the Pleistocene geology and definition of the glacial history of the region (Terasmae and Hughes, 1960; Bennett et al., 1967; Craig, 1969; McDonald, 1969). Skinner (1973) wrote the first comprehensive report on the Quaternary geology of the Moose River basin, from which stratigraphic information will be excerpted for comparison purposes in this study. Although the physical stratigraphic framework has been well developed, further temporal refinement of the model that Skinner (1973) proposed for advance and retreat of the ice sheet has been undertaken using amino acid and thermoluminescence geochronological techniques (Shilts, 1982; Andrews et al., 1983; Forman et al., 1987; Wyatt, 1989).

Previous workers in the area between Smoky Falls (at the southernmost limit of the Moose River basin) and Timmins have dealt for the most part with surficial deposits (Boissonneau, 1966; Hughes, 1956, 1959, 1965) and definition of specific topics related to the history of the Laurentide ice sheet (Flint, 1943), or glacial lakes Barlow-Ojibway (Antevs, 1925, 1928; Coleman, 1909), as few natural exposures exist, other than shallow cuts in the surface veneer of sediments. In the Timmins area, Richard (1983a, b), Tucker and Richard (1983), and Tucker and Sharpe (1980) published preliminary maps of Quaternary geology. Bird and Coker (1987) and DiLabio et al. (1988) described stratigraphy in the Timmins camp as it relates to drift prospecting. Unpublished subsurface drilling information, primarily depths to bedrock from reverse circulation drilling in the Timmins area, is available in the assessment files of the Mining Recorder's Office, Timmins, Ontario.

Location and access

The study area is bounded roughly between 83° and 81° longitude and 48°25' and 50°10' latitude and contains the population centres of Timmins, Cochrane, and Kapuskasing (Fig. 1). The smaller towns of Smooth Rock Falls, Fraserdale, and Smoky Falls figure prominently in this study. Fieldwork was conducted in the western half of both Cochrane (42H) and Timmins (42A), the eastern half of both Foleyet (42B) and Kapuskasing (42G), and the southeastern corner of Smoky Falls (42J) 1:250 000 scale map-sheets of the National Topographic System of Canada.

The Moose River drainage basin is immediately to the north of Smoky Falls and lies within the Phanerozoic sedimentary basin as defined by Sanford et al. (1968, p. 3). Overburden coring for this project was conducted within Precambrian terrane to the south although some work on natural river exposures within the Moose River basin, particularly Adam Creek, was conducted to complement the drilling. Major rivers and other bodies of water that are of note in the study area include the Abitibi and Mattagami rivers and their tributaries, as well as Kamiskotia and Harmon lakes.

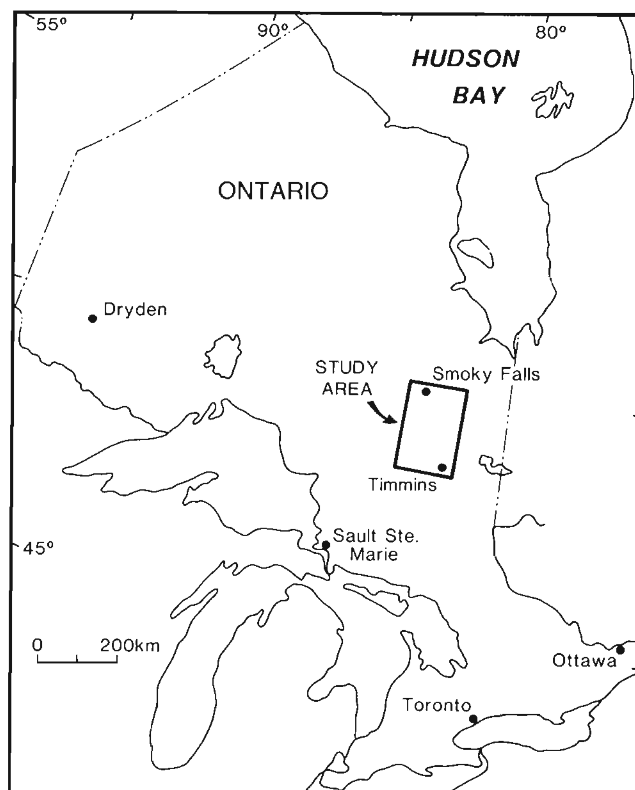

Figure 1. Location of study area in relation to Hudson Bay.

Access in the southern part of the study area is generally good where a network of paved or gravel roads exist, although large tracts of bush remain inaccessible to heavy equipment, except in winter. It is significant to note that many logging or other bush roads are built along eskers, which provide ample road-building material, but which are not good sites for stratigraphic drilling because esker sediments dominate the section. The major artery for access to Smoky Falls, the northernmost point to which it is possible to drive, is a partly paved road extending northward from Highway 11 (northern Trans-Canada Highway) from Smooth Rock Falls through Fraserdale. An alternate route northward from Kapuskasing is a gravel road maintained by Ontario Hydro for access to major hydroelectric installations at Smoky Falls and Harmon Lake. Adam Creek has been modified as a spillway for excess runoff from the Harmon Dam and provides steep, fresh exposures due to erosion from runoff of Harmon Lake.

Physiography

The study area lies within the Abitibi Uplands, a subdivision of the Canadian Shield physiographic province (Bostock, 1970). The Abitibi Uplands are a peneplain which straddles the Hudson Bay-St. Lawrence drainage divide. They are characterized by a persistent and generally thick cover of lake sediments or clay till, which has been informally called the "Clay Belt". This area is generally flat with few outcrops or other indication of the rugged bedrock topography beneath it. Bedrock in the study area has limited exposure except in the southeast corner near Timmins, in a zone southwest of Kapuskasing, and along the uplifted Precambrian-Paleozoic contact near Smoky Falls.

The average elevation rises about 160 m from 140 m a.s.l. at the northern edge of the study area to 300 m a.s.l. at the southern perimeter. Modern drainage is northward towards James Bay. Because of the low relief and low stream gradients, present drainage systems have not significantly incised the thick overburden cover. In the Moose River drainage basin however, modern rivers have incised deep, narrow channels into Quaternary sediments, with wide flood plains developed only along the lower reaches of the Moose River.

The majority of the study area is typified by a surface covered by poorly drained *Sphagnum* muskeg and black spruce-dominated forest.

Bedrock geology

Regional geology

Precambrian rocks of the Canadian Shield surrounding the Hudson Platform comprise metamorphosed Archean and Proterozoic crystalline, intrusive, and sedimentary rocks (Fig. 2). Archean terrane is dominated by gneisses, schist, and granites, locally intruded by diabase and gabbro dykes (Stockwell et al., 1970). The Cape Henrietta Maria Arch is an Archean dome which separates the Hudson Bay basin to the northwest and the Moose River basin to the south.

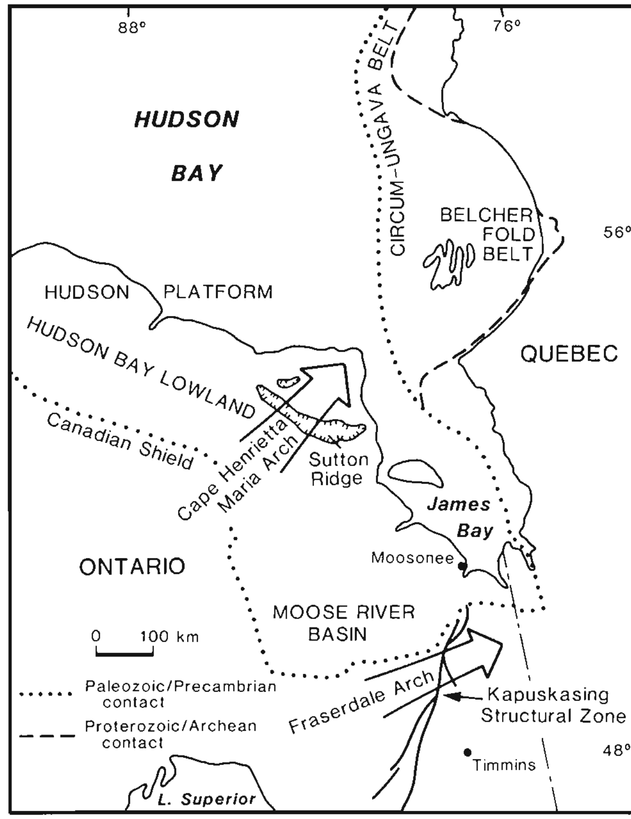

Figure 2. General geological features of the Hudson Bay area.

Proterozoic sedimentary rocks of interest to this study exist in the Sutton Ridge inlier within the Hudson Bay Lowlands, and in the Belcher Fold Belt sector of the Circum-Ungava Belt (Donaldson, 1986). Proterozoic formations of the Sutton Ridge, a prominent topographic feature which cuts transversely across the Cape Henrietta Maria Arch, comprise units of siliceous carbonate rocks, iron-formation, greywacke, and siltstone, with minor associated chert breccia-conglomerate (Bostock, 1971). Stratigraphy of the Belcher Fold Belt is complex and consists of basic igneous rocks which comprise up to 30% of exposed section in some areas of the Belcher Islands, as well as iron-formation, dolomite, greywacke, argillite, sandstone, and quartzite (Dimroth et al., 1970). In both Proterozoic sequences, metamorphic grade is low.

The relatively undeformed lower Paleozoic (Cambro-Ordovician to Late Devonian) rocks of the Hudson Platform comprise mainly carbonates and evaporites, with shale, siltstone, and sandstone making up a significant but minor proportion of the succession (Sanford, 1987). The Devonian rocks in the southern part of the Moose River basin are supratidal to shallow-marine in origin. The Sextant Formation consists of a wedge of terrigenous clastic debris reworked from Archean terrane to the south (Sanford and Norris, 1975). Post-early Middle Devonian ultramafic igneous dykes and sills of lamprophyric and kimberlitic composition have intruded Devonian sedimentary rocks in the vicinity of Sextant and Coral rapids on the Abitibi River (Bennett et al., 1967).

Mesozoic sediments are of limited areal extent and unconformably overlie Devonian strata or Precambrian terrane in the southern part of the Moose River basin. The Middle Jurassic Mistuskwia Beds, known from only a few boreholes in the northern part of the Mesozoic basin, consist of varicoloured clay and nonlithified quartz sand. Overlying the Mistuskwia Beds is a formation that differs from them lithologically and palynologically. This is the lower Cretaceous Mattagami Formation which consists of continental beds of silica sand, kaolin, varicoloured silt, and lignite (Telford, 1979; Telford and Long, 1986). The Mattagami Formation is exposed along some of the rivers in the southern part of the Moose River basin and outcrops of lignite are known from Adam Creek immediately north of the study area. Some early workers confused the Mesozoic lignite seams with glacially compressed Pleistocene peat (Keele, 1920) that are also exposed in Adam Creek. Mesozoic lignite has been incorporated locally into Pleistocene sediments by glacial erosion, and can pose problems during sampling for dating or paleoecological analysis.

Study area

The study area is floored by Precambrian crystalline terrane of the Superior Province of the Canadian Shield, and is bounded to the north by Phanerozoic sedimentary rocks and unconsolidated sedimentary cover of the Moose River basin (Fig. 3). The contact between the Precambrian and younger

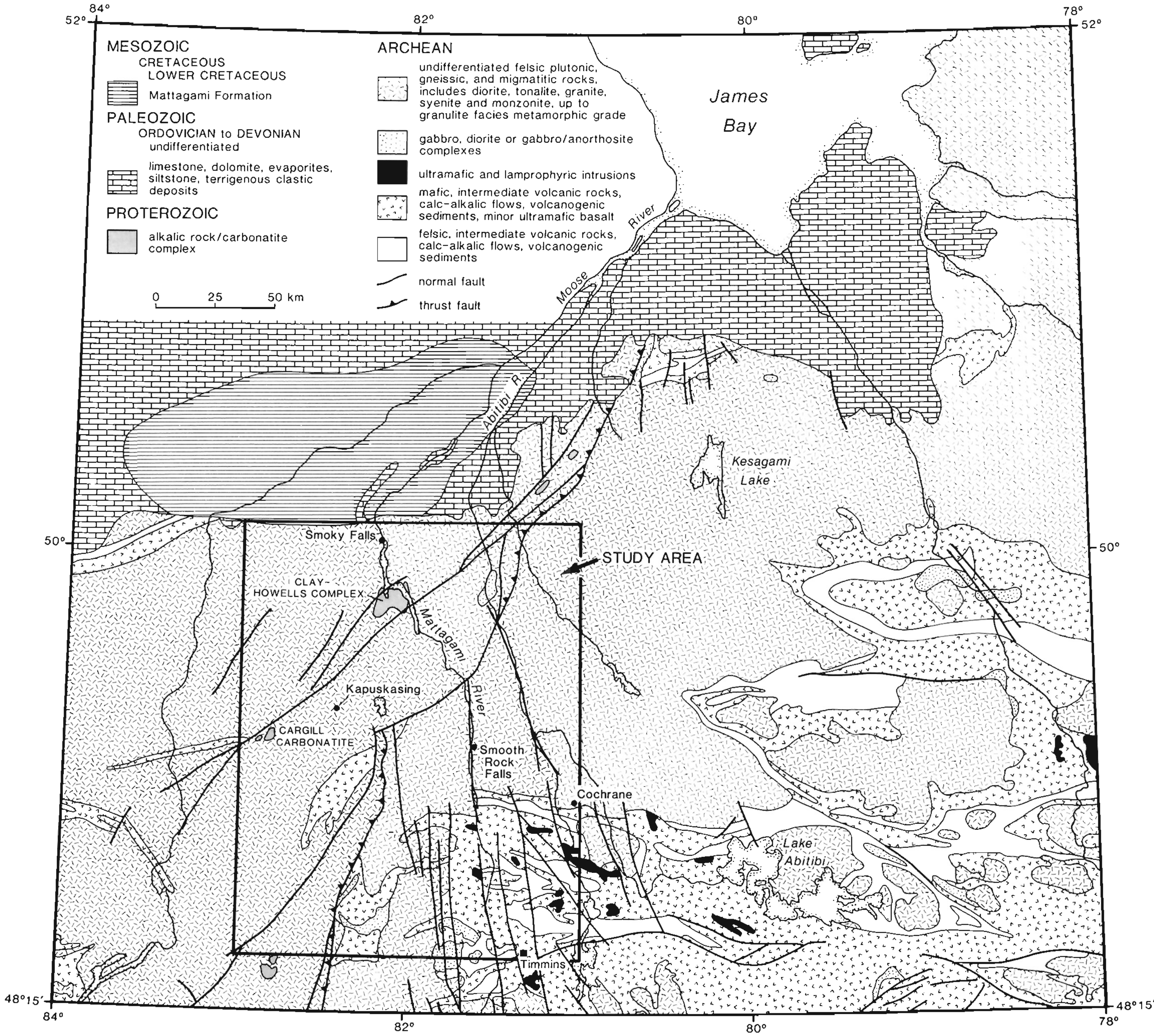

Figure 3. Bedrock geology of the study area and environs (modified from Card and Sanford, 1989).

terranes is a low but easily recognized escarpment developed on the Fraserdale Arch.

In the western part of the study area, the Quetico and Wawa subprovinces are divided from their eastern equivalents, the Opatica and Abitibi subprovinces respectively, by the Kapuskasing Structural Zone, a central tectonic element in this region (Fig. 4). The Quetico belt consists mainly of gneissic rocks, minor mafic volcanic rocks, and abundant biotite granite. Eastern Wawa Subprovince has several remnant greenstone belts, but consists mainly of tonalitic gneiss with local diorite to granite and syenite plutons. The Opatica belt comprises a similar assemblage of rocks as in the Quetico belt, dominated by gneisses and biotite granite. The Abitibi Subprovince is dominated by the Abitibi greenstone belt which comprises tholeiitic, calc-alkaline, and mafic to felsic sequences intercalated with volcanogenic sedimentary rocks. Plutonic rocks include gneiss, tonalite, and granodioritic suites (Card and Sanford, 1989).

Transecting the region is a discontinuous northeast-trending, fault-bounded zone of high-grade metamorphic rocks typified by granulite facies gneiss of the Kapuskasing uplift structure. Of greatest areal extent, the Val Rita block comprises amphibolite facies tonalitic gneiss and granite. Similarly, the northern Fraserdale-Moosonee block contains mafic gneiss, a suite of diorite, monzonite, and tonalitic rocks, as well as local gabbroic anorthosite. The northernmost part of the Chapleau block is dominated by mafic gneiss with minor tonalitic gneiss and anorthosite. Mafic dykes associated with the high-grade metamorphic rocks are linked to the intrusion of diabase dyke swarms (Percival, 1985; Leclair and Nagerl, 1988). A number of Proterozoic carbonatite-alkalic rock complexes such as the Clay-Howells and Cargill complexes, are associated in a linear fashion with the Kapuskasing Structural Zone. Kimberlitic and lamprophyric dykes intrude the northern Kapuskasing Zone (Card and Sanford, 1989).

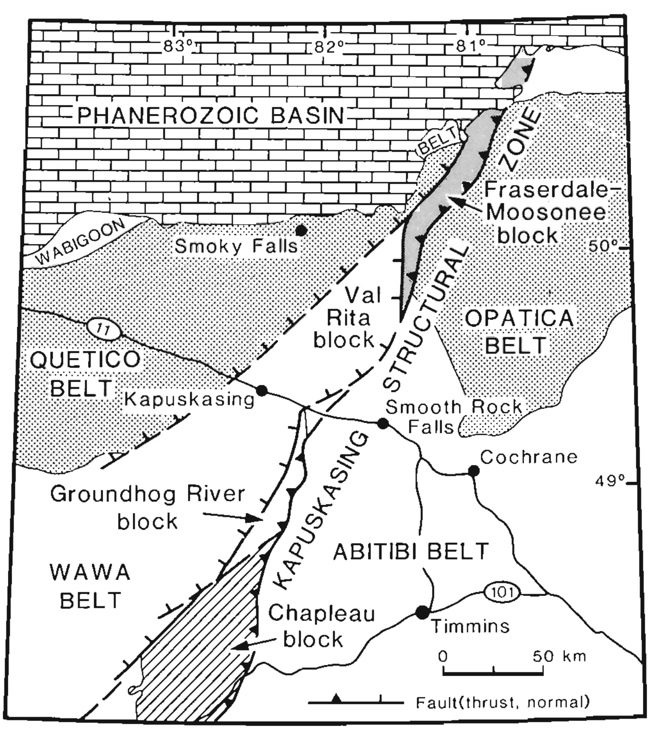

Figure 4. Regional tectonic elements showing features associated with the Kapuskasing Structural Zone (modified after Percival and McGrath, 1986).

Economic geology

Moose River basin[1]

A number of commodities have been identified as having a potential source in the Moose River basin: oil and gas, limestone, gypsum, lead and zinc, iron ore, copper, lignite, fire-clays, kaolin, quartz sand, and diamonds (kimberlites) (Brown et al., 1967; Sanford et al., 1968; Telford, 1979). However, only limestone and gypsum are presently of economic significance (Sanford and Norris, 1975).

The lead, zinc, iron ore, and copper potential lies within the Proterozoic rocks of the Sutton Ridge. Some veins exhibited traces of copper-bearing minerals near Sutton and Hawley lakes (Bostock, 1971, p. 53, 54) and lead and zinc are known from similar Proterozoic strata on the east side of Hudson Bay in the Circum-Ungava belt. The iron-formation mapped within the Sutton Ridges may be a potential source for hematite and magnetite (Sanford et al., 1968; Bostock, 1971). Other iron minerals are known from younger strata in the Moose River basin. Siderite and limonite occur as solution fillings in cavities, particularly in the Devonian Stooping River and Kwataboahegan formations (Sanford et al., 1968; Sanford and Norris, 1975). Siderite is also associated with silicate and carbonate facies of Proterozoic iron-formations (Lang et al., 1970).

Much effort has been expended in evaluating the reserves of the Lower Cretaceous Mattagami Formation lignite, fire-clay, and silica sand of the Moose River basin. Drilling and excavation at Onakawana by both private and government interests determined that there are considerable reserves of medium grade lignite. Development of the deposits is not feasible at this time due to thick cover of overburden, logistical considerations, and the need to determine the areal extent of the deposit (Onakawana Development Ltd., 1973; Vos, 1975; Watts, Griffis and McOuat Ltd., 1984). Fire-clays and associated silica sand and kaolin, outcrop along the Mattagami and Moose rivers and are known from exploratory drill cores (Vos, 1975).

Significant interest has been generated in the search for kimberlitic rocks in the Moose River basin. Kimberlitic heavy minerals have been extracted from river sediments in this area, and the James Bay Lowland has been suggested as the possible source for glacially transported diamonds found in the Great Lakes region (Tremblay, 1963; Brown et al., 1967). Bedrock lithologies in the Kapuskasing tectonic structure, and the association of alkaline and carbonatite intrusions or complexes, are similar to those in known diamond-producing areas (Brown et al., 1967). As yet no sources of the kimberlite indicator minerals have been

[1] For the purposes of this study, the name "Moose River basin" will be used in the remainder of this paper to refer to the drainage basin rather than the tectonic basin.

found, although certain Devonian intrusions on the Abitibi River at Coral and Sextant rapids have shown promise.

Study area

The study area, in NTS maps 42G (Kapuskasing) and 42H (Cochrane), is characterized by a significant lack of bedrock exposure, which has limited the number of showings or prospects of economic minerals. A few records of showings or prospects of iron, zinc, gold, silver, and uranium were reported by Rose (1985).

Two carbonatite intrusions and associated alkaline rocks, the Cargill and Clay-Howells complexes (Fig. 3), are known and have been investigated for their nickel, copper, phosphate, magnetite, and rare-earth element potential (Sage, 1988a, b). The Cargill deposit, comprising principally carbonatite and pyroxenite-amphibolite rocks in a locally defined karst system, contains thick residual accumulation of apatite, goethite, clay, siderite, and other stable minerals (Sandvik and Erdosh, 1977). In contrast, the Clay-Howells alkalic complex is dominated by pyroxene syenite. A magnetite-rich carbonatite intrusion in the southeast corner of the complex exhibits anomalous levels of niobium, tin, zinc, and molybdenum (Sage, 1988a). In the part of the study area on NTS map 42B, there are a few showings, and one larger deposit, of iron, copper, nickel, and zinc (Rose, 1985).

Although the study area does not include the Timmins-orcupine mining camp itself, there are showings, prospects, and mines related primarily to copper, zinc, lead, nickel, gold, silver, and iron mineralization in the area immediately northwest of Timmins (Rose, 1985). The world-class Kidd Creek Mine is still in operation, but in the Kamiskotia Lake area, the Kam-Kotia, Jameland, Canadian Jamieson, and Genex mines were past producers of copper, zinc, gold, and silver (Pyke and Middleton, 1970; Pyke, 1982). Of these deposits, only the Kam-Kotia and Kidd Creek orebodies outcropped at surface.

Quaternary geology

Lithostratigraphy of the Moose River basin

At least five glacial advances are documented by till units in the Moose River basin (McDonald, 1969; Skinner, 1973) (Fig. 5). The sequence from oldest to youngest consists of: 1) three till sheets separated by intertill sediments; 2) the interglacial Missinaibi Formation; 3) Adam Till; 4) Friday Creek nonglacial sediments; 5) Kipling Till; and 6) late and postglacial glaciolacustrine, marine, and terrestrial units. Shilts (1984, 1985) reported a sixth till at section 24M, apparently rich in kaolin, that is directly overlain at one exposure on Missinaibi River by the lowermost of Skinner's (1973) three pre-Missinaibi tills, a very compact, sandy, mauve-coloured till.

The pre-Missinaibi tills of Skinner (1973) are exposed together only at a few sites on Coal Creek and on Missinaibi, Soweska, and Pivabiska rivers. The best exposure of pre-Missinaibi units is at section 24M of Terasme and Hughes (1960, p. 3). The older units are correlated by their stratigraphic position relative to the Missinaibi Formation, as well as by gross lithologic similarity.

The lowermost till, Till I of Skinner (1973), is overlain by silt-clay rhythmites succeeded by bright orange to yellow, in places cemented, sand and interbedded diamicton. Paleocurrent indicators demonstrate that former current directions were opposite to the present gradient. A sandy, very compact, brownish-grey till, Till II, lying above the sand, was traceable over only a few miles from station 24M, and was identified by "counting-down" from the Missinaibi Formation. Till II is similar to Till I in boulder content and compactness (Skinner, 1973). Till II is overlain by oxidized, cemented sand and gravel with climbing ripple laminations again indicating drainage to the south. Immediately overlain by the Missinaibi Formation peat or forest bed is an oxidized, friable till with sand lenses, Till III. Oxidation is likely related to weathering during the Sangamonian Missinaibi interval. This till is sandy, calcareous, and much less compact than tills I and II.

The Missinaibi Formation as defined by Skinner (1973, p. 22) is divided into four members; (a) marine (Bell Sea), (b) fluvial, (c) forest-peat beds, and (d) lacustrine. Terasmae and Hughes (1960, p. 1) originally described the Missinaibi beds as "...layers of peat, organic silt, and clay..." and did not see the marine member of the sequence. The sedimentary facies of the Missinaibi Formation are analogous to those of the present interglacial, but the sediments themselves are compressed because of glacial overriding.

Thin (<1 m) fossiliferous marine sediments, generally very compact bluish-grey sand and silt, have been identified in situ at only a few locations, including the exposures on the Adam Creek spillway. Marine shells have been reworked into younger members of the Missinaibi Formation and into younger tills and Tyrrell Sea sediments. The

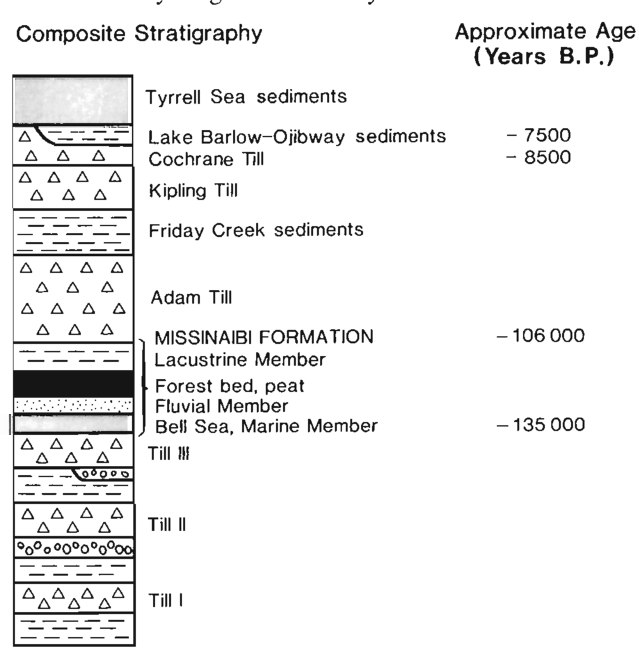

Figure 5. Lithostratigraphy of the Moose River basin and suggested timing of events (modified from Skinner, 1973; Andrews et al., 1983).

sea that inundated the Moose River basin while it was glacioisostatically depressed early in the Missinaibi interval, was named the Bell Sea by Skinner (1973). The relatively rarely exposed fluvial member, consisting of oxidized gravel, sand, and silt, commonly exhibits large-scale trough cross-stratification or planar bedding with current directions in the same sense as the modern rivers. Detrital organic material comprises wood, mosses, seed, sponge spicules, arthropods, and even beaver-chewed wood. This member is 2-3 m thick on average.

The forest-peat member is organic-rich and contains the stumps of trees, many in growth position, up to 12 cm in diameter. The average thickness of this unit is 2 to 5 cm, although it may reach up to 2 m where it is peaty. The forest bed rests on a weathered, noncalcareous diamicton interpreted to be a buried soil (Skinner, 1973). Overlying the forest-peat beds is the up to 30 m thick lacustrine member of the Missinaibi Formation. The cliff-forming character of the silt and clay is distinctive. The silt and clay rhythmites form couplets from 1 to 20 cm thick and locally contain starved ripples and show evidence of shearing due to glacial overriding (Skinner, 1973). Missinaibi Formation sediments form a significant regional, interglacial marker horizon.

Post-Missinaibi deposits consist of at least two tills separated by nonglacial sediments (McDonald, 1969; Skinner, 1973). The older of the two tills, Adam Till, named after its type section in Adam Creek (Skinner, 1973), is highly variable in character across the Moose River basin. In general, it is greenish, low in carbonate, has a fine texture, few boulders, and has locally incorporated elements of the Missinaibi Formation such as marine shells. Data from boulder striations and till fabrics, although few, suggest ice that deposited Adam Till flowed toward the southwest, perhaps from Labrador (Skinner, 1973). Adam Till is best identified by its position immediately above the Missinaibi Formation and its contrast with overlying materials. Adam Till is overlain by either Friday Creek sediments, or directly by Kipling Till from which it is separated by a boulder pavement.

Deposits of lacustrine sand and silt up to 20 m thick, informally termed Friday Creek sediments, are oxidized, calcareous, but rarely cemented. Rhythmites from 3 to 50 cm thick can occur at the base of the sequence and may exhibit climbing ripple lamination and cross-stratification. Sedimentary structures indicate that currents flowed to the south against the modern regional gradient.

The uppermost till identified in the Moose River basin is termed Kipling Till (Skinner, 1973), after the type locality at Adam Creek in Kipling Township. Kipling Till is 2 to 5 m thick at its type locality, brownish where oxidized and grey where fresh, more calcareous than older tills, especially Adam Till, and has a sharp lower contact. Regionally it can be recognized by low compaction, brown colour and stratigraphic position. Direction of ice flow, obtained from striations on boulders and till fabrics, indicate a radial pattern from southwestward in the western part of its outcrop, to south-southeastward in the eastern area of exposure (Skinner, 1973).

Late glacial and postglacial deposits comprise: 1) a glaciolacustrine unit, 2) a marine unit, and 3) a terrestrial unit in the Moose River basin. The lacustrine sediments are diamicton, sand and gravel, and rhythmites which overlie Kipling Till. The contact between these components is typically gradational. Up to 6 m of glaciolacustrine deposits have been recorded (Skinner, 1973). Tyrrell Sea marine deposits (Lee, 1968) overlie the glaciolacustrine sequence and occur in the northwest corner of the study area. Composed of clay-pebble gravel, clay and silt, and shallow-water sand and gravel, the marine beds are highly fossiliferous. A distinctive clay-pebble gravel forms the base of the marine beds and separates them from underlying glaciolacustrine sediments throughout the Moose River basin (Skinner, 1973). Terrestrial peat, alluvium, and eolian sand forms the surface blanket of the region (Skinner, 1973).

Andrews et al. (1983), Andrews (1989), Shilts (1982, 1984, 1985), Shiltz and Wyatt (1988), and Wyatt (1989) suggest that there is evidence in the form of physical stratigraphy and amino acid (alloisoleucine:isoleucine) ratios on marine shells to conclude that the stratigraphy of deposits postdating the last interglacial (Sangamon) is more complex than Skinner had envisaged. Aminostratigraphy of the upper Quaternary in the Moose River basin is constrained on one end by ratios from Bell Sea deposits and on the other by ratios from the Holocene Tyrrell Sea sediments. Between these end members, two intermediate groups of ratios were identified and correlated with aminostratigraphic units represented by the nonglacial Fawn River gravel and Kabinakagami sediments (Andrews et al., 1983). An independent age estimate based on thermoluminescence dates on silty clay suggests an average age of 74 ± 10 ka (Forman et al., 1987) for the correlative Fawn River gravels. The clay was correlated with the Fawn River gravels on the basis of amino acid ratios on shells found in growth position in the clay. Andrews et al. (1983) had predicted ages of 76 ka and 35 ka for the Fawn River gravels and Kabinakagami sediments respectively. Shilts (1984) assigned the Friday Creek sediments to the stratigraphic position previously labelled Kabinakagami sediments (Andrews et al., 1983) due to the latter's poorly defined type section (W.W. Shilts, pers. comm., 1989).

Shelly marine beds exposed on Abitibi River have been correlated tentatively with a marine unit exposed on Severn River in the central Hudson Bay Lowland (Thorleifson, 1989; Wyatt, 1989; W.W. Shilts, pers. comm., 1989) based on the similarity of their amino acid ratios. Wyatt (1989) associated the Severn River marine unit with ^{18}O isotope stage 5a, or approximately an 80 ka age, assuming the Bell Sea sediments are about 130 ka. However, Skinner (1973) identified till overlying marine sediments on Abitibi River as Adam Till, the same till unit that overlies Missinaibi Formation sediments and marine member (Bell Sea) at its Adam Creek type section. If the Abitibi River marine unit represents a period of significant marine incursion since the Bell Sea, then a re-evaluation of the two-till stratigraphy of Skinner (1973) is needed to tie the stratigraphy to amino acid data.

Lithostratigraphy of glacial sediments of the the study area

South of the limit of Precambrian outcrop there is limited stratigraphic information available due to the lack of natural exposures. A typical stratigraphic succession of the region comprises from oldest to youngest: "...1) sandy boulder till overlying bedrock of Precambrian age, 2) glaciofluvial sand and gravel, 3) Barlow-Ojibway varved clay (Antevs, 1925, 1928), 4) Cochrane Till, and 5) Cochrane sediments, in part varved" (Hughes, 1961). The oldest material, the "sandy boulder till" commonly identified in the study area by Boissonneau (1966) and Hughes (1965) has been named Matheson Till (Hughes, 1959). Deposits stratigraphically below Matheson Till are known primarily from exploratory reverse circulation drilling and limited Rotasonic drill core data from the Timmins area (Skinner, 1972; Bird and Coker, 1987; and assessment files). At most, four glacial episodes have been recorded by four till units (Fig. 6).

Bird and Coker (1987) interpreted four till units based on stratigraphic and dispersal studies at the Owl Creek open pit mine near Timmins. Stratigraphic units comprise from oldest to youngest, two unnamed tills, relatively locally encountered, the regionally extensive Matheson Till, and Cochrane Till and related sediments at the surface. The lowermost till is known only from the pit exposure and from one borehole. This unit is described as a compact silty till (DiLabio et al., 1988). Poorly preserved organic material and/or brown staining was recorded in several boreholes in fluvial or lacustrine sediments overlying this lowermost till (Bird and Coker, 1987). The next oldest till unit has been recorded from numerous boreholes drilled by Kidd Creek Mines in the Timmins area. DiLabio et al. (1988) described this unit as a hard, pebbly, silty, sand till.

Immediately underlying Matheson Till is a nonglacial assemblage of silt, clay, and sand, locally organic-rich, which is known largely from drill records and the single exposure at the Owl Creek Mine. The organic material is predominantly finely disseminated although numerous records of wood at this stratigraphic level are known (Brereton and Elson, 1979; DiLabio, 1982). DiLabio et al. (1988) informally named this succession the Owl Creek beds and they estimate that these beds are erratically preserved over an area of at least 2000 km^2.

Matheson Till, variable in character over the region, is described as a pebbly, silty, sand till (DiLabio et al., 1988), or as containing abundant large boulders and cobbles in a matrix of sand and silt (Hughes, 1965). Locally the till exhibits minor clay or "lenses up to 15 feet thick of silty gravel with poorly defined bedding" (Hughes, 1965). This unit is highly variable in pebble lithology with the amount of Paleozoic components ranging from <1 to 32% (Hughes, 1965, p. 542). It forms a discontinuous mantle over bedrock, as remnants, modified at the surface, against rocky hills or drumlins projecting above the clay plain, or lies beneath sand and varved silt and clay of the Barlow-Ojibway Formation (Hughes, 1965).

Matheson Till is locally overlain by glaciofluvial deposits of sand and gravel, associated with north-trending esker systems. Coarse, stratified glaciofluvial units

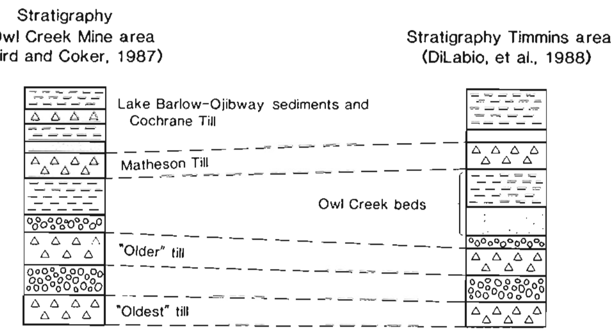

Figure 6. Lithostratigraphy of the Timmins area (from Bird and Coker, 1987; DiLabio et al., 1988).

interfinger with clay to form thick varves at the base of the overlying Barlow-Ojibway Formation (Hughes, 1965). Barlow-Ojibway Formation, as defined by Hughes (1965), is divided into two units of member rank. The lower member comprises varved strata lying directly on the till, as well as thin, massive silt, silty clay, and clay. North of the Hudson Bay-St. Lawrence drainage divide, Barlow-Ojibway varved sediments are divisible into three sequences, informally termed Lower, Frederick House, and Connaught sequences based on the varve series of Antevs (1925, 1928). The Lower sequence is typified by sandy proximal varves up to 33 cm thick which grade upward into thin, clayey varves. The Frederick House sequence contains 2.5 to 5 cm thick, silty clay varves at the base, which grade upwards into clayey varves less than 0.6 cm thick, overlain by silty, sandy clay varves. The uppermost Connaught sequence consists of varves 0.25 cm thick at the base, thickening upward to 10 cm in the middle of the unit, and thinning to 0.25 cm at the top. At the Wilkie Township type locality of the Barlow-Ojibway Formation, the lower member has a total thickness of 12.8 m (Hughes, 1965). Varved sediments of the Barlow-Ojibway Formation form a relatively continuous sheet throughout the Abitibi clay belt at least as far north as Island Falls, Abitibi River (Antevs, 1928).

The upper member of the Barlow-Ojibway Formation is dominated by sand, gravel, and boulders interpreted as near-shore deposits (Hughes, 1965). This unit forms a discontinuous veneer on bedrock or till, locally laps on to the lower varved clay near the margins of the clay plain, and ranges in thickness from several centimetres to 9 m (Hughes, 1965).

Cochrane Formation sediments cover the surface of most of the northern two-thirds of the study area, to the limit of the Cochrane readvance. Hughes (1965) defined the formation as comprising a lower transition zone, Cochrane Till, and Cochrane glaciolacustrine sediments. At the type section, undisturbed silt and clay couplets of the Barlow-Ojibway Formation grade upward into moderately to highly disturbed and contorted varves with irregularly distributed sand and pebbles (the transition zone). Clay till directly overlying the transition zone, grey, unoxidized and massive at the base, is dull red-brown and somewhat fissile at the top. Maximum observed thicknesses of the Cochrane Till are as much as 10 m, although 1.5 to 4 m is more typical. Pebble content is highly variable, ranging from 1 to

20% clasts greater than 2 mm, and lithology consists of 20 to 60% Paleozoic rocks (Hughes, 1965, p. 542).

Above Cochrane Till, light brown silty clay with about 1% pebbles, is interbedded with thin, dark brown clay laminae. Couplet thickness decreases upwards from about 25 to 1.3 cm. Stratification in the Cochrane glaciolacustrine sediments eventually becomes indistinguishable in the soil profile. The total thickness of the Cochrane Formation at the type locality is 7 m (Hughes, 1965).

Eolian, fluviatile, and organic deposits cap the succession. Fluvial silt, sand, and gravel are restricted to narrow valleys of rivers and stream channels. The development of thick organic deposits of impure peat is favoured by the low permeability of the clay plain and poor surface drainage.

Surficial deposits and landforms

The following description is derived largely from Boissonneau (1966) unless otherwise referenced. The surficial sediments of the Cochrane-Hearst area can be divided into broad physiographic classifications. The study area is dominated by gently to moderately rolling clay till plains, bounded to the south and to a lesser degree in the north, by gently undulating lacustrine plains. Outwash deltaic sand plains occur within the southern part of the lacustrine plain. Several unnamed end moraines occur along the southern boundary of the clay till plain.

Like Hughes (1965), Boissonneau described the stratigraphy of the clay till plain as being dominated by slightly gritty silty clay which grades upward from undisturbed clay and silt varves to clay till with no remnants of bedding. Sandy till deposits are associated with "moderately rolling uplands with sand till over bedrock", a physiographic division that is only locally represented in the extreme southwestern corner of the study area (Boissonneau, 1966, p. 561).

Glaciolacustrine deposits of the region consist of varved clay, unsorted silt that lies above the varved deposits, and massive clay which fills shallow depressions in the laminated clay. A number of raised beaches are found on the sides of bedrock topographic highs, and on the flanks of eskers (Boissonneau, 1966, p. 566, Fig. 3).

Eskers are prominent features of the region, many rising to 45 m above the ground surface. In the northern part of the study area, clay till caps or is draped over the eskers. The glaciofluvial deposits are composed of well sorted sand, gravelly sand, and coarse gravel with boulders. The Pinard moraine (Boissonneau, 1966) crosses Pinard and adjacent townships inside the northern limit of the study area. Small moraines occur south of Kapuskasing and Smooth Rock Falls.

Drumlinoid landforms and flutings were mapped broadly by Boissonneau (1966, Fig. 2) and are generalized on the Glacial Map of Canada (Prest et al., 1968). The majority of flutings and drumlinoid forms which occur in the clay plains parallel the direction of ice flow and are made up of ice-moulded lacustrine sediments. Typical drumlinoid landforms average 1.6 km long and 0.5 km wide and may only project 3 m above their surroundings. Narrow, elongate forms are also present in the clay plain, which resembles a fluted till plain on air photographs (Boissonneau, 1966; Hughes, 1956).

A recent compilation of surficial materials and landforms of northern Ontario published by Sado and Carswell (1987) provides additional detail within Boissonneau's (1966) generalized outline of the regional physiographic domains. On Sado and Carswell's map, streamlined landforms are differentiated into crag and tail and drumlinoid features. Within the study area, detailed surficial mapping is available for the Timmins, Pamour, Dana Lake, and Kamiskotia Lake areas at a scale of 1:50 000 (Richard, 1983a, b; Tucker and Richard, 1983; Tucker and Sharpe, 1980).

Quaternary history

Detailed examination of Quaternary exposures in the Hudson Bay Lowland by McDonald (1969) and Skinner (1973) revealed that several glacial episodes had occurred prior to deposition of the nonglacial Missinaibi Formation. The pre-Wisconsin tills were thought by Skinner to have been deposited into proglacial lakes by the fluctuating margin of a southwestward flowing ice sheet. Based on observations made at section 24M on the Missinaibi River, W.W. Shilts (pers. comm., 1989) concluded that the paleocurrent evidence was weak and that the geometry and texture of the sand bodies make the interpretation that they are nonglacial fluvial sediments equally probable. At this altitude, nonglacial fluvial sediments require an ice-free Hudson Bay as compared to higher elevations where the drilling was done.

McDonald (1969) contended that the Missinaibi beds are interglacial rather than interstadial (Terasmae and Hughes, 1960) in rank because of the following: 1) they are overlain and underlain by till, 2) marine strata require that Hudson Bay be at least partly open to allow influx of ocean water, 3) subaerial environments at low altitude with drainage toward the bay demands that both Hudson Bay and Hudson Strait be open, 4) disappearance of glacier ice in Hudson Bay indicates significant diminution of the ice caps and merits interglacial rank, and 5) the pollen record of Terasmae and Hughes (1960) indicates that local vegetation was "similar to that now present in the region". Skinner (1973), building on McDonald's conclusions, added further data in support of an interglacial rank for the Missinaibi Formation: 1) pollen assemblages indicate similar flora and probably similar climates as the present interglacial; 2) apparently the incursion and recession of the Bell Sea was similar to that of the postglacial Tyrrell Sea, which implied isostatic rebound resulting from significant diminution of an ancestral Laurentide Ice Sheet; 3) interglacial streams were incised to elevations the same as, or lower than modern streams; and 4) buried weathering profiles were observed to be comparable to those formed by postglacial weathering.

This major, nonglacial episode is generally attributed to the Sangamonian Stage or to much of oxygen isotope stage 5 from about 130 to 80 ka (Fulton, 1984). However, a narrower definition, based on evidence of temperatures relative to the present, would restrict the Sangamon to stage 5e, or approximately 130 to 120 ka, prior to extensive build up of a moderate ice cover (Andrews et al., 1983; Shilts, 1984). Andrews et al. (1983) argued that the Sangamonian Stage is represented by an interglaciation documented by the various facies of the Missinaibi Formation. They proposed that a glacial event which deposited a "brownish gray till", and a nonglacial event during which the Fawn River gravels were laid down followed the Sangamonian Stage, but preceded the major late glacial formation of the Laurentide Ice Sheet. Their proposal requires that Hudson Bay be ice-free at least once since the last (Sangamon) interglaciation.

A marine silt unit exposed along Abitibi River and overlain by nonglacial fluvial gravels and till has provided amino acid ratios that are relatively younger than those obtained on shells from nearby exposures of Bell Sea sediments (Wyatt, 1989). These sediments may have been deposited during a significant Wisconsinan marine incursion across glacioisostatically depressed terrain. Thorleifson (1989) and Wyatt (1989) concluded that the Abitibi River marine unit is contemporaneous with the Severn River marine unit of the central Hudson Bay Lowland, and represents an interval of climatic amelioration between the times when the Bell and Tyrrell seas existed. If this is the case, then a period of significant ice occupation existed prior to the incursion of the marine waters as recorded at Abitibi River. The possibility also exists that Adam Till exposed above the Abitibi River marine unit, as defined by Skinner (1973), may actually be two (or more) different tills, between which a significant stratigraphic break is not yet recognized. As no finite dates have been obtained on Missinaibi Formation or on younger nonglacial materials, other than Tyrrell Sea sediments, no further evidence is available to bracket the actual time span of these episodes in the James Bay Lowland.

Wisconsinan tills, defined by conventional usage, comprise Adam and Kipling tills, separated by Friday Creek sediments. Limited till fabric measurements, other directional data, and provenance data suggest that both Adam and Kipling tills were probably deposited by southwestward flowing ice (Skinner, 1973). A lacustrine interval, with evidence of southward drainage, was defined by Skinner (1973) in the James Bay Lowland to refer to Friday Creek sediments, bedded silt and sand immediately below Kipling/Cochrane Till, a usage retained by Shilts (1984). If Friday Creek sediments are Middle Wisconsinan, they signify a significant diminution of the ice sheets and relatively high sea levels, and they could correlate with part or all of the Abitibi River-Severn River-Fawn River-Beaver River nonglacial sediments. Alternatively, if they are of Late Wisconsin age, they suggest rapid retreat and readvance of the ice sheets during the time of rapid deterioration of the Laurentide Ice Sheet (Skinner, 1973). In the latter scenario, Friday Creek sediments would represent a northward extension of eskers and glaciolacustrine sediments in the glacial Lake Barlow-Ojibway system (Skinner, 1973; Dredge and Cowan, 1989).

South of the Moose River basin there is evidence for at least four distinct glacial episodes in the stratigraphic record (Bird and Coker, 1987; Steele et al., 1988; DiLabio et al., 1988). Figure 7 illustrates the possible stratigraphic relations between the Hudson and James Bay lowlands and the

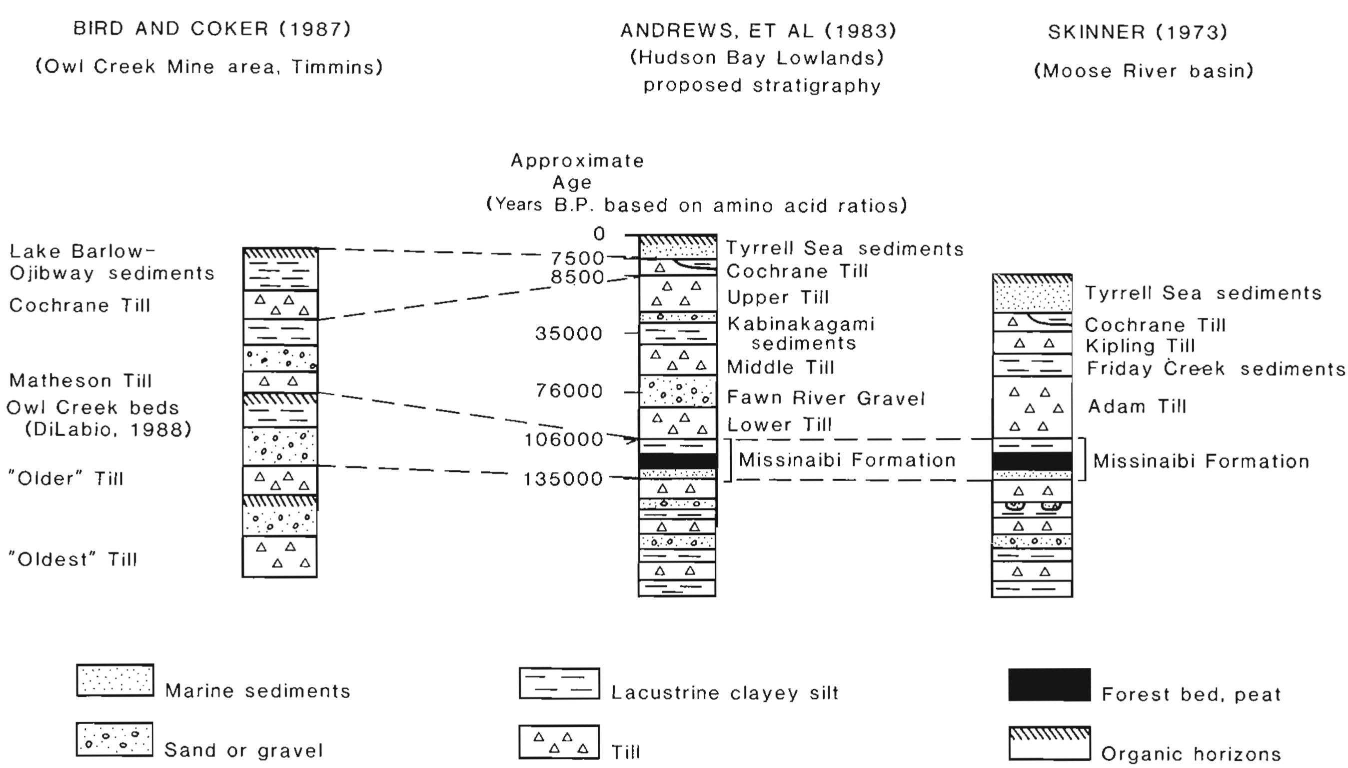

Figure 7. Stratigraphic columns and proposed correlations for the Hudson Bay Lowland, Moose River basin, and Timmins area.

Timmins vicinity. The name Kabinakagami sediments (Andrews et al., 1983) is no longer in use due to its poorly defined type section (W.W. Shilts, pers. comm., 1989), and Shilts (1984) instead referred to Friday Creek sediments in this stratigraphic position.

The oldest till unit in the study area has been correlated tentatively with striations that indicate an early ice advance from the northeast towards 240° ± 10° (Bird and Coker, 1987). Overlying this till is a younger till, also unnamed, which has been correlated with an ice advance towards 150° ± 5° based on a few striations and dispersal data (Bird and Coker, 1987). However, P.W. Alcock (pers. comm., 1989) and Steele et al. (1988) suggest that the flow directions associated with these two units are the reverse, towards 150° in the lowermost till and 240° in the upper unit.

Matheson Till, overlying the two lower units, is typically associated with abundant striation data that suggest deposition from ice moving towards the south (150° to 180°) in a somewhat radiating pattern across the region (Bird and Coker, 1987; Boissonneau, 1966). Veillette (1986) reported that the lower part of Matheson Till in the Abitibi area was deposited by ice first moving towards the southwest that shifted to southerly flow by the top of the unit, based on many observations of crosscutting striae related to the Matheson Till. In the study area, the glacier that deposited Matheson Till retreated northward, ponding glacial Lake Barlow-Ojibway at its front.

The last ice advance for which there is a stratigraphic record, the Cochrane readvance, probably represents late reactivation and surging of the ice front into proglacial Lake Barlow-Ojibway (Fig. 8). The earliest of the multiple "Cochrane" surges which took place around the southern and eastern coast of James Bay, was at about 8.2 ka based on radiocarbon dates coupled with varve chronology (Hardy, 1976, 1977; Hughes, 1965). Multiple lobes of ice moved generally southward to southeastward in a radiate pattern. Rapid retreat of the ice and incursion of the Tyrrell Sea took place after about 8 ka (Dyke and Prest, 1987). The Tyrrell Sea extended into the northwestern corner of the study area at its maximum (Fig. 9).

Acknowledgments

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Dr. G. Palacky and L. Stephens of the Mineral Resources Division of the Geological Survey of Canada coordinated and implemented the airborne and ground resistivity mapping for siting of the boreholes. They provided detailed interpretations of the data in order to assist siting of the boreholes. R. Gagné of Terrain Sciences Division of the Geological Survey of Canada undertook reflection seismic profiles at the Kam-Kotia mine site. Overburden drilling was done under contract by Midwest Drilling of Winnipeg, Manitoba. The Rotasonic Drill was first developed by Hawker-Siddely of Canada, Ltd. and the patent was purchased and adapted by Midwest Drilling. Sample preparation and geochemical analyses were done by Chemex Ltd., Mississauga, Ontario and Vancouver, B.C. Selected samples were prepared by Bondar-Clegg Ltd., Ottawa, Ontario. Heavy mineral separation and identification was provided under contract by Consorminex Ltee., Gatineau, Quebec. Tabling of samples for physical gold separation was done by Overburden Drilling Management Ltd., Nepean, Ontario. Ms. S. Balzer capably identified and counted pebble lithologies for most of the 1987 till samples.

The Sedimentology and Mineral Tracing Laboratory of Terrain Sciences Division, specifically P.J. Higgins, assisted with some sample preparation, Leco carbonate analyses, and monitoring of the contract sample work. Palynological analysis of organic-bearing intervals was done by R.J. Mott of the Geological Survey of Canada. Macrofossils from selected samples were analyzed under contract by R.F. Miller of the New Brunswick Museum. Dr. L. Ovenden identified mosses from the organic samples. Morris Magnetics of Lucan, Ontario, attempted magnetic microfabric analysis of several oriented core samples.

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QUATERNARY SEDIMENTS AND OVERBURDEN DRILLING

Geophysical surveys

Because of the vast, featureless nature of the terrane in the study area, a method that would provide subsurface information on depths to bedrock and the characteristics of the sediments was essential to planning the overburden drilling program. Resistivity mapping was identified as suitable for both reconnaissance and local, detailed surveys.

Airborne and ground resistivity (EM) mapping, monitored and carried out by Geological Survey of Canada geophysicists, was conducted along a number of routes selected for accessibility for the drill equipment. This mapping was initiated to provide both depth to bedrock data with which to select drilling sites, and to quantify and characterize the conductive properties of the glacial sediments to improve interpretation of EM modelling of the overburden (Palacky, 1986; Paterson and Reford, 1986).

Airborne EM surveys capable of differentiating layers with medium to low conductivities (1 to 30 millisiemens per metre) were done under contract to Aerodat Ltd. of Toronto. Approximately 830 line kilometres of helicopter EM surveys were flown in 1985. Two types of anomalies were distinguished using the airborne system: 1) narrow features of high conductivity associated with bedrock conductors; and 2) broad anomalies of medium conductivity due to conductivity changes in the overburden which might indicate thick tills or buried valleys; alternatively, it could

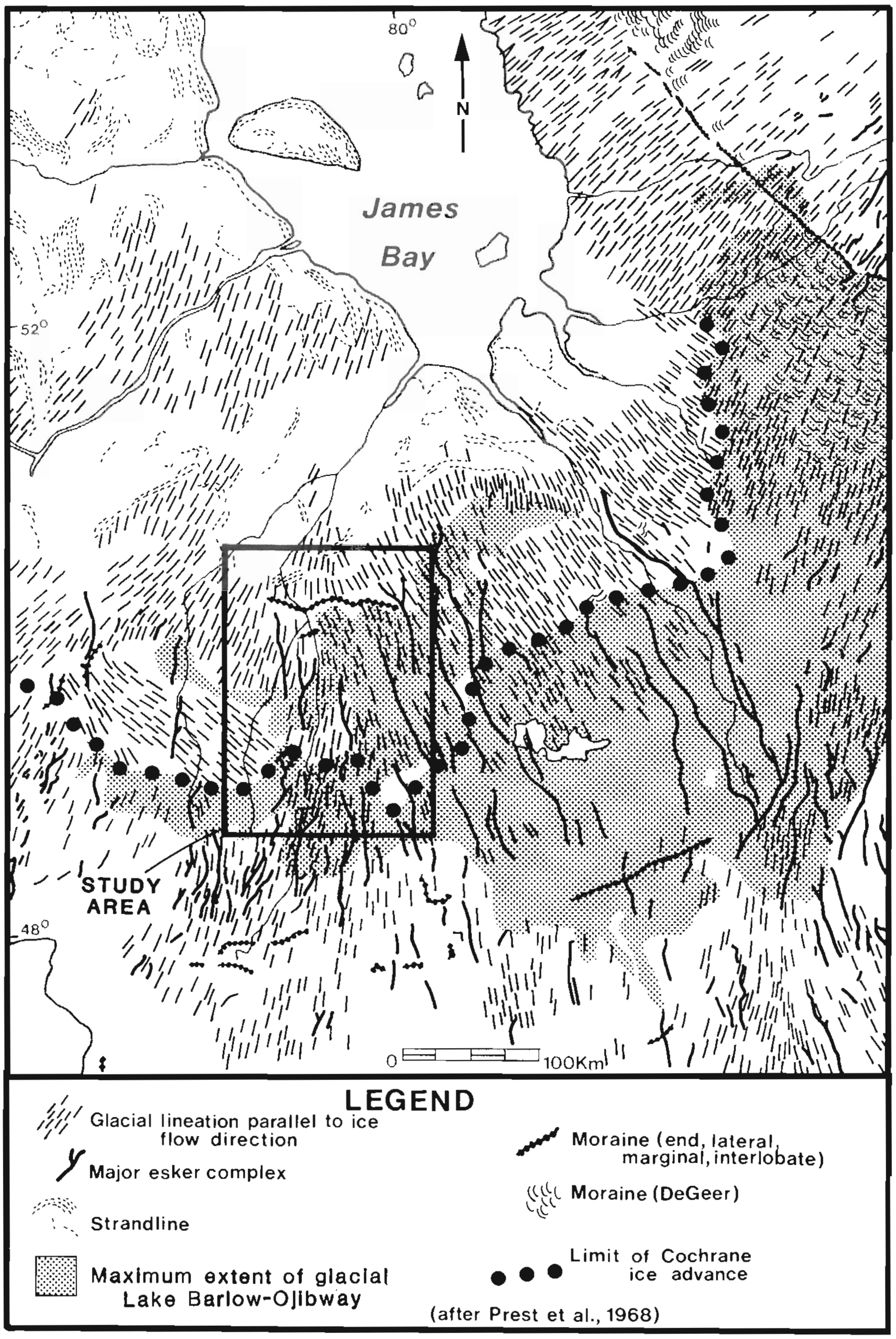


Figure 8. Maximum glacial Lake Barlow-Ojibway coverage and limit of Cochrane readvance in the study area (after Prest et al., 1968).

indicate a cluster of shear zones in the bedrock. The broad type of anomaly was targeted for more detailed ground EM surveys.

During the summers of 1987 and 1988, 136 km of ground electromagnetic measurements were conducted to follow up on anomalies (areas of interpreted thickest overburden) identified along the airborne EM transects. Lines of about 1 km with 100 m coil spacing were surveyed using horizontal coplanar coils with the MaxMin system developed by Apex Parametrics Ltd. of Uxbridge, Ontario. The operating frequencies ranged from 110 to 14 080 Hz. Detailed discussion of the techniques are beyond the scope of this paper and will not be given here. Palacky and

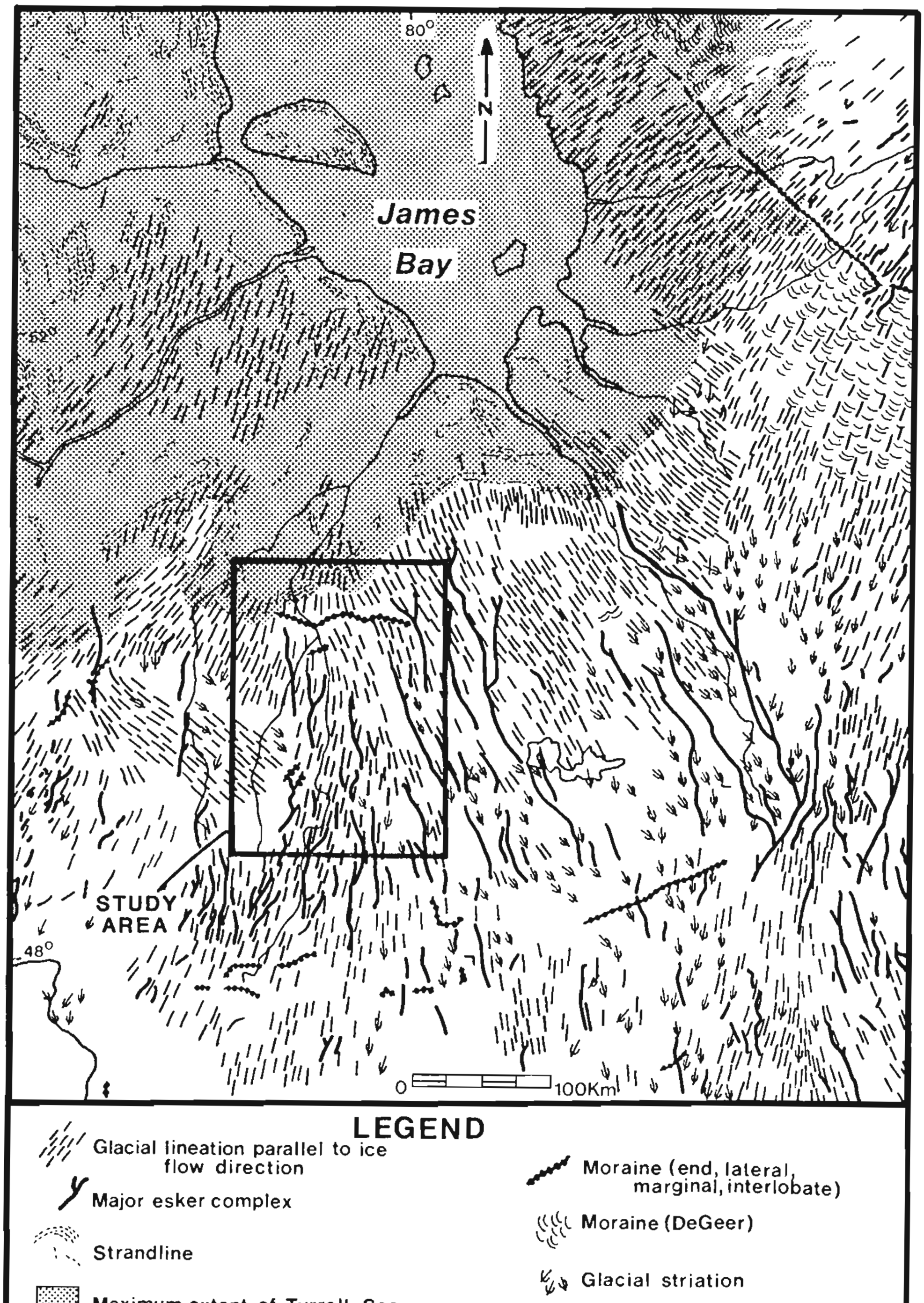


Figure 9. Extent of Tyrrell Sea and nature of surface features in the study area (after Prest et al., 1968).

Stephens (1988) provide a summary of the methodology and data interpretation.

In general, resistivity (or its inverse, conductivity) is suitable for approximating the nature and thickness of the overburden. Clay-rich sediments such as lacustrine deposits have higher conductivities (30 mS/m), tills are intermediate (average 15 mS/m), and sand and gravel have the lowest conductivity (<10 mS/m). If assemblages of different sediment types are present in a given profile, the in-phase and quadrature response is suitable for differentiating the materials based on a two-layer model. The relative amounts of each component present are visually estimated from computer plots. Two-layer mathematical modelling of the EM signal from ground surveys produced an estimate over the line spread of the depths to bedrock and its buried topography that is accurate within a 10% error for the most part, based on comparison of projected with actual depths. This magnitude of error was acceptable within the scope of the drilling as the geophysical information was used only to site the boreholes in areas of deepest fill.

Other signals, such as man-made interference from culverts, power lines, or linear conductors in the bedrock such as faults or mineralized zones, can also be distinguished on the profiles. A few sites were drilled in order to determine the origin of a particular bedrock conductor signal. In these cases, abundant sulphides, mostly pyrite, were concentrated in the bedrock core samples.

At selected sites in the Kamiskotia area where drilling was closely spaced, reflection seismic surveys were run along selected profiles as a comparison with the EM MaxMin measurements. This provided a unique opportunity to calibrate the reflection measurements with known overburden thicknesses and types based on the coring, and to compare the effectiveness of this system with the EM data. In general, it was found that reflection seismic surveys were not so effective in very shallow, sand-dominated sediment sequences in areas of high topographic relief. Reflection seismic surveys were capable of differentiating the lower tills from overlying laminated clay/silt sediments with greater accuracy than was possible with the EM method. The lowermost till (Till II) in these boreholes appeared to be much more compact than the overlying till (Matheson Till) and this interface was also distinguishable by reflection.

The EM surveys over the same lines were able to define the different conductors, sand, silt, clay, and till, although initial computer inversion modelling of the data was subsequently modified based on drilling information. The EM instrumentation was capable of differentiating bedrock conductors from overburden conductors or thick overburden in this area of known mineralization. Both systems were capable of defining overburden sediments given the limitations described above, although seismic surveys are probably more expensive than the MaxMin instrument, which can be operated by a team of two people. The EM MaxMin data, however, require detailed computer interpretation as well as modelling that is operator-dependent. The accuracy of geophysical modelling of any unknown terrain is ultimately dependent upon "ground-truth" provided by drilling.

Overburden drilling

In order to maximize the amount and quality of information for stratigraphic studies, intact, 10 cm diameter cores of sediment to, and including the upper 1 to 2 m of bedrock, were recovered using the Rotasonic (TM) drill operated by Midwest Drilling of Winnipeg, Manitoba (Fig. 10). In comparison with reverse circulation drills that use water to return a slurry sample, the high frequency vibration (up to 4000 RPM) and rotation of the Rotasonic drill produces continuous cores of unconsolidated sediment and bedrock with minimal disturbance or washing of the materials. The large cores provide undeformed sediment columns that allow interpretation of genesis and stratigraphy of sediments, at the same time supplying a large enough sample for analysis of very small concentrations of elements such as gold. Due to the increased cost of this type of drilling, as compared with reverse circulation techniques, it has not been utilized as a reconnaissance tool for mineral exploration, but is more suited to detailed studies.

As all of the drilling steel was measured in feet, this unit of measure will be used in the following description of the drilling process. Sediment is cored using 4 inch diameter (10 cm), thick walled, 10 foot (3 m) long core barrels which are lowered with narrower drill rods. The cutting bits of both the core barrel and the casing are armoured with tungsten-carbide teeth. Boreholes are alternately drilled and cased to the limit of drilling for each "run" of core recovered. The casing prevents down-hole caving of sediments thereby reducing the possibility of contamination. The unconsolidated sediments are cored about 30 feet (9 m, or three core barrels) at a time, or less, depending upon the resistance of the material. They are extruded using vibration and water pressure, into a plastic sleeve, 5 feet (1.5 m) at a time (Fig. 11). The cores are then placed in 5 foot (1.5 m) long, individually labelled, core boxes for transport and storage. For a detailed treatment of the Rotasonic drilling technology the reader is referred to Averill et al. (1986).

Boreholes were sited across the study area based on the following rationale: 1) sites located along transects rather than in a grid provide a regional subsurface profile of the Quaternary succession from north to south; 2) transects were constrained by the availability of road access for the

Figure 10. Rotasonic drill in operation. (GSC 204731-B)

drilling trucks; 3) sites were distributed to give as great a regional coverage along the transects as possible; 4) buried bedrock valleys were targeted preferentially rather than areas of little bedrock relief; and, 5) sites were selected by indications from resistivity mapping that the sediments contained a significant component of till rather than strictly fine grained sediments or sand (Fig. 12). Other factors that entered into the selection of drill sites was the local site access for the drill. It was not always possible to place the drill at the exact spot planned on the EM profile. The option was also available to drill two or more holes on the same profile, if the first showed promise of particularly interesting or complex stratigraphy. In this case, two cores on the same 1 km EM profile, would approximate a section with the possibility of local lateral continuity of stratigraphic units that is lacking in solitary cores. Two sites were selected for multiple cores spaced about 50 m apart.

Bedrock topography is highly irregular beneath the cover of overburden and depths to bedrock range from near zero to 100 m, with no distinguishable surface expression. Relatively steep bedrock valleys were preferentially targeted because of the greater likelihood that a more complete Quaternary sequence with old sediments would be preserved. It was thought to be unlikely that glacial ice would have scoured to the bottom of steep-sided valleys during each ice advance. This rationale was applied to the regional drilling program.

Figure 11. Extrusion of drill core. (GSC 204319)

In the Kamiskotia area near Timmins, concentrated local drilling, well constrained by the abundance of previous information as to depths to bedrock and sediment type (Skinner, 1972), was done as a case study for drift prospecting because of the economic interest in this area (Fig. 13). The intact overburden cores supplied more detailed stratigraphic information than the reverse circulation methods previously applied, as well as large samples for geochemical analysis. Geochemical dispersal from known, outcropping, mineralized sources in the Kamiskotia area, was documented on a local scale and, in conjunction with local erosional ice flow direction indictors, aided identification of till units. Local stratigraphy and ice flow directions were extrapolated to support the regional synthesis and vice-versa.

Core logging and description

Logging of the cores was done at a local core storage facility (a rented garage) using an objective, descriptive code modified after Eyles et al. (1983). In this nongenetic approach to sediment description, "diamicton" refers to poorly sorted materials which generally have a fine grained matrix and greater than 5% clasts (granule to larger size). There is no glacial or nonglacial connotation. The term "till" as used in this paper, refers strictly to those sediments interpreted to have been deposited directly from ice. Because glaciers advanced and retreated while fronting in deep water of proglacial lakes, the sedimentary sequence can exhibit diamictons from >1 m to <1 cm in thickness. These diamictons are poorly sorted glacial debris that entered the lakes as mudflows from glaciers and are virtually indistinguishable from till deposited directly by ice, other than by their regular and intimate interstratification with glaciolacustrine sediments.

Diamictons were described according to field-observable characteristics such as matrix:framework ratio (clast versus matrix supported), matrix texture (approximate percentages of sand, silt, clay), Munsell color, structures (planar, graded bedding, etc.), nature of contacts (sharp, gradational), clast lithologies (visual approximation of carbonate versus local lithologies in order to differentiate tills), and the degree of compaction (approximated by the shape and cohesiveness of the core). Waterlain sediments were described by their texture; gravel, sand, and fine (silt/clay) size fractions; as well as sedimentary structures, if any. The silty clay units in general had well preserved sedimentary structures with minor secondary, drilling-induced deformation and rare organic-rich intervals.

Sediment size nomenclature used in this report approximates the grade scale developed by Wentworth (1922) with some modifications. The size range of granules will be used in this report to refer to the 2 to 5.6 mm range and the upper size limit for clay minerals is considered to be 2 rather than 4 μm. Unless specific reference is being made to laboratory separated and processed size fractions, some terms like sand and silt refer to the dominant component,

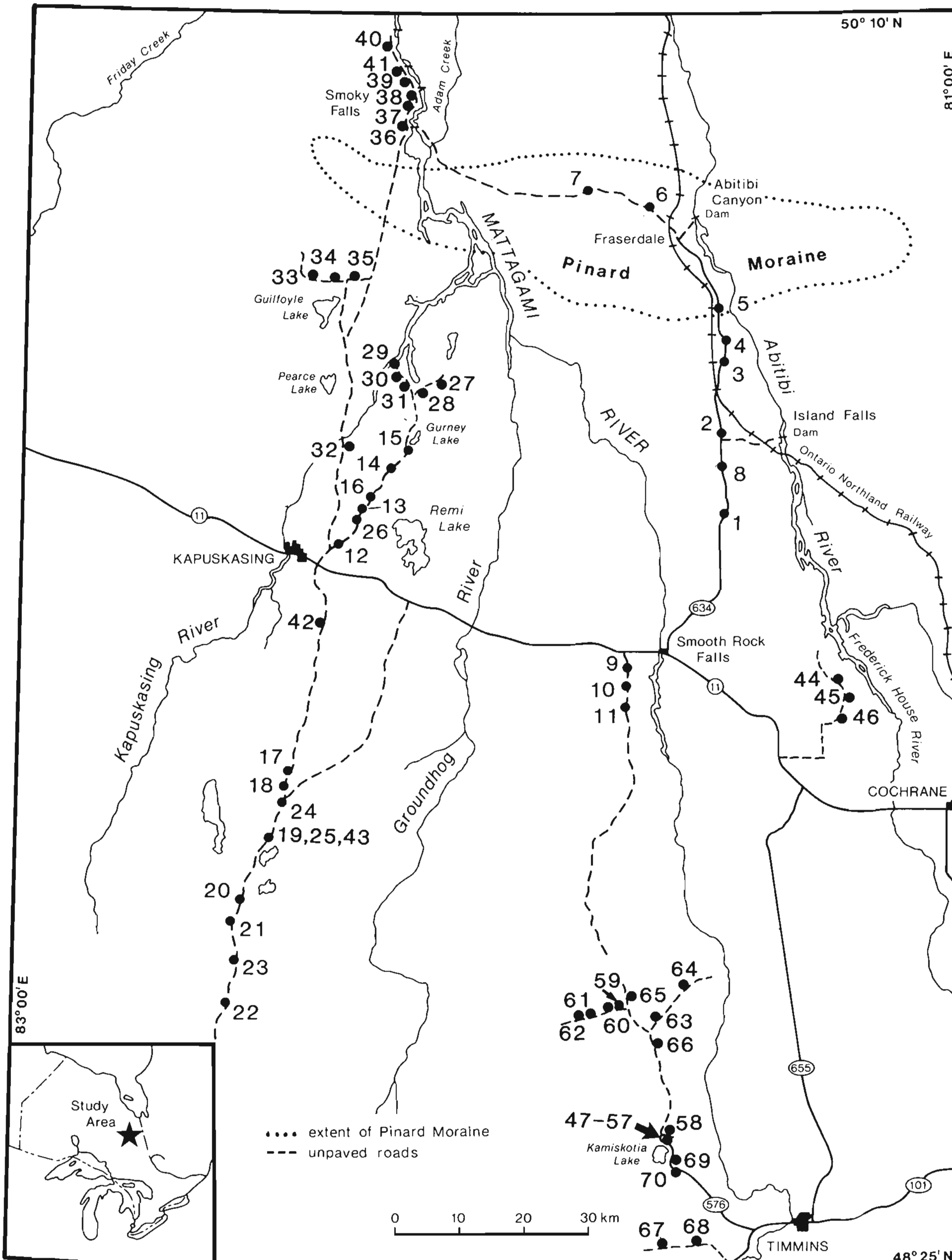


Figure 12. Location map of regional borehole sites.

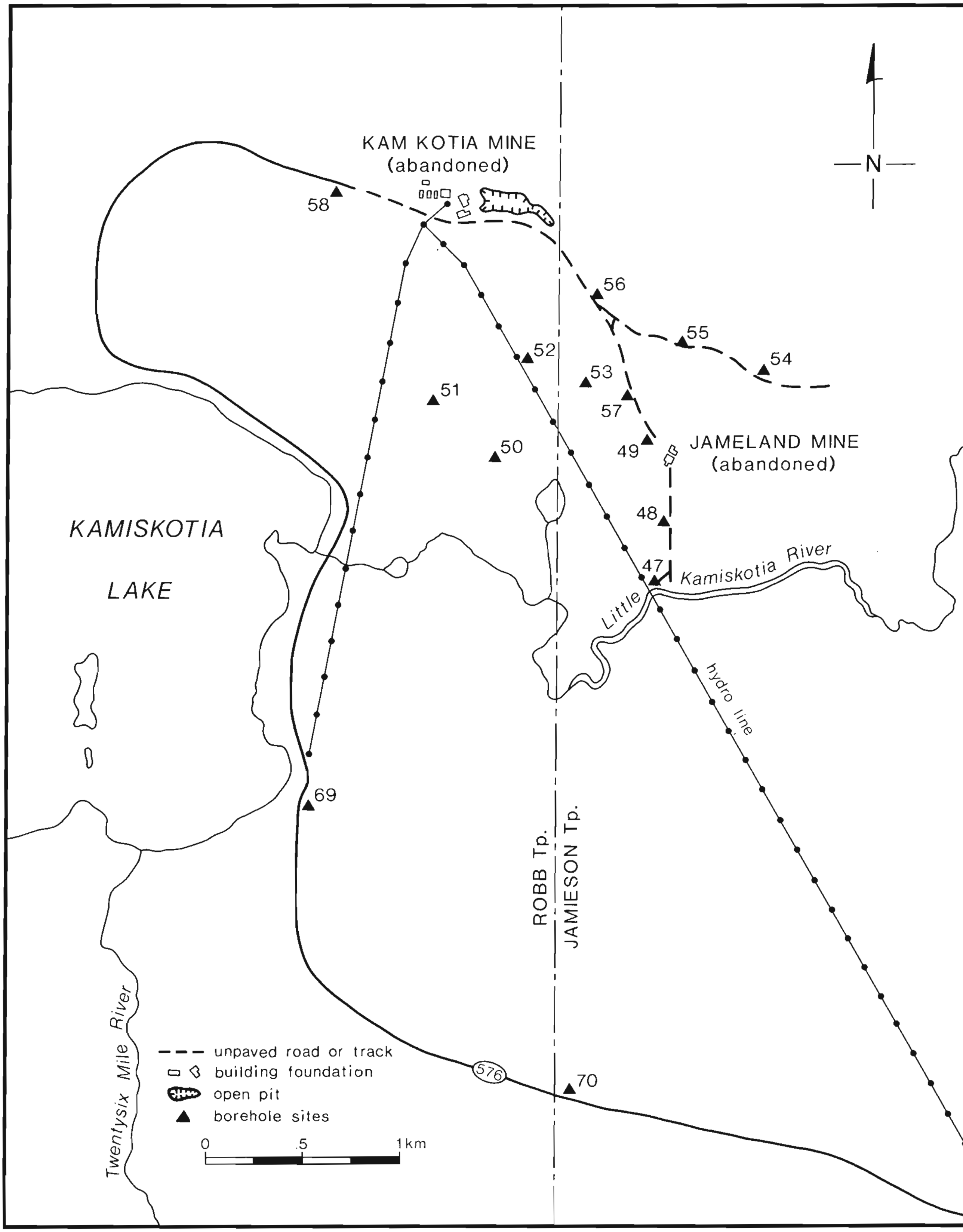


Figure 13. Map of closely spaced borehole sites in the Kamiskotia area.

but may encompass more than the resticted size range definition. The term "sand" was used loosely to refer to a range of fine to medium sand sizes. In a general description of sediment units, some overlap in casual usage will be noted, primarily for the descriptor "clay" which may include a silt component. The larger size range names are more difficult to apply as the core diameter is a limiting factor. However, "boulder" rather than "cobble" was used to refer to a cored rock that comprised over 7 cm of core depth. The term "matrix" in poorly sorted and nonsorted sediments refers to interstitial material of less than 0.25 mm in diameter, and "clast" refers to sediment particles of granule and larger sizes. Coarse and very coarse sand which falls between these categories, is generally not a major component of the diamictons and is considered part of the matrix, but is logged as such for the water-sorted intervals.

Recovery of sediments by the Rotasonic method is generally good. Elongation of cores (i.e. more length of core recovered than actual depth drilled) occurred in some materials, which results from displacement of sediment by the volume of the drilling steel. Diamictons, which tend to be cohesive, i.e. hold a cylindrical shape after extrusion, in the majority of the study area showed complete recovery with minimal elongation of cores. Fine grained lacustrine sequences, which might be susceptible to liquifaction by vibration in other regions (Smith and Rainbird, 1987), contain a sufficient silt component in this area that liquifaction was not a problem. Massive silt and clay was locally subject to elongation by up to 20% of its length due to squeezing. In contrast to fine grained sediments and diamicton, sand and gravel exhibited generally poor recovery because of a lack of a binding matrix which resulted in a tendency for it to fall out of the core barrel upon retrieval and extrusion. Sand- and gravel-dominant cores became square by settling in the core box and were generally saturated by water during extrusion.

Drilling-induced deformation of cores, which can for the most part be differentiated from primary features (Smith and Rainbird, 1987), is manifested in a number of ways: 1) laminar sedimentary structures exhibit down-warping along the edges of the core, 2) fractures or microfaults may be induced to form in cohesive, fine grained material by compressive stress, 3) very cohesive, undersaturated materials, primarily diamictons, can shear off along parting planes, or other planes of weakness, to form "pucks", and 4) only large scale bedding or grading was preserved in the coarse grained, sorted materials, probably due to the vibratory nature of the coring.

A graphic legend which incorporates the bulk of textural information, was developed to illustrate core sediments and structures as in the simplified core logs of this report. Additional information can be found in the accompanying descriptions for each core in the appendix.

Core sampling and analytical methods

Note that the complete geochemical and lithological data set from core samples is published as a document separate from this report as it comprised a very large number of results (Smith, 1990).

Sampling

Samples of various sediment types, averaging up to 2 kg in weight, were collected at regular intervals with spacing modified for detailed sampling at contacts or in intervals of specific interest such as tills (Fig. 14). The average sample spacing is about 2 m in the cores for a total of approximately one thousand samples. Thick, waterlain sequences were sampled at wide intervals, usually every 3 m minimum, compared to units interpreted as tills. Tills were analyzed in detail in order to aid regional correlation of till sheets by composition, to define provenance areas or directions of flow for the regionally defined units, and to decipher incorporation of anomalous materials of economic interest, such as gold or nonferrous sulphides. Core samples were grouped into three categories based on sediment type: 1) diamicton; 2) well sorted, fine grained sediments (predominantly lacustrine); and 3) sorted sand and gravel.

Diamictons were processed to provide clay (<2 µm), silt+clay (<63 µm), heavy mineral (63 to 250 µm, specific gravity >3.3), and pebble (2 to 5.6 mm) fractions for

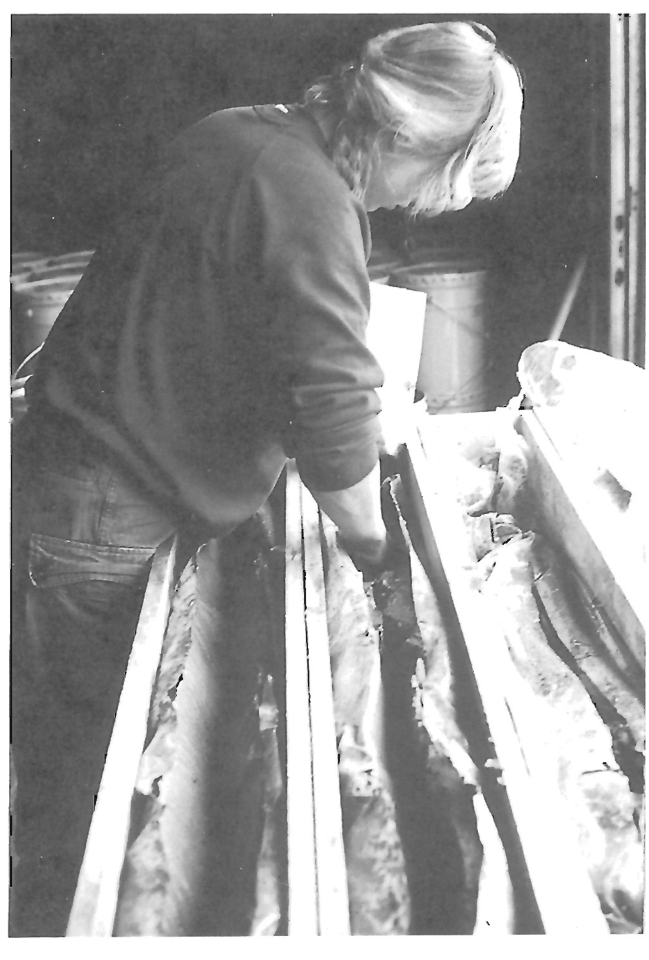


Figure 14. Sampling of drill core. Note the excellent preservation of rhythmites shown in the split core on the left. (GSC 204731-T)

geochemical and lithological analysis. Geochemical analysis comprised a suite of 32 trace elements for each of the clay, silt+clay, and crushed heavy mineral fractions. Selected silt+clay samples were further analyzed for gold, platinum, and palladium. Heavy mineral grain identification was carried out on a subsample of 150 or 300 mounted grains. Pebbles were identified as to rock type and grouped into one of six classes which reflect dominant provenance areas. Leco carbonate and grain size analyses were performed on a selected suite of samples. Approximately 70 samples from economically interesting areas were tabled and panned for gold grains.

Fine grained sediments, predominantly massive to laminated silt and clay with rare granules or pebbles, were processed to separate clay and silt+clay fractions for geochemical analysis. Selected samples were also seived to remove pebbles for identification. Leco carbonate and grain size analyses were completed for a subset of these samples. Sand and gravel samples were collected and archived.

Sample preparation

In all of the following sample preparation descriptions, approximately 1 kg of bulk sample was processed. Most of the sample preparatory work was carried out under contract to Chemex Labs Ltd. of Mississauga, Ontario.

The clay-sized fraction was separated from bulk till samples which had been initially dispersed and agitated in distilled water. After agitation, the suspended material, generally finer than 63 μm, was removed and centrifuged for 3 minutes at 750 rpm in a DPR6000 model centrifuge produced by IEC with a 4-place head and 1000 ml cups. The supernatant, which contained the <2 μm material was decanted and centrifuged again for 14 minutes at 2800 rpm. The 2 to 0.2 μm-size sediment which settled out was removed and dried before geochemical analysis. This procedure has been standardized by the Sedimentology Laboratory of the Geological Survey of Canada. Sediment finer than 63 μm (silt and clay-sized) was recovered from the original sample by dry-sieving through a 250-mesh stainless steel sieve, and was retained for geochemical analysis. The carbonate content of the <63 μm fraction of the 1987 samples was determined using a modified version of the Leco method described by Foscolos and Barefoot (1970).

The wet-sieved, fine to very fine sand-size fraction (63 to 250 μm) was utilized for heavy mineral separation (Dreimanis and Vagners, 1969). The procedure followed, as used in the Sedimentology Laboratory of the Geological Survey of Canada and outlined in Paré (1982), comprised gravity settling in glass separatory funnels with methylene iodide (specific gravity 3.3). Approximately 30 to 50 g of sample (63 to 250 μm) was processed from which the heavy minerals (s.g. >3.3) were retained and the "light" minerals (s.g. <3.3) were archived. The heavy minerals, from which the magnetic fraction was removed, were washed with acetone. Approximately 0.05 g of heavy minerals were separated to be mounted in araldite and used for grain identification counts. The remaining sample was crushed and 0.5 g extracted for geochemical analysis.

The pebble fraction (2 to 5.6 mm) was sieved and washed. A maximum of 20 to 30 g of pebbles per sample, or approximately several hundred pebbles, was separated into vials for subsequent rock type identification. If fewer than 20 g of pebbles were present, as was the case in clast-poor diamictons, the samples were also processed, but the smaller quantity of pebbles was possibly not as representative of the true weight percentages of each of the lithologic classes as in the larger samples.

Geochemical analysis

The sieved portions of the samples were analyzed in a commercial laboratory by inductively coupled plasma (ICP) for a suite of 32 elements on 0.5 g of prepared material of the following: 1) heavy minerals (0.25 to 0.063 mm, s.g. >3.3), crushed to a powder that passes a 250-mesh screen; 2) silt/clay (<0.063 mm); and 3) clay (<0.002 mm) size fractions. Elements determined were: Al, Ag, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, Hg, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ti, Tl, U, V, W, Zn, Pt, Pd, and Au. The hot nitric acid-aqua regia digestion that was used may have only partially digested minerals containing Al, Ba, Be, Ca, Cr, Ga, La, Mg, K, Na, Sr, Tl, Ti, and W. Selected samples were analyzed for gold and platinum group elements in the silt/clay size fraction; a minimum of 20 g of <63 μm material was required for analysis by fire assay/ICP-atomic fluorescence spectroscopy.

Heavy mineral identification

Mineralogical analysis was done in a commercial laboratory on a cone-and-quartered split of the nonmagnetic heavy mineral grains. Approximately 0.05 g of heavy mineral grains were identified using either 150 or 300-grain counts. Till samples collected in 1987 were analyzed using 300-grain heavy mineral counts, following the guidelines given by Gwyn and Dreimanis (1979) on the optimum number of grains to count. For the purposes of this project, it was then decided that 150-grain counts optimized the information, while at the same time minimizing "noise". Furthermore, the 150-grain analyses were less expensive and less time-consuming to perform than 300-grain counts. In both cases, the number of grains of specific minerals was expressed as a percentage so that the databases could be integrated.

The mineral suite identified included the following minerals; hypersthene, bronzite, diopside, garnet, epidote, hematite, goethite, pyrite, siderite, hornblende, rutile, leucoxene, ilmenite, chromite, titanite (sphene), staurolite, kyanite, monazite, zircon, unknowns, and contaminants. Several of these classes were subdivided by shape (rounded, angular, etc.) to further reflect possible source areas. Even though amphiboles and pyroxenes were identified in the pebble counts, their specific gravities straddle that of methylene iodide and so these minerals were not used for comparison purposes.

Pebble lithology counts

Identification of rock types in the pebble fraction (2.0 to 5.6 mm) was done visually using both a binocular microscope and the naked eye. The pebbles were grouped into 6 categories representing major provenance areas and their dominant rock types. These groupings were then weighed and recorded as weight percentages of the total sample.

Provenance categories differentiated were: 1. granitic or crystalline (Archean metamorphic terrane); 2. dark, fine grained argillites or greywackes (Proterozoic with minor Archean greenstone belt contribution); 3. light coloured carbonate (Paleozoic basin); 4. pink or red arkosic sandstone (Devonian Sextant Formation of the Hudson Platform); 5. Lignite and highly rounded, frosted, quartz grains (Mesozoic basin); and 6. wood fragments (Quaternary Missinaibi Formation). The lithologic categories were chosen for the ease of identification of the rock types, and their usefulness in distinguishing source areas, as has been demonstrated by Shilts (1980, 1985), Nielsen and Dredge (1982), and Prest and Nielsen (1987) for example. A more detailed breakdown of rock types failed to yield a greater amount of information because of the small size of the fragments (pegmatitic rocks, for instance, could not be differentiated because their mean grain size is greater than maximum clast size) and difficulty of identifying sources of rock types in an area of minimal bedrock exposure. A detailed breakdown would be more useful in a small-scale study using larger samples of larger clasts.

Occasional misidentification of rock types did not appear to impart a significant error in the weight percents of a given sample and did not alter the trends of lithologic change as recorded through the suite of samples from individual cores. The category with the greatest probability of error is the Proterozoic greywacke/argillite/iron-formation group. Dark grey, black, and greenish, fine grained lithologies could also be derived from fine grained dyke rocks, volcanic rocks, and Archean greenstone belts such as north of Lake Abitibi.

INTERPRETATION OF CORE STRATIGRAPHY AND GEOCHEMISTRY

Description of stratigraphic units

Introduction

The following sedimentary units are described and labelled, from youngest to oldest, based on examination of the cores: postglacial sediments, Cochrane Formation, Barlow-Ojibway Formation, Till I (Matheson Till), intertill I-II sediments, Till II, intertill II-III sediments, Till III, and older till and intertill sediments. For ease of nomenclature, previously defined stratigraphic unit names from the study area have been retained for the purposes of description. However, Matheson and Cochrane tills are probably contemporaneous with Adam and Kipling tills, respectively, at least in the Smoky Falls area.

In contrast to geological convention, the author has reversed the order of discussion of the stratigraphic units, in order to reflect the order of intersection of the different units (i.e. top to bottom) and their relative degree of preservation in coring. It was decided to describe the units in a descending order, from well known and represented units, to the least known or preserved, oldest unit. Young materials are proportionately much better represented in the cores than more sporadically preserved old units and thus correlation is more certain and sedimentological information is more easily extrapolated areally. The upper few stratigraphic units can comprise up to 90% of the sediment pile in many parts of the study area. Till units older than Matheson Till (Till I) that have not been formally named, have been designated as Till II, III, etc. Until they have been formally designated, these old tills will be dealt with in this report, in a "counting-down" manner. Because of the uncertainty of the nature and duration of the Cochrane readvance(s), the Cochrane Till was not assigned a Roman numeral label in order to differentiate it from the lower, more regionally distributed tills.

Correlation, or the similarity in stratigraphic position and age of geological units, is judged using several criteria. The first approximation was obtained by "counting down" units from the top of a core. This was subsequently refined for diamictons interpreted as tills, based on the similarity of compositional data trends from site to site. The nature of contacts, sharp versus gradational, between materials of similar type, such as diamictons, was used to infer a stratigraphic break if corroborated by other evidence such as compositional changes. The nature and thickness of intertill sediments was used to interpret breaks between successive glacial events. For instance, the presence of glaciolacustrine intertill sediment is interpreted as resulting from a significant, but not necessarily complete, withdrawl of the ice to create a proglacial lake in drainage basins that now slope toward Hudson Bay. At the same time, the lake sediments would require Hudson Bay to be blocked by ice so that the laminated sediments themselves do not necessarily indicate interglacial conditions. In other cases, rare oxidized surfaces at the tops of tills buried deeply below the water table represent weathering, perhaps due to subaerial exposure during an interstade or interglacial stage or simply oxidation along permeable horizons.

It must be kept in mind that sedimentary facies tend to repeat themselves with each advance-retreat cycle so that a clay till, a varved sequence, a subaqueous outwash, etc., cannot always be assigned to a specific stratigraphic level, especially if one part of the cycle deposited no sediments. This cyclicity of deposition is important to understand and consider in making interpretations.

Few regionally traceable marker horizons were identified and no tills can be positively identified by any one compositional or textural characteristic. In any case, several generalizations can be made regarding the sediments recovered in the cores; these generalizations can aid in making region-wide correlations.

1) The majority of cores contain some anthropogenically reworked material at the very top (up to 1 m including surface vegetation) as many sites were on the shoulders of roads. In most cases in which "road-fill" approximated a diamicton, the material is locally derived, having been excavated from the adjacent ditches (Cochrane Formation).
2) Many cores contain an interval of uniform, massive clay with rare clasts (granule or pebble-size), which typically overlies a thinner interval of rythmically laminated silt and clay. The laminated sediments are interpreted as Lake Barlow-Ojibway deposits and are locally distorted or convoluted at the interface. This structureless clay attains thicknesses of 28 m in the northern part of the study area and, in combination with the underlying rhythmites, forms an easily recognized regional unit.
3) The total number of differentiable diamicton units, interpreted as tills deposited during one glacial event, is relatively low; a maximum of 4, or rarely 5 were recovered from a total of 70 cored sites in the region. They are not preserved together in any one of the cores. Individual tills are regionally similar except for a shift in the dominant grain size of the matrix material, from very clay-rich in the north, resulting from erosion and comminution of Paleozoic rock fragments, to sandier with a greater volume of pebbles in the southern part of the study area, where coarse, crystalline or hard lithologies of the Shield were eroded. Individual till units were correlated based on gross similarity in geochemistry, lithology, and relative stratigraphic position. Where till units are in direct contact, they are generally differentiable based on lithologies of their clasts.
4) One of the 5 till units usually lies directly on bedrock and typically contains a marked component of clasts derived from the local, underlying rock. In a thick till lying on bedrock, the effect of the local bedrock signature is most pronounced in the lower half metre of the till and may grade up into material exhibiting a more distant provenance as indicated by pebble lithology data. This bottom till is typically overconsolidated.
5) Organic-bearing horizons are represented at several different stratigraphic levels in the cores and are likely the result of repeated reworking of very old material. The identification of organic "marker" horizons was not possible from the drilling, although debris was distributed across the whole region.

Postglacial sediments

Easily identified by their surface position in the cores, postglacial sediments comprise soils, peat or other organic deposits, alluvial and colluvial materials, or laminated lake sediments deposited postglacially. The upper boundary of this material is typically obscured by road-building activities which import foreign or locally-derived fill which may form at least the upper few feet of section in the cores. In the Kamiskotia area, eolian and organic deposits cap the thick glaciofluvial outwash sands that comprise the upper several metres of sediment in these cores. Modern and postglacial sediments exhibit a carbonate-rich geochemical signature derived from Cochrane Formation sediments from which they were reworked.

Cochrane Formation

In the northern part of the study area, a stone-poor clayey diamicton locally caps eskers, the Pinard moraine (Fig. 15), and other glaciofluvial outwash deposits. This discontinuous diamicton has been called Cochrane Till, and is defined as part of the Cochrane Formation (Hughes, 1965). The maximum thickness of this unit is 1 m in section or up to 7 m in cores. In surface sections, it is typically blocky in texture, clast-poor, clay-rich, calcareous, and brownish (Fig. 16).

In most of the cores containing Cochrane Till, it is overlain by thinly-laminated sediments termed Cochrane glaciolacustrine sediments (Hughes, 1965) (cores 44 to 46 for example), which probably represent local ponding at the ice front during retreat of Cochrane ice. The lack of significant thickness of laminated sediment laid down in ephemeral postglacial lakes or subaqueous outwash fans, suggests rapid retreat and diminution of ice after the last ice advance (Boissonneau, 1966). Where diamicton-like Cochrane Till is absent, this stratigraphic break is documented by an abrupt change down-core from a cap of silt/clay rhythmites to massive, slightly stony clay. At least part of the massive clay may constitute a till that had reworked strictly fine grained lacustrine materials. Little evidence of the "transition zone" described by Hughes (1965) of disturbed, layered Barlow-Ojibway sediments immediately below Cochrane Till was observed in the cores, as Cochrane Till was typically underlain by massive clay. Below the massive clay, rhythmites were typically slightly contorted, due either to sediment loading, dewatering, or glacial overridding. Glaciofluvial outwash and esker deposits associated with the Cochrane event are poorly developed.

The limit of Cochrane ice advance is placed 10 km north of Timmins. Cores 61 and 62, in the lee side of a bedrock topographic high, intersected a 15 m thick diamicton which is lithologically similar to the other surface clay tills encountered in the boreholes. This unusual thickness of till probably represents a moraine that marks the limit of readvance in that area, as was previously mapped, but not named, by Boissonneau (1966).

In the cores at Smoky Falls (cores 36 to 41) up to three surface diamictons, interbedded with sand, are correlative

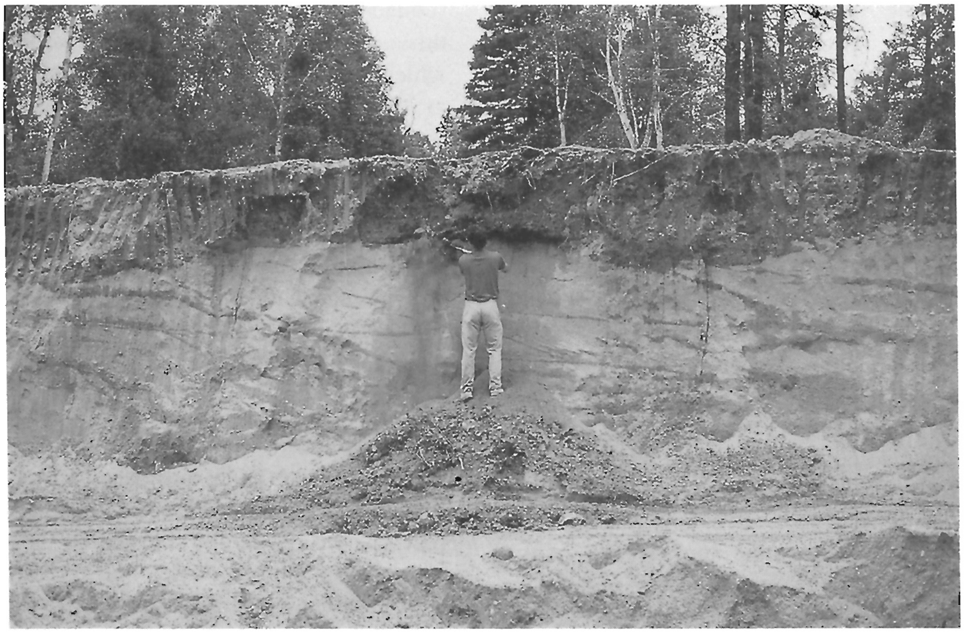


Figure 15. Cochrane Till capping Pinard moraine in fresh exposure northwest of Fraserdale. (GSC 204874)

Figure 16. Characteristic blocky, clast-poor texture of Cochrane Till in the study area, overlying esker deposits south of Kapuskasing. (GSC 204731-L)

based on visual inspection of marked similarity of pebble lithology and other compositional data. They could represent either more than one surge of the "Cochrane" ice front, or more likely, a single till containing lenses of sorted sand.

The average content of clasts >2 mm for Cochrane Till is between 2 to 5% as compared to about 10 to 15% for other till units. Pebble lithologies for this till and within overlying rhythmites, are dominated by carbonates, averaging from 70 to 90% by weight, up to 100%. Deviation from this characteristic carbonate signature is pronounced where the core was collected immediately down-ice from outcrops of crystalline bedrock that produced local influxes of crystalline Shield debris. Boreholes 44 to 46 are in an area near the type section of the Cochrane Formation as described by Hughes (1965) that also exhibits abundant outcrop of granitic rock. Core 44 contains 50% by weight carbonate pebbles in the surface till. In the same till unit in adjacent cores 45 and 46, the carbonate pebble content is only 20% due to erosion of adjacent Archean bedrock and concomitant dilution of the carbonate-rich till.

Multi-element geochemical analyses of various size fractions of Cochrane Till samples also indicates a very strong Paleozoic carbonate signature. Geochemistry of the silt+clay (<63 μm) and clay (<2 μm) size fractions as well as Leco carbonate analysis, all reflect very high levels of calcium carbonate in the matrix of the till. Calcium abundance in the Cochrane Formation seems to be linked as well to an increase of magnesium, potassium, and aluminum. An enhancement in iron concentration may be due either to primary hematite derived from the Moose River basin, or in shallow samples may be a byproduct of postglacial weathering processes. Geochemistry of the heavy mineral fraction similarly indicates a slight increase in the major elements calcium, aluminum, and magnesium, compared to lower till units, which can be attributed to erosion of clay-rich, but heavy mineral-poor, Paleozoic source rocks.

In the northern part of the study area, specifically near Smoky Falls, the clay-rich surface till (Cochrane or Kipling) contains heavy minerals that are unusually enriched in Cu, Zn, Ni, Pb, and As. This enrichment is apparently specific to cores from this region; the average concentrations of these metals is greater even than those in samples from the Kamiskotia mining area. The unusual abundance of these elements can likely be tied directly to provenance in the mineralized Proterozoic rocks to the north and northeast, as no sources of this type are known from Phanerozoic rocks. Cochrane Till samples from other cores do not exhibit such anomalous amounts of metals, although the total number of samples analyzed is low compared to other tills, in part due to the low sand content which resulted in insufficient amounts of heavy minerals in the separates. The weight per cent of the heavy mineral fraction in a bulk Cochrane Till sample is relatively low compared to other tills, due to textural incorporation of heavy mineral-poor glaciolacustrine sediments.

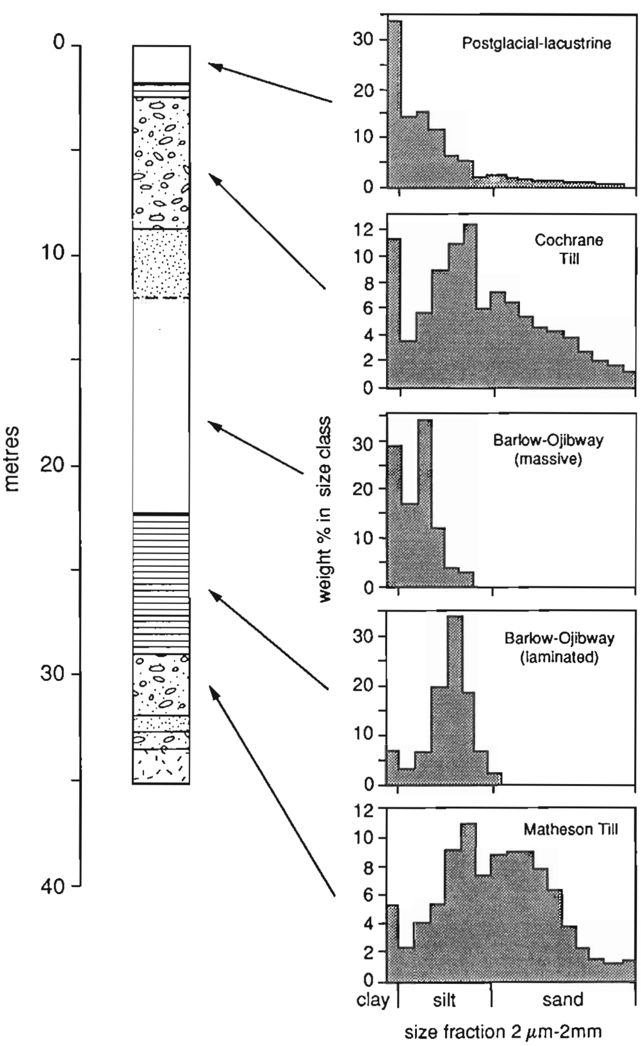


Figure 17. Grain size analyses of selected samples from core 46. Note the fine grained, massive clay of the Barlow-Ojibway Formation.

Grain size analysis of samples from selected cores of tills and lacustrine sediments, indicates that Cochrane Till is very fine grained compared to older till units, probably due to incorporation of silt and clay-rich glaciolacustrine sediments of the Barlow-Ojibway Formation (Fig. 17). Other fine grained tills have been noted lying on Missinaibiage glaciolacustrine sediments in the Moose River basin, indicating that the clay-rich texture is primarily caused by reworking of fine grained glaciolacustrine sediments and is not necessarily a reliable stratigraphic criterion.

Barlow-Ojibway Formation

The Barlow-Ojibway Formation as defined by Hughes (1965) comprises largely "varved" strata locally capped by irregularly distributed nearshore sand and gravel deposits. Hughes (1965) described the underlying glaciofluvial deposits separately from the Barlow-Ojibway Formation lacustrine deposits but they will be described together here because both facies are ubiquitous parts of the regional stratigraphic column.

The varved sediments are described as "a more or less continuous sheet throughout the Clay Belt" (Hughes, 1965, p. 543) but little mention is made of the massive silt or clay that locally overlies the stratified lacustrine sediments. Rotasonic coring has revealed that the massive clay immediately overlying relatively thin deposits of silt and clay rhythmites of Hughes' "lower member" is regionally widespread and very thick (up to 28 m). The apparently structureless clay contains rare or no granules or pebbles at the base, but coarse clast content increases up-core to constitute in some cases just under 1% of the total sediment volume. Little silt is present in this interval indicating that it is a very uniform clay. Grain size analysis has indicated that it is finer grained than both the underlying Barlow-Ojibway Formation rhythmites and Cochrane Till that locally overlies the clay (Fig. 17). The massive clay is locally directly overlain by rhythmites.

Pebbles in samples from the massive clay are very rich in carbonate lithologies, increasing upward to virtually 100 weight % carbonate clasts. It must be remembered that the total quantity of pebbles in this stratum is very low, so the weight percentages of the different lithologies can be biased by just a few pebbles. Nevertheless, the pebble lithology information is corroborated by silt+clay (<63 μm fraction) geochemistry which indicates that calcium increases upward through the fine sediments to a peak at the contact with the Cochrane Formation. Leco carbonate analysis shows that the

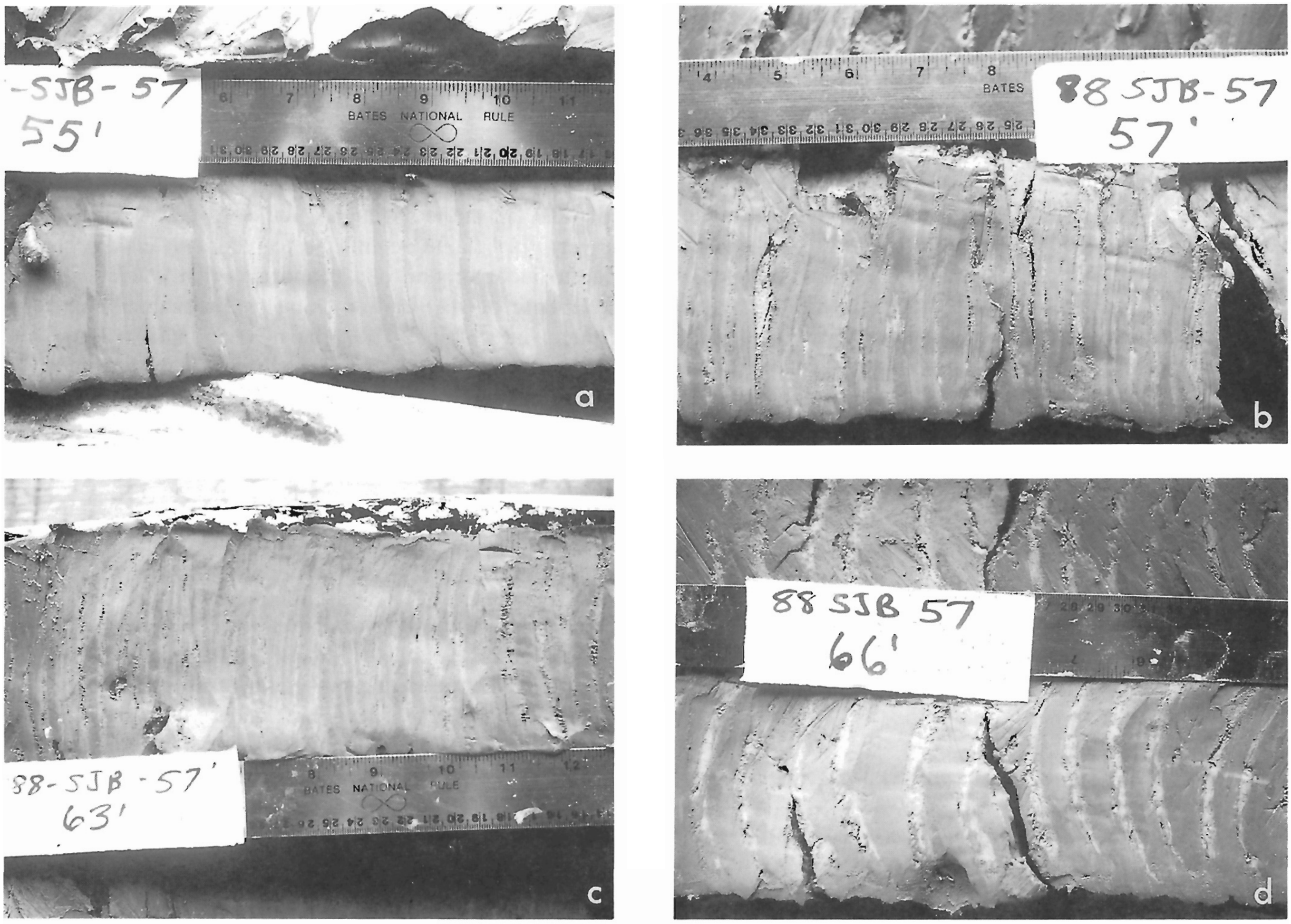


Figure 18. Barlow-Ojibway rhythmites are well preserved in the Kamiskotia cores, borehole 57 is illustrated: a) Detail of 3 cm thick rhythmites in which the lighter coloured, slightly siltier component is actually composed of multiple thin laminae. Note the microfaults due to compressive stress. This sample is from the 55 foot depth. (photo 204731-1H); b) Detail of thinly laminated silt and clay couplets at 57 feet deep. (GSC 204731-F); c) Detail from the 63 foot depth. Note the gradation through thin clay-dominant rhythmites back into thicker, silt-bearing couplets. This interval of thin clay laminae was identified in a number of the cores from the Kamiskotia area. (GSC 204731-1E); d) The bottom of the laminated sequence at about 66 feet depth, displays relatively thick, regular silt/clay couplets. (GSC 204731-1D); e) Rhythmites are discontinuous and disrupted at the lower, gradational contact with fine sand at about 68 feet. (GSC 204731-1B)

equivalent $CaCO_3$ concentrations increase upward as well. The increasing Paleozoic signature is probably due to influence from the southwardly readvancing Cochrane ice front which deposited carbonate-rich sediment in the lake basin, culminating in the Paleozoic-rich Cochrane sediments. No analyses were performed in the coarser fractions of the basal sand and gravel.

Graded couplets of silt and clay are regular and varve-like. In many cases, the rhythmites locally thicken upward reflecting increased sediment supply. Very detailed, fine structures are well preserved in cores from the Kamiskotia area (Fig. 18) and these exhibit little massive clay above them. In general, the laminated fine sediments comprise the smallest part of the Barlow-Ojibway succession cored in this region. Where overlain by massive clay, the rhythmites exhibit some contorted laminae at the interface in many cores, probably due to sediment loading or dewatering.

The third component which, for the purposes of this paper will be considered together with the Barlow-Ojibway Formation is thick, generally structureless sand or gravel that lies below, and locally interfingers with, glaciolacustrine silt and clay of the lower member. Generally fine- to medium-grained sand up to 25 m thick underlies the laminated silt and clay. It is locally graded but does not retain any bedding, unless it has been obscured by the drilling process. The general lack of primary structure could result from relatively rapid deposition. The sand directly overlies Matheson Till in all cores where a till was intersected below this stratigraphic level.

Till I (Matheson Till)

Matheson Till, the most widespread till in the study area, is regionally the most texturally and compositionally variable compared to other till units. Clast content ranges from 5 to 20% with rare clast-supported intervals within a silty to sandy till. It may be very compact and show fissile texture. Parting planes may be further accentuated by the presence of silt wisps or sand lenses along them. Undoubtedly, some of the textural variation may be related to the style of deposition of this till in different regional settings. In core 21 (Fig. 19), the top of Till I is brownish, organic-bearing, and oxidized. At no other site in the coring was an oxidized upper horizon recorded for Matheson Till. As the presence of a "weathered" horizon at 23 m below the surface raises significant questions as to the style of deglaciation immediately prior to the formation of glacial Lake Barlow Ojibway, it is more likely that the stratum in core 21 is oxidized because of groundwater flow along the contact between the Matheson Till and the Barlow-Ojibway Formation.

In the Kamiskotia area, the most southerly part of the study area, Matheson Till is distinctly coarser than it is in the north. It is sandy with abundant crystalline Shield clasts, and loosely consolidated compared to the underlying clay-rich till. The contact is evident as a distinct change in cohesiveness between the two tills. Reverse circulation drilling (Skinner, 1972) failed to distinguish Matheson Till from sandy glaciofluvial sediments at the Kam-Kotia mine site; this is a difficult distinction to make using that type of drilling.

Matheson Till is best identified by its relative stratigraphic position immediately below Barlow-Ojibway sediments. No consistent compositional criterion could be found to correlate Matheson Till from core to core in the study area. It is markedly less rich in Paleozoic-derived materials than Cochrane Till, but all of the lower tills are similarly impoverished in carbonate erratics. In the northern part of the study area, calcium concentrations in the silt+clay fraction are about 8 to 10% compared to 5 to 7% farther south. Where a large component of locally derived bedrock has been incorporated, these averages can be much

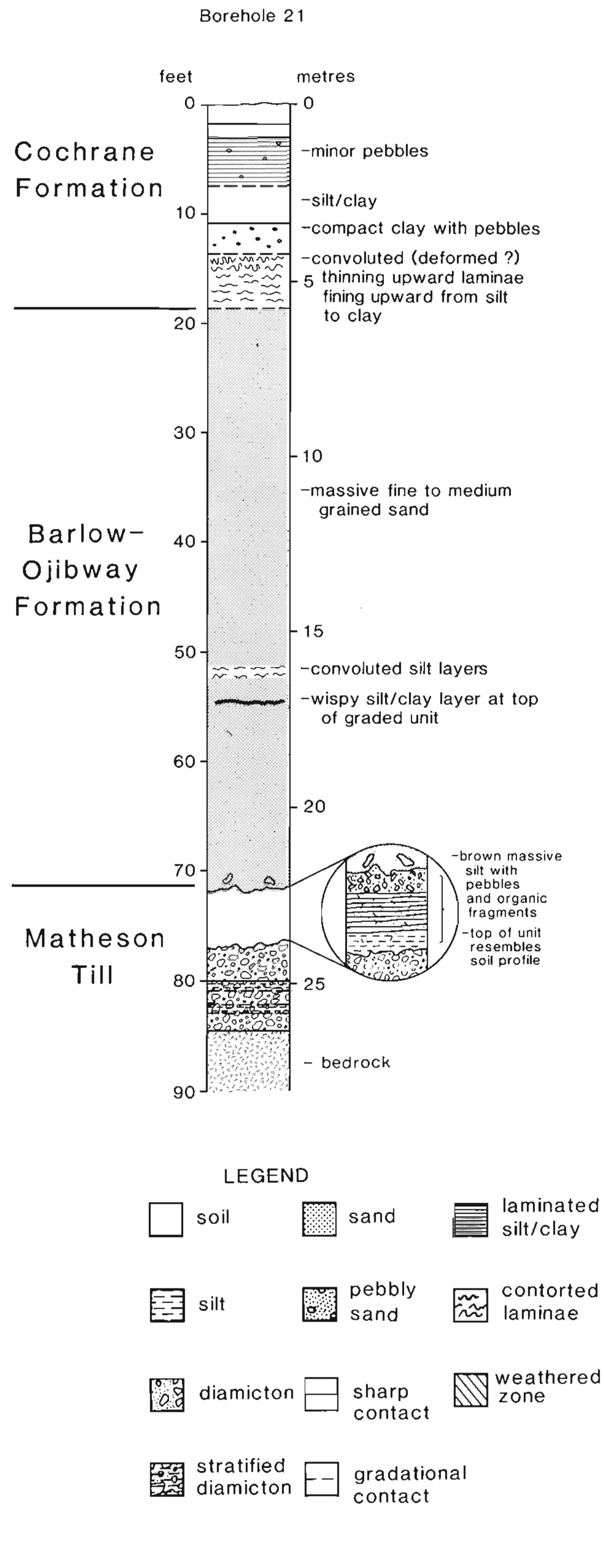


Figure 19. Interpretation of sediments in core 21, with particular reference to the upper oxidized surface of Matheson Till (modified after Smith and Wyatt, 1988).

lower. Pebble lithology data are not as consistent as silt+clay geochemistry but they generally indicate roughly equal concentrations of Paleozoic and Precambrian constituents. Towards the southern limits of the region sampled, Paleozoic erratics are depleted.

Garnet, the most abundant heavy mineral in Matheson Till, tends to decrease upward through many of the cores, although in some cores the pattern is erratic. The farther south that Matheson Till was sampled in the study area, the greater was the concentration of crystalline Archean erratics in the clast fraction.

Intertill sediments (I-II)

Sediments between Till I (Matheson Till) and Till II are only preserved locally. Without tills as marker horizons, it may be difficult to distinguish these waterlain sediments from those of the Barlow-Ojibway Formation.

This complexity can be illustrated by borehole 6, the deepest of this project at 85 m, was completed to bedrock through the Pinard moraine. The upper approximately 17 m of sand and underlying laminated clay, defined by a sedimentologic break with lower sand and clay, could be correlated with the Barlow-Ojibway Formation. The sand and lacustrine material below the Barlow-Ojibway sediments could be correlated tentatively with intertill I-II sediments, which were protected by the steep valley from erosion during the Matheson glaciation.

However, in the absence of Matheson Till as a marker, it is possible that much of this sediment pile in the Pinard Moraine could have been deposited during a stillstand in the retreat of Matheson ice. This deep bedrock depression could have filled with the 50 m of sand as the Matheson ice advanced. Glaciolacustrine sediments at the base of the core were deposited in the lower parts of the depression when the ice front was more distal, but while drainage was blocked.

In this latter, more probable interpretation, a small readvance of the ice could produce the observed thin cap of Cochrane Till. Compared to other buried valleys, it is unusual to find no till at the base of the sequence, but till may be present in other parts of the valley that were not drilled.

Sand units were not sampled for compositional analysis so the only data obtained came from the glaciolacustrine facies. The lowermost glaciolacustrine stratum in borehole 6 (Pinard moraine) contains slightly elevated levels of calcium in the silt/clay fraction compared with the interpreted Barlow-Ojibway laminated stratum at about 17 m depth. This compositional difference could support the separation, within the Pinard moraine, of the two glaciolacustrine sequences into Barlow-Ojibway Formation and intertill I-II respectively. If, alternatively, both sequences are part of the Barlow-Ojibway Formation that was deposited during the retreat of Matheson ice, this difference may be solely provenance-related.

Disseminated, fine grained organic debris was observed sporadically in interval I-II throughout the region.

Till II

Lying either in direct contact with Matheson Till, or separated by intertill sediments, Till II is texturally and compositionally somewhat distinct from the Matheson. Till II has a lower clast content in general, averaging 5 to 10% as compared to 15% in Matheson Till. The matrix tends to be somewhat finer grained in Till II. In addition, parting planes or fissility are present typically and the till can be very compact compared to Matheson Till. However, in some cores, the two till units may be texturally identical. In such cores, they can be differentiated only by a compositional change at the contact. In the north, the contact between the two tills is not marked by textural change, but in the south, Matheson Till exhibits a coarser texture that renders it distinct from Till II which, as in the north, is very compact with a clay and silt-rich matrix. Where studied in detail in the Kamiskotia area, Till II is very compact, locally fissile, and contains about 5% clasts.

Some Kamiskotia area cores exhibit oxidation spots in zones at the top of Till II, suggesting the influence of weathering processes. The oxidation is not pervasive, but tends to occur as local spotting below the contact. If the oxidation is due to weathering, then the break between Matheson and Till II could represent a significant retreat or diminution of the ice sheet. Alternatively, this oxidation could be the result of groundwater moving preferentially along the top of the less permeable Till II.

In the southern part of the study area, compositional differences between Till II and Matheson Till are muted by the diluting influence of increased glacial erosion of crystalline terrane. To the north, Till II exhibits a greater content of Shield components than Matheson Till, manifested in both the higher Archean component in the pebble fraction and by lower calcium percentages in the silt+clay fraction. It is not possible to differentiate this till at Kamiskotia solely by comparing Archean versus Paleozoic compositional indicators.

Intertill sediments (II-III)

As with intertill I-II sediments, this unit is not well represented in the cores. It consists of either massive fine grained, well sorted sand, or rare laminated silt and clay that is locally contorted. This unit is recognized largely by its stratigraphic position below Till II and it often constitutes the only apparent break between the texturally similar tills that lie above and below it. No analyses were performed on this material.

Till III

Till III is the most variable, both texturally and compositionally, among the tills encountered, and was identified in 11 drill cores. It ranges from a sandy to a silty matrix, and is typically, although not always, very pebble- and cobble-rich, containing up to 25% clasts with many cobbles 4 to 6 cm in diameter. In some cores large clasts are in contact, creating local clast-supported zones. Till III is locally fissile or contains sand lenses.

Till III is generally enriched in components derived from underlying or nearby bedrock, which explains its variability. At one site (boreholes 19 and 43), the till is greenish because the matrix is composed almost solely of an underlying green saprolite. In cores 61 and 62 it has oxidation spots and streaks throughout the unit, although concentrated at the top, possibly due to weathering. In all cases, Till III is overconsolidated, having been overridden during at least two later glacial events.

As with the colour and texture, which seem to be locally influenced, composition also reflects random incorporation of locally derived debris, closely linked to adjacent types of bedrock. In the northern part of the study area, Till III is depleted in Paleozoic indicators compared to Till II. This compositional contrast is reflected in both pebble lithologies, which average 30% by weight of carbonates, and by silt+clay geochemistry. Garnet concentrations in heavy mineral counts are also elevated.

Carbonate erratic clasts and a few other foreign pebbles constituted the only means of differentiating this till from underlying saprolitic bedrock in cores 19 and 43. However, at the base of cores 61 and 62, carbonate erratics are anomalously enriched to as much as 60% by weight. Calcium percentages in the silt+clay fraction are slightly elevated but, in contrast, the garnet component of the heavy mineral counts is greater in this unit than in Till II.

Older tills and intertill sediments

Two units interpreted as intertill III-IV and Till IV respectively were identified in only one core. In Godfrey Township, core 67 contained a very complex succession of diamictons. The presence of intertill gravel and a compositional change compared to Till III were used to infer the presence of an older unit, Till IV. Till IV, if a legitimate stratigraphic unit, is rarely preserved, even in the deep buried valleys drilled in other parts of the study area.

Till IV is texturally variable through the core at its one known locality. It is sandy, with about 15% pebbles and cobbles at its base, very fissile and compact with minor silt wisp stratification developed along parting planes, and is a distinctly darker colour than Till III. Till IV has minor oxidation along some parting planes and contains some inclusions of green saprolite above bedrock.

In the single borehole from which it was recovered, Till IV contains fewer Paleozoic carbonate clasts than Till III (less than 20% as compared to about 25 to 30% for Till III). The lower concentration of carbonate clasts is mimicked by markedly reduced calcium content in the silt+clay fraction. The abundance of fine grained volcanogenic lithologies indicates very local derivation from the Kamiskotia bedrock complex to the northeast. Garnet grains are less abundant than epidote in the heavy mineral counts as compared to Till III.

Organic-bearing strata

The Missinaibi Formation in the Moose River basin is recognized as interglacial, and no stratum, other than the sporadically preserved Owl Creek beds (DiLabio et al., 1988), has been correlated with it in the study area. The organic materials in the cores were investigated in detail, through palynology and macrofossil analysis, in the hope that they would reveal if a significant interstadial or interglacial interval is recorded.

Organic-bearing sediments were identified at three stratigraphic levels within several cores (similar to those given by DiLabio, 1982). The organic components comprised generally fine grained detrital material, mostly moss fragments and small twigs, associated with silty lacustrine sediments or, in one case, a weathered horizon. Disseminated organic material was collected from sediments equivalent to, or younger than the Cochrane Formation (core 63 and 55, stratigraphic level I), immediately below, and within the base of laminated silt and clay deposited in glacial Lake Barlow-Ojibway (cores 21, 28, 58, and 61; stratigraphic level II). Organic remains were collected also from intertill sediments I-II (cores 61 and 63, stratigraphic level III). Organic materials from laminated silty sediments exposed in the southern end of the Adam Creek spillway, were grouped tentatively with stratigraphic level II.

Palynological analysis was performed on a suite of organic-bearing samples from the different stratigraphic horizons from the cores (Fig. 20). All of the stratigraphic levels are dominated by *Picea* and *Pinus* pollen, significant amounts of Cyperaceae pollen and *Sphagnum* spores, and lesser amounts of other trees, shrubs, and herbs (R. Mott, pers. comm., 1989). Pollen concentrations are highly variable, with the greatest concentration at the top of Matheson Till in core 21. The assemblages obtained from all of the the samples are similar to those characteristic of both the Missinaibi Formation and Owl Creek beds. Cool, northern boreal forest conditions probably prevailed during growth of the organic material (J. Matthews, pers. comm., 1989). It is impossible to differentiate the stratigraphic horizons, or determine if they are primary, in situ deposits, based solely on the palynology (R. Mott, pers. comm., 1989).

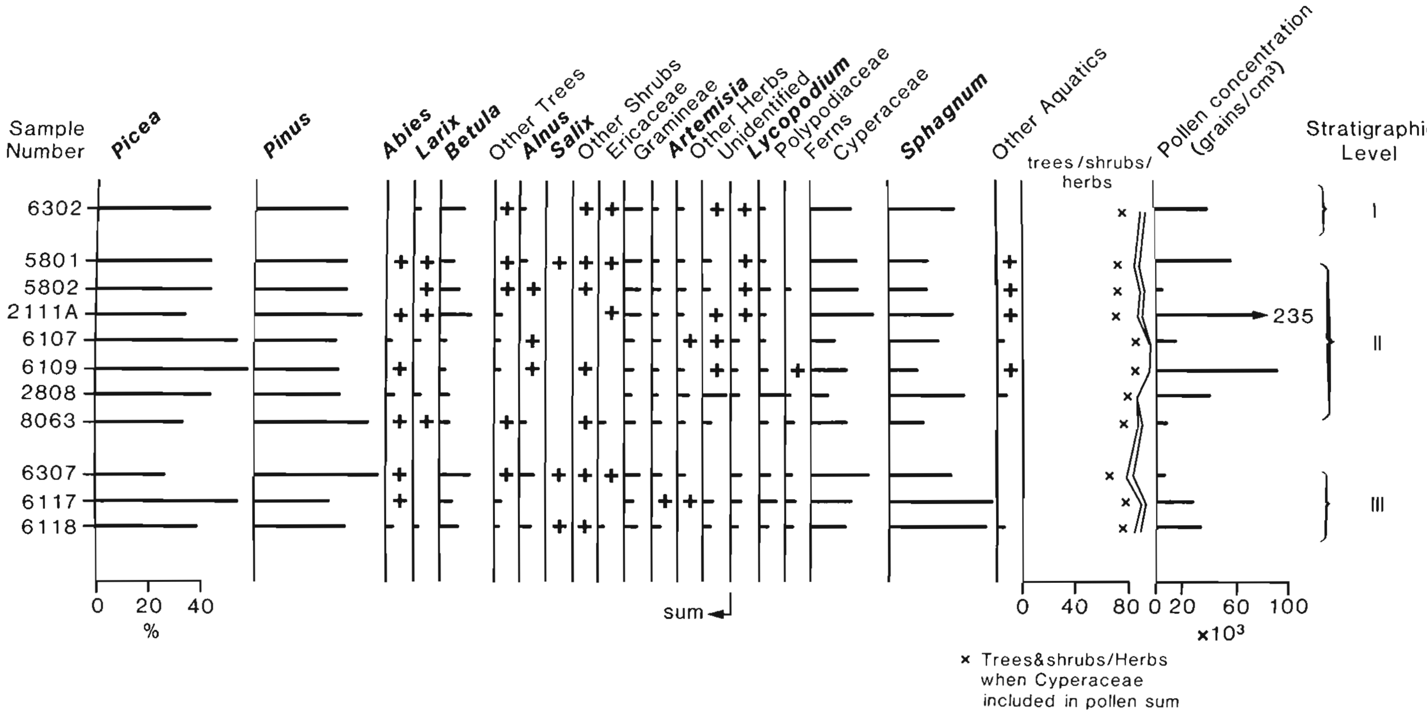


Figure 20. Summary palynology from selected core samples. Stratigraphic level indicators refer to I) the base of the Cochrane Formation, II) the base of the Barlow-Ojibway Formation, and III) intertill I-II sediments (pre-Matheson Till).

A selected suite of samples were analyzed for their moss flora. Most of the samples were relatively low in organic content and none represent in situ deposits or true peats (L. Ovenden, pers. comm., 1989). The moss assemblage, other than in core 28, comprises mosses of peaty wetlands, and would not grow in sites that produce inorganic, sandy deposits such as the sediments that enclose them. Core 28 contains mosses from a more alluvial habitat but they were not sufficiently preserved to make precise identifications. All of the mosses are found in this region at the present time and are documented from pre-Wisconsinan organic material of the Hudson Bay and James Bay lowlands. Therefore, it is impossible to distinguish stratigraphy based on the moss assemblage, or even to conclude that they were in situ rather than reworked (L. Ovenden, pers. comm., 1989).

As with the moss flora, the samples contain very poor assemblages of insect or other macrofossil remains. All species identified have distribution which can be classified as transcontinental-boreal (R. Miller, pers. comm., 1989) (Fig. 21). Given the scarcity of macrofossils and the uniformity of their distribution, they are not useful for defining stratigraphy on that criterion alone.

All radiocarbon dates on Owl Creek sediments have so far been nonfinite, greater than 37 000 years (R.N.W. DiLabio, pers. comm., 1989). No core samples, other than those from core 28, provided enough woody material to date by conventional radiocarbon methods. The woody

Stratigraphic Level	Sample Number	Carabidae	***Carabus* cf. *maeander***	genera undetermined	Staphylinidae	***Acidota* cf. *A. crenata***	cf. ***Eucnecosum***	***Olophrum* spp.**	***Stenus* spp.**	Family ?	cf. ***Agathidium***
I	5501			+			+	+			
	6301			+		+			+		+
II	2110						+		+		
	2111							+	+		
	5802		+								
	6109			+							
	6110							+			
III	6117	no insect fossils									

Figure 21. Taxonomic list of animal and plant macrofossils from selected core samples. Stratigraphic levels refer to I) the base of the Cochrane Formation, II) base of the Barlow-Ojibway Formation, and III) intertill I-II sediments (pre-Matheson Till).

fragments in all of the samples seemed to exhibit varying degrees of humification which may explain the apparent contrasting suites of wood fragments; one in which the twigs are black and brittle, the other in which they look much fresher, similar to modern, slightly weathered wood. In borehole 28 a well developed, 40 cm thick wood-bearing sandy interval was sampled immediately below Barlow-Ojibway laminae. The lower contact is sharp, and it graded upward into the silty laminae, suggesting in situ deposition. Large wood chunks up to 2.5 cm long were sampled and submitted for radiocarbon dating. An inconclusive age of

>39 000 years (GSC-4738) supports the conclusion by R.J. Mott (pers. comm., 1989) that the wood is reworked from the Missinaibi Formation.

In spite of the seeming lack of definitive data from the organic material, the possibility remains that a true organic interval, likely correlative with the Missinaibi Formation, will be found in this area, but was not encountered in the drill cores. R.N.W. DiLabio (pers. comm., 1989) correlates the Owl Creek beds with the Missinaibi Formation. No younger organic stratum was identified in this region. Other workers have discovered organic material at the base of the Barlow-Ojibway sediments in adjacent areas but an infinite date of >39 000 years (GSC-4718) supports the conclusion of reworking of old material (J. Veillette, pers. comm., 1989)

Regional stratigraphic profiles

Core logs were compiled to form two major, north-south oriented, regional cross-sections representing subsurface stratigraphy. The summary lithostratigraphic diagram represents an estimate of the distribution of the sedimentary units along the drilling transects (Fig. 22, in pocket). The accompanying interpretation (Fig. 23, in pocket) is compiled from the lithostratigraphic and compositional information. Interpolations of subsurface geology between the boreholes have been made for illustrative purposes, but where available, the EM records were used to provide information to bridge those gaps. In this section, the sediment succession will be described from top to bottom because the topmost units are the best preserved of the stratigraphic sequence and make up the greatest proportion of the cores.

Cochrane Formation

The uppermost sediments below the veneer of postglacial materials, the Cochrane and Barlow-Ojibway formations, together comprise the greatest proportion of the sediment pile. Cochrane glaciolacustrine sediments are locally preserved at the tops of the cores and were interpreted to reflect rhythmic deposition of silt and clay in local ephemeral lakes at the rapidly retreating margin of Cochrane ice (Hughes, 1965; Boissonneau, 1966). However, it is difficult to envisage how small, short-lived lakes would form in the Hudson Bay drainage basin during glacial retreat without draining the Bay of ice.

Cochrane Till itself reflects incorporation of the persistant bed of fine grained glaciolacustrine sediment that underlies it. It generally has less than 2% material coarser than fine sand. Cochrane Till is only sporadically intersected in the cores, or if it had few larger clasts, was not distinguishable from the underlying massive clay that has been grouped with the Barlow-Ojibway Formation. All Cochrane sediments, and postglacial materials derived from them, are extremely carbonate-rich, based on pebble lithology, silt+clay geochemistry, and on carbonate data determined for the silt+clay fraction.

Barlow-Ojibway Formation

The Barlow-Ojibway Formation, which, for the purposes of this discussion includes the underlying sand and gravel, is up to 40 m thick in parts of the region, being typically thinner southward through the study area. It comprises, from bottom to top, thickly bedded, sorted, fine sand to gravel, graded couplets of silt and clay, and structureless, very well sorted silty clay with rare pebbles or granules. The laminated sediments (varves) comprise the smallest overall proportion of material in the Barlow-Ojibway succession, but where encountered, consist of well-preserved graded couplets up to several centimetres thick. At the top of the varves, up to 10 cm of laminated silt and clay display varying degrees of deformation or contortion at the contact with the overlying massive clay.

The massive clay is possibly related to deep basin deposition of abundant, very fine, clay-sized material ultimately derived from erosion of sources in the Moose River basin to the north. Stratification is not visible to the naked eye in this uniform, fine grained material. Barlow-Ojibway sediments generally exhibit an upward trend of increasing concentration of material derived from Paleozoic carbonate terrain by the advancing Cochrane glacier. The possibility remains that lacustrine sediments, perhaps laminated, were churned up by the advancing Cochrane ice front forming the structureless fine grained material and, in this case, could be grouped with Cochrane Till, as they seem to have a local gradational contact. However, this does not satisfactorily explain the extreme thickness of this facies encountered in the northern part of the study area, or why the rhythmite-massive clay contact is so sharp, albeit somewhat convoluted.

The northernmost limit of the thickest part of the Barlow-Ojibway Formation lies along the Pinard moraine. Two cores, only one of them completed to bedrock (borehole 6, see Appendix) through the moraine, failed to reveal coarse, poorly sorted morainic sediments. The upper part of the core consisted predominantly of delicately bedded fine sand and silt, with minor coarser sand beds. This sequence overlies lake sediments consisting of massive clay at the base, coarsening upwards into silt/clay rhythmites. The whole sequence resembles a coarsening-upward deltaic assemblage deposited where the sediment supply was great, such as would be formed close to an ice margin.

Matheson Till

The Barlow-Ojibway Formation is underlain by at least one till in most of the cores from which it was recovered. In the northern part of the study area, none of the diamictons interpreted as till are easily distinguishable on the basis of their texture or pebble lithology content. All tills have a silt-clay matrix, possibly reflecting incorporation of easily erodable Paleozoic debris which is readily comminuted to fine sizes. Tills have between 5 and 15% clasts on average and are matrix-supported. Because of the lack of meaningful or useful textural contrasts, tills are differentiated and correlated regionally by comparing geochemical trends, lithological trends, and relative stratigraphic position. No single, regionally consistent criterion can be used to identify any of the four lowermost till units.

The first till encountered below the Barlow-Ojibway Formation sediments, Matheson Till (Till I), is regionally preserved and mappable although it is variable in texture and composition. It has a clay-rich matrix in the north and a sandy matrix in the southern part of the study area, due to increasing concentration of coarsely crystalline Precambrian Shield debris with distance down-ice from the Paleozoic lowlands. This southward shift in texture is accompanied by decreasing concentrations of Paleozoic carbonate erratics and by decreasing calcium and carbonate contents. Matheson Till, in contrast to older and younger tills, is the only till unit to display such a drastic textural and compositional change across the region. Matheson Till has limited direct contact with bedrock as it typically is underlain by older till and intertill sediments.

Pre-Matheson sediments

Older tills are rarely preserved and, because of that, are somewhat difficult to correlate. They were compared and identified on the basis of similarity of compositional trends, texture, and, to a large extent, relative stratigraphic position. Tills preserved below Matheson Till are more likely to display compositional signatures related to nearby bedrock than is the Matheson. Intertill sediments below Matheson Till are correlated almost solely on stratigraphic position relative to the till units. Intertill materials intersected in the cores are predominantly sand, or silty lacustrine deposits, which locally bear organic debris.

Till and intertill materials older than Matheson Till, are best preserved in bedrock depressions, particularly in steep-sided paleovalleys. Just south of the Pinard moraine, a hump of till that comprises Matheson Till and Till II marks the boundary between the fine grained lake sediments to the south and the ice-contact deposit (Pinard moraine) to the north. Perhaps there is a positive bedrock feature, undetected by the EM surveys, up-ice, to account for this unusual, positive accumulation.

Organic debris, encountered at three stratigraphic levels within the cores, revealed no distinctive features that could be useful for correlation. The presence of disseminated organic material is probably due to reworking of older materials such as the Missinaibi Formation. No evidence for in situ deposition of organics was confirmed in any of the cores.

Local stratigraphic profiles

Kamiskotia area

A total of 14 boreholes were drilled in the former Kam-Kotia/Jameland mine area down-ice from the outcropping orebody at Kam-Kotia. Skinner (1972) drilled approximately 90 reverse circulation drill holes in this same area and the logs of Skinner's holes were used as a guide to planning the Rotasonic drilling. The original work indicated both a multiple-till stratigraphy and enough evidence of dispersal from the orebody to warrant detailed follow-up drilling. It was hoped that an investigation of dispersal from a known source, using the detailed stratigraphy derived from continuous cores, would confirm regional trends in ice flow direction deduced from the study of more widely spaced cores.

Reverse circulation drilling records (Skinner, 1972) were scanned and areas with evidence of multiple tills at depth were selected for Rotasonic drilling. Sites were further constrained by access for the drilling trucks. Geophysical profiles, both seismic reflection and EM, were run along a number of available roads to pinpoint areas of deepest fill, as no trace remained of the locations of the original drilling sites. Figures 24 and 25 compare the results of the two techniques in the vicinity of borehole 57. The initial EM data have been modified subsequent to drilling to model the bedrock contour, and to approximate conductivity values for the different materials. The seismic survey readily distinguished between the different sediment types and their interfaces, wheras the EM signal produced an average over the whole overburden column which then had to be interpreted by using a multilayer computer model. Subsurface stratigraphy corroborated the geophysical profiles.

As a result of the Rotasonic drilling, both the subsurface data as originally interpreted by Skinner and the detailed Rotasonic logs were integrated to compile a number of cross-sections, oriented to maximize the amount of information available (Fig. 26). The bedrock topography as indicated by the drilling and geophysical data is very irregular with a deep, buried valley oriented southwest-northeast immediately down-ice from the Kam-Kotia orebody outcrop. This is also illustrated in a cross-section in Shilts (1976, Fig. 5).

Overburden stratigraphy consists of two, or rarely three, diamicton units, interpreted as tills, below glaciolacustrine sand, finely laminated silt and clay, and glaciofluvial outwash deposits which cap the succession. The tills are differentiable based on texture, composition, and weathering. The uppermost till, Matheson Till, is sandy, loosely consolidated, and is the most widespread. It is unoxidized in the boreholes. The next oldest till in the sequence, Till II, is more silt and clay-rich, and is highly compacted or overconsolidated. The contact between Matheson Till and Till II is marked by a distinct change in compaction and cohesiveness, and in two of the cores, well sorted sand is present between the two units. Till II retained a cylindrical shape after extrusion whereas Matheson Till is not cohesive enough to produce an intact core. The top of Till II, in most but not all cores, is stained brown by oxidized pyrite which suggests alteration either by weathering processes or from groundwater. This surface oxidized layer may have been eroded from the top of this till in cores where no colour break was apparent. The lowermost till, Till III, is preserved in only two of the fourteen boreholes. It is preserved below a distinct contact marked by a concentration of cobbles. It has a clayey texture and is fissile. It is very enriched in local rock types.

Pebble lithology data (particularly the ratio of Paleozoic to Precambrian erratics) are not very useful in differentiat-

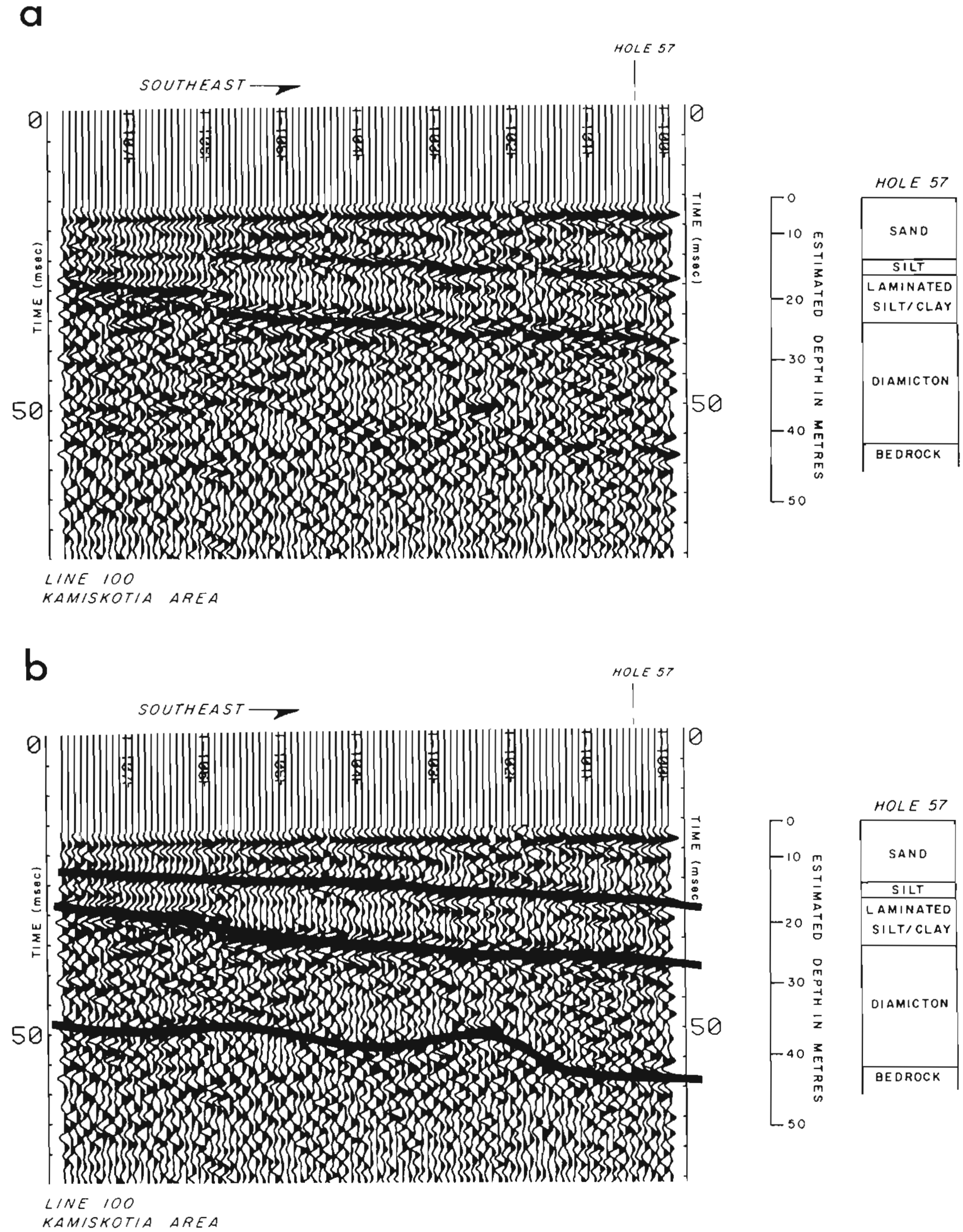


Figure 24. a) Seismic reflection subsurface profile at Kamiskotia. b) Subsurface interpretation is supported by borehole data; Refer to Figure 13 for borehole location.

ing the till units in the Kamiskotia area, although some generalizations can be made: 1) all three tills are rich in crystalline erratics, but the till unit lying directly on bedrock contains a significant component of locally derived, metavolcanic rock, at least in the lower 30 cm of the core; 2) Matheson Till contains 20% Paleozoic carbonate erratics on average, which in several cores increased to 30 to 35% Paleozoic erratics at the top; 3) Till II typically ranged from 0 to 10% carbonate pebbles at its base to 25 to 30% at the top and had slightly lower carbonate concentration in the 2 to 5.6 mm fraction than Matheson Till in general.

It was not possible to distinguish a loose, sandy till from pebbly sand using reverse circulation drilling because of the loss of fines in the water slurry. It seems probable that the majority of what was initially plotted by Skinner (1972) as sand below the lacustrine sequence is sandy till. Interpretation of dispersal of metals from the bedrock source was hampered in the 1970s by the design of the reverse circulation drill, which resulted in contamination of the samples with metal particles from the drill (Proudfoot et al., 1975). Rotasonic drilling is clearly the more effective method to recover and therefore recognize, the sandy tills typical in

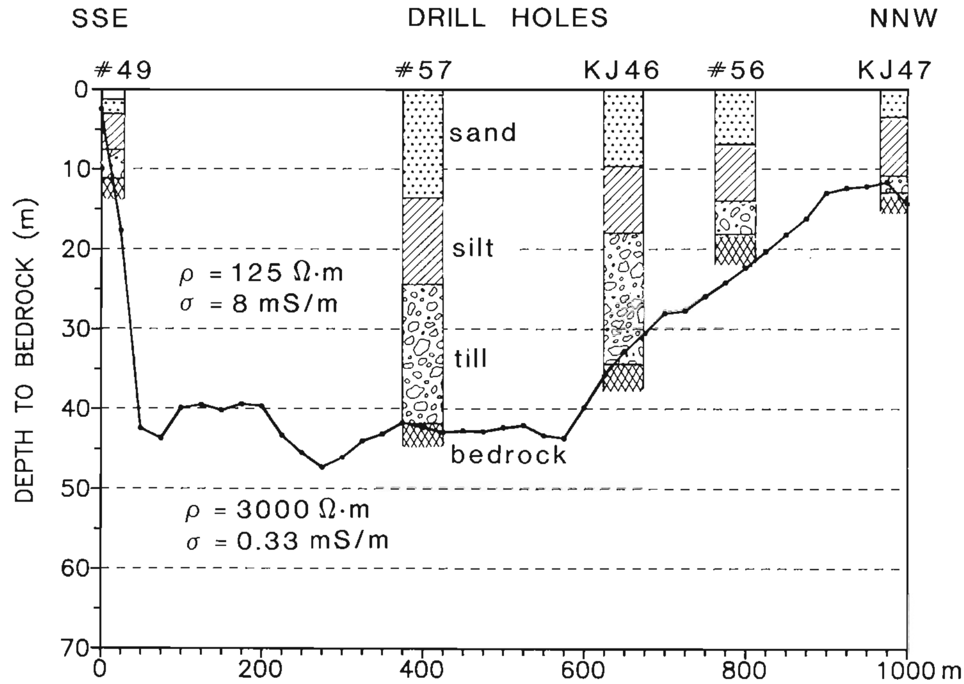


Figure 25. EM resistivity profile along a transect at Kamiskotia superimposed by drillcore data. Note the resolution of depths to bedrock but the lack of definition of the sediment contacts, as compared to the seismic reflection profile of Figure 24. (P=resistivity, σ=conductivity) Refer to Figure 24b) for location of profile.

this area. Rotasonic drilling should be used to verify and amplify reverse circulation drilling data, particularly in areas of loose sandy tills such as near Kamiskotia.

Smoky Falls-Adam Creek

Six boreholes (numbered 36-41 inclusive) were drilled along an access road west of the Mattagami River (Fig. 12) in order to compare stratigraphy from the cores with that from known natural exposures in the adjacent Moose River basin. The cores were relatively closely spaced and form a cross-section approximately parallel to several kilometres of continuous exposure in the southern end of Adam Creek. All were cored over crystalline bedrock, including core 41 which intersected a pocket of Mesozoic kaolin in a depression in the Precambrian rock.

These cores revealed a complex stratigraphy of diamictons interbedded with thin sand or silt beds. All of the diamictons interpreted as tills have a clay-rich, cohesive matrix, and cannot be differentiated by texture alone. The upper tills exhibit identical vertical compositional trends, distinct from the lower tills, and were therefore grouped together, as the same unit, with the sand interpreted as local inclusions, suggesting that the ice was reworking sandy fluvial material laid down prior to readvance. It is often unclear whether or not the sand layers are continuous, or were merely incorporated as "clasts" of sorted material.

Skinner (1973) recognized two post-Missinaibi tills, the Kipling and Adam in the region north of the Pinard moraine. Following Skinner's terminology from the Moose River basin, the two uppermost till units cored at Smoky Falls are considered to be Kipling Till and Adam Till. From the coring and subsequent development of regional stratigraphic profiles, Kipling and Adam tills, at least in the area immediately north of Smoky Falls, seem to occupy the same relative stratigraphic positions as Cochrane and Matheson tills, respectively to the south. They are also similar in texture and in geochemical and lithological composition. For continuity, Moose River basin nomenclature will be used for the stratigraphy of the cores at Smoky Falls. Skinner (1973) identified the upper till unit at Adam Creek as Kipling till, separated by Friday Creek glaciolacustrine sediments from the Adam Till, the type section of which is farther north on Adam Creek. On Adam Creek these three stratigraphic units are exposed continuously for over 30 km from the Harmon Lake spillway to the junction of Adam Creek and the Mattagami River.

Kipling Till in the cores is relatively carbonate-rich, as indicated by pebble lithologies and silt+clay geochemistry, and is locally enriched in manganese in the sand-size heavy mineral fraction. These compositional parameters suggest Paleozoic provenance even where Kipling Till lies on the Precambrian bedrock that outcrops south of Moose River basin. Local anomalous concentrations of As, Cu, Zn, Pb, and Cr in the heavy mineral fraction, are possibly associated with material distally derived from the eastern side of Hudson Bay since the local Paleozoic and Mesozoic rocks contribute few heavy minerals other than pyrite and manganiferous siderite. An upper till unit cored over Mesozoic

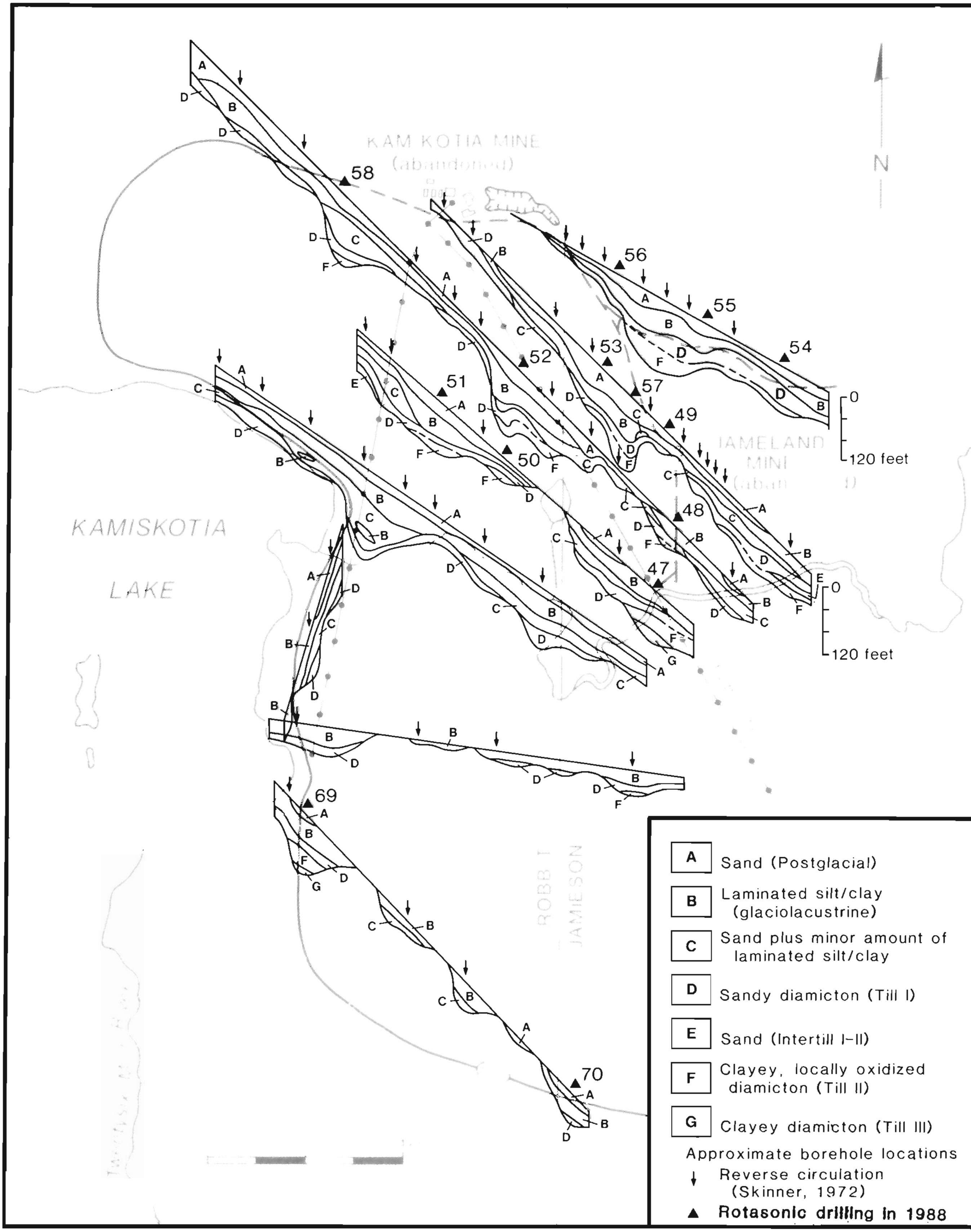


Figure 26. Multiple stratigraphic cross-sections of the Kamiskotia area compiled from both Rotasonic and reverse circulation drilling data.

bedrock during earlier Rotasonic drilling in nearby Kipling Township, was very enriched in carbonate clasts and was tentatively correlated with Kipling Till (Kettles and Wyatt, 1988). Kettles and Wyatt's upper till probably correlates with the upper till complex in the Smoky Falls cores.

Below the Kipling Till "complex", two tills separated by a discontinuous sand layer are differentiated from the upper complex by geochemical and lithological trends. Adam Till, immediately below carbonate-rich Kipling Till, exhibits compositional and lithological indicators that suggest approximately equal incorporation of Paleozoic carbonate and Precambrian crystalline material. The lowermost till, which will be labelled temporarily as Till "B" to prevent confusion with Skinners' Roman numeral designations for pre-Missinaibi tills, is more carbonate-rich than Adam Till, but not as enriched in carbonate pebbles as Kipling Till. Immediately above the bedrock contact (local bedrock is Precambrian gneiss), Till "B" is enriched in local crystalline lithologies. This lower till which is recorded in the cores, is not exposed in section in the southern part of Adam Creek. Whether or not Till "B" predates or postdates the Missinaibi Formation is unclear.

In sections in the southern few kilometres of the Adam Creek spillway, the upper till or till complex (Kipling Till) is locally separated from underlying Adam Till by planar and crossbedded silt and fine sand of the Friday Creek sediments (Fig. 27). The silt unit, mapped as Friday Creek sediments by Skinner (1973) thickens toward the southern end of the section, with southward current indicators, toward the Pinard moraine. Where Kipling and Adam tills are directly superimposed, a distinct textural and colour change is evident at the contact, which is commonly marked by a boulder pavement (Fig. 28).

If the Matheson ice front retreated northward from the Pinard moraine before readvancing as the Kipling/Cochrane readvance, the Friday Creek sediments would be correlative with the Barlow-Ojibway Formation. Sediments cored from the Pinard moraine are similar to those recorded in section in the southern end of the Adam Creek spillway, about 5 km to the north of the moraine. It is probable that the Pinard moraine represents a subaqueous ice-contact deposit that marks only a pause in the northward retreat of the Matheson ice front.

Figure 27. Thick accumulation of Friday Creek bedded silts that separate Kipling and Adam tills. The exposure is at the southern end of Adam Creek. (GSC 204874-B)

Figure 28. The contact between the upper, blocky, brownish, clast-poor Kipling Till, and the lower stony, grey Adam Till is marked by a local boulder pavement. The exposure is in the southern end of the Adam Creek spillway in Harmon Township. (GSC 204731-D)

Glacial dispersal and ice-flow directions

Introduction

Glacial dispersal and ice-flow directions are inferred from compositional data, such as pebble and heavy mineral lithology, and clay, silt+clay, and heavy mineral geochemistry. The composition of different till units can be interpreted in terms of provenance from the dominance of erratics and matrix compositions from either Phanerozoic or Precambrian source areas. In this section, compositional data from tills from the cores will be discussed, and directions of ice advance inferred for the individual units. Relatively sparse striation data recorded in the study area will be used to corroborate ice flow directions derived from composition of diamictons.

Pebble lithology of the 2 to 5.6 mm fraction of till is most easily linked with probable source areas on a regional scale. The two most obvious drawbacks to utilizing only the pebble fraction, are: 1) the lack of bedrock exposure in the region inhibits the association of a distinctive rock type with a particular outcrop area, and 2) the small clast size results in underrepresenting or difficulty of recognition of erratics from the coarsely crystalline bedrock lithologies typical of Precambrian terrain. Thus, the determination of provenance has been generalized, and in its most useful form is reduced to a ratio between Phanerozoic carbonate-dominated versus Precambrian crystalline-dominated composition. Tills deposited by ice that moved predominantly over Paleozoic terrane (i.e. south-southeastward) should have deposited sediments that display a dominant signal from that source. Southwestward- or westward-moving ice should have deposited sediments more enriched in Precambrian, siliceous crystalline debris. With this simple ratio it is difficult or impossible to differentiate two superimposed tills that were deposited by ice moving in similar directions. In addition, in individual till sheets, the farther away from the Phanerozoic basin that the unit is sampled, the less pronounced the carbonate signature becomes, due to dilution by Precambrian bedrock debris in the dispersal area. Clay-rich tills, such as the Cochrane, are low in overall pebble content, so large samples must be taken to ensure a statistically significant quantity of pebbles.

Heavy minerals complement pebble analysis as they represent the mineralogy of diverse rock types in each of the main provenance areas. Heavy minerals were recovered from the 0.063 to 0.25 mm size fraction of till, the textural class which has been shown by Dreimanis and Vagners (1969) and by Shilts (1975) to be composed largely of mineral grains. The relative quanitities of nonmagnetic and magnetic heavy minerals can be used, in some cores, to differentiate between predominantly Archean versus Paleozoic domains, as the latter shed very little heavy minerals compared to the former. Heavy minerals of economic interest, such as gold, sphalerite, etc. can also be readily identified and are useful indicators of the presence and nature of mineralization.

Geochemistry of the fine and heavy mineral fractions can be considered to indicate source areas generally, but geochemistry may be influenced by factors other than bedrock composition, such as various chemical processes associated with weathering (Shilts and Smith, 1989). Except near the surface, very little weathered material was encountered in the boreholes, so the majority of till samples analyzed are unoxidized. Geochemistry is useful to support the trends indicated by the pebble lithology and heavy mineral data, particularly if one or both of these are unavailable for a particular sample (i.e. low pebble concentrations in Cochrane Till). Also, the geochemical signature imparted by a buried or predominantly buried outcrop, can be evaluated more effectively than by pebble lithologies which, to be effective, depend on knowledge of subcrop extents.

The terrane eroded by the glaciers as they advanced from different directions should impart a recognizable signature to the geochemistry and lithology of the respective till units. The fine fraction of till may, in theory, become generally enriched in far-travelled debris with distance, and may, therefore, be more useful than coarser fractions for differentiating provenance subtleties of till units at increasing distance from source areas. Based on data for the clast fraction, particularly carbonates, this pattern seems to be present in the study area. As subsequent ice advances took place, the ice reworked and incorporated unknown quantities of sediments deposited during or after the preceding glaciation. The compositional and textural expression of this reworking for the most part affects only the lower metre, at most, of the overlying till, based on visual inspection of data trends. A shift in ice flow direction during the course of a single glacial event may be reflected by related changes in composition from the base to the top of a single till unit.

Lithology of pebble fraction

As a regional approximation, pebble lithology data generally indicate an upward trend of Paleozoic carbonate pebble concentration, from about 20% by weight at the base, on average, to 60 to 80% at the top of the cores.

In the northern half of the study area, Matheson Till locally exhibits a slight upward increase in carbonate pebble abundance. In the Smoky Falls area, Till II is more carbonate-rich than Adam Till (Fig. 29, in pocket). The lower till units, Matheson Till, Till II, Till III, and rarely preserved Till IV, are very similar in overall carbonate clast content, particularly in the southern half of the study area as illustrated by data from the Kamiskotia site (Fig. 30, in pocket). Where resting directly on crystalline basement rocks, a given till may be nearly devoid of Paleozoic components in the pebble fraction, having been diluted by locally derived materials.

The base of the Barlow-Ojibway Formation, although poor in overall pebble content, generally reflects a similar Paleozoic carbonate pebble signature as the immediately underlying till, usually Matheson Till. At the top of this succession of lacustrine sediments, the carbonate clast content has increased, on average, from 30% (at the base) to 80% or locally to 100% at the top. The trend toward high concentrations of carbonate clasts continues upward into the Cochrane Formation which was reworked primarily from Barlow-Ojibway sediments.

An isolated exception to these general observations is in the till unit (Till III) at the base of cores in holes 61 and 62. Pebble lithology data at these sites indicate 60% carbonate pebbles at the base of Till III, decreasing to 35% at the top of the unit. In this case, an upward decrease in concentration of the carbonate pebbles and in carbonate in the silt+clay fraction corresponds to an upward increase in garnet content in the heavy mineral counts (Fig. 31, in pocket). The anomalous carbonate signature could be explained, other than by analytical error, by invoking the presence of nearby a Paleozoic outlier to account for the high carbonate content. The distinctive Precambrian signature at the top of the unit may reflect dilution by adjacent Shield rocks.

In a mirror image of the Paleozoic carbonate trends Archean crystalline rock types show a distinct decreasing upward pattern. The third largest lithologic group, dark, fine grained lithologies, identified as Proterozoic sedimentary rocks (dark erratics of Shilts et al., 1979), display a trend similar to the decreasing upward trend of the crystalline lithologies, except that the signal is much more muted. However, the "dark erratic" group locally reflects the trend of the carbonate rocks in particular till units, suggesting a possible areal link between Paleozoic and Proterozoic source rocks. The general abundance of "dark erratics" is inconsistent, tapering off in the middle of the study area, and increasing again to the south. The increase in the southern part of the study area is interpreted tentatively as an influx of local, fine grained supracrustal rock types indistinguishable from distant Proterozoic source rocks in the Belcher Islands and Sutton Ridge. At Kamiskotia, the local fine grained volcanic rocks have probably also been included in this category, which can be interpreted as reflecting, at least in part, the local bedrock.

Other indicator lithologies are also present in the tills. The overall abundance of presumed Proterozoic rock types is low, ranging from 0% to about 15%. Devonian red, terrigenous sandstone only constitutes up to 2% by weight of the pebble fraction. Mesozoic lignite and recycled quartz may comprise up to 5% by weight of a sample pebble fraction, and observed trends of Mesozoic detritus in cores are generally similar to those of the Devonian erratics. Mesozoic and Devonian lithologies are found primarily in cores from the northern part of the study area (Fig. 32, in pocket). In some samples, vein quartz from crystalline terrane may have been indistinguishable from, and included in, the Mesozoic rounded quartz category, particularly in the southernmost cores.

Pebble lithologies such as Proterozoic dark, fine grained rocks, Mesozoic lignite and quartz, and Devonian red, terrigenous sandstones, are not as directly useful for inferring ice flow directions as Paleozoic or Precambrian lithologies because of their low abundance and somewhat erratic distribution patterns.

Heavy minerals

Sand-sized heavy mineral content is generally low (mean of 1.17 weight %) in tills of this region, due to dilution by heavy mineral-poor Paleozoic components. In general, tills rich in carbonate components, such as Kipling or Cochrane tills in the northern part of the study area, are heavy mineral-poor, averaging 1% or less of the 63 to 250 µm (s.g. >3.3) fraction. Conversely, tills with a greater concentration of crystalline Shield erratics, have heavy mineral concentrations averaging up to 2%. Notwithstanding these generalizations, the variation of heavy mineral weight percentages within a given core generally cannot be used to differentiate the different till units, other than in a general sense. Cochrane Till is typically deficient in sand-sized components, so larger samples have to be taken to recover sufficient heavies to do both grain counts and geochemistry.

Microscope identification of 150 and 300 grain heavy mineral mounts was done for each of the till samples. A complex suite of 21 mineral species were identified, although many were of low concentration, or showed no identifiable trends or differences between till units. Minerals in low concentration, typically less than 0.5% by weight, include kyanite, monazite, bronzite, rutile, chromite, and staurolite. Mineral species of low to moderate abundance include hornblende, sphene, and the alteration minerals goethite and leucoxene. Abundant mineral species include diopside, hypersthene, garnet, epidote, hematite, pyrite, siderite, and ilmenite. Several of the more abundant species may have multiple sources within Paleozoic and Precambrian terranes. For this reason, minerals such as pyrite, hematite, and garnet were initially further subdivided on the basis of grain morphology into rounded, euhedral, botryoidal, aggregate, or earthy classes. This morphological division did not improve our ability to infer ice flow direction or provenance.

Several mineral types are here termed indicator species because of their usefulness in allowing inferences to be made concerning ice flow from specific source areas. They can usually be related to their dominant source areas, either in Phanerozoic or Precambrian terrain. Siderite has been associated primarily with Devonian Kwataboahegan and Stooping River formations (Skinner, 1973; Sanford and Norris, 1975; Holmes, 1984; and Sacré, 1986) as well as with Proterozoic iron-formation (Lang, et al., 1970). Pyrite occurs commonly as clasts or solution fillings in Paleozoic limestone terrane but is also common in some clastic Mesozoic sediments. Pyrite may also be derived from sulphide-bearing crystalline rocks but it tends to occur as cubes or fractured cubes in contrast to the botryoidal form of Phanerozoic pyrite. Hematite can have multiple sources and may have, in large part, been eroded from Proterozoic iron-formation in the Belcher Islands or Sutton Ridge, although it is not possible to interpret what percentage of the total hematite signature is definitely related to a Proterozoic source area.

Different heavy mineral species from the same general source area are said to form a sympathetic relationship if they exhibit similar concentration trends (Holmes, 1984). For example, garnet, epidote, and pyroxene tend to form a sympathetic assemblage representing the Precambrian suite of minerals. Because siderite occurs primarily north and northeast of the Phanerozoic/Precambrian contact, in the Moose River basin where pyrite concentration curves mimic siderite, the pyrite can also be presumed to be derived largely from this terrane. An antithetic relationship occurs where an increase in one component corresponds to a decrease in the other. This is generally the case between Precambrian and Phanerozoic indicators and makes evaluating sympathetic relationships within either group difficult.

Garnet is the most common resistate heavy mineral, ranging from 0 to 72% by weight with an average of 40%. Although the ortho- and clinopyroxenes such as hypersthene and diopside together comprise the next most common minerals identified, averaging 16 and 3.8% respectively, pyroxenes are not considered to represent a complete suite of minerals as their range of specific gravities straddles that of methylene iodide (3.3). Any variation in the specific gravity of this fluid or in operating procedure can cause non-provenance related inconsistencies in the pyroxene content of the heavy mineral separate. Epidote is the next most common mineral with an average concentration of 12.2%, slightly more than ilmenite which averages 8.5 weight %. Hematite, pyrite, and siderite are the lowest in abundance of the indicator minerals with averages of 3.5, 5.2, and 1.8% by weight respectively.

The heavy mineral most useful in determining compositional trends is garnet. An increase in garnet content usually denotes a corresponding decrease in other mineral species, although it is often sympathetically linked with epidote. Garnet is typically very abundant at the base of the cores, due to incorporation of local metamorphic bedrock. It exhibits a decreasing upward trend which is mirrored by a corresponding upward increase in carbonate indicators in the pebble fraction and geochemistry (Fig. 33, in pocket). Siderite, hematite, and pyrite heavy minerals derived largely from the Phanerozoic basin, are not as useful in differentiating till units because their variations are low. Nevertheless, this suite displays a subtle increasing upward trend. Siderite becomes much less frequent in tills in the southern half of the study area, due to dilution by Precambrian mineral species with increasing distance from its source area.

Geochemistry

Introduction

Geochemical analysis for a suite of 32 elements was performed on three size fractions, clay (<2 μm), silt+clay (<63 μm), and heavy minerals (63-250 μm, specific gravity >3.3, nonmagnetic fraction). The clay-size fraction, while exhibiting local enrichment in certain elements such as zinc, copper, silver, barium, lead, nickel, chromium, and arsenic, does not display consistent concentration trends, except for calcium and magnesium. This lack of variation contrasts with the clear trends shown by data from pebble lithologies and heavy mineral analyses. The silt+clay data are generally correlative with the vertical and areal concentration patterns in the other data sets although anomalous element concentrations are markedly lower than in the clay fraction, suggesting textural influence (dilution). The proportion of silt to clay appears to be relatively constant over the region, except in the coarser grained Matheson Till. Therefore, the silt+clay fraction (<0.063 mm) seemed to be useful for determining geochemical trends in the fine fractions of unweathered samples, especially when one considers the low cost of preparing silt+clay separates. The clay-size fraction analyses can be used to emphasize anomalous values that are more muted in the silt+clay analyses.

One consideration that may affect the accuracy of the analytical results is the possibility that a number of minerals, including those containing calcium, may be incompletely digested by the nitric acid-aqua regia digestion used in the inductively coupled plasma (ICP) process. The elements Al, Ba, Be, Ca, Cr, Ga, La, Mg, K, Na, Sr, Tl, Ti, and W may not be expressed as "totals". For the purposes of comparison of data trends, rather than absolute values, the possible errors are presumed to have been relatively equally distributed. Phosphorus and sodium concentrations in the clay fraction are not meaningful because the clays are dispersed in sodium hexametaphosphate. Because of a laboratory error, an unknown number of clay separations performed on samples from the 1987 program may have been incomplete, a condition reflected by anomalously low aluminum contents, caused by dilution of the clay fraction by quartz-rich silt.

Clay and silt+clay geochemistry

Analytical differences between the clay and silt+clay fractions are evident in average concentrations of specific elements. For example, aluminum, a direct measure of relative quantity of phyllosilicate minerals, is about 2.5 to 4% in the clay separate, and ranges from 0.5 to 1.5% in the silt+clay fraction. Metals such as Cu, Ni, Pb, and Zn, that may be enriched in clay minerals, exhibit average concentrations of 48, 56, 11, and 99 ppm respectively in the clay fraction, whereas they are less abundant at 15, 16, 3.5, and 29 ppm respectively in the silt+clay. Manganese is twice as abundant in the clay fraction as it is in the silt+clay fraction. Similarly, iron is three times as concentrated in the finer fraction. There is no consistent or significant difference in the concentration of the rest of the elements in the analytical suite between both the clay and silt+clay data sets. This comparison of the clay and silt+clay data sets suggests that the silt+clay fraction is also useful for interpretation of ice flow direction based on composition of tills in the cores.

In the silt+clay fraction, calcium displays a very pronounced, upward increasing trend throughout the stratigraphic column that is analogous to the trends for pebble lithology and carbonate data (Fig. 34, in pocket). This is paralleled, although somewhat mutedly, by magnesium, which also can be directly related to the Paleozoic source area.

Heavy mineral geochemistry

Within a given core, the major element contents of the heavy mineral fraction exhibit patterns similar to those of the silt+clay fraction. The heavy minerals have an upward increasing calcium concentration in the stratigraphic column, although the overall calcium abundance is somewhat lower than in the finer fractions. This calcium may be present in siderite, in which it commonly substitutes for iron. Manganese, which is also considered to reflect siderite abundance and predominantly Phanerozoic source areas, also increases upwards through the cores and is very enriched in the northern part of the study area.

Because most samples analyzed are unweathered, heavy mineral geochemical analyses faithfully reflect chalcophile trace metal concentrations derived from usually labile mineral phases. Several trace elements from till have average values up to three times those in the clay fractions. Arsenic, cobalt, copper, iron, manganese, lead, and zinc have average concentrations throughout the study area of 21 ppm, 61 ppm, 119 ppm, 6.1%, 1347 ppm, 37 ppm, and 153 ppm respectively.

Several trends evident in the geochemistry of this fraction are interesting when interpreted in terms of ice flow directions, both between the individual till units in a core, and in a regional context. A notable areal pattern derived from heavy mineral geochemistry shows that several elements of potential economic interest are more concentrated, on average, in the the northernmost cores, than in tills sampled from more southerly cores, even those drilled immediately down-ice from a known mineralized area at Kamiskotia. In the Smoky Falls cores (36 to 41 inclusive), Ag, As, Co, Cr, Cu, Ni, Pb, W, and Zn have higher average and maximum values in tills I (Adam Till) and II than in correlative units in the Kamiskotia cores (47 to 58 inclusive), i.e. Matheson Till and Till II respectively (Table 1). Kipling (or Cochrane) Till at Smoky Falls also exhibits generally enhanced concentrations of these elements compared to the regional average for all till units, although the low number of sample points makes direct comparison qualitative. Adam Till is slightly more enhanced in these elements than the lower unit, Till II, which indicates a greater influence from crystalline source areas in the Adam Till.

In the Kamiskotia cores, Matheson Till is more enriched in zinc than the underlying Till II, which was expected to have a higher concentration of components derived from the mineralization at the Kam-Kotia Mine. However, Till II is relatively enriched in As, Co, Cr, Cu, Ni, and W (Table 1). Ice that deposited Till II probably had more direct contact with the local bedrock, and was expected to have eroded areas of mineralization and transported the debris towards the southwest. Unfortunately, the configuration of the borehole sites was such that southwestward dispersal from the Kam-Kotia deposit could not be detected.

A number of anomalous concentrations of elements of possible economic interest from the analyses of heavy minerals from various cores and different till units are summarized in Table 2. These anomalies are qualitatively judged to be significant with respect to the regional trends and average values. It is not possible to determine whether the anomalies are derived from local or from distant sources, except perhaps in the case of core 68. Till III in this core exhibits the highest silver values recorded among all the heavy minerals analyzed, and several showings, such as that at the former Genex Mine at Aconda Lake, are known in the area north of this drill site (Fig. 35).

Table 1. Comparison of heavy mineral geochemical data for selected metals in different till units from Kamiskotia and Smoky Falls cores; det = below detection limit.

Element	Ag	As	Co	Cr	Cu	Mn	Ni	Pb	W	Zn
Detection	0.2ppm	5ppm	1ppm	1ppm	1ppm	1ppm	1ppm	2ppm	10ppm	10ppm
Cores 47-58,69,70 Kamiskotia										
Matheson Till										
max. value	0.2	40	66	284	222	1700	48	46	60	1920
min. value	det	det	9	33	17	565	7	20	det	39
avg. value	0.2	14.1	32	71.3	70.5	1260	28.6	30.2	10.3	113.1
no. samples	51	51	51	51	51	51	51	51	51	51
Till II										
max. value	0.2	1120	1870	300	488	2113	276	72	120	124
min. value	det	det	8	40	det	678	7	18	det	21
avg. value	0.2	43.2	83.3	90.7	76.8	1336	39.8	32.9	17.8	69.3
no. samples	38	38	38	38	38	38	38	38	38	38
Cores 36-41 Smoky Falls										
Kipling Till										
max. value	0.2	100	220	274	470	6680	243	304	215	926
min. value	det	det	15	74	24	822	16	18	det	31
avg. value	0.2	33.2	59.4	111	118.9	1938	64.1	79.4	52.9	286.6
no. samples	7	7	7	7	7	7	7	7	7	7
Adam Till										
max. value	1.4	135	200	247	374	7050	293	218	200	8746
min. value	det	det	23	29	70	866	25	30	det	133
avg. value	0.2	21.8	60.8	82.1	128.6	1636	84.3	58.1	20.2	505.2
no. samples	44	44	44	44	44	44	44	44	44	44
Till II										
max. value	0.2	50	140	83	324	9935	177	72	130	304
min. value	det	det	23	29	71	927	38	14	det	88
avg. value	0.2	16.1	52.4	62	127.1	1993	84.1	35.8	17.8	178.2
no. samples	25	25	25	25	25	25	25	25	25	25

Mineralized source areas

A number of economically interesting minerals and deposits were examined in the course of this study in order to ascertain their value in the regional synthesis of ice flow directions. Known deposit types of restricted areal extent, such as kimberlites, carbonatites, Cretaceous silica sand, kaolin deposits, and sulphides could indicate dispersal directions through a suite of components that could be detected in the geochemistry or lithology of sample materials. Anomalous metal concentrations in the core samples, such as copper, lead, zinc, gold, silver, and pathfinder accessory elements were of limited use for the interpretation of ice flow directions because of the lack of information as to sites of buried mineralization.

With the on-going interest in the potential for kimberlite occurrences in the Moose River basin, perhaps associated with Devonian intrusive rocks such as the kimberlitic vein at Coral Rapids, kimberlite indicator minerals, such as pyrope, were sought. The cores at Smoky Falls are approximately 40 km down-ice in a southwesterly direction from the kimberlitic exposure at Coral Rapids. This particular deposit does not exhibit the "typical" kimberlite suite of indicator heavy minerals, such as magnesian ilmenite, chrome diopside, and pyrope garnet (Brown et al., 1967), but these minerals have been recovered from alluvial sediments in other parts of the Moose River basin. A number of authors have speculated that diamonds recovered in the Great Lakes area, were dispersed in a southwesterly direction from the Moose River basin. As no kimberlite indicator minerals were identified in any of the till samples, no further comment can be made to lend any support to this theory.

Carbonatites also can provide a diverse suite of distinctive components to glacial debris (Ford et al., 1988). The Clay-Howells alkalic rock complex contains a small carbonatite-like intrusion enriched in magnetite, niobium, tin, zinc, and molybdenum in a pyroxene syenite host rock. Heavy mineral separates from the group of cores that are nearest to this deposit, cores 27 and 28 in particular, exhibit at the base of the lowermost till elevated levels of zinc, molybdenum, iron, nickel, lead, copper, chromium, and cobalt (Fig. 36). No corresponding geochemical enrichments in the clay or silt+clay fraction were apparent. It is possible that the enhanced metal levels are associated with dispersal from the Clay-Howells complex in a southwesterly direction during an early glacial episode. However, enhanced amounts of siderite detected in heavy mineral grain counts from the same samples suggest possible derivation of some or all of this material from within or north of the Moose River basin. This association clearly points out the problems inherent in trying to differentiate a local from a distant provenance signal; both can be equally strong regardless of distance of transport. Drill sites to the northeast and east of the Clay-Howells complex, showed no indication of similar enrichments in the heavy mineral geochemistry, suggesting that at this site the trace element enhancement is local and fortuitously corresponded with till that has suffered little dilution by far-travelled components.

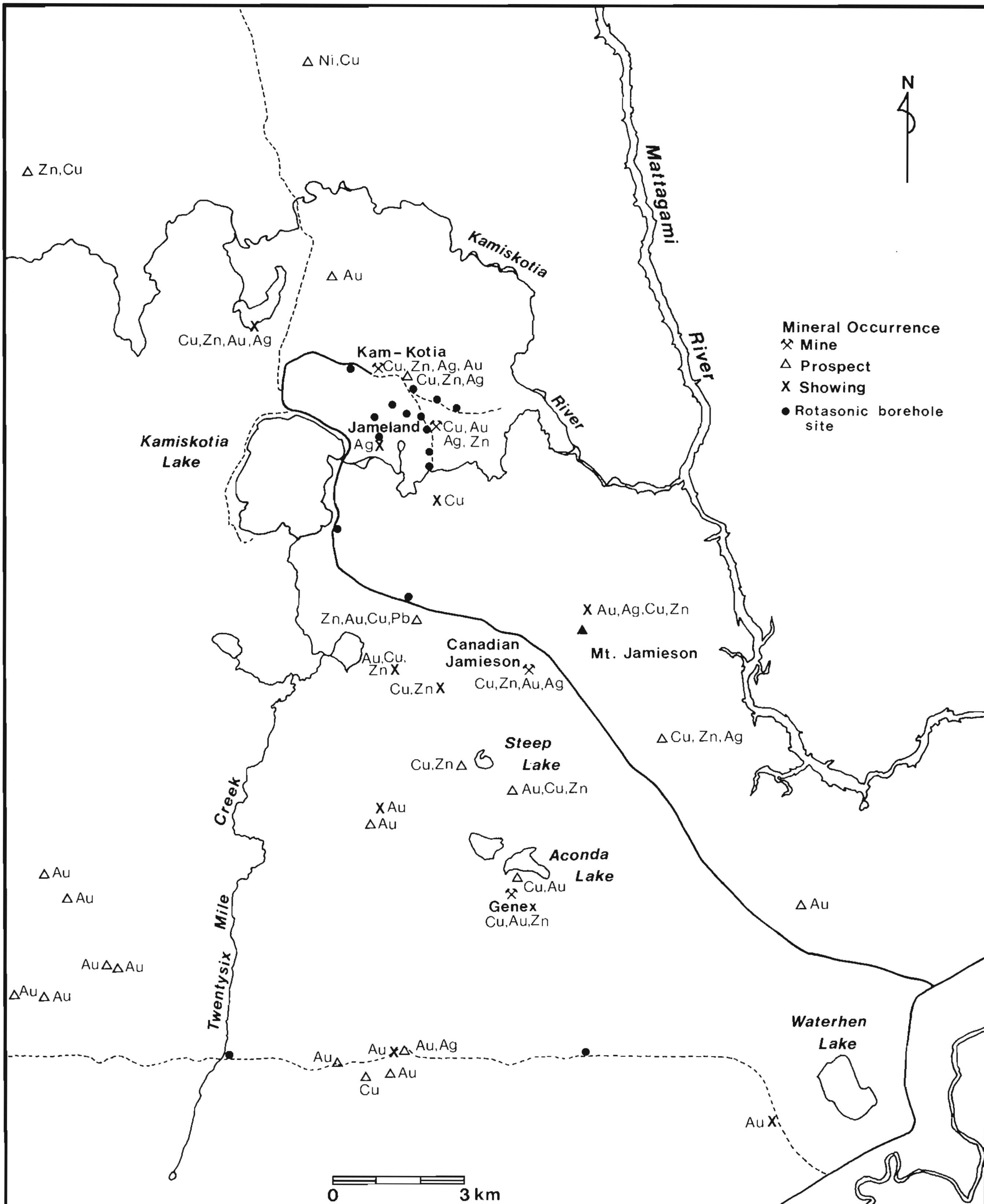
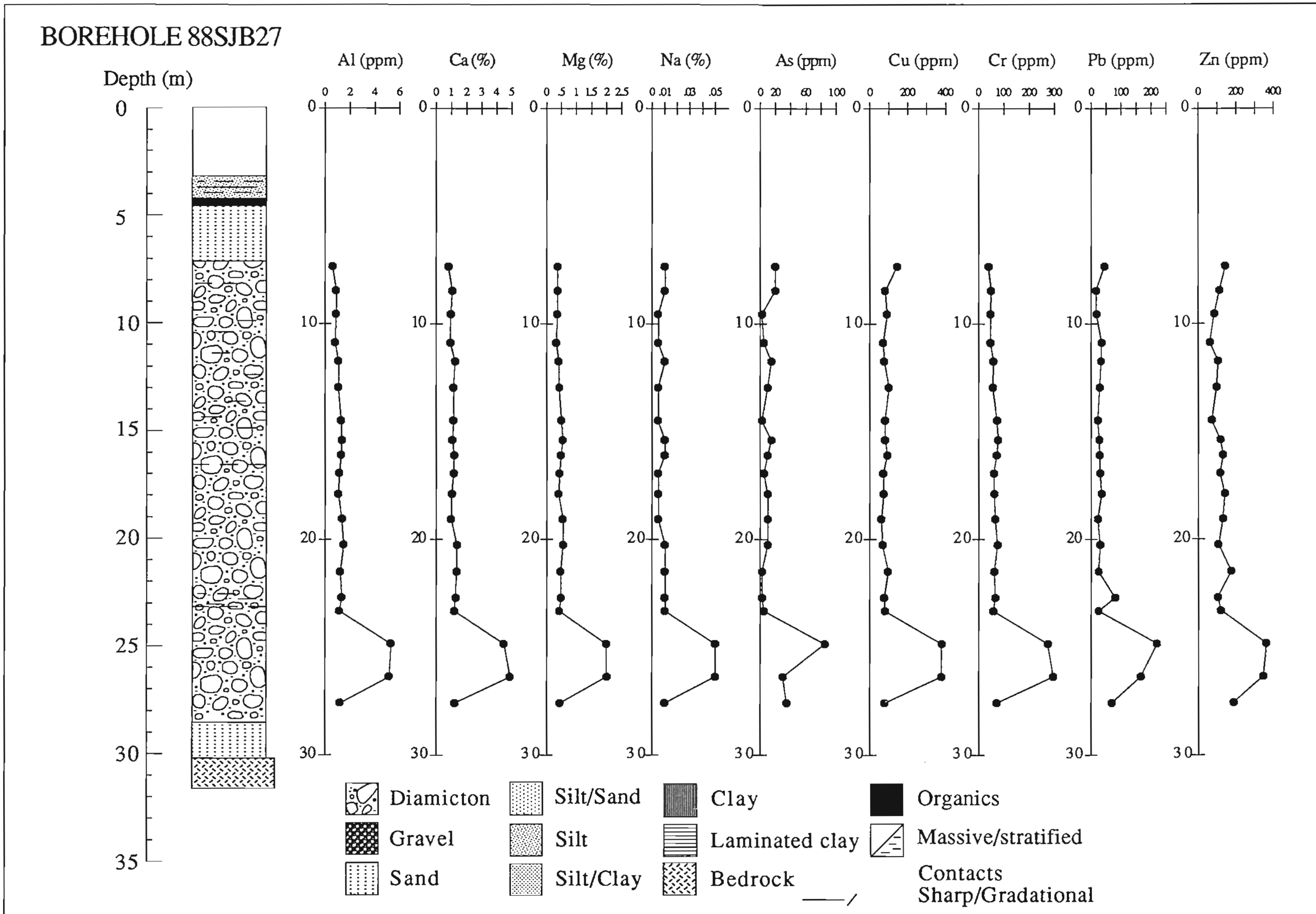


Figure 35. Mineralized showings in the Kamiskotia area (from Rose, 1985). Refer to Figure 13 for borehole numbers.

a



BOREHOLE 88SJB27
Depth (m)
Al (ppm)
Ca (%)
Mg (%)
Na (%)
As (ppm)
Cu (ppm)
Cr (ppm)
Pb (ppm)
Zn (ppm)
Diamicton
Gravel
Sand
Silt/Sand
Silt
Silt/Clay
Clay
Laminated clay
Bedrock
Organics
Massive/stratified
Contacts
Sharp/Gradational

b

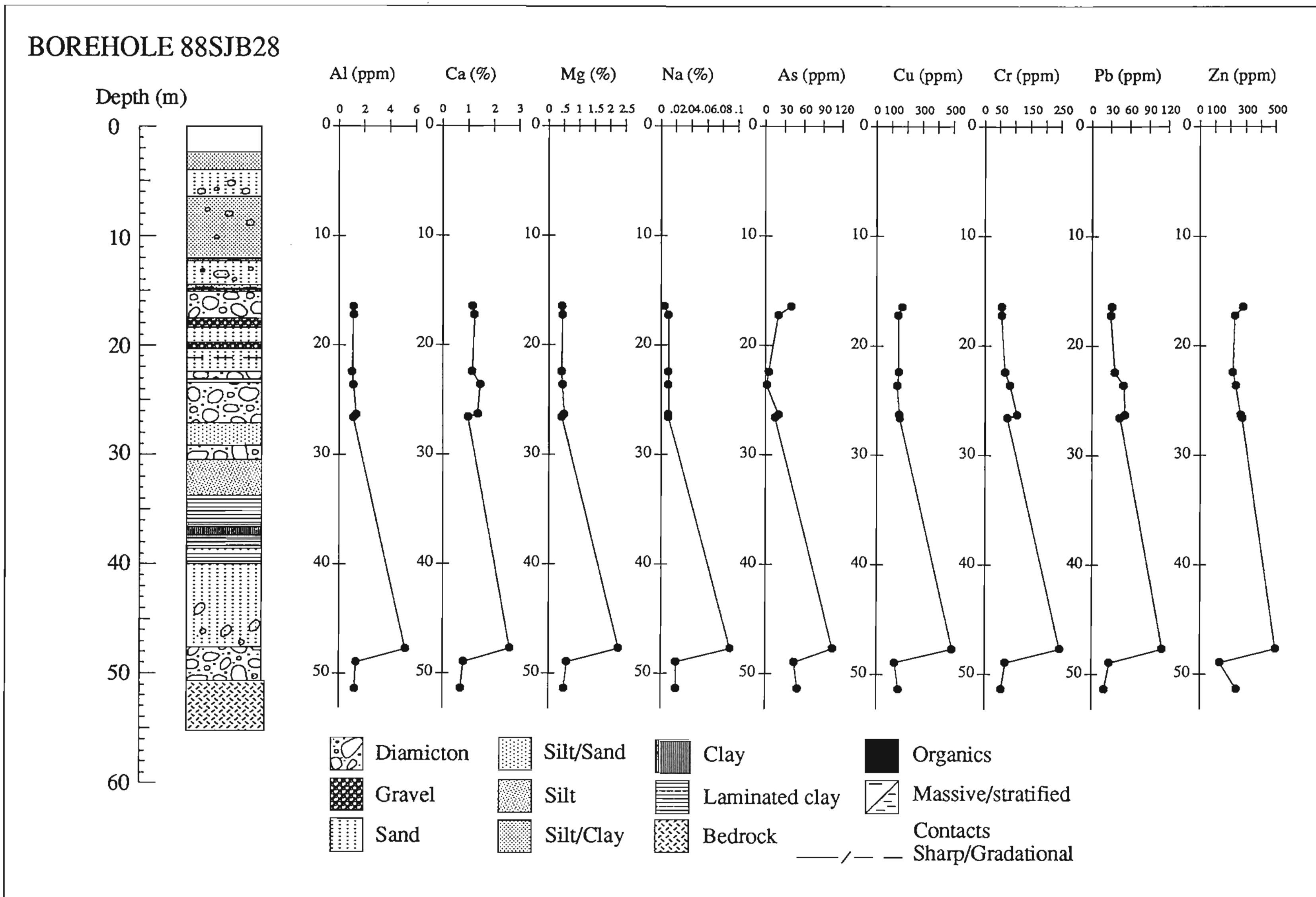


Figure 36. Heavy mineral geochemistry of selected elements from a) core 27 and b) core 28.

Table 2. Summary of heavy mineral geochemistry of selected metals showing their regional abundance in different till units; det = below detection limit.

Element Detection	Ag 0.2ppm	As 5ppm	Co 1ppm	Cr 1ppm	Cu 1ppm	Mn 1ppm	Ni 1ppm	Pb 2ppm	W 10ppm	Zn 10ppm
					REGIONAL TOTAL					
Cochrane Till										
max. value	0.4	100	220	274	470	6680	243	304	215	926
min. value	det	det	3	26	2	683	7	14	det	24
avg. value	0.2	16.2	38.7	68.4	73.5	1255	37.9	40.4	16	118.2
no. samples	34	34	34	34	34	34	34	34	34	34
Matheson Till										
max. value	1.4	165	301	284	374	7050	293	218	4350	8746
min. value	det	det	9	22	17	300	5	8	det	26
avg. value	0.2	18.4	55.9	65	115.9	1306	61.9	39.2	46.1	200.7
no. samples	207	207	207	207	207	207	207	207	207	207
Till II										
max. value	2	1120	1870	300	1284	9935	860	220	2170	496
min. value	det	det	8	18	det	335	7	10	det	21
avg. value	0.2	28.8	77.6	74.2	121.9	1467	70.4	35.7	47.1	114.2
no. samples	125	125	125	125	125	125	125	125	125	125
Till III										
max. value	13.6	130	626	285	3323	1885	229	48	1485	205
min. value	det	det	4	28	4	267	4	det	det	15
avg. value	0.9	21	91.2	70.5	315.1	1039	64.8	26.1	138.1	81.8
no. samples	21	21	21	21	21	21	21	21	21	21

The Cargill carbonatite is covered by an extensive residual mantle of potentially easily eroded debris. It has been explored primarily for its copper, nickel, and apatite potential as well as for rare-earths, residual clays, and silica sand. The carbonatite contains sideritic mineral phases. Several cores southeast (down-ice) from this deposit displayed elevated siderite concentration in heavy minerals from Matheson Till samples (cores 21, 19, 25, and 43). Silt+clay geochemistry indicates a slight elevation in phosphorous concentrations in the siderite-bearing samples, perhaps related to the extensive apatite deposits. Heavy minerals in Matheson Till samples have elevated concentrations of copper and nickel at this stratigraphic level, suggesting that enrichment of these two elements may be related to southeastward dispersal from the carbonatite source.

Many specific deposits of copper, zinc, lead, etc. are known throughout the region, except in areas of thick overburden cover. Therefore, it is difficult to tie anomalous concentrations of copper, for example, to one among the many known sites of copper mineralization. Bostock (1970) suggested that lead-zinc deposits may be associated with Precambrian bedrock that underlies Paleozoic cover beneath the Cape Henrietta Maria Arch. Disseminated Pb-Zn is known to be associated with the Proterozoic Manitounuk Group on the east coast of Hudson Bay (Stevenson, 1968). Pyrite and chalcopyrite are known in veins near Hawley Lake (Hawley, 1926), although pyrite was present in the majority of bedrock samples cored in this project. Sulphides have been associated with the Kapuskasing structural zone in general, so local mineralized intrusions could be expected to be relatively common. Of course, volcanogenic massive sulphide deposits are associated with the greenstone terrane. However, even dispersal from a known outcropping orebody can lend an erratic geochemical signature to glacial material derived from it as illustrated by the results from core samples down-ice from the Kam-Kotia mine site near Timmins.

A suite of silt+clay separates from till from cores throughout the region were analyzed for gold, platinum, and palladium. Most of these exhibited, at most, the detection limit for the analytical techniques. The maximum values recorded for these elements are 18 ppb (Au), less than detection (Pt), and 52 ppb (Pd). The highest values for gold and palladium (18 and 52 ppb respectively) were determined for samples taken close to or perhaps partly in the tailings materials near the former Genex Mine at Aconda Lake. Sources of gold grains are notoriously difficult to pinpoint and the grains themselves are rare in till samples in this region. Gold showings in the study area are likewise

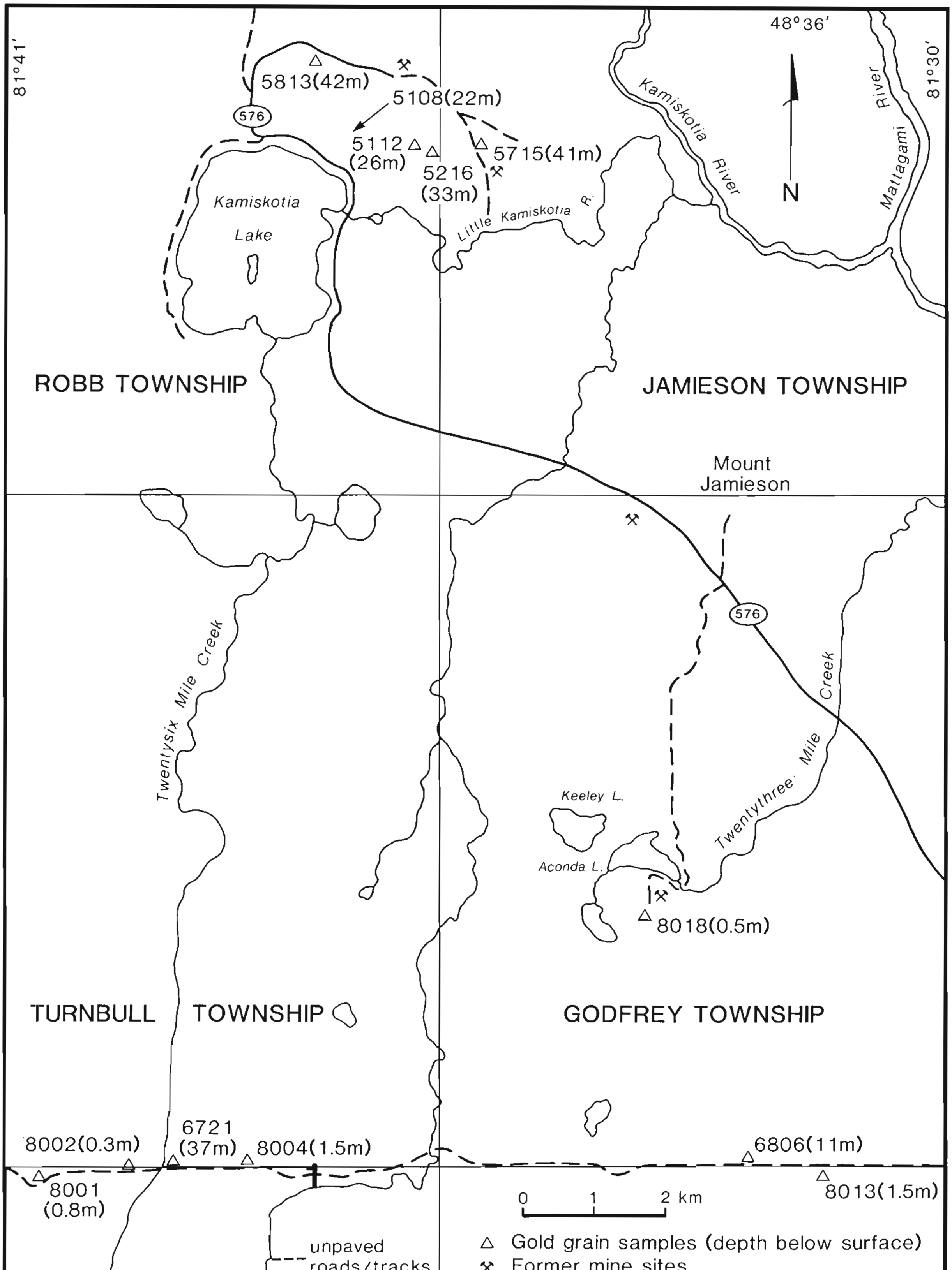


Figure 37. Location map of sites of samples containing visible gold grains. Grains are described in Table 3.

Table 3. Summary of sizes and shapes of gold grains recovered from core and surface samples in the Kamiskotia area. Refer to Figure 37 for the sample localities.

Sample number	Diameter (μm)	Thick. (calc.)	abraded	irregular	delicate	total number of grains	CALC V.G. ASSAY PPB	REMARKS
5108	25 x 25	5	1			1		EST. 7% PYRITE
	50 x 75	13	1			1		
	Total					2	20	
5112	25 x 75	13	1			1		
	Total					1	44	
5216	100 x 100	20		1		1		EST. 0.5% PYRITE
	325 x 475	68	1			1		
	Total					2	5577	
5715	25 x 25	5	1			1		EST. 0.5% PYRITE
	75 x 100	18	1			1		
	Total					2	110	
5813	50 x 100	15	1			1		
	Total					1	34	
6721	50 x 75	13	1	1		2		EST. 0.5% PYRITE
	250 x 275	48	1			1		
	Total					3	2399	
6806	50 x 50	10	1			1		
	Total					1	12	
8001	75 x 125	20		1		1		
	Total					1	71	
8002	25 x 25	5	1			1		NO SULPHIDES
	50 x 50	10	1			1		
	50 x 75	13	1			1		
	100 x 125	22	1			1		
	Total					4	108	
8004	400 x 525	76	1			1		EST. 0.25% PYRITE
	1075 x 1075	100	1			1		
	Total					2	56362	
8013	25 x 25	8	1			1		NO SULPHIDES
	100 x 100	29	1			1		
	150 x 175	31	1			1		
	Total					3	389	
8018	50 x 50	10		1	4	5		TRACE PYRITE
	50 x 75	13		1	3	4		
	50 x 100	15	1		1	2		
	75 x 75	15	1	1	1	3		
	75 x 100	18			2	2		
	225 x 250	44		1		1		
	Total					17	1082	

rare, and typically comprise quartz veins and stringers associated with pyrite (Pyke, 1982). Approximately 30 till samples from cores and surface samples in the Timmins area were processed on a shaking table for separation of visible grains (Fig. 37). Table 3 summarizes the sizes and shapes of the gold grains recovered. The largest grain recovered was slightly larger than 1 mm long (Fig. 38). Although no significant gold was detected in our Kam-Kotia drilling, Kirwin (1987) indicated anomalous gold values in basal till from a drilling transect south of the Kam-Kotia and Jameland mine properties.

Elements often associated with gold mineralization, such as silver and arsenic are locally enriched in till, but it is difficult to identify their source if they are linked with elusive gold mineralization. The greatest silver concentration, 13.6 ppm in the heavy mineral fraction, was recorded for a sample in core 68, southwest and down-ice from the former Genex mine site, in an area dotted with gold showings and prospects. It could have originated from any one of a number of sites. Similarly, the highest arsenic concentration in a heavy mineral fraction (1120 ppm) occurred in a till at the base of borehole 53 near the Kam-Kotia mine site. The arsenic may be associated with sporadic gold mineralization in the sulphide orebody, but on a regional scale, arsenic is not particularly useful in determining potential mineralization, because of its low abundance in all fractions analyzed.

Industrial minerals, silica sand, and kaolin, have attracted attention to the Mattagami Formation in the southern end of the Moose River basin. Detailed drilling by Carlson Mines in Kipling Township was intended to establish the viability of these resources (Kettles and Wyatt, 1988). The cores from Smoky Falls exhibited some incorporation into the tills of well rounded and frosted quartz granules in the pebble lithology counts. This component dropped off rapidly southward. It is not known how much Cretaceous sand in the 0.063 to 0.25 mm sand size range was separated into the light split from heavy mineral processing of these till samples.

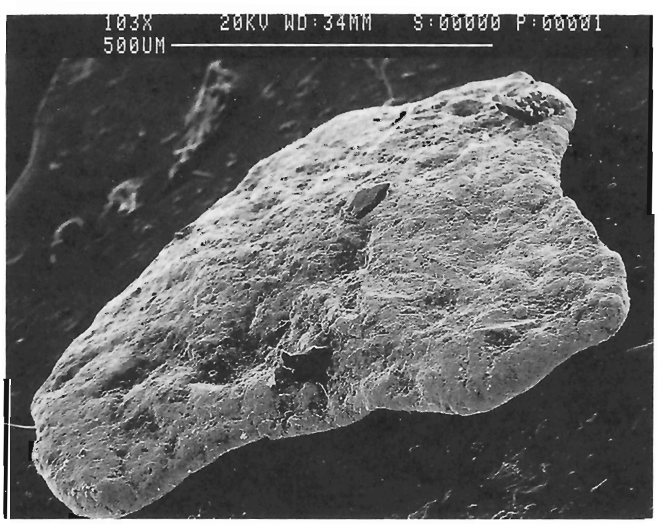


Figure 38. Scanning electron microscope backscatter image of gold grain from sample 8018 (see Fig. 37 for locality).

Kaolin, used as a fire clay in ceramics, occurs as relatively clean deposits associated with the silica sand. Borehole 41 intersected approximately 5 m of clean, blue-grey kaolin (Fig. 39) at its base in a bedrock depression. The overlying till had incorporated clasts eroded from the clay. Detailed clay mineralogical study of till units in this area, focusing on identification of kaolin, would likely be able to define glacial dispersal of this material south from the Cretaceous sources in the Moose River basin. Clay mineralogy may be a useful tool to prospect for deposits of this type.

Striation records

Although Skinner (1973) used till fabric and striated boulder pavements to infer ice flow directions for various tills in the Moose River basin, the sonic drill cores can not provide this type of information. Even very compacted tills experienced some reorientation in the drilling process. An attempt to extract microfabrics by magnetic analysis of carefully collected, oriented cores was unsuccessful. Thus, ice flow directions in the study area are largely inferred from compositional data. For later glacial events, these data are compared to and supported by scarce striation data from the study area.

Striated bedrock outcrop is very rare in accessible parts of the study area. Striated outcrops were sought along the access routes used for drilling and in areas of known extensive outcrops in the vicinity of Kamiskotia Lake and southwest of Kapuskasing in Cargill and adjacent townships. Active logging and road-building south of Kapuskasing provided access to cleared areas with freshly excavated outcrops. Striae were well exposed by mining activites at Kam-Kotia, and at the site of the former Genex Mine, where bedrock has been stripped of overburden for exploration and mining (Fig. 40).

The relative abundance of both cleared and natural outcrop near Kamiskotia Lake provided one of few opportunities to investigate erosional traces of multiple ice flow events. Multiple striation directions are well preserved on smooth, polished metavolcanic and volcanogenic sedimentary rocks in this area (Fig. 41). On the open pit periphery, bedrock exposures that were rich in sulphide minerals (pyrite and chalcopyrite) exhibited well developed, recessed grooves down-ice from small, weathered pits that once housed these mineral grains (Fig. 42). On nearby outcrops, small quartz veins or nodes provided erosion-resistant knobs behind which were developed rat tail striae (Lortie and Martineau, 1987) as flow direction indicators. In general, the fine scale striae developed in this area average a millimetre or so in width and may be several centimetres long. Crosscutting age relationships could frequently be determined where multiple directions were preserved on the same outcrop.

The youngest ice-flow direction recorded in the Kamiskotia area, indicated by crosscutting relationships, is toward approximately 150° to 160°. The other strong, next oldest ice flow direction is southward and ranges from 170° to 190° (Fig. 43). Both of these directions may be represented at one site with equal intensity of scouring. At several sites, the 170° striations were seen to crosscut, and are younger than, the 190° striae. The oldest direction of ice movement preserved as striations is toward about 220° with an intermediate direction of 200° to 205° sporadically represented. Where surfaces are flat and unobscured, multiple crosscutting relationships were observed (Fig. 44). However, at a number of sites, striations were observed to "wrap around" curvature on the sides of the outcrop itself. These curving striae were interpreted as being related to one of the already described directions but locally altered by topography.

The other area of significant outcrop within the bounds of this study, lies southwest of Kapuskasing, primarily in Cargill and adjacent townships. Figure 45 summarizes striation measurements on exposed bedrock in this area.

Figure 39. Approximately 5 m of clean, blue-grey kaolin cored at the base of borehole 41. (GSC 204731-1K)

a

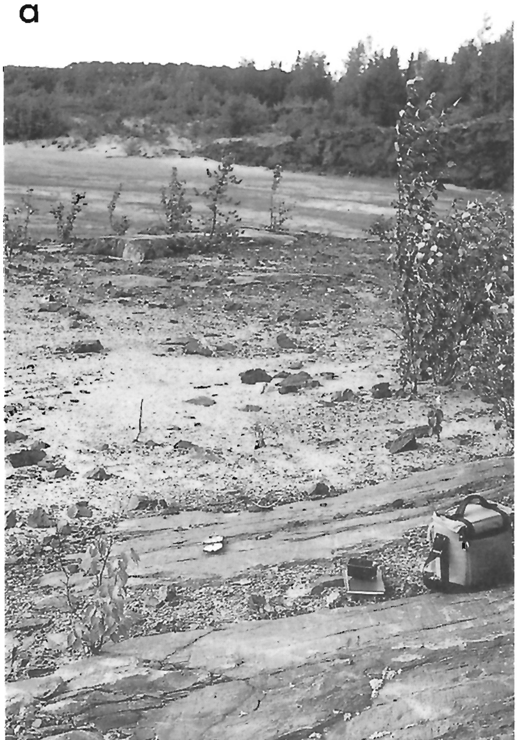


Figure 40. a) view looking north at the edge of the Kam- Kotia Mine open pit. Note well striated, sulphide-rich bedrock in foreground. (GSC 204731-L); b) Manual clearing at former Genex Mine has exposed well striated and sculpted pillow lavas. (GSC 204874-A)

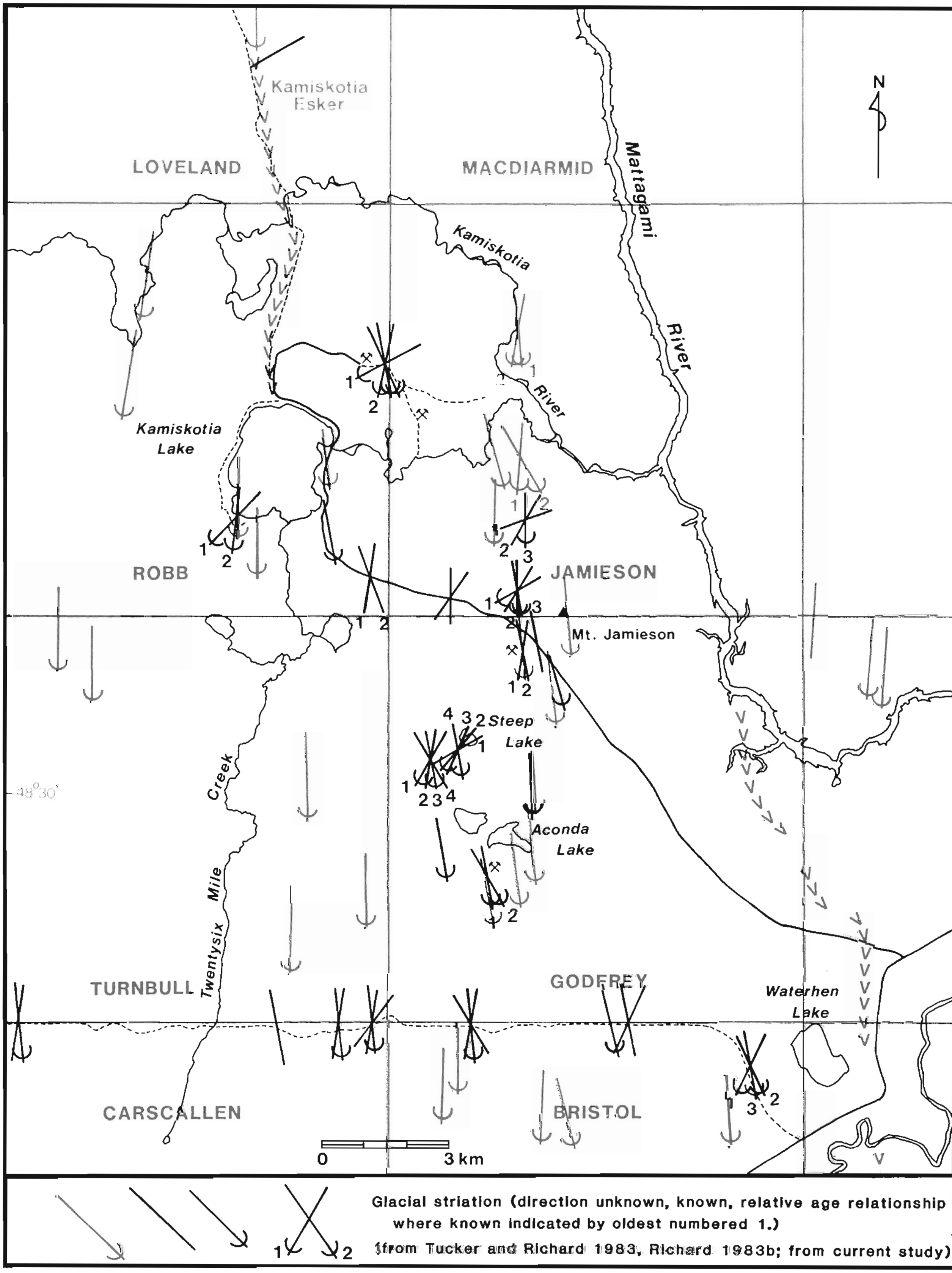


Figure 41. Summary of measurements of glacial striae and their age relationships, where evident, for the Kamiskotia area.

Figure 42. a) Example of small grooves, probably due to ice erosion but may also have been formed by water, and mineral pits from the weathering of sulphide minerals prior to glacial scouring, parallel to a southward flow direction; southeastern edge of Kam-Kotia Mine open pit. Compass points up-ice. (GSC 204731-X); b) Grooves may change direction and "wrap" down into larger, older glacial groove as evident in foreground. Compass points southward. (GSC 204731-Y)

Figure 43. Striations at the southeastern edge of the Kam-Kotia pit range in direction from 160°-180°. (GSC 204731-M)

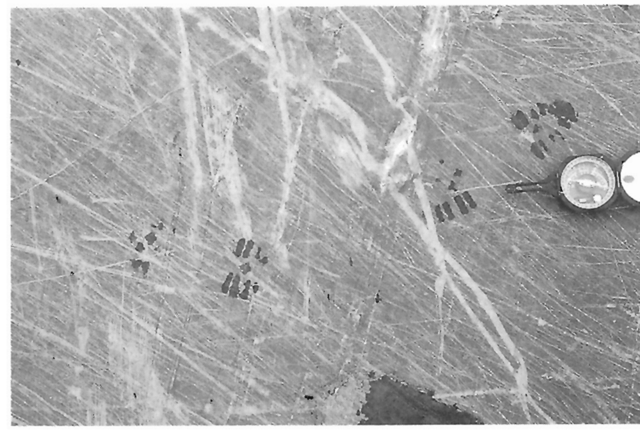


Figure 44. Striated surface with ice flow directions, from oldest to youngest, towards 205°, 155°, and 170°; Bristol Township. At all other sites that preserved both younger directions, 155° appeared to be the youngest direction of flow. Compass points to 155°. (GSC 2204731-R)

Southwest of Kapuskasing the rock types are primarily fine grained granite or gneiss, with local mafic intrusions/dykes as at the Sherrit-Gordon mine site in Cargill Township. Much of the land in Cargill Township has been cleared by logging, which makes bedrock exposure easy to locate. Figure 46 shows a photograph of an outcrop with the dominant direction towards 130°, with an earlier (older) 180° direction preserved in a lee-side groove in the granitoid bedrock. The strong, southeasterly oriented striae are interpreted as younger than the southward flow based on several clearly determined sets of crosscutting striae. Both directions were easily identified at about 15 sites within the zone of southeasterly oriented striae (Fig. 47).

Ice flow indicators in the 130° direction, occur only within a limited area and are transverse to the "normal" regional flow indicators. This area was labelled "Zone A" by Boissonneau (1966, p. 563), and is readily apparent on the Glacial Map of Canada (Prest et al., 1968). On these maps the zone was defined predominantly by drumlinoid landforms and flutings. Although Boissonneau (1966) reported crossing striae at one site at Lowther that he interpreted as being ice flow first southeastward (about 130°) and then southwestward (about 220°), the evidence is strongly to the contrary in Cargill Township. The southern boundary and southeastern extent of this zone is poorly defined due to lack of access.

A westward ice flow direction, moderately well developed, was preserved at only one site in the study area (Fig. 45, 48). If a westward flow existed, it appears to predate a southwestward advance and was definitely older than the youngest 130° regional flow direction on the basis of one weak striation site within the zone of 130° flow. One poorly preserved striation site in the floor of the Adam Creek spillway was oriented with a trend of 175°, which may represent the early phase of Adam Till flow, or the southward Kipling advance.

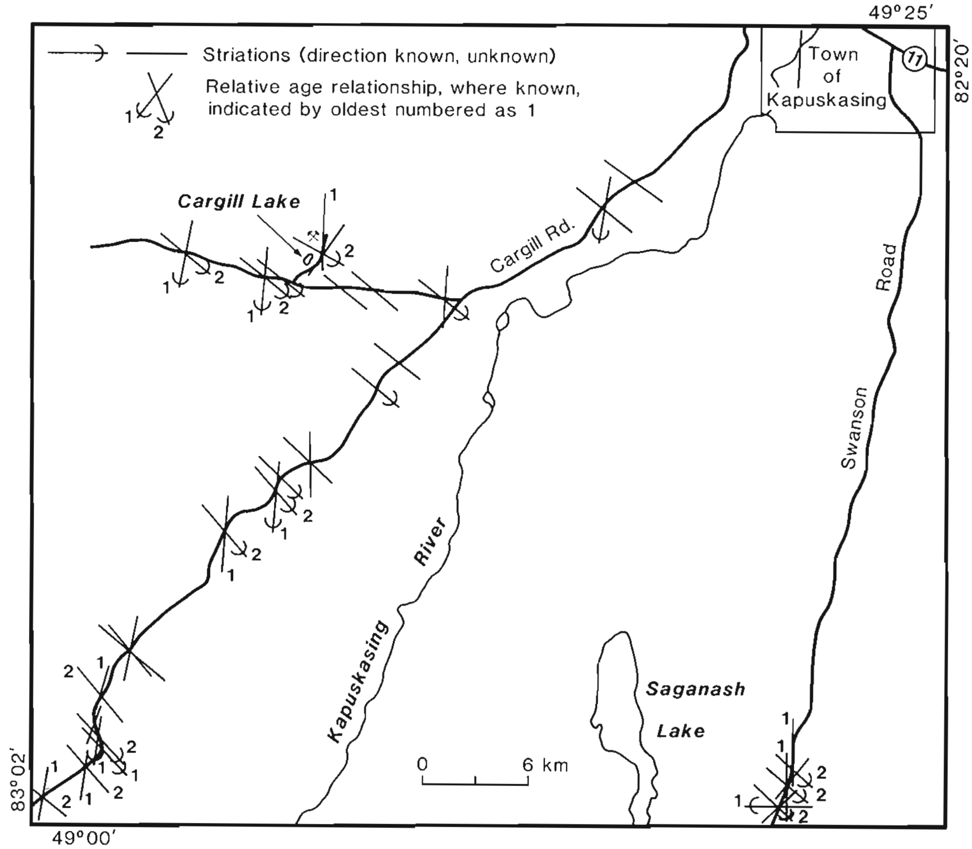


Figure 45. Striations recorded during the 1988 field season in the area southwest of Kapuskasing.

In general, the striation records, although sparse given the size of the study area, seem to indicate that the oldest flow is southwestward, shifting gradually to southeastward. Within a single advance such as the Matheson glaciation, ice may have shifted from south-southwestward at its base to southeastward in the latter stages as documented in the Abitibi area (Veillette, 1986) which would explain the range of striae directions (i.e. 170° to 190°) that may be related to the same event in the Timmins area.

Figure 46. Strongly sculpted and striated granitic bedrock in Cargill Township. The major direction of flow towards the southeast (130°) obviously postdates the direction toward 190° which is preserved only in the lee side of the gulley in the top right-hand portion of the photo. (GSC 204731-Q)

Ice flow directions

Ice flow direction indicators, inferred from provenance of distinctive materials in tills, distinct compositional differences between tills, and regional compositional trends through the stratigraphic cross-sections, can be linked with the sparse regional striation measurements to provide a plausible sequence of successive flow directions for the study area. It is postulated that ice flow shifted from southwestward (220° to 230°) in Till II and possibly Till III, to southward (190° to 175°) in Matheson Till, which was still influenced by southwestward flow at its base, to the latest southeastward (175° to 150°) advance of Cochrane Till. The southwest ice flow direction appears to have been a direction of dominant or sustained flow. A "tongue" of ice, perhaps part of a more regional event, surged toward 130°, which postdated other advances in that area. A single striation record of westward ice flow cannot confidently be integrated into this model, except perhaps as a component of the southwestward events.

The regional summary of down-core compositional data consistently indicates upward increases in Phanerozoic basin components from the bottom to the top of the stratigraphic

Figure 47. a) Striated outcrop south of Kapuskasing with the compass pointing toward the southeastward flow direction (130°). An older set of striae with a trend of about 180° is preserved on the lee side of the outcrop visible at the right-hand side of this photograph. (GSC 204731-O); b) Preservation of two sets of striations, towards 140° and 190°, at another site near Kapuskasing. No relative age relationship was evident at this site. (GSC 204731-1A)

Figure 48. A striated outcrop in Fenton Township, south of Kapuskasing, that preserved three ice flow directions, marked by sticks to amplify their visibility in the photograph. From oldest to youngest they are 049° (no sense of direction evident), and towards 270° and 133° respectively. An intermediate, southerly direction was poorly represented. The westerly direction was not observed on any other exposure. Top of the photo is looking east. (GSC 204731-P)

column. This is a strong argument for the shift in ice flow directions from the southwestward (Archean-dominated provenance), to the south-southeastward. In tills deposited by south-southeast flow Phanerozoic debris comprised a significant proportion of the derived materials, diluted somewhat by crystalline lithologies with increased distance of transport from the Paleozoic/Precambrian contact. The regional contrast in provenance is most pronounced in the area near the Paleozoic/Precambrian contact, specifically at the sites drilled at Smoky Falls.

Kipling Till is correlated with Cochrane Till and Matheson Till is correlated with Adam Till in the Smoky Falls cores on the basis of relative stratigraphic position and associated glaciolacustrine sediments. In addition, the ice flow directions inferred from composition in each till, indicates similar provenance. Both Kipling and Cochrane tills are extremely rich in carbonate components, which is consistent through the study area. This last ice advance is correlated with southward to southeastward striation data which corroborates a largely Phanerozoic provenance based on geochemical and lithological data.

Although Skinner (1973) measured some southwestward till fabrics in Kipling Till in the Moose River basin, the compositional evidence from this study suggests a more southerly ice flow direction. Two till fabrics from the southern Adam Creek spillway section, measured in Kipling and Adam tills, suggest a southeastward and stronger southwestward orientation of pebbles respectively (Fig. 49). Adam Till has been associated, at least in part, with a southwesterly ice flow direction based on limited till fabric and striated boulder measurements (Skinner, 1973). This southwesterly component is probably representative of the lower part of the compositionally complex Matheson Till. As is typical of the two uppermost tills of the region, Adam/Matheson Till was probably deposited by ice flowing radially from a centre to the northeast, or alternatively, from a shifting centre of flow, which would account for the apparent shift of ice flow directions from southwestward, to more southerly in the southern part of the study area. Perhaps the majority of the fabrics measured in Adam Till by Skinner (1973), are representative of an earlier phase of southwestward flow that shifted southward as the advance progressed, similar to the change described in the Abitibi region by Veillette (1986).

A strong argument for a southwestward to southeastward ice-flow shift is also evident in geochemical analyses of heavy minerals. The increased concentration of Ag, Cu, and Zn in the heavy mineral geochemistry of tills in the Smoky Falls cores suggests that the ice was tapping a source rich in these components, probably from mineralized showings in Proterozoic sedimentary rocks in either the Sutton Ridge, or the Belcher Fold Belt. The relatively high concentration of these elements is due, in part, to the lack of dilution by

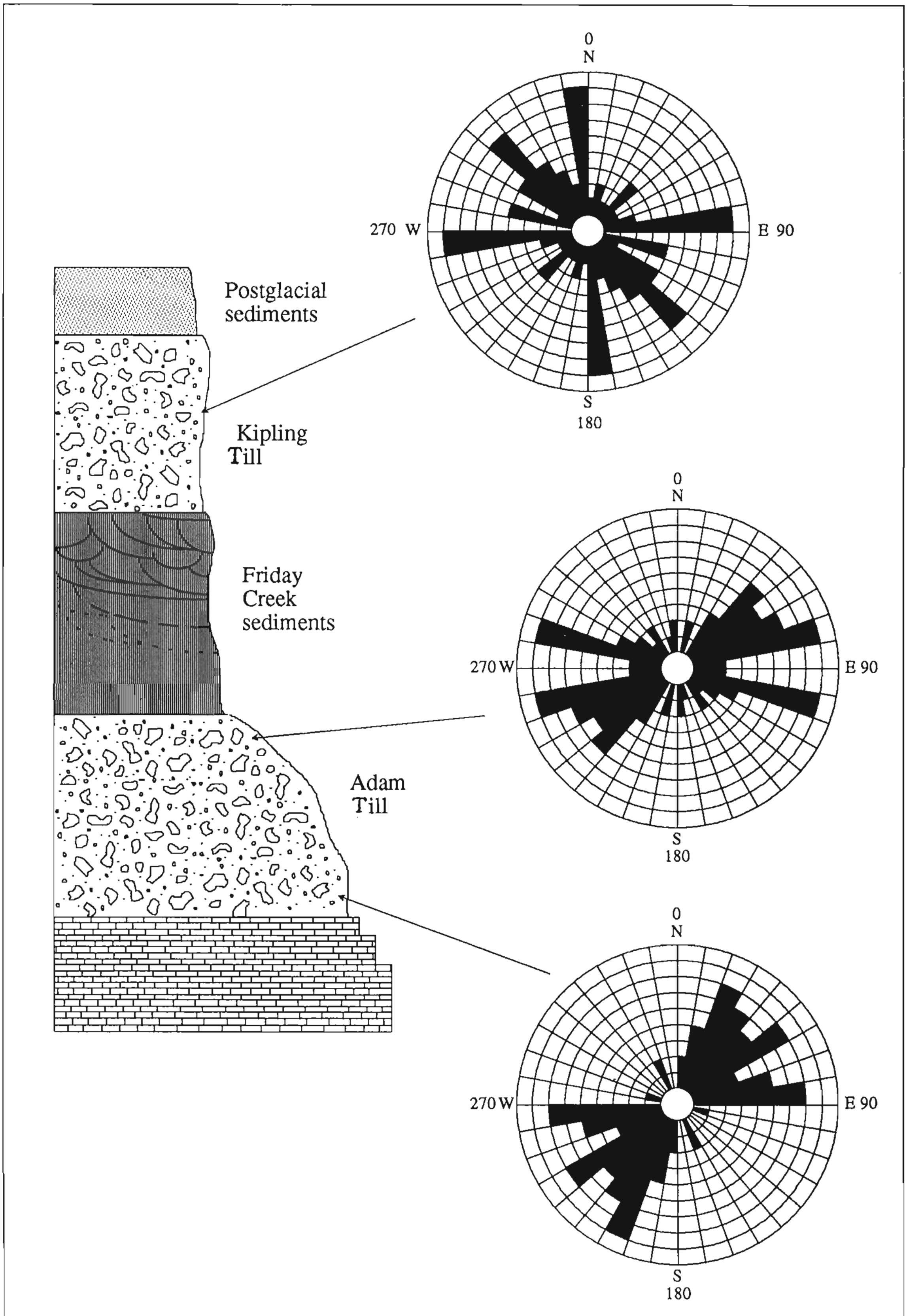


Figure 49. Sketch of composite Adam Creek spillway section with till fabric diagrams.

other heavy minerals, as the Phanerozoic terrane does not contribute a significant quantity of heavy minerals, other than siderite and pyrite, compared to crystalline terrane. With increased distance of transport southward onto crystalline terranes of the study area, these heavy mineral suites are diluted by metal-poor siliceous heavies of the higher metamorphic grade Archean bedrock. South of the Phanerozoic/Archean contact, the rate of depletion of heavy minerals from the Proterozoic source areas may be exponential with distance (Shilts, 1984).

Ice that deposited the three tills recognized in the Smoky Falls area tapped Proterozoic source areas in the Sutton Ridge or the Belcher Belt, based on the heavy mineral geochemistry and on clast lithologies. In the uppermost till, Kipling (Cochrane) Till, the intensity of the geochemical signals from trace elements, in combination with an inferred southerly flow direction, suggests provenance in the Sutton Ridge area. In the lowermost tills, Adam (Matheson) Till and Till II, ice flow directions of west of south and southwest respectively, indicate a provenance largely in the Circum-Ungava Belt from the east side of Hudson Bay. Ice that deposited Adam Till may also have had some influx of material from the Sutton Ridge in the later stages of flow, when the ice shifted from about 210° to 180°. The relatively higher content of Cu and Zn in the upper samples of the unit is inconclusive at present. These data corroborate the sequence of ice flow directions for the three tills represented at Smoky Falls as southwest, west of south to south, and southerly to southeasterly, from oldest to youngest repectively.

At Kamiskotia, dispersal of indicator metals from the sulphide showing was not detectable as a definable dispersal train, probably due to the somewhat limited areal distribution of the drill sites. Unfortunately, much of the area southwest and down-ice of the mine site was inaccessible to the drilling equipment. Therefore, inferences about ice-flow direction from dispersal trains are restricted to qualitative evaluation of contoured sample points (Fig. 50). From these diagrams, it was estimated that the lower till, Till II, was deposited from ice moving towards the south-southwest, compared to the more south-southeasterly Matheson advance. Alternatively, Till II could represent an earlier phase of Matheson flow prior to the ice shifting to the southeast, but this cannot be confirmed.

Depositional models

Each time ice advanced or retreated in the Moose River basin and southward, it did so against the regional gradient, causing the cyclical formation of proglacial lakes ponded against the ice margin, into which fine grained sediments were deposited. This phenomenon is well represented in the stratigraphic column as all tills in the Moose River basin, both pre- and post-Missinaibi, are interbedded with glaciolacustrine deposits. Glacial erosion of this material by subsequent ice advances is largely responsible for the fine grained character of most of the tills deposited in the study area. Deposition of fluvial sands and gravels with current directions northward, parallel to present drainage, represent free drainage with an open Hudson Bay.

The proglacial lake for which there is the most significant stratigraphic record, comprising up to 50 to 90% of the sediment pile in parts of the study area, is glacial Lake Barlow-Ojibway. Sand at the base, perhaps deposited in front of subglacial conduits, is overlain by up to 5 m of rythmically laminated silt-clay couplets, which are in turn overlain by thick, structureless, stone-poor clay. The rythmites traditionally have been thought to represent seasonal deposition of fine material in a large proglacial lake (Antevs, 1925). They are typically slightly to moderately contorted or convoluted at the top of the sequence, immediately below the sharp contact with the overlying massive clay. The unlaminated clay of the succession was probably deposited from turbid suspension in the distal, deep part of the lake after the ice front had retreated substantially. It has been overridden, and to some degree reworked, by the subsequent Cochrane readvance, but the thick, massive clay is not solely a by-product of churning up of the laminated sequence because the mean grain size is much finer in the massive material. Boissonneau (1966) described 1.5 to 3 m thick exposures of massive clay overlying laminated sediment as depression fillings in the Lake Abitibi region but attributed its structureless nature to subaqueous slumping of layered material. Large quantities of clay also could be interpreted as a till deposited from glacial erosion of a very erodable, clay-rich Paleozoic substrate. At its thickest point in the cores, this unit is 28 m. Based on the EM geophysical surveys, this unit is areally extensive and is thickest in the northern part of the study area.

The glacial Lake Barlow-Ojibway succession is the best preserved analog of earlier glaciolacustrine sequences, of which only remnants have been protected from glacial erosion. If this is the case, then abundant fine grained sediments were available for incorporation into tills after each nonglacial interval. Cochrane Till has incorporated significant amounts of clay from the Barlow-Ojibway Formation sediments as is apparent from its clast-poor silt and clay-dominated texture. Thus, during each ice advance, extensive lacustrine rhythmites and clay would provide a source of abundant fines, as well as a readily deformable substrate over which the ice could glide.

Two models of glacial deposition can be recognized that are directly tied to the nature of the bedrock substrate. Quaternary stratigraphy in the Moose River basin and northward is very complex, the composite stratigraphic column comprising up to 6 or 7 till units and interbedded waterlain materials (Skinner, 1973; Andrews et al., 1983). The Moose River basin and James Bay Lowland consist of nearly flat-lying carbonate sedimentary rocks that are relatively erodable. Quaternary stratigraphy, as cored over Precambrian terrane is less complex than that of the Moose River basin, to a maximum of 4 or 5 till units represented. This is likely due to the lack of preservation of old sediments by enhanced glacial erosion, rather than a lack of deposition.

Relative to Phanerozoic lowlands, Precambrian bedrock is very irregular with extreme topographic relief in places. Much of the relief is subdued by infilling with glacial sediments. Irregular relief at the base of the ice may have

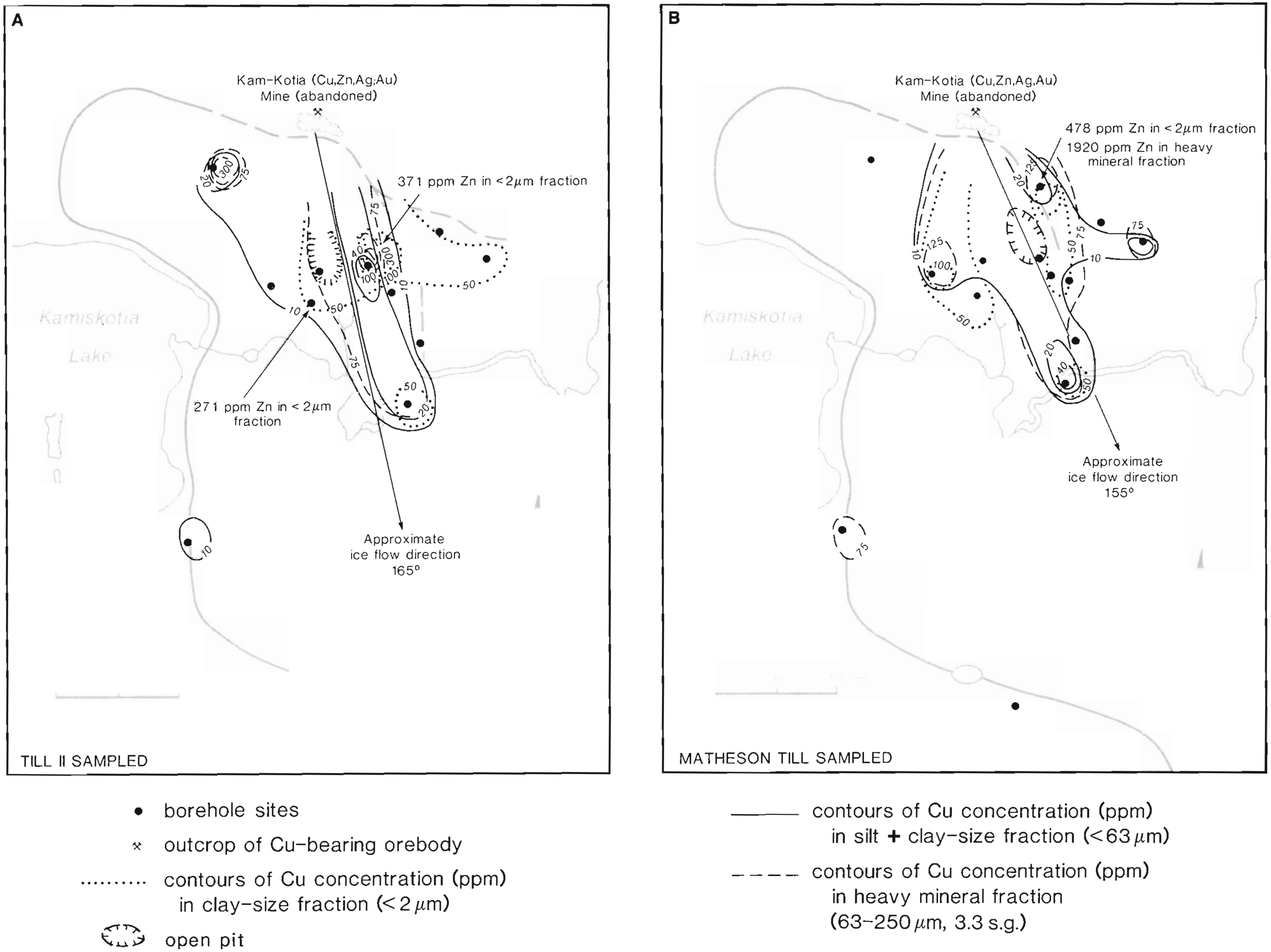


Figure 50. a) Contoured copper concentrations in different size fractions of Till II samples. Note general southerly (165°) dispersal pattern; b) Contoured copper concentrations in different size fractions of Matheson Till from cores at Kamiskotia. Note general southeasterly (155°) dispersal.

promoted erosion of debris, even though crystalline rocks are generally more resistant to erosion than Paleozoic sedimentary rocks. The Shield topography may have caused a large quantity of material to be sheared upward and transported englacially or superglacially, to be deposited thinly over a greater area. In the very erodable, Paleozoic carbonate terrane, the debris-rich ice would likely have been at the base or dominated by basal transport. The flat-lying nature of the basin could have provided a uniform substrate for likewise blanket-like deposition of glacial tills. Rugged terrain is characterized by deposition in buried valleys or other bowl-like depressions, in contrast to the "layer-cake" type of deposition associated with the more deformable terrane to the north. In relatively less rugged areas of Precambrian basement, the stratigraphy is dominated by the latest glacial units, supporting the concept of effective glacial erosion of older debris.

The nonglacial sequence of the Missinaibi Formation, well represented as terrestrial, marine, and lacustrine members north of Smoky Falls almost to James Bay, was not identified in any of the 70 cores to the south. Deposition and erosion of this marker horizon have probably also been influenced by the irregular topography of the Shield. Development of the forest-peat marker horizon could have been limited strictly to isolated basins in bedrock depressions, and/or was extensively eroded by ice in subsequent advances. South of the Moose River basin, only the lacustrine member was cored. Disseminated organic debris identified as Missinaibi-like, was dispersed through several stratigraphic levels in the cores, but no in situ deposit was found.

It is difficult to believe that formation and deposition of the Missinaibi Formation sediment assemblage was restricted to the Moose River basin, as one would expect at least the peat to be regionally extensive because of widespread climatic influences. Therefore, it could be concluded that the process of glacial erosion on Shield terrain is more effective than glacial erosion of sediments in the Phanerozoic basin. This is manifested as well by the extreme thicknesses of sediment preserved over carbonate terrane, upwards of a hundred metres (Watts, Griffis and McOuat Ltd., 1984), compared to an average of 30 m in buried valleys of the "Clay belt" physiographic domain. In areas lacking the thick blanket of glacial Lake Barlow-Ojibway clays, the average Quaternary overburden thickness is less than 5 m except in local deep bedrock depressions.

The predominant depositional model in the study area is one of repeated ice advance over fine grained, deformable, lake basin sediments, coupled with effective erosion of sediments not protected in steep-sided bedrock depressions. In addition, the mode of entrainment and transport of glacial debris was apparently different in the "soft", erodable, flat-lying carbonate terrane compared to the relatively rugged, highly erosion-resistant crystalline terrane of the Canadian Shield. These differences are manifested by the texture, thickness, and lack of stratigraphic complexity of the overburden sediments observed in cores from Precambrian terrane, compared to that of natural sections in the James Bay Lowland.

Glacial history of the region

The study area and the Moose River basin, located close to the former geographic centre of the Laurentide Ice Sheet should bear record of the glacial pulses that occurred over the history of this continental ice mass. It is important to review briefly the somewhat conflicting concepts of the configuration and dynamics of the Laurentide Ice Sheet on a regional scale in order to discuss local Quaternary history and ice flow directions. For the purposes of this discussion and paper, the stage and substage terminology and their associated time spans as outlined by Fulton and Prest (1987) will be followed.

Tyrrell (1898, 1913) published comprehensive discussions of the Quaternary evolution of Hudson Bay in which he proposed a multiple ice sheet model. In his model, a Keewatin ice sheet experienced several episodes of expansion and contraction followed by expansion of Labradorean ice across the southern part of Hudson Bay. Tyrrell (1913) also proposed the existence of a Patrician centre of ice flow between Hudson Bay and Lake Superior. According to Tyrrell, northward flow from this centre affected areas as distant as the Nelson River in Manitoba.

Flint (1943), basing his theories on the limited geological information available at the time and citing the apparent pattern of postglacial uplift of the Hudson Bay region, proposed that the last central North American (Wisconsin) ice sheet, which had by then been termed the Laurentide Ice Sheet, formed a single dome, the centre of which was located over Hudson Bay, throughout most of the Wisconsin stage. Flint suggested that this configuration existed until late-glacial sea level rise split the dome into two ephemeral ice sheets centered in Keewatin and Labrador. He suggested that these late-glacial centres subsequently produced the observed geomorphic evidence of ice flow. Subsequent investigations in the 1950s confirmed the existence of ice divides on the east and west sides of Hudson Bay, although Flint's concept of a single ice dome could still be explained if the divides were considered to be late glacial phenomena (Lee et al., 1957).

A number of important ideas concerning the Quaternary history of the Hudson Bay region and the dynamics of the Laurentide Ice Sheet have been developed within the past ten years. Basically two schools of thought have emerged, those who apply modern glaciological principles to Flint's model of the configuration and history of the ice sheet (Sugden, 1977; Denton and Hughes, 1981, 1983; Budd and Smith, 1987), and those who base their interpretations of multiple, coalescing centres of outflow in Keewatin and Quebec-Labrador throughout the Wisconsin on petrographical, geochronological, and geological data (Andrews et al., 1983; Dyke et al., 1982; Boulton et al., 1985; Dyke and Prest, 1987; Prest and Nielsen, 1987; Shilts, 1980, 1982, 1985, 1986). The latter, more complex interpretation, favours the idea that dispersal data can be best explained by ice moving from several independent dispersal centres, although debate still exists as to the configuration and positions of ice divides, domes, ice streams, and the ice sheet margin itself (Prest, 1984; Fisher et al., 1985; Dyke and Prest, 1987). Debate also continues as to whether there was a discrete Patrician ice centre that produced northwestward-oriented striations in parts of northern Ontario (Wyatt, 1989; L.H. Thorleifson, pers. comm., 1988). Perhaps, such a dome was active during inception of the last ice sheet, rather than serving as a major centre of outflow (Dredge and Cowan, 1989) throughout the last glaciation. The following discussion will focus on the southern Hudson Bay Region as it is most relevant to this study.

Dyke et al. (1982) defined an ice sheet configuration with Hudson Ice distinct from Labrador and Keewatin ice. Dredge and Cowan (1989) present a comprehensive discussion of this multi-dome model of late glacial flow in the southern Hudson/James Bay area. The model of Dyke et al. (1982), which inferred an ice dome over southern Hudson Bay at the Late Wisconsinan maximum, attempted to deal with ice sheet asymmetry and still explain at least some of the dispersal patterns of distinctive erratics southwest into Hudson Bay Lowland (Fig. 51). A Hudson Ice Divide south of the Belcher Islands was envisaged as separating the onshore flow in southern Hudson Bay from northward funneling flow in the northern part of the bay. This configuration could have migrated during episodes of shrinkage and regrowth early in Late Wisconsinan time (Dyke and Prest, 1987).

Shilts et al. (1979) and Shilts (1980) proposed a two-domed model of the Laurentide Ice Sheet at the Late Wisconsinan maximum in which Labrador ice flowed southwestward across northern Ontario (Fig. 52), to explain the distribution of dark erratics from the Proterozoic circum-Ungava belt on the east side of Hudson Bay, carbonate dispersal onto the Shield (Fig. 53), and erosional and depositional glacial features. Adshead (1983a, b), Henderson (1983, 1989), and Paré (1982) asserted that the ice mass affecting the Hudson Bay Lowland was centered in Quebec, based on heavy mineral studies of glacial and derived sediments. Subsequent authors have questioned whether there may be alternative source areas for these rock types, if they are polycyclic, or redispersed by a later flow that was not centered in Quebec-Labrador (Dyke et al., 1982; Prest and Nielsen, 1987; Dredge and Cowan, 1989). Southwestward to southward flow and dispersal of these erratics could also be attributed to the development of a saddle extending across Hudson Bay joining domes in Keewatin and Quebec (Dyke and Prest, 1987; Dredge and Cowan, 1989).

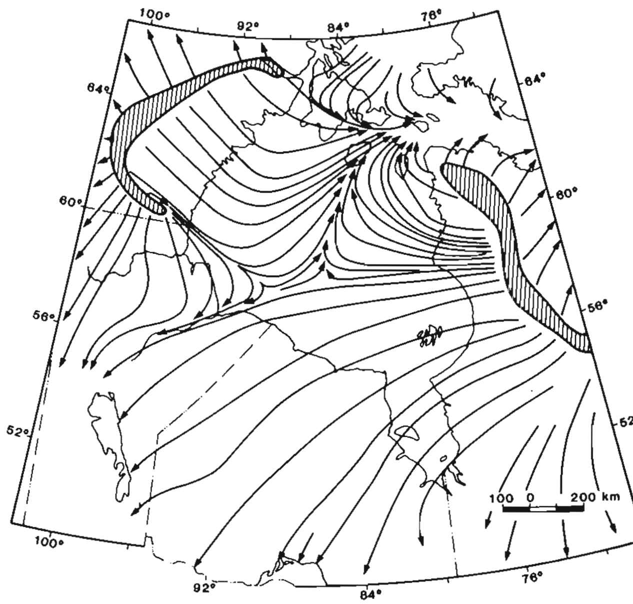


Figure 52. Flow lines reconstructed from dispersal patterns of erratics reflecting the postulated configuration of the Laurentide Ice Sheet at its Late Wisconsinan maximum (from Shilts, 1980).

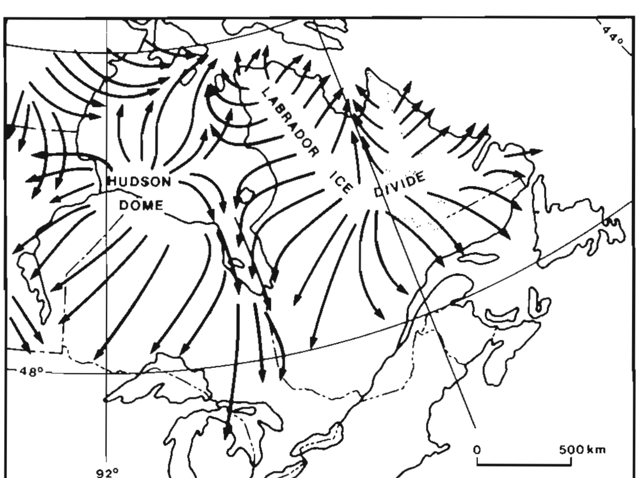


Figure 51. Model of multidome Laurentide Ice Sheet showing position of postulated Hudson Dome at the Late Wisconsinan maximum (from Dyke et al., 1982).

Multiple, lobate advances, termed the Cochrane "readvances" (Prest, 1970; Hardy, 1976), flowed generally southward in a radial pattern to blanket a large area south of James Bay during the Holocene (Hughes, 1965; Boissonneau, 1966; Hardy, 1977; Veillette, 1986). Prest (1969) considered the 800 to 1200 km readvances to be from an ice mass retreating towards Labrador, whereas Hardy (1976, 1977) viewed the southeasterly advances as coming from a Hudson-based ice mass. Shilts (1980, 1985) described the major Cochrane event as emanating from ice retreating to a Keewatin centre (Fig. 54). Dredge and Cowan (1989) preferred the interpretation of a series of 50 to 75 km surges along a continuously retreating Hudson Ice front, based on evidence of Cochrane flutings. Hughes (1965) estimated the minimum age of the Cochrane in southern James Bay as 8275 BP, by taking a radiocarbon date for initiation of the Tyrrell Sea at 7875 ± 200 BP and adding 400 years for the varve chronology of the area.

Given the variation in interpretation of the configuration of the Late Wisconsinan ice mass, a number of observations can be made from the study area that may have bearing on the glacial history of southern James Bay. Compositional data and ice flow directions inferred from it in the course of this study, have delineated an ice flow history shifting from southwest (oldest) to southeast in the final ice advance. The

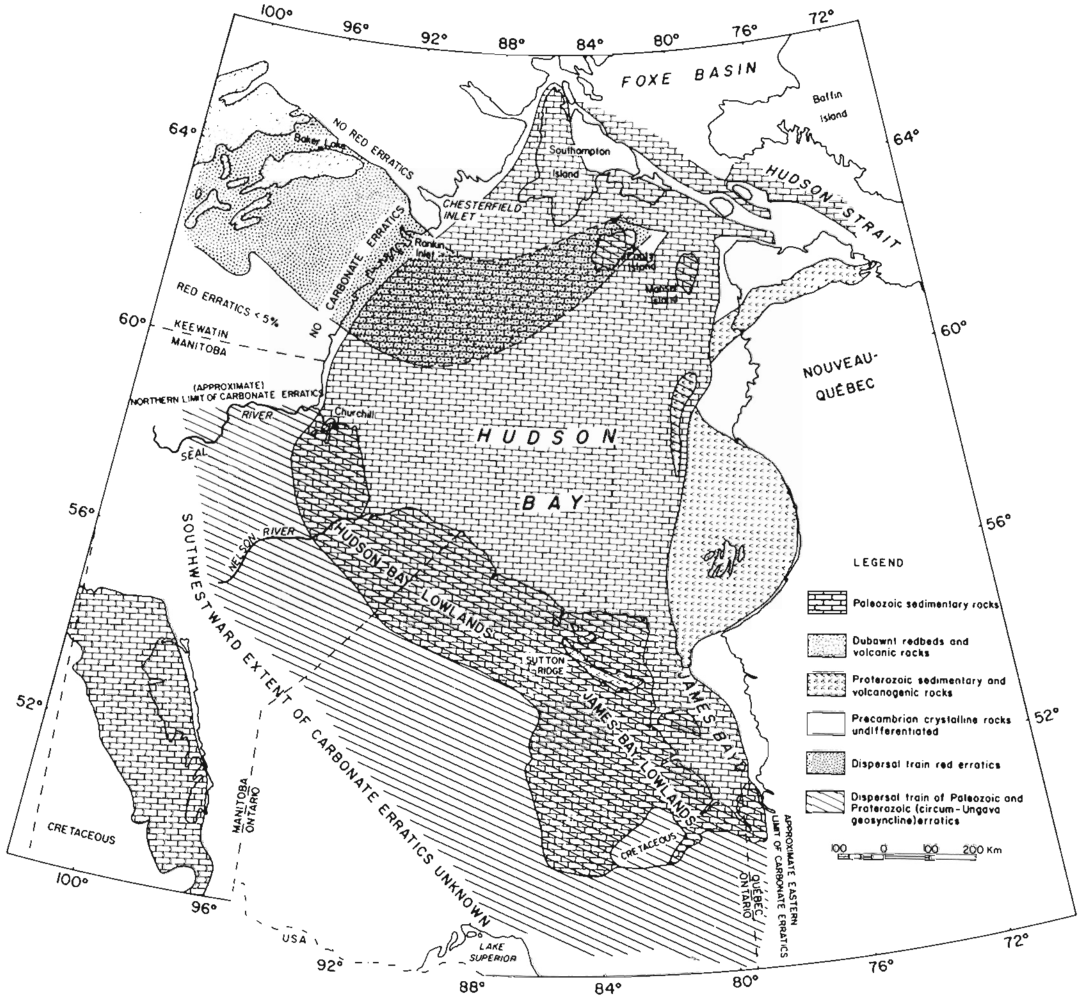


Figure 53. Major dispersal trains of the Laurentide Ice Sheet. Note the approximate southeastward limit of Paleozoic carbonate and Proterozoic erratics from Hudson Bay (from Shilts, 1982).

oldest recognized till is so sparsely preserved that an ice flow direction cannot be estimated for it, although a westward direction was preserved at one weak striation site. Westerly ice flow through the region, possibly as a component of a major southwest event, cannot be ruled out. There is a greater body of evidence for a westerly ice flow direction in central and northwestern Hudson Bay Lowland (Wyatt, 1989; L.H. Thorleifson, pers. comm., 1989). An isolated striation occurrence could, however, be misinterpreted.

Based on dispersal of material from distinctive provenance areas such as Phanerozoic, Proterozoic, and Archean terranes, the flow lines as envisioned by Skinner (1973) and Shilts (1980) at the Late Wisconsinan maximum, are supported by the geochemical and lithological findings in this study (Fig. 55). Certainly, ice flow from a Labradorean source was dominant through at least this, and perhaps older parts of the glacial record preserved in the cores.

The Hudson saddle model of Dyke and Prest (1987) does not seem to be supported by the compositional data from the study area, except as a late glacial feature, perhaps associated with the Cochrane readvances. However, the relatively high concentration of metals of economic interest, as displayed in the heavy mineral geochemistry of the Cochrane/Kipling Till unit, is so distinctive that it must have been derived from north of the James Bay Lowlands. The nearest sources are in Proterozoic rocks to the north (Sutton Ridge) and northeast (Belcher Fold Belt). The heavy mineral geochemistry and pebble lithology of the Kipling/Cochrane Till from cores and sections, indicates provenance predominantly from the Sutton Ridge, and possibly in part from the Belcher Islands.

During the last stages of glacial retreat, prior to the rapid incursion of the Tyrrell Sea into the James Bay Lowland, the southern ice margin was bounded by a complex of glacial lakes (Agassiz and Barlow-Ojibway) (Vincent and Hardy, 1979; Vincent et al., 1987). Stabilization of the mobile ice front is marked by moraines, many deposited subaqueously at the ice front. The Pinard moraine was probably formed as an ice-contact delta or immense subaqueous fan as interpreted from the cores and as suggested by Dredge and Cowan (1989). This moraine probably represents a pause in the retreat of the lake-

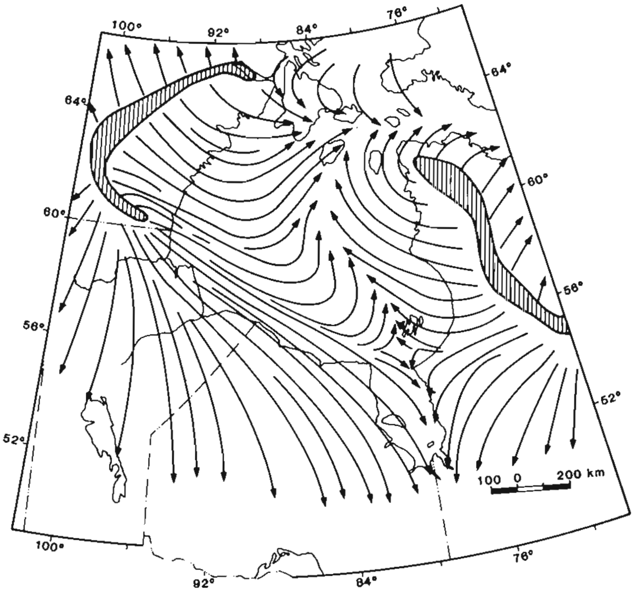


Figure 54. Flow lines reconstructed from striation and dispersal evidence that may reflect the ice flow configuration either early or late in the development of the Laurentide Ice Sheet (from Shilts, 1985).

bounded ice margin which was subsequently punctuated by "Cochrane" surges during re-equilibration and dissipation of the ice.

In light of compositional and stratigraphic evidence from this study, Kipling Till is viewed as correlative with Cochrane Till and Adam Till with Matheson Till, at least in the Adam Creek area immediately north of Smoky Falls. Because Cochrane Till drapes the Pinard moraine, it is

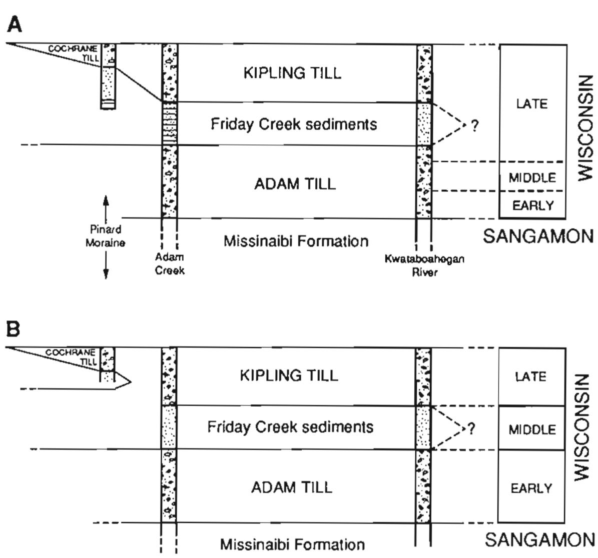


Figure 55. Two alternative models of Wisconsin glacial and interglacial events and relative time interval (Skinner, 1973). See text for dicussion.

thought that ice paused during its retreat to produce the moraine, subsequently retreated farther north to an unspecified point, and readvanced to deposit the Kipling/Cochrane Till. If the ice did retreat farther north than the Pinard moraine, as also suggested by Skinner (1973) and Kettles and Wyatt (1988), then the relative rates of retreat and advance would be rapid. Lee (1968) and Hughes (1965) both suggested that a rate of retreat of 300 metres per year was reasonable for this region.

Implications for drift prospecting

A generalized methodology for drift prospecting in this area is summarized in Figure 56. It consists of 1) defining the target area; 2) geophysics to map the subsurface and define drilling targets; 3) drilling to define stratigraphy from intact cores; 4) reverse circulation drilling to sample tills at depth; 5) identification of anomalous concentrations of elements of interest; and 6) following the anomaly up-ice to the source area by repeating this procedure in adjacent areas.

Geophysical surveys

Depending on the size of the property being investigated and the budget available, survey areas should be large enough to permit the detection of a suitably sized dispersal

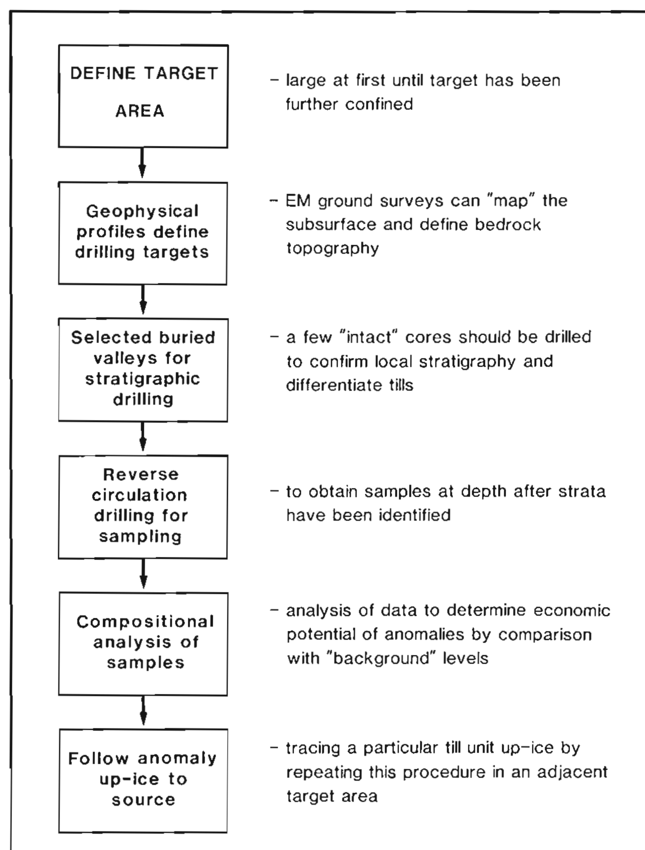


Figure 56. Schematic diagram of suggested drift prospecting methodology in the area north and northwest of Timmins.

train. Geophysical cross-sections of the ground to be covered should be as densely spaced as budget will allow. Geophysical surveys can locate buried valleys to be evaluated for drilling. Electromagnetic surveys with an Apex MaxMin system were successful at subsurface mapping of sediment types and depths, to an accuracy of ±10% (Fig. 25), and reflection seismic methods also produced satisfactory results at Kamiskotia (Fig. 24). Both methods have drawbacks, however. Reflection seismic appears to be more costly and time-consuming although it was not tested regionally, whereas accurate interpretation of the EM signal via computer modelling requires an experienced operator. Narrow, deep, buried valleys, targeted by the EM technique, are more likely to preserve older tills at the bottom than a wide depression, which is more susceptible to glacial scouring.

Bedrock topography is highly irregular, with little or no surface expression, so drilling without geophysical data can be quite random and unlikely to intersect the deep parts of buried valleys where the best stratigraphy is preserved. Again, EM ground resistivity mapping can pinpoint areas of shallow, but buried bedrock. Some subjective decisions can be made in order to target deep areas to drill. Even on the apparently flat Shield terrain, areas of deep fill are typically associated with modern lakes or river systems because they tend to form in slight surface depressions due to the compression of the thick sediment pile that fills the depressions. Buried valleys oriented transverse to the last major southward flow have the greatest potential of preservation of old sediments at depth.

Impediments to drift prospecting in the area north and northwest of Timmins are significant and include: thick glaciolacustrine cover, irregular bedrock topography, lack of bedrock outcrop with which to pinpoint source areas and, thus, ice flow directions, and problems with differentiation of till units which are only locally preserved. By far the greatest impediment to drift prospecting in this region is the thick accumulation of glacial Lake Barlow-Ojibway sediments (20 to 40 m thick) which makes drilling costly and presents difficulty in the prediction of till at depth without the application of geophysical backup to "map" the subsurface. Fortunately, the EM MaxMin system appears to be effective for mapping the extent of the clay-rich basin and is not likely to confuse tills with the much more conductive clays or with less conductive sand. Many of the ground EM profiles that were completed for this study, were not drilled because the signal indicated that the sediment at that site was predominantly silt/clay or sand with little or no till (G. Palacky, pers. comm., 1987, 1988).

Overburden drilling and till sampling

At least limited drilling should be carried out with the Rotasonic drill at selected sites in order to define local stratigraphy once exploration targets have been defined. Follow-up drilling with reverse circulation for sampling purposes can then be done much more effectively because it can be determined which strata are being sampled. It must be kept in mind, however, that reverse circulation methods return a slurry sample, so some fine materials are lost in the process. The potential for contamination of samples from one stratum to another is also much greater in reverse circulation drilling compared to the Rotasonic method. Considering the average depth of non-till sediment that blankets the region, and the cost of a drilling exploration program, reverse circulation can be the most cost-effective type of drilling for sampling purposes, providing that sufficient preliminary geophysical and Rotasonic drilling work is carried out as described.

Sediments to be targeted for sampling in a drift prospecting program are those tills deposited from ice that was most likely to have made contact with potentially mineralized bedrock. Because of various directions of flow of different glaciations and relative dilution by nonglacial lacustrine sediments, sampling of each stratigraphic unit enhances chances of intersecting a train in one of them. Common practise in the past has been to sample only the lowermost till. Cochrane Till is the least useful of the stratigraphic units as it is extremely rich in Paleozoic components and has primarily reworked Barlow-Ojibway lacustrine sediments, of little interest to explorationists. Similarly, the glacier that deposited the regionally widespread Matheson Till, although carrying a greater Shield component, had less chance of local bedrock contact than older glaciers.

Tills older than Matheson Till are preserved as depression infillings, suggesting that Matheson Till might be strongly compositionally influenced by high points on the bedrock surface. Relative resistance to erosion implies that granitoid crystalline or gneissic rocks would comprise these peaks for the most part, preferentially imparting signatures from these rock types to Matheson Till. More erodable areas, such as those underlain by supracrustal rocks, sulphide-bearing ore bodies, or structural discontinuities such as shear zones or faults could be expressed as depressions. This rationale favours sampling of older, depression-filling tills in areas of rugged bedrock topography, particularly in the southern part of the study area. Where only moderate bedrock relief is indicated by geophysics, Matheson Till may be in direct contact with a broader area of local bedrock, and should provide useful samples to the exploration program.

Irrespective of the relative age of a till, in any given glacial advance other than the Cochrane, whether local glacially eroded materials are carried as basal or englacial debris can be related, in part, to bedrock relief. In areas of rugged terrain, the basal facies may be carried longer distances through the lower levels of the landscape. The composition of the basal facies may contrast sharply with the englacial debris that may be tapping the higher parts of the surrounding terrain (Shilts and Smith, 1989). Alternatively, basal debris might be thrust into the englacial position by a glacier shearing upward over a bedrock prominence. Basal tills, generally deposited primarily from the debris-rich basal zone of a glacier, are very compact in section and in cores. Englacial debris typically forms a loosely consolidated mantle which may consist solely of a mantle of boulders at the top of a lodgment till or comprise a till stratum above the lodgment facies. Ablation debris may show more evidence of reworking or winnowing by water during deposition. The distinction between basal and englacial or superglacial facies must be kept in mind for a sampling program as the entrainment and transportation history of a glacial sediment has significant bearing on interpretation of distance of transport and composition (Shilts and Smith, 1989).

Tills in the study area seem to have been deposited largely by lodgment or basal meltout processes. They are very compact, exhibit no sorting by water, and may have laminar partings that could represent original stratification of debris bands within the glacier ice. Minor boulder mantles or sandy diamictons that cap compact tills may represent the englacial or supraglacial load and are recognized in some cores. This layer is generally somewhat sorted and may lack matrix entirely. Boulder pavements also are observed in section at the southern end of the Adam Creek spillway.

Identification of anomalies

Borehole and sample spacing and analytical technique can be tailored to the anticipated size of a target. In the first stages of defining an anomaly, spacing will of necessity be wide, and can be further reduced as more detail is acquired. The analytical technique used, and the sample size fraction chosen for examination, will depend on factors such as cost, reproduceability of results, and the degree of contrast between background and anomalous values (Shilts, 1976). If the proportion of silt to clay can be shown to be relatively constant over the study area, then the less than 0.063 mm (250-mesh) fraction is the most economical medium to sample and analyze. In the study area, heavy mineral grain identification, pebble lithology, and geochemistry of the silt+clay fraction (<0.063 mm, -250 mesh) provided the most useful compositional information for definition of stratigraphic units.

As a first approximation, tills can be differentiated by relative stratigraphic position, and compositionally by their Phanerozoic versus Precambrian constituents, but this distinction is less pronounced the farther away the area of interest is from the Moose River basin. Close to Timmins, pebble lithologies alone were insufficient to separate tills on compositional grounds. This may, in part, be due to dilution by local materials in any till resting directly on crystalline bedrock, and it may reflect the high degree of homogenization of the tills by glacial recycling. Once a till was identified as suitable for sampling, the samples were analyzed for anomalous concentrations of the elements of interest. What constitutes an anomaly is a somewhat subjective decision based on the variance from the normal range of background values in the size or specific gravity fraction being separated for that till. The intensity of an anomalous signal is also obviously related to distance of glacial transport. Dispersal of elements, or rock types, forms an exponential curve, with the peak of concentration at or close to source, and an exponential decline in the direction of transport (Shilts, 1976).

The direction of transport is unique for each till in the study area. Older tills have been laid down from ice moving generally southwestward (240° to 210°). The Matheson glacier, although starting out flowing southwestward, shifted gradually to the east to complete its advance towards the south-southeast (170° to 150°). It is not known whether or not one of the tills below Matheson Till can be associated with a westward ice flow direction.

This drift prospecting methodology can be repeated in adjacent areas in order to trace an anomaly up-ice to its source. It cannot be overemphasized that the effectiveness of a drift exploration program is directly tied to the soundness of the Quaternary stratigraphic and sedimentologic models upon which decisions are based.

CONCLUSIONS

Regional stratigraphy

Development of the regional stratigraphic profiles would not have been possible without access to modern drilling and geophysical technologies which are only just beginning to be applied on a broad scale. The degree of refinement of the results lends a much greater confidence level to subsequent interpretations of the data than was available a decade or two ago. The other factor that has made this study feasible in the area north of Timmins, is the fortuitous ocurrence of contrasting, adjacent provenance areas (i.e. carbonate and crystalline terranes) that can be correlated with different ice flow directions through the succession of glacial events.

Up to 90% of the sediment pile, as interpreted from stratigraphic cross-sections, is representative of the last major glacial advance (Matheson glaciation) and subsequent late and deglacial history of the region, primarily ponding of glacial Lake Barlow-Ojibway and a brief readvance of Cochrane ice prior to dissipation of the ice sheet. Although stratigraphy interpreted from 70 intact cores drilled to bedrock is complex, a maximum of 5 till units have been recorded and described. Stratigraphy comprises from youngest to oldest, postglacial sediments, Cochrane Formation, Barlow-Ojibway Formation, Matheson Till (Till I), and older tills (Till II, III, and IV) and intertill sediments.

Ice flow history

Glacial dispersal data and limited striation records indicate that the oldest flow toward the southwest (225° to 215°) was superceded by a gradual shift in ice flow direction southward (190° to 165°) and lastly toward the southeast (155°), the youngest direction of ice advance. A restricted zone of ice flow toward 130° may be related to an ice lobe or stream that surged during the final stages of dissipation of the ice. Correlations can be made between units in the Moose River basin, and those described from the Timmins mining camp, based on regional and local stratigraphic cross-sections. Cochrane and Kipling tills, and Matheson and Adam tills are considered to represent the same glacial events respectively, at least in the region immediately north of the study area. The Matheson ice front is interpreted to have retreated north of the Pinard moraine, an undetermined distance, prior to a readvance that deposited the Kipling/Cochrane Till. Thus the Friday Creek sediments north of the Pinard moraine, itself a subaqueous deposit, may be in part contemporaneous with glacial Lake Barlow-Ojibway sediments.

Ice sheet configuration

Dispersal data and other ice flow direction indicators have shed some light on the development of models of Late Wisconsinan and Holocene configuration of the Laurentide Ice Sheet. Initial southwesterly ice flow directions indicate sustained flow from a Labrador/Quebec dispersal centre. The model of ice configuration at the Late Wisconsinan maximum of Shilts (1980, 1985) seems to be corroborated, at least in the study area and environs. The model of Dyke et al. (1982) and Dyke and Prest (1987) is not supported by the observed dispersal data. Retreat of the Cochrane ice front towards a Keewatin source area (Shilts, 1985) was not confirmed, based on the information from this study. Certainly no evidence was uncovered to support Flint's (1943) single-dome theory.

Even if details of the configuration of the Laurentide Ice Sheet and related timing of events during the Wisconsinan Glaciation are not yet consolidated, there is no doubt about the significant impact that this ice sheet imparted to the North American continent. At its peak, it effected major climatic changes, changes in ocean levels and atmospheric circulation, depression of the crust, and moulding and scouring of the land surface. Understanding of the processes of modification and erosion of the land, and related transport and deposition of derived materials, is necessary for the differentiation of glacial stratigraphy and implementation of effective drift prospecting programs.

Drift prospecting

Impediments to drift prospecting in this area include a thick cover of the glaciolacustrine Barlow-Ojibway Formation, a general lack of exposure of bedrock, and the difficulty of "mapping" the subsurface in order to define drilling targets. However, an effective exploration program could be carried out by following the methodology outlined in this report. Rotasonic drilling to recover intact cores to bedrock is an essential component of any comprehensive drift prospecting program north of Timmins, in order to work out the potentially complex Quaternary stratigraphy in a given area. A successful exploration program must build upon a solid framework of stratigraphic knowledge for accurate interpretation of results.

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APPENDIX

Systematic core descriptions

The sediments will be described from top to bottom in the 70 cores in order of borehole number. Sedimentary units are divided, based on different textures and the nature of contacts. Accompanying down-hole graphic logs are not illustrated in numeric order; rather they are grouped along the drilling transects so that lateral stratigraphic and facies relationships are more apparent. Detailed borehole locations, illustrated on accompanying diagrams taken from the relevant topographic maps, are given by latitude and longitude, NTS map sheet number, and the name of the township in which the borehole was located. The total depth drilled is indicated in the heading for each core. Note that for the purposes of description, depths in the descriptions are retained in feet, the units used during drilling and logging. Metric equivalents are provided on the graphic core illustrations, for the thicknesses of the units, and for descriptions of sedimentary structures, clast diameters, etc.

Borehole 1: Adanac Township, 49°28'00", 81°30'30", NTS 42H/5E, depth drilled 135 feet (41.1 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Diamicton: 2.5Y6/4, oxidized, minor largepebbles, granules, may be disturbed at top, gradational lower contact.	6.25, 2.1	0-7
Sand/silt: 2.5Y6/4, massive, minor stratification of sand and silt evident at lower gradational contact.	1.5, 0.5	7-8.5
Silt/clay: 5Y5/1, massive, minor fine sand and pebbles/granules lower contact sharp.	4, 1.2	8.5-12.5
Diamicton: 5Y4/2, sand/silt matrix, some textural banding in sandier zones, fine laminations near top.	4, 1.2	12.5-16.5
Diamicton: 2.5Y5/2, gradational contacts, sand matrix, higher content of granules and cobbles.	0.4, 0.1	16.5-16.9
Diamicton: 2.5Y5/2, clay matrix, massive.	6.3, 1.9	16.9-23
Silt/clay: 5Y5/1, clay-rich fine grained sediment, few pebbles/granules, clast content decreases downward, massive.	95, 29	23-118
Silt/clay: 5Y4/1, 0.5 cm-thick silt/clay couplets, minor pebbles.	3.5, 1.1	118-121.5
Diamicton: 5Y4/1, sandy matrix, clasts comprises mostly local bedrock types.	8.5, 2.6	121.5-130
Bedrock: hornblende-biotite granodiorite.	5, 1.5	130-135

Borehole 2: Adanac Township, 49°34'30", 81°30'30", NTS 42H/12, depth drilled 151 feet (46 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Sand/silt: oxidized to 6 ft. with organic lenses, locally laminated, grades downward into silty sand.	20, 6.1	0-20
Sand: unoxidized fine sand displays convoluted bedding defined by fine grained organic matter along bedding planes, between 35 and 44 ft. sand contains less silt than above.	27, 8.2	20-47
Silt/clay: 5Y5/1 silt matrix with rare pebbles or granules, sharp upper contact, loading structures in convoluted bedding at 55 ft., local weakly developed laminations, well sorted.	13, 4	47-60
Silt: 5Y5/1, slightly coarser grained than above, minor clasts.	5, 1.5	60-65
Clay/silt: 5Y5/1, massive, mostly clay, clast rare, fines downward.	31, 9.4	65-96
Clay/silt: rhythmically laminated silt and clay, couplets average 5-6 cm thick, no clasts evident, laminae contorted for upper 40 cm of unit, slightly siltier below 108 ft., few pebbles, beds are contorted at base.	17.5, 5.3	96-113.5
Sand/silt: gradational upper and lower contact, small clasts of clay, minor pebbles, massive, less sorted than above.	3.5, 1.1	113.5-117
Diamicton: 5Y5/1 at top darkens down core through 5Y4/1 to 5Y6/1, sand-silt matrix, local bedrock pebble content increases near base, relatively homogenous.	47.5, 14.5	117-144.5
Silt: dark green colour reflects local bedrock incorporation, sharp upper contact, massive.	0.25, 0.0	144.5-144.75
Bedrock: garnet-biotite metasedimentary gneiss.	6.25, 1.9	144.75-151

Borehole 3: Homuth Township, 49°41'00", 81°31'00", NTS 42H/12, depth drilled 135 feet (41.1 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Clay/silt: 10YR5/3, oxidized, mottled, laminated, abundant clay rip-up clasts.	2,	0.6	0-2
Silt: similar to above but more pebbles, few clay clasts present, poorly preserved local bedding.	3.5,	1.07	2-5.5
Silt: oxidized, no pebbles, convoluted laminations, cohesive, gradational contacts.	2,	0.6	5.5-7.5
Sand: Well sorted fine sand, rare pebbles at the base of the unit, slightly silty at top coarsens downward into fine sand, local convolute redding in silt at top, possible trough crossbedding at 15 ft., minor disseminated organics in lower half of unit.	24.5,	7.5	7.5-32
Diamicton: 5Y5/1, contacts sharp, massive.	2.5,	0.8	32-34.5
Sand: massive, medium grained, sorted.	2.5,	0.8	34.5-37
Diamicton: 5Y5/1, very compact.	6,	1.8	37-43
Diamicton: 10YR6/2, clast-supported, sand/silt matrix, sharp contacts.	2,	0.6	43-45
Diamicton: 5Y5/1, massive, very compact, homogenous.	20,	6.1	45-65
Silt: massive, no pebbles, minor clay, drilling disturbed in part.	1.5,	0.5	65-66.5
Sand: fine sand, massive with pebbles and granules and minor silt.	1,	0.3	66.5-67.5
Silt: massive silty clay, no pebbles.	1,	0.3	67.5-68.5
Diamicton: 5Y5/1-5Y6/1, silt matrix, top 0.2 metres is clast supported (possibly drilling-induced) and grades downward into matrix-supported diamicton, abundant crystalline and carbonate pebbles, more clay in matrix towards 88 feet.	19.5,	5.9	68.5-88
Diamicton: gradational upper contact, sand matrix, very cohesive, may be stratified at 93 ft., 20 cm-thick interval of clast-supported at 94 ft., cobbles up to 10 cm, fining downward below 94.5 feet to clay/silt matrix, sand silt at base, relatively homogenous.	19,	5.8	88-107
Sand: Medium- to coarse-grained, minor silt in matrix, local stony layers are matrix-poor.	3,	0.9	107-110
Diamicton: Silt/sand matrix.	1,	0.3	110-111
Sand: Coarse, pebbly.	2,	0.6	111-113
Diamicton: Silt/clay matrix, sharp contacts.	1,	0.3	113-114
Sand: Coarse- to very coarse-grained at the top fining downward to fine sand at the base, few pebbles, textural layering of fine- and medium-grained sand in lobe-like structures may represent flow noses.	11,	3.4	114-125
Bedrock: garnet-biotite metasedimentary gneiss.	10,	3	125-135

Borehole 4: 49°42'30", 81°30'00", Homuth Township, NTS 42H/12, depth drilled 125 feet (38.1 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: Massive fine sand and silt at top, local silt-rich layers at 3, 7, 11, 15, and 17 ft. depths exhibit convolute bedding and 2-3 mm-thick silt/clay laminae, few pebbles, 2.5Y6/2 at 27 ft., colour banding present, grades downcore to medium to coarse sand with pebbles at the base (5Y6/2).	40,	12.2	0-40
Diamicton: 5Y5/1, sharp upper contact, silt/clay matrix, pebble content increases from 5-15% downcore, compact, lower contact gradational.	5,	1.5	40-45
Diamicton: 5Y5/1, matrix silty, amount of pebbles decreases from 15-2%, gradational contacts.	6,	1.8	45-51
Silt: Minor convolute lamination expressed as colour and textural bands, rare pebbles, laminae are locally wrapped around a large cobble at 55 ft.	4,	1.2	51-55
Sand: silty-fine sand, massive, sharp angular contact with lower unit, gradational from upper silt.	1,	0.3	55-56
Diamicton: 5Y5/1, clay/silt matrix coarsens to sandy at 59 feet, fissile, discontinuous parting planes, 5-10% pebbles, stratification as silt lenses from 80-81 ft., boulder at 92 ft., colour change to 10YR5/1 at base of unit, lower contact sharp.	49,	15	56-105
Clay: minor silt, 5 cm-thick laminae, few pebbles, laminae thin downward.	2.0.6		105-107
Diamicton: 5Y5/1, similar to above, silt matrix, large boulder from 108-112 ft., 5Y6/2, bituminous-smelling and clay-rich from 112-114 ft., may be fracture infilling.	7,	2.1	107-114
Bedrock: metavolcanic (?) fault rock.	11,	3.4	114-125

Borehole 5: 49°45'15", 81°31'00", Avon Township, NTS 42H/13, depth drilled 118 feet (36 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Silt/clay: Contorted bedding, no pebbles.	6,	1.8	0-6
Silt/sand: Gradational upper contact, coarsens downward to silt and fine sand, no pebbles present.	9,	2.7	6-15
Sand: Sharp upper contact, brown fine to medium sand, disseminated organics.	21,	6.4	15-36
Sand: Sharp break with upper sand at coarse sand with granules from 36-38 ft., fine to medium moderately sorted sand below 38 ft., unoxidized, coarse sand below 46 ft., lower erosional contact.	24,	7.2	36-50
Clay/silt: Convolutely laminated silt and clay, rare granules, rip-up clasts, lower contact gradational, grades downward to sandy with faint laminations.	7,	2.1	50-57
Diamicton: 5Y5/1, fissile, sandy matrix, clast-poor, predominantly granule-sized clasts, lower contact gradational.	33,	10.1	57-90
Silt: laminated for upper 0.3 m, massive below 91 ft., granules present.	2,	0.6	90-92
Diamicton: sandy to silt matrix, 5Y5/1, boulder 100-103 ft. is same as local bedrock, lower contact gradational, bituminous odour.	16,	4.9	92-108
Diamicton: clay/silt matrix, abundant granules and pebbles, thin, very convoluted laminations.	4.5,	1.4	108-112.5
Bedrock: biotite tonalite gneiss.	5.5,	1.7	112.5-118

Borehole 6: 49°54'00", 81°40'00", Pinard Township, NTS 42H/13, depth drilled 277 feet (84.4 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: 10YR6/4, sandy/silt matrix, massive, lower contact sharp.	9,	2.7	0-9
Diamicton: 5Y4/1, silt/clay matrix, compact.	1,	0.3	9-10
Sand: silty-fine sand.	0.5,	0.2	10-10.5
Diamicton: silt/sand matrix, 5Y4/2, lower contact sharp.	0.5,	0.2	10.5-11
Diamicton: 5Y4/1, massive, upper contact erosional.	6.5,	2	11-17.5
Diamicton: 2.5Y4/2, upper contact interbedded with overlying diamicton, bituminous odour.	0.5,	0.2	17.5-18
Sand: Grades downward from silty to fine sand, granules in upper 24 cm of interval.	6,	1.8	18-24
Silt: sharp upper contact, clayey silt with convoluted laminations, grades downcore into fine sand.	1.5,	0.5	24-25.5
Sand: fine sand, weakly stratified.	10,	3.1	25.5-35.5
Silt: sharp contacts, minor clay, convoluted laminations, possible dewatering structures and flow noses present.	1.5,	0.5	35.5-37
Sand: fine sand grades down into silty/fine sand, massive with local ripple/bedding structure preserved.	28,	8.5	37-65
Silt: 5Y4/1, minor clay, convoluted laminations, no pebbles or granules, lower contact gradational.	10,	3.1	65-75
Sand: very silty for upper 9 m and between 140-143 ft., grades downward into massive fine sand, minor stratification, bedded below 185 ft.	137,	41.8	75-212
Silt: sandy, no clasts, contorted laminae, contacts gradational, homogenous.	27,	8.2	212-239
Silt/clay: massive, pebbles and granules present, more sand and pebbles at base.	31,	9.4	239-270
Bedrock: biotite tonalite gneiss.	7,	2.1	270-277

Borehole 7: 49°55'30", 81°47'30", Sheldon Township, NTS 42H/13, depth drilled 105 feet (32 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: fine sand, oxidized.	7,	2.1	0-7
Sand: silty, small granules, silt lenses.	6.5,	2	7-13.5
Silt/clay: Upper contact gradational, flow nose structures, contorted laminae.	3.5,	1.1	13.5-17
Sand: medium sand, pebble-sized carbonate concretions that ehxibit bedding, moderately sorted, planar bedded.	38,	11.6	17-55
Sand: well sorted medium sand, no pebbles or concretions.	4,	1.2	55-59
Sand: moderately to well sorted, fine- to medium-grained sand, rare pebbles, concretions uncommon.	46,	14	59-105

Borehole 7: Continued

Note: This hole was disconinued at this depth due to drilling difficulties. It might have been deep as in borehole 6 which was drilled nearby in the Pinard moraine.

Borehole 8: 49°32'00", 81°30'30", Adanac Township, NTS 42H/12, depth drilled 135 feet (41.1 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Diamicton: 10YR5/3, massive, clast-poor, lower contact deformed by drill.	9.5, 2.9	0-9.5
Diamicton: 5Y5/1, massive, pebble/granule content 2-3%, lower contact is very gradational (arbitrarily chosen at 23 ft.) and marked by a reduction in clast content, very fine grained at base.	13.5, 4.1	9.5-23
Clay: massive, 5Y5/1, few small clasts at top, well sorted, silt lense at 63 ft., slight increase in sand and granule content 72-73 ft., grades into clay at base.	68, 20.7	23-91
Silt/clay: sharp upper contact, poorly developed, nonuniform laminations, thickness of rhythmites variable, no clasts evident, laminae at upper contact are contorted, those at the base are planar.	15.5, 4.7	91-106.5
Diamicton: sharp upper contact, 5Y6/1, silt/sand matrix, massive, high clast content.	22, 6.7	106.5-128.5
Bedrock: hornblende-biotite diorite gneiss.	6.5, 2	128.5-135

Borehole 9: 49°17'30", 81°42'30", Haggart Township, NTS 42/5E, depth drilled 135 feet (41.1 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Diamicton: 10YR4/2, <5% clasts, weakly laminated, sharp lower contact.	6, 1.8	0-6
Clay: massive, rare granules/clasts, minor clasts and ripped up clay clasts from 25-28 ft., grades downward into 0.9 m of thick clay/silt rhythmites at base, some beds appear to be rotated.	37, 11.3	6-43
Bedrock: biotite tonalite gneiss.	4, 1.2	43-47

Borehole 10: 49°13'30", 81°42'00", Haggart Township, NTS 42 H/4, depth drilled 23 feet (7 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Diamicton: 10YR5/3, minor, wispy layering, similar to hole 9, sharp lower contact.	9, 2.7	0-9
Clay: massive, 5Y5/2, rare sand grains, rare clasts up to 3 cm diameter, thin grey, silt wisps near base of hole drill-deformed.	9, 2.7	9-18
Bedrock: hornblende-biotite granodiorite.	5, 1.5	18-23

Borehole 11: 49°11'30", 81°42'30", Haggart Township, NTS 42 H/4, depth drilled 141 feet (43 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Clay: 10YR5/3, colour is mottled at top, rare clasts, gradational lower contact.	5, 1.5	0-5
Silt/clay: laminations 1-2 mm thick, very contorted at base, sharp lower contact.	3, 0.9	5-8
Clay: 5Y5/1, massive with minor silt, rare clasts, gradational lower contact.	12, 3.7	8-20
Silt/clay: faintly laminated, rare granulesized clasts, laminae very contorted toward base, sharp lower contact.	10.5, 3.2	20-30.5
Diamicton: 5Y6/1, massive, silt/sand matrix, abundant large clasts and pebbles, contains few clasts, minor silt from 45-47 ft., 30% clast content from 47-48 ft.	17.5, 5.3	30.5-48
Diamicton: 5Y6/1, massive silt/clay matrix, contorted bands of clay between 54-59 ft., lower contact interfingered.	14, 4.3	48-62
Sand: minor silt, interbedded with overlying unit, contains granules and minor cobbles, lower contact gradational.	12.5, 3.8	62-74.5
Diamicton: 5Y5/1, sand/silt matrix, more sand in matrix from 82-90.5 ft., gradational lower contact.	16, 4.9	74.5-90.5
Diamicton: 5Y5/2, clast-supported, matrix silty, lower contact sharp.	3, 0.9	90.5-93.5
Diamicton: 5Y5/1, massive, silt matrix uniform texture.	29.5, 9	93.5-123

Borehole 11: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: massive, medium grained sand, nature of contacts unknown.	0.5,	0.2	123-123.5
Diamicton: 10YR5/1 at top, grades down to 5Y5/1 to 5Y4/1 at base, bituminous odour, massive, very cohesive.	13.5,	4.1	123.5-137
Bedrock: syenite.	4,	1.2	137-141

Borehole 12: 49°25'30", 82°20'00", O'Brien Township, NTS 42 G/8, depth drilled 101 feet (30.1 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Silt/clay: oxidized, 10YR6/3, irregular, contorted laminae, clasts rare, grades downward.	5,	1.5	0-5
Sand: 2.5Y6/4, minor silt to very fine sand, massive at top with distorted bedding features from 10-14 ft., local bands or clasts of silty clay, lower sharp contact is colour and textural break.	9,	2.7	5-14
Sand: 5Y6/1, finer grained than above but coarsens downward.to fine sand, bedding features distorted, textural banding, sharp lower contact.	13,	4	14-27
Sand: massive, medium grained sand, no clasts, very well sorted.	15,	4.6	27-42
Sand: massive, medium grained sand with pebbles and granules.	8,	2.4	42-50
Sand: coarse grained sand with abundant pebbles and granules, sharp lower contact.	13,	4	50-63
Diamicton: 5Y5/1, massive.	3,	0.9	63-66
Sand: sharply bounded fine sand with no clasts.	1,	0.3	66-67
Diamicton: 5Y5/2, minor stratification with thin layers of dark grey clay, sharp lower contact, very cohesive, 15% clasts.	7.5,	2.3	67-74.5
Diamicton: 5Y5/1, clay matrix better sorted than above, moderately compact, 10% clasts, lower contact sharp.	8.5,	2.3	74.5-83
Sand: coarse grained sand with pebbles, granules, large cobble at top.	1.5,	0.5	83-84.5
Sand: massive, fine to very fine sand, moderately sorted, lower contact sharp.	1.5,	0.5	84.5-86
Diamicton: 5Y6/1, massive, silt matrix slightly finer grained toward base, to 5Y4/2 at 93 ft., cohesive.	10,	3.1,	86-96
Bedrock: hornblende tonalite gneiss.	5,	1.5	96-101

Borehole 13: 49°27'30", 82°17'00", Teetzel Township, NTS 42 G/8, depth drilled 120 feet (36.6 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: disturbed gravelly road-bed	3,	0.9	0-3
Silt/clay: 10YR5/3, laminated, mottled, oxidized.	2,	0.6	3-5
Sand: massive, medium sand, few clasts.	1,	0.3	5-6
Clay/silt: 2.5Y6/4, laminated, oxidized, clasts present, lower contact is limit of surface oxidation.	1.5,	0.5	6-7.5
Clay/silt: massive, 5Y4/1, lower contact gradational, clasts content increases downward.	3.5,	1.1	7.5-11
Diamicton: 5Y5/1, massive, silt matrix, grades downcore to 5Y5/2, abundant pebbles above lower sharp contact.	22.5,	6.9	11-33.5
Diamicton: 5Y6/1, sand/silt matrix, disseminated wood fragments, lower contact sharp.	4,	1.2	33.5-37.5
Sand: massive, well sorted, medium sand, local accumulation of lignitized wood fragments, grades downward into coarse sand, minor pebbles in lower 1.5 m of unit, contact sharp.	14.5,	4.4	37.5-52
Diamicton: 5Y4/2, thin wisps of silt along parting planes end at 70 ft., more cohesive and clast rich (>15%) below 70 ft., 3 or 4 very thin silt laminae at 84 ft.	34.5,	10.5	52-86.5
Sand: poorly sorted, medium sand, sharply bounded, with pebbles and granules.	10,	3.1	86.5-96.5
Diamicton: 5Y5/1, silt/sand matrix, massive, very compact, local parting planes.	18.5,	5.6	96.5-115
Bedrock: hornblende-biotite granodiorite gneiss.	5,	1.5	115-120

Borehole 14: 49°32'00", 82°13'00", Gurney Township, NTS 42 G/9, depth drilled 42.5 feet (12.9 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: mixed clast lithologies, local backfill for road, oxidized.	5,	1.5	0-5
Peat: buried modern lake level, sharp contacts.	1,	0.3	5-6
Clay: cobbles at top of unit immediately under peat, limit of oxidation (10YR4/3) is at 10 ft. massive clay, 5Y6/1, with minor, rounded pebbles, wispy laminae of silty clay at 20 ft., minor, angular silt clasts at 29 ft., abundant small clay inclusions and distorted silt/clay laminae in lower 0.9 m of unit.	32.5,	9.9	6-38.5
Bedrock: hornblende-biotite granodiorite gneiss.	4,	1.2	38.5-42.5

Borehole 15: 49°33'20", 82°11'30", Gurney Township, NTS 42 G/9, depth drilled 33 feet (10.1 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: 10YR6/4, sandy, mottled colour, top 0.9 metres have been bulldozed, lower 1.5 m very compact, gradational lower contact, fissile.	8,	2.4	0-8
Silt/clay: laminations locally contorted, drill-induced folds, rare large clasts, large, rotated clay clasts in lower laminae, laminae contorted at base, gradational lower contact.	7,	2.1	8-15
Silt: massive, large, angular clay inclusions may represent thick (40 cm) varves, rotated clay layer at 22 ft., stratification diminishes downward.	15,	4.6	15-30
Bedrock: gneiss.	3,	0.9	30-33

Borehole 16: 49°29'00", 82°15'45", Gurney Township, NTS 42 G/8, depth drilled 120 feet (36.6 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: mixture of road-fill gravel and diamicton, locally derived.	2,	0.6	0-2
Sand: massive, fine grained, 5Y6/3 at top to 5Y6/1 below 10 ft., abundant disseminated organic fragments, fines downward into sandy silt, lower contact interfingered.	20,	6.1	2-22
Diamicton: massive, 5Y6/1, lower contact irregular (interfingered).	1.5,	0.5	23.5-25
Clay/silt: massive with faint, contorted laminations, angular clay clasts, sharp lower contact.	3,	0.9	25-28
Clay: massive, no clasts.	2,	0.6	28-30
Clay/silt: convoluted, finely laminated silt and clay laminae, local 30 cm-thick layers of silt, minor pebbles, abrupt lower contact.	10,	3.1	30-40
Clay/silt: less silt than above, massive, local, thin laminations, several large carbonate clasts, silt inclusions at base, lower contact gradational.	9.5,	3	40-49.5
Clay/silt: rhythmically laminated, no clasts, sharp lower contact.	1.5,	0.5	49.5-51
Diamicton: 5Y6/1, clay/silt matrix.	8,	2.4	51-59
Sand: medium sand, pebbles, inclusions of diamicton, sharply bounded.	0.5,	0.2	59-59.5
Diamicton: 5Y6/1, similar to above unit.	0.5,	0.2	59.5-60
Diamicton: 5Y4/2, upper contact is marked by sharp colour change, silt partings up to 3 cm-thick.	3,	0.9	60-63
Sand: well sorted, diamicton inclusions, sharply bounded.	1,	0.3	63-64
Diamicton: 5Y5/1, massive, compact, clay-silt matrix, oxidized 80-81 ft., no contact evident.	17,	5.2	64-81
Bedrock: weathered, disaggregated gneiss.	9,	2.7	81-90

Borehole 17: 49°06'15", 82°25'30", Casselman Township, NTS 42 G/1, depth drilled 115 feet (35.1 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Silt/clay: massive, oxidized, mottled colour, lenses of diamicton-like material, likely road-fill, gradational lower contact.	3,	0.9	0-3
Clay: massive, minor clasts up to 1 cm diameter, amount of pebbles/granules decreases downward to 30 ft., clay is well sorted, gradual change to slightly more clasts, rare pebbles up to 3 cm-diameter at base, lower contact gradational.	37.5,	11.4	3-40.5

Borehole 17 Continued		
Lithology	**Thickness** (ft., m)	**Interval** (ft.)
Clay/silt: upper 20 cm are deformed rhythmites, well preserved graded rhythmites 5 cm thick to 45 ft., rhythmites thicken downward, silt layers thicken downward to 7 cm-thick.	22.5, 6.9	40.5-63
Sand: fine grained, minor pebbles, abundant organic debris, massive, rare clay layers 1-2 cm thick, local, convoluted silt laminae at 81 ft., lower contact sharp.	20, 6.1	63-83
Sand: very fine grained, upper contact at top of graded clay/silt layer 15 cm thick, siltier than overlying sand unit, organics (many lignitized) common, contorted silt laminae from 99-103 ft., lower contact gradational.	20, 6.1	83-103
Clay: massive, 2.5Y4/0, sharp lower contact.	0.5, 0.2	103-103.5
Sand: massive, minor clay wisps and clasts, organics present, pebbly layer on bedrock.	6.5, 2	103.5-110
Bedrock: mafic gneiss.	5, 1.5	110-115

Borehole 18: 49°05'00", 82°26'00", Casselman Township, NTS 42 G/1, depth drilled 121 feet (36.9 metres)

Lithology	**Thickness** (ft., m)	**Interval** (ft.)
Diamicton: road fill, locally derived.	4, 1.2	0-4
Soil: buried soil profile and organics.	0.5, 0.2	4-4.5
Diamicton: clay/silt matrix, clasts up to 2-3 cm-diameter, 2.5Y5/4, mottled colour, oxidized to 11 ft., poorly sorted.	6.5, 2	4.5-11
Clay: massive, very compact, 2-5% pebbles, 2.5Y5/2, both contacts gradational.	4, 1.2	11-15
Silt/sand: layers of oxidized sand inter-bedded with silt/clay rhythmites, locally convoluted, 2.5Y6/6.	7, 2.1	15-22
Silt/clay: convoluted, finely laminated silt and clay, both contacts abrupt.	3, 0.9	22-25
Sand: massive, fine- to medium-grained, abundant organic fragments, colour slightly mottled.	28, 8.5	25-53
Silt/clay: 3 horizontal, graded, laminae of silt and clay, 2.5Y6/4, sharp contacts.	0.2, 0.1	53-53.2
Sand: fine- to medium-grained, rare silt lenses, abundant lignite fragments.	16.8, 5.1	53.2-71
Silt/clay: sharp contacts, several silt/clay rhythmites.	1, 0.3	71-72
Sand: massive, medium grained, lower contact sharp.	2, 0.6	72-74
Diamicton: massive, sandy/silt matrix locally silt-rich, clast-supported for top 5 cm, rare silt wisps along parting planes, predominantly granitic pebbles, very compact, generally fissile below 100 ft., 5Y4/2, no obvious contact but textural change.	42, 12.8	74-116
Bedrock: mylonite.	5, 1.5	116-121

Borehole 19: 49°00'15", 82°28'15", Fenton Township, NTS 42 G/1, depth drilled 125 feet (38.1 metres)

Lithology	**Thickness** (ft., m)	**Interval** (ft.)
Clay: 10YR5/4, road-bed over soil profile for top 20 cm, laminated, colour mottled, few pebbles, sharp lower contact.	4, 1.2	0-4
Clay: massive, 2-5% small clasts, clast content decreases downward, 2.5Y5/4, 1 cm-thick pebbly sand bed at 4.5 ft., gradational contacts.	3, 0.9	4-7
Boulder: crystalline gneiss	2, 0.6	7-9
Diamicton: 5Y4/1, sandy matrix, mixed pebble lithologies, cohesive.	2, 0.6	9-11
Boulder: crystalline.	1.5, 0.5	11-12.5
Sand: fine sand and silt, convoluted silt wisps, angular clay clasts, graded clay laminae spaced about 20 cm, flame structures in fine sediment, large-scale rhythmites.	5.5, 1.7	12.5-18
Sand: minor silt, fine sand at top coarsens downward to medium grained sand, clay beds 1-2 cm thick at 23 and 30 ft., conformable, lower contact gradational.	22, 6.7	18-40
Sand/gravel: moderately sorted, pebbly clasts from 1-60 mm diameter, fine to medium sand in matrix, no silt, clast supported, lower contact sharp.	11, 3.4	40-51
Diamicton: 5Y5/1, variable texture, silt matrix to 55 ft., sandy 55-79.5 ft., 12 cm-thick boulder at 55 ft., fissile with silty parting planes from 58-60 ft., very compact below 70 ft., lower contact sharp with silt laminations (5Y3/2).	28.5, 8.7	51-79.5
Diamicton: 5Y5/1, sand matrix grades downcore to silty clay, poorly cohesive, 5-10% clasts, mixed lithologies, lower contact sharp.	15.5, 4.7	79.5-95

Borehole 19: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: stratified fine to very fine sand, <1% granules and clay clasts for top 1.5 m, massive, well sorted below 100 ft., clay bed at 107 and 110 ft., pebbly sand above lower, sharp contact.	18,	5.5	95-113
Diamicton: Bluish-olive-green, composed largely of reworked local saprolite, foreign clasts noted, silt matrix, cobble at lower, gradational contact.	1,	0.3	113-114
Bedrock: saprolite.	11,	3.4	114-125

Borehole 20: 48°55'20", 82°31'12", Seaton Township, NTS 42 B/15, depth drilled 85 feet (25.9 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: mixture of clay and pebbles, likely altered by road building.	4,	1.2	0-4
Peat: modern, former surface layer.	0.5,	0.15	4-4.5
Silt/clay: graded, well defined silt/clay rythmites up to 1 cm thick, sharp lower contact.	3.5,	1.1	4.5-8
Clay: massive, minor sand or granules concentrated at top, 2.5Y5/2, fining downward, lower contact sharp.	17,	5.2	8-25
Clay/silt: chaotically interbedded silt and clay, definition of primary structure decreases downward.	10,	3	25-35
Clay: massive, remnants of silt inclusions or stratification, no pebbles, rare sand grains, sharp lower contact.	14,	4.3	35-49
Diamicton: variable, fine sand matrix and silt, locally clast-supported, minor cobbles, coarsens downward, lower contact gradational, very pebbly, 5Y5/1.	16,	4.9	49-65
Sand: sorted, pebbly, fine- to medium-grained at top, coarser at base, cobbles and large pebbles common, sharp lower contact.	6,	1.8	65-71
Diamicton: silt matrix, 5Y5/1, about 5% clasts, moderately cohesive.	3,	0.9	71-74
Bedrock: porphyritic hornblende diorite.	11,	3.4	74-85

Borehole 21: 48°53'30", 82°32'00", Seaton Township, NTS 42 B/15, depth drilled 90 feet (27.4 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Clay: massive, minor clasts, surface roots, road bed, mottled colour, lower contact sharp.	1.5,	0.5	0-1.5
Clay: 10YR5/4, finely laminated clay rhythmites, colour banded, <2% pebbles, lower contact gradational.	5.5,	1.7	1.5-7
Clay: massive, lower contact sharp, unoxidized.	3,	0.9	7-10
Clay: cohesive, 2% clasts, rare pebbles to 3 cm diameter, 10YR4/3, mottled with dark brown smudges, lower contact gradational.	3,	0.9	10-13
Clay/silt: very thinly laminated at top, convoluted, 5Y6/1, thicker, siltier laminae at base, gradational lower contact.	3,	0.9	13-16
Sand: massive, fine to very fine sand at top, rare clay clasts, coarsens downward to medium sand, deformed silt layers at 53 ft., 2 cm-thick silt layer at 57 ft. with sharp upper and gradational lower boundary, lower contact erosional with rip-up clasts.	56,	17.1	16-72
Silt: 5Y3/2, massive, pebbles up to 3 cm diameter, organic fragments and brown smudges, lower contact sharp.	1,	0.3	72-73
Silt: finely laminated, colour banded, rare pebbles, visible woody chunks and organics, laminae thicken and coarsen slightly downward, faintly laminated at base, sandy, resembles soil profile, vertical cracks in the sediment have white calcareous deposit, lower contact angular, erosional.	4,	1.2	73-77
Diamicton: 5Y5/1, 10% clasts, sandy-silt matrix, soft due to drilling, lower contact sharp.	3,	0.9	77-80
Diamicton: 5Y5/1, silt/clay matrix, silt lenses along fissile parting planes, inclusion of brown, organic-bearing silt, abundant clasts including carbonates, very compact.	5,	1.5	80-85
Bedrock: porphyritic hornblende diorite.	5,	1.5	85-90

Borehole 22: 48°46'40", 82°32'30", Lisgar Township, NTS 42 B/15, depth drilled 178 feet (54.3 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Clay/silt: laminated for top 2 ft., massive, 2-5% clasts, minor sand in the matrix, 10YR5/3, soil profile and road bed at top, lower contact sharp.	9,	2.7	0-9
Clay: 10YR4/3, massive, rare pebbles or clasts, colour slightly mottled, lower contact abrupt.	13,	4	9-22
Silt: 2.5Y4/2, fine sandy silt, lower rontact abrupt.	2,	0.6	22-24
Clay: 10YR4/2, massive, no granules, lower contact sharp.	2,	0.6	24-26
Silt/clay: graded silt/clay couplets up to 1 cm-thick, very deformed to 31 ft., lower contact sharp.	9,	2.7	26-35
Silt/sand: massive to weakly laminated at top, inclusions of oxidized clay, coarsens downward to fine sand, lower contact abrupt.	8,	2.4	35-43
Sand/gravel: stratified, alternating intervals of very coarse sand, pebbly sand and gravel, large cobbles at lower, sharp contact.	112,	34.1	43-155
Diamicton: silt/clay matrix, 5Y4/1, 10-15% clasts, clast content decreases downward, very compact, boulder 164-166 ft.	18,	5.5	155-173
Bedrock: gabbro.	5,	1.5	173-178

Borehole 23: 48°50'10", 82°31'20", Lisgar Township, NTS 42 B/15, depth drilled 115 feet (35.1 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Clay: 10YR5/3, <5% clasts, colour banded, mottled to intermittently laminated, laminae are locally convoluted, lower contact sharp.	8,	2.4	0-8
Clay/silt: massive, <2% clasts, some colour mottling, minor sand, clast content decreases downward, brown/grey interlayering at 14 ft. may be depth of oxidation, 3 layers of silt spaced 40 cm at 27 ft., lower contact sharp.	23,	7.0	8-31
Clay/silt: laminated silt/clay, very chaotically deformed rhythmites with clay inclusions to 43 ft., well preserved graded couplets 2-5 cm thick to 47 ft., highly contorted ripped-up silt layers to 55 ft., lower contact gradational.	24,	7.3	31-55
Sand: massive, very fine sand well sorted at top, medium- to coarse-grained sand and pebbly sand to 90 ft., grades downward to medium to coarse sand with minor pebbles at base of unit.	55,	16.8	55-110
Bedrock: biotite granite.	5,	1.5	110-115

Borehole 24: 49°03'45", 82°26'15", Casselman Township, NTS 42 G/1, depth drilled 34 feet (10.4 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand/diamicton: local road-bed material.	2,	0.6	0-2
Sand: sharp contacts, coarse grained.	3,	0.9	2-5
Clay/silt: laminated, minor granules, mottled colour, sharp contacts.	0.5,	0.2	5-5.5
Diamicton: 5% clasts, massive, matrix moderately sorted silt/sand, colour change at lower gradational contact, 2.5Y4/2.	2.50.8		5.5-8
Clay/silt: massive, <2% pebbles, brown/grey interfingering is likely drilling-induced, 10YR5/4 and 2.5Y5/2, local beds of well sorted clay with no clasts, sharp lower contact.	10,	3	8-18
Sand: massive, fine grained.	10,	3	18-28
Bedrock: sheared iron formation.	6,	1.8	28-34

Borehole 25: 49°00'20", 82°28'06", Fenton Township, NTS 42 G/1, depth drilled 94 feet (28.7 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Clay: mottled colour, 10YR5/3 to 11 ft., 5Y4/2 to 16 ft., minor pebbles, remnants of deformed clay laminae from 6-10 ft., lower contact sharp.	16,	4.9	0-16
Boulder: crystalline	1,	0.3	16-17
Sand: massive fine sand, clay layers 1-2 cm thick at 17.5, 20, 25, and 33 ft., 15 cm-thick clay bed at 38 ft. with load structures on top, pebbly sand at bottom, lower contact gradational.	24,	7.3	17-41

Borehole 25: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: very poorly sorted gravel and diamicton mixture, locally clast-supported, some cobbles, lower contact sharp.	2.5,	0.8	41-43.5
Diamicton: fine sand/silt matrix, 5Y5/1, very compact at top and base, variable, boulder 0.5 m-thick at 50 ft., fissile at 66 ft., 10-15% clasts, clast-supported and saturated 55-56 ft. likely due to drilling, boulder of local bedrock at 75 ft., sandy above bedrock, fine silty laminae on bedrock surface.	35.5,	10.8	43.5-79
Bedrock: saprolite.	1,	0.3	79-80
Intermediate gneiss poorly recovered.	14,	4.3	80-94

Borehole 26: 49°27'30", 82°17'00", Teetzel Township, NTS 42 G/8, depth drilled 103 feet (31.4 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: gravel and diamicton mixture as road embankment.	3,	0.9	0-3
Silt/clay: 10YR4/3, graded, 5 cm-thick rhythmites, sharp lower contact.	2,	0.6	3-5
Clay: gmassive, mottled, 5% granules or sand, few pebbles, fines downward, sharp lower contact.	2.5,	0.8	5-7.5
Silt/clay: laminated, minor pebbles, lower contact gradational.	2,	5,0.8	7.5-9
Sand: fine sand, few pebbles, lower contact gradational.	1.5,	0.5	9-10.5
Silt/clay: deformed and ripped-up thin laminae, lower contact irregular, sharp.	1,	0.3	10.5-11.5
Diamicton: 5Y5/2, silty fine sand matrix, 15-20% clasts, uniform, slightly sandier at base, pebbles up to 3 cm, lower contact sharp.	32.5,	9.9	11.5-44
Sand: poorly sorted, gravelly, fine sand, lower contact sharp.	5,	1.5	44-49
Diamicton: 5Y5/1, sand/silt matrix, compact, lower contact abrupt.	8,	2.4	49-57
Clay: massive, <2% sand, cohesive, fining downward, lower sharp contact marked by silt wisps.	8,	2.4	57-65
Diamicton: 5Y5/1, massive, poorly defined stratification, very clast-poor, sand matrix, layered silt beds at 70-73 ft., massive fine sand 73-76 ft., contacts poorly defined.	32,	9.7	65-97
Bedrock: hornblende granite.	6,	1.8	97-103

Borehole 27: 49°39'40", 82°08'30", Torrance Township, NTS 42 G/9, depth drilled 103 feet (31.4 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: Sandy matrix, bulldozed road bed, embankment built into lake.	10,	3.1	0-10
Silt: mostly massive, minor discontinuous laminae with clay, organic-rich.	4,	1.2	10-14
Peat: peat with wood in silt.	1,	0.3	14-15
Sand: massive, fine sand/silt with no clasts grades downward to coarse sand with pebbles and cobbles, disseminated organics, unoxidized.	8,	2.4	15-23
Diamicton: 2.5Y4/0 at top, 5Y5/1 below 24 ft., silty/clay matrix, locally fissile, very compact, crystalline boulder at 43 ft., lower contact gradational, large cobbles at upper surface.	31,	9.4	23-54
Diamicton: more massive than above, 5Y5/1, sand matrix, compact, abundant carbonate clasts, lower contact sharp, deformed laminae at base (5Y6/1).	21,	6.4	54-75
Diamicton: 5Y5/1, very cohesive core, minor clasts, abundant carbonates, lower contact at crystalline boulder.	19,	5.8	74-93
Sand: medium to coarse pebbly sand, minor fine sand laminae on bedrock contact.	5,	1.5	93-98
Bedrock: biotite gneiss.	5,	1.5	98-103

Borehole 28: 49°38'50", 82°09'00", Torrance Township, NTS 42 G/9, depth drilled 179 feet (54.6 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: locally-derived road fill, clay-rich matrix, few pebbles, oxidized.	8,	2.4	0-8
Silt/clay: massive, 5Y6/1, contains wood and peat, lower contact gradational.	5,	1.5	8-13
Sand: fine-medium sand, coarsens downward, few pebbles, lignite fragments at base, lower contact gradational.	8,	2.4	13-21
Silt/clay: massive, 2% pebbles and granules, 5Y5/1.	18,	5.5	21-39

Borehole 28: Continued

Lithology	Thickness (ft., m)	Interval (ft.)
Silt/clay: rhythmites 1-1.5 cm thick, large striated cobble at upper, gradational contact, lower contact sharp.	1, 0.3	39-40
Sand: medium-coarse sand, abundant pebbles up to 3 cm, lower contact sharp.	6, 1.8	40-46
Silt: faintly laminated, disseminated organics, woody layer at base, coarsens downward, lower contact sharp.	2.5, 0.8	46-48.5
Sand: coarse pebbly sand, sharp lower contact.	4, 1.2	48.5-52.5
Diamicton: 2.5Y6/2, fine sand/silt matrix, very cohesive, locally fissile, lower contact at end of bag.	4.5, 1.4	52.5-57
Sand/gravel: very coarse sand to gravel.	3, 0.9	57-60
Sand: fine sand, minor silt, about 2% pebbles, coarsens upward, lower contact sharp.	4, 1.2	60-64
Gravel: very coarse sandy gravel, lower contact abrupt.	2, 0.6	64-66
Sand: fine-medium sand, about 10% clasts, silt/clay layer 1 cm thick at 67 ft..	3, 0.9	66-69
Sand: fine sand and silt, large stone at lower gradational contact.	4, 1.2	69-73
Diamicton: sandy, 5Y5/1, poorly cohesive, lower contact sharp.	2, 0.6	73-75
Sand: medium grained, pebbly.	1, 0.3	75-76
Diamicton: 5Y5/1, fine sand/silt matrix, poorly consolidated, lower contact gradational, boulder at 85 ft., coarser matrix with abundant clasts above lower contact.	12, 3.7	76-88
Sand/silt: very fine grained, massive, locally fissile, lower contact gradational.	7, 2.1	88-95
Diamicton: 5Y4/1, silt/sand matrix, about 20% pebbles, compact, fissile, lower contact gradational.	4, 1.2	95-99
Silt: massive, minor fine sand, fissile, 5Y5/1, <5% pebbles, clay-rich at base, lower contact gradational.	11, 3.4	99-110
Silt/clay: rhythmites, 1-5 cm thick, fines downward, lower contact gradational.	9, 2.7	110-119
Clay: 5Y6/1, massive, cobble at 121 ft.	3, 0.9	119-122
Silt/clay: rhythmites, 1-5 cm thick, lower contact sharp.	4, 1.2	122-126
Sand: fine sand, massive, sharp contacts.	1, 0.3	126-127
Silt/clay: rhythmites as above.	3, 0.9	127-130
Sand: massive, fine sand at top grades to medium sand at base, clay/silt layers up to 10 cm thick at 135, 139, 141, and 142 ft., 15% clasts, large cobbles below 142 ft., lower contact sharp.	25, 7.6	130-155
Diamicton: 5Y5/1, sand matrix, 15% pebbles and cobbles, lower contact unclear.	10, 3.1	155-165
Bedrock: gneiss, surface highly reworked.	14, 4.3	165-179

Borehole 29: 49°40'30", 82°11'00", Torrance Township, NTS 42 G/9, depth drilled 55 feet (16.8 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Sand: coarse grained, gravelly, top is road fill material.	8, 2.4	0-8
Sand: fine to medium sand, gravel bed from 14-15 ft., coarse sand at base, lower contact sharp.	17.5, 5.3	8-25.5
Clay: massive, silt wisps, lower contact unclear.	1, 0.3	25.5-26.5
Diamicton: silt/clay matrix with sandy pockets, very cohesive, 5Y4/2, rare clasts to 2.5 cm, abundant carbonates, lower contact abrupt.	9.5, 2.9	26.5-36
Diamicton: silt/clay matrix, clasts more abundant than above, 5Y4/2, sandy and cobbly above bedrock.	8, 2.4	36-44
Bedrock: garnet-biotite gneiss, poor recovery.	11, 3.4	44-55

Borehole 30: 49°39'30", 82°11'00", Torrance Township, NTS 42 G/9, depth drilled 66 feet (20.1 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Organic: roots, vegetation, road bed.	0.5, 0.2	0-0.5
Diamicton: silt/sand matrix, massive, 2.5Y5/4, few clasts, abundant carbonates, local plant roots, may have been imported to fill road depression, lower 30 cm is mixed with underlying modern peat.	5.5, 1.7	0.5-6
Peat: loose, silty, woody, black, lower contact gradational.	4, 1.2	6-10
Silt/clay: massive to weakly bedded, 5Y5/2, clay-rich at base, no clasts.	8, 2.4	10-18

Borehole 30: Continued

Lithology	Thickness (ft., m)	Interval (ft.)
Clay: massive, 5Y4/2, no clasts, sharply bounded.	1.5, 0.5	18-19.5
Sand: fine sand, <2% clasts, lower contact gradational, massive.	18, 5.5	19.5-37.5
Silt/clay: massive, rare clasts, rare silt wisps, very cohesive, lower contact sharp.	7.5, 2.3	37.5-45
Clay: discontinuous silt laminae in clay, no clasts, lower contact sharp.	1.5, 0.5	45-46.5
Diamicton: clay/silt matrix, 5Y5/2, massive, 15% clasts, fewer clasts and siltier matrix at base.	13.5, 4.1	46.5-60
Bedrock: gneiss.	6, 1.8	60-66

Borehole 31: 49°38'40", 82°10'50", Township, NTS 42 G/9, depth drilled 88 feet (26.8 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Organic: peaty vegetation.	0.5, 0.2	0-0.5
Diamicton: silty matrix, oxidized for upper 1.5 m (10YR5/3) with disseminated organics, silty with minor sand below 1.5 m, 2.5Y5/3, <5% clasts.	13, 4.0	0.5-13.5
Silty/clay: massive, minor discontinuous silt wisps below upper, sharp contact, 2.5Y 6/2.	1.5, 0.5	13.5-15
Silty/clay: massive, 5Y5/2, rare granule to pebble clasts, grades to sandier downcore.	25, 7.6	15-40
Clay: sandy, very cohesive, silt wisps, 5Y5/2, lower contact sharp.	3, 0.9	40-43
Gravel/clay: massive clay interbedded with coarse grained sand and gravel, 5Y5/2.	8, 2.4	43-51
Gravel: coarse sand and gravel, clay clasts.	4, 1.2	51-55
Sand/gravel: coarse grained sand and gravel, silt matrix for lower 2 m.	26, 7.9	55-81
Bedrock: coarse grained biotite gneiss.	7, 2.1	81-88

Borehole 32: 49°34'20", 82°18'45", Teetzel Township, NTS 42 G/9, depth drilled 75 feet (22.9 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Diamicton: locally-derived road fill, silt/clay matrix, interbedded with coarse, pebbly sand, minor vegetation, oxidized.	6.5, 2	0-6.5
Silt/clay: colour banding may be primary lamination, <2% granules, rare larger clasts up to 4 cm, 10YR5/3, disseminated organics.	3.5, 1.1	6.5-10
Silt/clay: massive, 2.5Y4/2, less silty than above, clast content decreases down-core, colour change to 5Y4/2 through unit.	10, 3.1	10-20
Clay/silt: massive clay with small wisps of silt, 5Y4/2, sharp lower contact.	4, 1.2	20-24
Sand: fine sand, minor silt/clay in matrix, few larger clasts, 5Y4/2, lower contact gradational.	12, 3.7	24-36
Clay/silt: massive clay with contorted silt laminae, 5Y3/1, very cohesive, lower contact gradational.	2, 0.6	36-38
Sand: fine grained, few clasts, 5Y5/3, massive, coarser at base of unit just above bedrock, 0.3 m-thick laminated, cohesive, silt/clay interval 54-55 ft., 5Y4/1.	30.5, 9.3	38-68.5
Bedrock: Chlorite schist with 5% visible pyrite.	6.5, 2	68.5-75

Borehole 33: 49°47'40", 82°22'30", Guilfoyle Township, NTS 42 G/16, depth drilled 48 feet (14.6 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Organic: surface materials, grades downward.	1, 0.2	0-1
Diamicton: silt/clay matrix, 10YR5/4 at top, grades to 2.5Y6/6, mottled, <5% clasts, very cohesive, oxidized, lower contact gradational.	4, 1.2	1-6
Clay: massive, slightly mottled, grades from 10YR5/4 to 5Y4/2 at base, minor pebbles and granules, clasts decrease downcore, boulder at 31.5-32 ft., rare oxidation around clasts.	34, 10.4	6-40
Bedrock: coarse grained, quartz-rich gneiss.	8, 2.4	40-48

Borehole 34: 49°47'50", 82°21'10", Guilfoyle Township, NTS 42 G/16, depth drilled 138 feet (42.1 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: locally-derived road fill, sandy.	4,	1.2	0-4
Diamicton: massive, silt matrix, oxidized, 2.5Y5/4, 10% clasts, sharp lower contact, very cohesive.	5,	1.5	4-9
Sand: silty, massive, fine grained, 2.5Y6/4.	1,	0.3	9-10
Clay/silt: massive, 2.5Y6/2, sharp contacts.	1,	0.3	10-11
Sand: massive, coarsens downward, 0.2 m-scale graded bedding, few clasts.	4.5,	1.4	11-15.5
Silt: 5Y5/2, massive, no clasts, sharp contacts.	1,	0.3	15.5-16.5
Sand: fine sand, minor silt, 5Y5/2, 1% clasts, coarsens downward to medium sand.	29.5,	9	16.5-46
Silt/clay: cohesive, laminae contorted, discontinuous, sharp contacts.	1,	0.3	46-47
Sand: medium grained, no clasts, massive.	0.5,	0.1	47-47.5
Silt/clay: contorted laminae as above, sharp contacts.	0.5,	0.1	47.5-48
Sand: fine grained, massive, no clasts, 5Y6/2.	2,	0.6	48-50
Silt/clay: finely laminated, fissile, contorted, <2% clasts, mottled 2.5Y5/2 to 5Y4/2, sharp contacts.	3.5,	1.1	50-53.5
Sand: coarse, pebbly, 5Y5/2.	0.5,	0.1	53.5-54
Silt/clay: laminated, sharp contacts.	0.5,	0.1	54-54.5
Diamicton: sand/silt matrix, 2-3% pebbles, fissile, 5Y5/2.	0.5,	0.1	54.5-55
Silt/clay: laminated, sharp contacts.	1,	0.3	55-56
Sand: coarse grained, fines downward, no clasts, 5Y5/2.	2,	0.6	56-58
Diamicton: massive, silt/clay matrix, 5% clasts, 5Y5/2, fissile, sharp contacts.	1,	0.3	58-59
Sand: medium to coarse, pebbly sand grades downward to fine sand, 5Y5/2, massive.	10,	3.1	59-69
Diamicton: silt matrix, sandy at top, 5-10% pebbles and granules, striated clasts, 5Y4/1, fissile, contacts sharp.	14,	4.3	69-83
Silt/clay: rhythmically laminated, <1 mm thick, couplets thin downward, cohesive, silt wisps at top of unit, mottled 5Y4/1, lower contact gradational.	3,	0.9	83-86
Clay/silt: massive, soft, 5% clasts up to 5 cm, 5Y6/2, sharp lower contact.	1.5,	0.5	86-87.5
Silt/clay: rhythmically laminated, as above, lower contact at large clast.	1,	0.3	87.5-88.5
Sand: massive fine sand with silt, silt clasts, medium grained at 95 ft., fining downward to silty sand at base of unit, 10% clasts decrease downward.	31.5,	9.6	88.5-120
Diamicton: sandy matrix, fissile, moderately cohesive, 5Y5/1, 10% granule clasts, sharp contacts.	4,	1.2	120-124
Sand: poorly sorted, granular sand, minor silt and clay inclusions, 5Y6/1, massive finesand at base, sharp lower contact.	6.5,	2	124-130.5
Diamicton: poorly cohesive, abundant clasts, up to 6 cm, 5Y4/1.	1.5,	0.5	130.5-132
Bedrock: Gneiss with visible pyrite.	6,	1.8	132-138

Borehole 35: 49°47'40", 82°20'35", Guilfoyle Township, NTS 42 G/16, depth drilled 113 feet (34.4 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: sand/gravel road bed grades downward to fine silty sand with pebbles and granules, compact at base, sharp lower contact.	4,	1.2	0-4
Sand: massive, fine grained, 10YR7/6, loose, plant debris, pebbly at base.	1.5,	0.5	4-5.5
Sand: sharp upper contact, fine sand, some pebbles, granules and lignite fragments, 2.5Y6/3, finely laminated silt/clay interval 16.5-17 ft., oxidized along parting planes, disseminated organics increase downward.	31.5,	9.6	5.5-37
Sand: fine sand, abundant disseminated organics, wood fragments, peaty, gradational contacts.	15.5,	4.7	37-52.5
Sand: massive, medium- to fine-grained, coarsens downward, oxidized at top.	26.5,	8.1	52.5-79
Sand: coarse grained, well sorted, unoxidized, 2.5Y6/4, upper contact gradational, lower contact sharp.	17,	5.2	79-96
Sand: fine grained, massive, no clasts, 5Y6/1, lower contact may be abrupt.	6,	1.8	96-102
Diamicton: massive, sand/silt matrix, fines downward to silty, 15% granule to pebble clasts, 5Y6/1, very cohesive.	6,	1.8	102-108
Bedrock:	5,	1.5	108-113

Borehole 36: 50°00'00", 82°11'30", Harmon Township, NTS 42 J/1, depth drilled 62 feet (18.9 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: medium to coarse, granular, road fill.	2,	0.6	0-2
Clay: massive, 2.5Y6/4, mottled, organics, 2-5% granule clasts, sharp contacts.	1,	0.3	2-3
Sand: medium to coarse, fines downward.	1,	0.3	3-4
Diamicton: fissile, oxidized at top, 2.5Y6/4, 5Y5/1 below 9.5 ft., <10% clasts, variable sand content in matrix, moderate to very cohesive, sharp contacts.	8,	2.4	4-12
Sand: fine silty sand at top, grades downward to coarse pebble sand at 23-24 ft., fines downward to sand/silt layer at base of unit, 5Y5/1, lower, sharp contact marked by several large cobbles.	14,	4.3	12-28
Diamicton: blocky, 5Y5/1, moderately cohesive, silt/fine sand matrix, 10% clasts, lower contact gradational.	12,	3.7	28-40
Diamicton: 5Y4/2, silt matrix, 10% clasts, very fissile and compacted, lower contact gradational.	5,	1.5	40-45
Diamicton: 5Y4/1, clay/silt matrix, cohesive, massive, 10% clasts, wood fragment at 50 ft.	11.5,	3.5	45-56.5
Bedrock:	5.5,	1.7	56.5-62

Borehole 37: 50°02'00", 82°10'10", Harmon Township, NTS 42 J/1, depth drilled 77 feet (23.5 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: pebbly sand/gravel road fill.	2.5,	0.8	0-2.5
Diamicton: fine sand and silt, minor pebbles, poorly consolidated, may be road bed, weakly laminated clay at base with disseminated organics, oxidized, sharp lower contact.	2.5,	0.8	2.5-5
Sand: poorly sorted, coarse sand, cobbles, fines downward to medium, pebbly sand.	1,	0.3	5-6
Diamicton: 10YR6/4, large cobble in organic-bearing clay marks upper contact, fine sand to silt matrix, moderately cohesive, becomes fissile at base, 10% clasts, sharp lower contact.	4.5,	1.4	6-10.5
Sand: fine to medium-grained, massive, 10YR6/4.	11,	3.4	10.5-21.5
Sand/silt: 1 cm-thick clay/silt laminae, sharp contacts.	1,	0.3	21.5-22.5
Sand: massive, medium sand, highly oxidized, 10YR 7/4, rare clay clasts.	1.5,	0.5	22.5-24
Silt/clay: 5Y5/2, massive, sharp contacts.	1,	0.3	24-25
Sand: massive, coarse grained, 2.5Y7/4, lower contact sharp.	4,	1.2	25-29
Diamicton: massive, clay/silt matrix, 5Y6/2, <10% clasts, very cohesive, rare discontinuous silt wisps/partings through unit, fining downcore to clay-rich, cobbles up to 20 cm below 59 ft., some striated, 5Y4/2 at base.	43,	13.1	29-72
Bedrock: gneiss.	5,	1.5	72-77

Borehole 38: 50°02'10", 82°09'55", Harmon Township, NTS 42 J/1, depth drilled 72 feet (21.9 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: sandy silt road bed.	2,	0.6	0-2
Diamicton: massive, silt/clay matrix, <5%clasts, 10YR5/3, mottled, very cohesive, sharp contacts.	3,	0.9	2-5
Sand: oxidized, interbedded medium to coarse sand, graded beds average 0.5 m thick, locally pebbly, minor layers of massive, silty clay, sharply bounded.	19,	5.8	5-24
Diamicton: massive, locally fissile with rare silt wisps, 5Y5/2, <5% clasts, mostly pebbles, granules, contacts sharp, no textural change through unit.	36.5,	11.1	24-60.5
Sand/gravel: coarse grained, poorly sorted, sharp lower contact.	3,	0.9	60.5-63.5
Sand: fine to medium sand, minor granules, 5Y6/1.	1.5,	0.5	63.5-65
Bedrock: Biotite gneiss.	7,	2.1	62-72

Borehole 39: 50°04'30", 82°10'40", Harmon Township, NTS 42 J/1, depth drilled 99 feet (30.2 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: pebbly, coarse road fill.	0.5,	0.1	0-0.5
Diamicton: clay/silt matrix, <5% clasts, cohesive, 10YR4/2 mottled, oxidized, sharp lower contact.	1,	0.3	0.5-1.5

Borehole 39: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: poorly sorted, loose, cobbly, lower contact gradational.	0.5,	0.1	1.5-2
Diamicton: Clay/silt matrix, <10% clasts, mostly granules, very cohesive, fissile, 5Y5/2, upper contact mottled, lower contact marked by large cobble.	8,	2.4	2-10
Sand: coarse grained, poorly sorted, minor silt, abundant pebbles, sharp lower contact.	3,	0.9	10-13
Diamicton: silt/clay matrix fines downward to clayey, 5Y5/2, 5-10% granule clasts, fissile, more cohesive and blocky downcore, lower contact gradational.	5,	1.5	13-18
Clay: massive, 5Y4/2, <1% clasts somewhat blocky, contacts gradational.	3.5,	1.1	18-21.5
Diamicton: silt/fine sand matrix, 15% clasts up to 6 cm cobbles, sand inclusion at 23 ft., 5Y4/2, very cohesive.	12,	3.7	21.5-33.5
Diamicton: fine sand matrix, 10% clasts, 5Y4/2, mottled, oxidation spots, moderately compact, massive, gradational contacts.	12.5,	3.8	33.5-46
Diamicton: silt/fine sand matrix, 5Y5/2, moderately fissile, cohesive, clast contentvariable, <5-10%, lower contact sharp.	5,	1.5	46-51
Diamicton: silt/fine sand matrix, very cohesive, fissile, 5Y5/2, 10% clasts. lower contact sharp.	7.5,	2.3	51-58.5
Sand: massive, medium sand fines downward to silty sand, 3 cm of contorted clay and silt at top of unit, 5Y5/2.	1.5,	0.5	58.5-60
Diamicton: 5Y4/2, variable in cohesiveness from moderate to extreme, 5-10% clasts, rare cobbles up to 6 cm, locally fissile, lower 20 cm may be pulverized bedrock.	26,	7.9	60-86
Bedrock: fossiliferous, impure limestone.	13,	4	86-99

Borehole 40: 50°05'35", 82°11'50", Harmon Township, NTS 42 J/1, depth drilled 86 feet (26.2 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: loose road bed, sharp lower contact.	3,	0.9	0-3
Diamicton: massive, silt/clay matrix, 10% clasts, mottled, 5Y4/3, lower contact sharp.	1.5,	0.5	3-4.5
Sand: 5Y6/2, poorly sorted, fine to pebbly sand, oxidized.	2,	0.6	4.5-6.5
Diamicton: silt/clay matrix, 5Y4/2, fissile, cohesive, 5-10% clasts, contacts sharp.	5.5,	1.7	6.5-12
Sand: medium to coarse, massive, minor silt, pebbles, fines downward, oxidized at top.	3,	0.9	12-15
Diamicton: silt/fine sand to silt/clay matrix, 5-10% clasts up to 3 cm, variable cohesiveness, fissile where most compact, fines downward, contacts sharp.	12,	3.7	15-27
Diamicton: 5Y4/2, silt/clay matrix, 5% clasts, extremely compact, boulder 27.5-28 ft., locally fissile, lower contact sharp.	11,	3.4	27-38
Sand: medium to fine sand with silt, 5Y4/2.	1,	0.3	38-39
Diamicton: fines downward from fine sand to silt/clay matrix, 5Y5/2, 5-10% clasts, moderately cohesive, contacts sharp.	8,	2.4	39-47
Gravel: poorly sorted gravel/coarse sand with cobbles to 6 cm, massive, lower contact unclear.	0.5,	0.2	47-47.5
Diamicton: sandy matrix, 5Y5/2, 5-10% clasts, pebbles up to 3 cm, moderately cohesive and fissile, fines downward.	10.5,	3.2	47.5-58
Diamicton: clay/silt matrix, very compact, 5Y3/2, 10% clasts up to 6 cm, locally very fissile, upper contact abrupt.	23,	7	58-81
Bedrock:	5,	1.5	81-86

Borehole 41: 50°04'40", 82°10'50", Harmon Township, NTS 42 J/1, depth drilled 84 feet (25.6 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Gravel: oxidized, road bed.	3,	0.9	0-3
Diamicton: clay matrix, oxidized, 10YR5/3, 10% granule clasts, minor cobbles, fissileat base.	4,	1.2	3-7
Sand: coarse, pebbly, 2.5Y6/4, sharp contacts, no fines in matrix.	1,	0.3	7-8
Diamicton: clay matrix, 2.5Y6/4, massive, contacts sharp, 10% clasts.	3,	0.9	8-11
Sand: medium to fine sand, coarsening downward, oxidized, mottled, 2.5Y6/4.	1,	0.3	11-12
Diamicton: silt/clay matrix, oxidized at top, 5Y5/3, 8-12% clasts, fissile/blocky for top part of unit, sharp contacts, lower contact marked by large cobble, abundant carbonates.	11,	3.4	12-23

Borehole 41: Continued

Lithology	Thickness (ft., m)	Interval (ft.)
Sand: pebbly sand with fines grades down into fine sand/silt, 5Y5/1, lower contact mottled, sharp, clay-rich.	3, 0.9	23-26
Diamicton: sand matrix, poorly cohesive, 5Y5/2, 5% clasts, fissile, lower contact gradational.	3, 0.9	26-29
Sand: massive, fine grained, 5Y5/1, lower contact interfingers with diamicton.	3, 0.9	29-32
Diamicton: sand/silt matrix, colour variable, 5Y6/2-5Y5/1, very compact, fines downward into clay matrix, 10-15% clasts, abundant carbonates, sharp lower contact.	14.5, 4.4	32-46.5
Sand/silt: interbedded fine sand/silt and clay layers about 2 cm, grades downward into interbeds of stony, clay-rich diamicton up to 10 cm, minor interlayers and clasts of white kaolin clay.	11, 3.4	46.5-57.5
Silt: well sorted, blocky, minor pebbles at base, grades downward into diamicton-like at base, clasts of kaolin clay, lower contact abrupt, irregular.	3.5, 1.1	57.5-61
Kaolin: blue-white, clean kaolin clay, local clay concretions, Cretaceous.	18, 5.5	61-79
Bedrock: fossiliferous, clastic carbonate.	5, 1.5	79-84

Borehole 42: 49°19'15", 82°21'10", Swanson Township, NTS 42 G/8, depth drilled 120.5 feet (36.7 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Clay: massive, mottled, oxidized, may be reworked by road building, peat layer at base.	4, 1.2	0-4
Clay/silt: finely laminated, mottled at top, <2% clasts, pebbles diminish toward base, lower contact gradational, cohesive, colour banded, 7YR5/3 at top, 2.5Y4/2 at base.	11, 3.4	4-15
Clay: massive, no clasts, sticky, highly drilling disturbed, 5Y5/2.	7, 2.1	15-22
Clay: laminated, cohesive, oxidized, disseminated organics, sharp contacts.	1, 0.3	22-23
Clay: massive, sticky, 5Y5/2, rare silty lenses, 5 mm red clay clasts at 45 ft., rare pebbles, increase slightly downward, 3 cm clast with rind of oxidized clay at 52 ft., extremely sticky from 60-79 ft., rare silt lenses and clay intraclasts below 60 ft., minor pebbles and sand below 82 ft., gradational, discontinuous silt/clay couplets from 93-95 ft., rare pebbles in massive clay at base of unit, lower contact sharp.	81, 25	23-104
Silt/sand: 5 mm-thick silt and clay laminae overlying 10 cm of massive, fine grained sand, lower contact sharp.	1, 0.3	104-105
Clay: massive, <1% granules, well sorted, cohesive.	4, 1.2	105-109
Sand: massive, minor granules and clay at base, very fine grained, coarsens downward, 6 cm layer of massive clay at 109.5 ft.	6.5, 2	109-115.5
Bedrock:	5, 1.5	115.5-120.5

Borehole 43: 49°00'20", 82°58'10", Fenton Township, NTS 42 G/1, depth drilled 145 feet (44.2 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Sand/silt: pebbly road fill.	1.5, 0.5	0-1.5
Clay: massive, blocky, oxidized, 2.5Y5/4, minor sand/silt lenses, plant roots, mottled.	1.5, 0.5	1.5-3
Clay: massive to faintly laminated, <2% mixed lithology clasts, mottled, 2.5Y6/4, lower contact sharp.	5, 1.5	3-8
Diamicton: sand/silt matrix, abundant large cobbles, boulder at 9 ft., 15-20% clasts, oxidized, 10YR5/4, lower contact at boulder.	5.5, 1.7	8-13.5
Sand: massive, consistently fine grained, no clasts, rare silty lenses, 5Y7/2, lower contact sharp.	24.5, 7.5	13.5-38
Diamicton: 5Y5/1, sand/silt matrix, very stony, very cohesive, large cobbles at top, fissile, rounded, striated carbonates, lower contact at gneiss boulder.	13.5, 4.1	38-51.5
Sand/gravel: very poorly sorted interval of bouldery sand, locally diamicton-like, washed by drilling, lower contact at thin layer of sandy matrix diamicton, 25% clasts, greenish.	4.5, 1.4	51.5-56
Sand: medium grained, sharply bounded.	1, 0.3	56-57
Diamicton: 5Y5/1, bouldery, upper contact at boulder, very compact, fissile, 10% granules, abundant crystalline lithologies, lower contact sharp.	3, 0.9	57-60
Sand: medium grained, 5% pebbles, well sorted.	3, 0.9	60-63

Borehole 43: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: silt matrix, 20% clasts, abundant cobbles/boulders at top of unit, locally fissile, medium sand layer at 59 ft., 5Y4/2, matrix sandy downcore, clast content decreases downcore, 5Y5/2 below 72 ft., very cohesive, lower contact at boulder.	8.5,	2.6	63-71.5
Diamicton: massive, sand/silt matrix grades downward into sandy, 5Y4/2, 10% clasts, very cohesive lower contact gradational, rare silt and clay clasts.	20.5,	6.2	71.5-92
Sand: well sorted, medium sand, 5Y7/1, few pebbles, lower contact sharp.	5,	1.5	92-97
Diamicton: fine sand/silt matrix, massive, 10% clasts, abundant quartz granules, green-grey colour has incorporated local saprolite, oxidized along parting planes, large cobbles at top.	1,	0.3	97-98
Boulder: gneiss, green colour.	6,	1.8	98-104
Sand: fine grained, massive, green, may be ground-up bedrock but sorted.	1,	0.3	104-105
Saprolite: dark blue-green, highly foliated, micaceous, soft, alternates with rusty-brown weathered intervals, did not recover any unaltered basement rock.	40,	12.2	105-145

Borehole 44: 49°15'50", 81°15'35", Leitch Township, NTS 42 H/6, depth drilled 23 feet (7.0 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: silt/clay to clay matrix, 2% clasts to 5% pebbles at base, moderately cohesive, 10YR 5/4, mottled, sharp lower contact, oxidized, mixed lithologies.	8.5,	2.6	0-8.5
Clay/silt: weakly laminated at top, 5% clasts at top decrease downward to 2%, massive in general, well defined rhythmites at 8.5-9 and 10.5-11 ft., lower contact sharp.	4,	1.2	8.5-12.5
Diamicton: 5Y6/1, poorly cohesive, sandy matrix, massive, 10-15% clasts up to 4 cm, lower contact sharp.	3.5,	1.1	12.5-16
Diamicton: fine sand/silt matrix, mottled, cohesive, 10-15% clasts, rounded carbonates, abundant green saprolitic/chloritic material incorporated.	0.5,	0.2	16-16.5
Bedrock:	6.5,	2	16.5-23

Borehole 45: 49°13'35", 81°13'50", Leitch Township, NTS 42 H/3, depth drilled 80 feet (24.4 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Clay/silt: very disturbed, locally clast-rich, abundant peat and roots, fissile, poorly cohesive, may be slump, contact abrupt.	5,	1.5	0-5
Silt/clay: thin, peaty layers at top, <2% clasts up to pebble-size, oxidation spots to 10 ft., 5Y5/2 to 2.5Y5/4, minor sand lenses, lower contact sharp, massive.	5,	1.5	5-10
Silt/clay: rhythmites, 6-7 cm thick, well defined, unoxidized, sharp contacts.	3,	0.9	10-13
Diamicton: sand matrix, massive, organic bed at 15 ft., 10-15% clasts up to 3 cm, 5Y5/2, lower contact sharp.	19,	5.8	13-32
Sand: massive, coarse grained, pebbly, minor fines, grades down to fine sand at 40 ft., no clasts at base of unit.	10,	3	32-42
Silt/clay: finely laminated, <2% granules, sharp contacts, 25 cm-thick sand layer at 44.5 ft.	3.5,	1.1	42-45.5
Sand: massive medium to fine sand, 5Y5/2, 5% granules and pebbles up to 5 cm, grades downward into coarse, granular sand with minor silt 71-73 ft., sharp lower contact.	27.5,	8.4	45.5-73
Diamicton: 5Y6/2, massive, moderately compact, 15-20% clasts up to 5 cm, silt matrix.	1,	0.3	73-74
Bedrock:	6,	1.8	74-80

Borehole 46: 49°12'10", 81°12'10", Leitch Township, NTS 42 H/3, depth drilled 115 feet (35.1 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Clay/silt: interbedded clay, silt and peat, <2% clasts in upper 1 m, granules, 2.5Y7/2, sandy with disseminated organics and pebbles in lower part of unit, may be reworked by slumping, road building.	6,	1.8	0-6
Clay/silt: contorted, fine laminae, <5% clasts up to 3 cm, 10YR5/3, large cobble at lower contact.	3,	0.9	6-9

Borehole 46: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: fine sand matrix, 5Y4/1, 10% clasts up to 7 cm, poorly cohesive, stratified for lower 2 m, lower contact sharp.	20,	6.1	9-29
Sand: massive, medium sand, 5Y6/1, sharp lower contact.	2,	0.6	29-31
Sand/silt: interbedded fine to medium sand, minor pebbles, clay clasts, silt layer 10 cm-thick, lower contact gradational.	9,	2.7	31-40
Silt: massive, minor clay clasts, faint layering below 40 ft., sharp upper contact, 5Y6/1, thin clay laminae, 2-3 cm-thick, spaced from 1-1.7 m apart, 72-88 ft., rare pebbles associated with clay layers, sharp lower contact.	45,	13.7	40-95
Diamicton: sand matrix, moderately cohesive, 20% clasts, rare clasts up to 6 cm, grades downward into silt matrix, clast content decreases downcore, 5Y6/2.	10,	3	95-105
Sand: massive, coarse sand, minor clasts up to 4 cm, sharp contacts.	2,	0.6	105-107
Diamicton: sandy matrix, very clast-rich, 5Y6/2, cohesive, mixed lithologies.	3,	0.9	107-110
Bedrock:	5,	1.5	110-115

Borehole 47: 48°34'25", 81°35'25", Jamieson Township, NTS 42 A/12, depth drilled 96 feet (29.3 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand/clay: mixed road bed/tailings material, abundant surface organics.	3,	0.9	0-3
Clay/silt: oxidized, 2.5Y6/2, 1 cm-thick graded couplets, contorted layer at 3 ft.	1,	0.3	3-4
Clay/silt: graded rhythmites 1.5-3 cm-thick, unoxidized, 5Y5/2, couplets thicken and coarsen downward, lower contact sharp.	6,	1.8	4-10
Clay: 5 mm-thick clay laminae, no silt.	1,	0.3	10-11
Clay/silt: graded couplets 2-3 cm at top to 5 cm-thick at base, thick clay beds at base, unoxidized, lower contact sharp.	7,	2.1	11-18
Clay: highly contorted rhythmites, predominantly clay, minor silt, lower contact gradational.	6,	1.8	18-24
Clay/silt: graded couplets 3-4 cm thick, thicken and coarsen downward, silt layers to 5 cm, clay 1 cm-thick at base, lower contact gradational.	11,	3.4	24-35
Silt: massive, 35-37 ft., 4-5 cm clay layer at 38 ft., lower contact sharp.	6,	1.8	35-41
Sand: massive, fine grained, lower contact sharp.	1.5,	0.5	41-42.5
Diamicton: sand matrix, pebble-rich, 10-15% clasts, unoxidized, 5Y5/2, massive, boulder at 50 ft., fissility and silt bands below boulder, local oxidation staining at 52 ft., 10YR4/6, moderately cohesive and fissile at base, lower contact sharp.	23,	7	42.5-65.5
Sand: medium, granular sand, sharp contacts.	0.5,	0.2	65.5-66
Diamicton: sand matrix, 5% clasts, cohesive, 5Y5/2.	3,	0.9	66-69
Sand: fine to medium sand, well sorted, sharp contacts.	0.5,	0.2	69-69.5
Diamicton: sand/silt matrix, oxidized along fracture planes 70-78 ft., moderately to very cohesive, more fines in matrix than above unit, blocky, massive toward base, fissile above bedrock 5-10% clasts, 15% large pebbles/cobbles above bedrock.	18.5,	5.6	69.5-88
Bedrock: fresh pyrite, very broken up, some rocks appeared rounded as in a fluvial deposit, in situ bedrock may not have been reached.	8,	2.4	88-96

Borehole 48: 48°34'37", 81°35'20", Jamieson Township, NTS 42 A/12, depth drilled 45 feet (13.7 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Gravel: mixed tailings/road bed, built-up.	4,	1.2	0-4
Peat: organics buried below road.	1,	0.3	4-5
Silt/clay: mottled, organic-bearing, massive, thin (<5 mm) colour bands/stratification at 9 ft., lower contact sharp.	4,	1.2	5-9
Clay/silt: 4 cm thick, graded beds, lower contact sharp.	5,	1.5	9-14
Clay/silt: graded couplets, thicken downward from 1.5-3 cm, lower contact abrupt.	6,	1.8	14-20
Clay/silt: very contorted laminae, lower contact gradational.	1,	0.3	20-21
Clay: planar laminated (<5 mm-thick), lower contact gradational.	1,	0.3	21-22

Borehole 48: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Silt/clay: 1-2 cm silt layers with minor clay, coarsen and thicken downward below 25 ft., grades to massive silt with minor clay layers 31-34 ft., sharp lower contact.	12,	3.7	22-34
Diamicton: poorly consolidated, sand matrix, 10-15% clasts, 5Y5/2, sharp lower contact.	5,	1.5	34-39
Diamicton: moderately cohesive compared to above unit, silt/fine sand matrix, 5% clasts up to 1 cm, mixed lithologies, local bedrock clasts common.	1,	0.3	39-40
Bedrock:	5,	1.5	40-45

Borehole 49: 48°34'45", 81°35'57", Robb Township, NTS 42 A/12, depth drilled 41 feet (12.5 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Gravel: mixed tailings and sand on built-up road bed.	4,	1.2	0-4
Sand: fine to medium sand, oxidized to 6 ft., very coarse pebbly sand 6-6.5 ft., fines downward to silty, fine sand, lower contact sharp.	5,	1.5	5-9
Clay/silt: 1 cm graded couplets at top, grade downward to 2-3 cm-thick rhythmites by 11 ft., lower contact sharp.	2,	0.6	9-11
Clay/silt: uniform 1-1.5 cm graded couplets, thinning and coarsening downward, silty layers near base, sharp lower contact.	3.5,	1.1	11-14.5
Clay: extremely thin laminae (<5 mm), lower contact abrupt.	0.5,	0.2	14.5-15
Silt/clay: variable thickness rhythmites, 1-1.5 cm to 16 ft., 2-3 cm to 17 ft., 0.5-1.5 cm to 18.5 ft., lower contact sharp.	3.5,	1.1	15-18.5
Silt/clay: thin, convoluted rhythmites.	0.5,	0.2	18.5-19
Clay/silt: 1-3 cm graded couplets, thicken and coarsen downward, contacts sharp.	2.5,	0.8	19-21.5
Silt/clay: very convoluted silt/clay beds, grades downward to silty, lower contact gradational.	0.5,	0.2	21.5-22
Silt: massive, with minor clay beds at 23.5 and 24.5 ft., may be large-scale rhythmites to 25 cm-thick, lower contact sharp.	3,	0.9	22-25
Diamicton: poorly cohesive, sandy matrix, 10% clasts, mostly granules to pebbles, 5Y5/1, coarsens downward, abundant local lithologies.	11,	3.4	25-36
Bedrock: fine grained, metavolcanic with visible, abundant sulphide minerals.	5,	1.5	36-41

Borehole 50: 48°34'50", 81°35'55", Robb Township, NTS 42 A/12, depth drilled 37 feet (11.3 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Gravel: road bed of mine debris.	1,	0.3	0-1
Sand: very oxidized, medium sand, fines downward to fine sand at base, sharp lower contact at boulder (5-6 ft.).	5,	1.5	1-6
Sand/silt: massive, minor clay, colour banding suggests weak stratification, mottled, lower contact gradational.	2,	0.6,	6-8
Diamicton: sand/silt matrix, very disturbed-looking (may be drill-induced), abundant large pebbles, locally colour banded, oxidized along lower, abrupt, contact, 2.5Y6/3.	2,	0.6	8-10
Diamicton: sand matrix, massive, poorly cohesive, 5Y5/1, 5-10% clasts, slightly oxidized at top, lower contact gradational.	10,	3	10-20
Diamicton: silt matrix, fissile, silt wisps at upper contact, very compact, 15% clasts, more large clasts than above unit, abundant carbonates, 5Y4/1.	12,	3.7	20-32
Bedrock: broken-up mixture of unweathered and saprolitic bedrock, drill-induced deformation suspected.	5,	1.5	32-37

Borehole 51: 48°34'58", 81°36'10", Robb Township, NTS 42 A/12, depth drilled 93 feet (28.3 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Silt: aeolian veneer of fine materials.	0.5,	0.2	0-0.5

Borehole 51: Continued

Lithology	Thickness (ft., m)	Interval (ft.)
Sand: medium grained sand, oxidized to 12 ft., 2.5Y7/2, unoxidized below 12 ft., 5Y6/1, coarse to medium sand below 6 ft., fines downward to massive, fine sand at base, sharp lower contact.	27.5, 8.4	0.5-28
Clay: massive, 6 cm cobble at lower, sharp contact, no other clasts.	2, 0.6	28-30
Silt/clay: 1 cm-thick graded couplets at top, thickens downward to 3 cm and coarser, no clasts, lower contact gradational.	5, 1.5	30-35
Clay/silt: thin (1 cm), clay-rich couplets, uniform, coarsens slightly downcore, lower contact abrupt.	5, 1.5	35-40
Silt/clay: highly deformed convoluted laminations, laminae are less distinct at base of unit, lower contact gradational.	4.5, 1.4	40-44.5
Silt: massive, 5Y5/2, no clasts, rare, thin clay layers, minor fine sand incorporated, no apparent bedding, lower contact sharp.	22.5, 6.9	44.5-67
Diamicton: sandy matrix, poorly cohesive, abundant granules, pebbles up to 1 cm, 10-15% clasts, 5Y6/2, massive, lower contact abrupt (at end of core bag).	5, 1.5	67-72
Diamicton: fissile, very cohesive, local, discontinuous silt wisps, silt/fine sand matrix, clast content variable, up to 20%, abundant pebbles 1-2 cm, abundant local lithologies, 5Y5/2, massive at base.	16, 4.9	72-88
Bedrock: fine grained, mafic volcanic rock, minor pyrite.	5, 1.5	88-93

Borehole 52: 48°34'55", 81°35'56", Robb Township, NTS 42 A/12, depth drilled 117 feet (35.7 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Sand: coarse to medium sand at top, sharp contact with fine sand at 6 ft., oxidized to 7 ft., fining downward, lower contact abrupt.	34, 10.4	0-34
Sand/silt: interbedded silt/clay laminae and sand in 3-4 cm couplets, thickens downcore, to massive silt layers, lower contact sharp.	5, 1.5	34-39
Clay: thickly laminated (4 cm), graded clay, lower contact abrupt.	2, 0.6	39-41
Clay/silt: thinly laminated silt and clay (<1 cm) at top, thickens slightly downcore, uniform, minor fine sand lenses, lower contact abrupt.	6, 1.8	41-47
Clay/silt: 1 cm-thick clay beds are highly convoluted, lower contact sharp.	1, 0.3	47-48
Clay/silt: <1-2 cm-thick graded couplets, thicken downcore, uniform to 52 ft., irregular thickness and slightly convoluted below 52 ft., lower contact sharp.	8, 2.4	48-56
Silt: massive, 2 cm clay bed below 56 ft., 5 cm clay bed at 61 ft., 4 cm of laminated silt/clay at base of unit above sharp contact.	11, 3.4	56-67
Diamicton: sandy matrix, saturated, poorly consolidated, 10-15% pebbles/granules, cobble at 82 ft., silty stratification between 86 and 87 ft., 5Y5/1, massive, lower contact sharp.	20.5, 6.2	67-87.5
Diamicton: fissile at top, 15-20% clasts, sand/silt matrix, very cohesive, 5Y5/2, abundant cobbles of local lithologies at base.	24.5, 7.5	87.5-112
Bedrock:	5, 1.5	112-117

Borehole 53: 48°34'59", 81°35'40", Jamieson Township, NTS 42 A/12, depth drilled 96 feet (29.3 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Sand: aeolian veneer of very fine sand.	0.5, 0.2	0-0.5
Sand: massive, fine to medium sand, fining downward, 2.5Y6/2, oxidized to 5 ft., well sorted, disseminated organics around 43 ft., lower contact sharp, weakly layered at base.	44.5, 13.4	0.5-45
Clay/silt: 2-3 cm graded couplets, mostly clay, fining downward, lower contact gradational.	4, 1.2	45-49
Clay/silt: finely laminated (1-1.5 cm) clay and silt, siltier toward base, very clay-rich 54-54.5 ft., thickening downward to 2 cm, contact is gradational.	9, 2.7	49-58
Clay/silt: 2-3 cm-thick rhythmites, very contorted and ripped-up, clay layers visible at top but decrease downward, more silt toward base, lower contact gradational.	7, 2.1	58-65
Silt: massive silt, minor clay layers may represent 30 cm-thick graded couplets, contorted 6 cm-thick clay bed at 69.5 ft., lower contact sharp, at 3 cm pebble.	9.5, 2.9	65-74.5

Borehole 53: Continued		
Lithology	**Thickness** (ft., m)	**Interval** (ft.)
Diamicton: massive, sand/silt matrix, 15% clasts, mostly granules, striated carbonate pebbles, moderately cohesive, local silty partings, lower contact abrupt, 5Y5/1.	5.5, 1.7	74.5-81
Diamicton: silt matrix, very fissile, very cohesive, 15% clasts, abundant larger clasts, large, angular, 6 cm cobbles at upper contact, minor oxidation along fractures, 5Y5/1, lower contact sharp.	8, 2.4	81-89
Saprolite: green, sheared, locally-derived debris, 5Y5/4, grades downward into very weathered-looking, rusty-brown, clastic material, lower contact sharp.	2, 0.6	89-91
Sand: sorted, medium grained sand.	1, 0.3	91-92
Saprolite: as above, 2.5Y6/4, angular clasts except for a rounded carbonate, matrix at base is like peanut butter, very bottom of core intersected some highly disturbed, but unweathered bedrock, metavolcanic.	4, 1.2	92-96

Borehole 54: 48°34'58", 81°34'35", Jamieson Township, NTS 42 A/12, depth drilled 80 feet (24.4metres)		
Lithology	**Thickness** (ft., m)	**Interval** (ft.)
Sand: medium sand, abundant pebbles and granules, sharp lower contact, oxidized, ripped-up clay bed at base.	11, 3.3	0-11
Silt/clay: rythmites, 1 cm-thick, oxidized to 12 ft., 10YR5/3, mottled, lower contact sharp.	1, 0.3	11-12
Clay/silt: thickly laminated (5-6 cm) graded couplets, minor silt, rare silty clasts, fine sand layer at 14 ft., lower contact abrupt.	2.5, 0.8	12-14.5
Silt/sand: silt/fine sand couplets up to 6 cm thick, deformed by drilling, lower contact sharp.	1.5, 0.5	14.5-16
Diamicton: sandy matrix, poorly cohesive, 10-15% granule clasts, 5Y5/1, abundant carbonates, clast content decreases downcore, massive, very uniform, texture, lower contact sharp.	56.5, 17.2	16-72.5
Sand: medium to coarse, pebbly sand, lower contact sharp.	1.5, 0.5	72.5-74
Diamicton: sandy matrix, 20% clasts, mostly local lithologies, 5Y5/2, reworked by drill.	1, 0.3	74-75
Bedrock:	5, 1.5	75-80

Borehole 55: 48°35'08", 81°35'15", Jamieson Township, NTS 42 A/12, depth drilled 82 feet (25 metres)		
Lithology	**Thickness** (ft., m)	**Interval** (ft.)
Sand: fine to medium sand, oxidized to 16 ft., disseminated organics and lenses 16-20 ft., fine sand below 16 ft. fines down-ward to very fine sand/silt at base, locally bedded, lower contact gradational.	38, 11.6	0-38
Silt/sand: thinly laminated.	0.5, 0.2	38-38.5
Clay : very finely laminated, no silt, sharp contacts.	0.5, 0.2	38.5-39
Clay/silt: 1 cm-thick graded couplets, minor silt, lower contact abrupt.	1, 0.3	39-40
Clay/silt: 2-4 cm, clay-rich couplets.	1.5, 0.5	40-41.5
Clay/silt: clay-rich rhythmites, thicken downward from 0.5-1 cm, sharply bounded.	5.5, 1.7	41.5-47
Clay/silt: very convoluted rhythmites, 1 cm thick, grades down into planar laminated couplets.	1, 0.3	47-48
Clay: very thin (<5 mm) clay laminae, lower contact gradational.	0.5, 0.2	48-48.5
Silt/clay: thickening, coarsening downward silt/clay rhythmites, silty with thick, graded clay beds by 55 ft., rhythmites grade downward into a jumble of contorted couplets below 55 ft., irregular bedding 55-69 ft., silt beds up to 25 cm-thick with abundant clay rip-up clasts toward base, lower contact sharp.	20.5, 6.2	48.5-69
Diamicton: 5Y5/1, sandy matrix, 5% clasts, poorly cohesive and distorted by drill, lower contact gradational.	5, 1.5	69-74
Diamicton: 5Y5/2, sand/silt matrix, cohesive, locally fissile, poor recovery.	3, 0.9	74-77
Bedrock:	5, 1.5	77-82

Borehole 56: 48°35'10", 81°35'35", Jamieson Township, NTS 42 A/12, depth drilled 63 feet (19.2 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: oxidized to 7 ft., medium sand, fines downward to fine sand, massive, lower contact sharp.	23,	7	0-23
Clay/silt: very thin (<5 mm) clay laminae, discontinuous silt layers, lower contact gradational.	0.5,	0.2	23-23.5
Clay/silt: 2-3 cm-thick rhythmites, 10% silt, thicknen downcore.	1.5,	0.5	23.5-25
Clay/silt: somewhat variable thickness, graded couplets, 0.5-1 cm, coarsens downward, sharply bounded.	5,	1.5	25-30
Clay: very thin (<5 mm) clay laminae, sharp contacts.	0.5,	0.2	30-30.5
Clay/silt: thickening downward rhythmites, to 2 cm, more clay-rich at base, lower contact abrupt.	3.5,	1.1	30.5-34
Clay/silt: highly distorted, clay laminae and thick silt beds, very soft core, poorly preserved structures, silt-rich at base, lower contact gradational.	4,	1.2	34-38
Silt: massive, rare clay rip-up clasts, thin intact clay layer at 40 and 42 ft., lower contact distorted by drill.	9,	2.7	38-47
Diamicton: 5Y5/1, sand matrix, poorly cohesive, 5-10% clasts, mostly granules and small pebbles, striated carbonates, local lithologies abundant at base, cobble at 55 ft.	11,	3.3	47-58
Bedrock:	5,	1.5	58-63

Borehole 57: 48°34'56", 81°35'30", Jamieson Township, NTS 42 A/12, depth drilled 142 feet (43.3 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: medium sand, oxidized to 7 ft., fines downward to fine sand 25-40 ft., gradational interval of pebbly sand 33-36 ft., very fine sand and silt 40-45 ft., massive, lower contact sharp.	45,	13.7	0-45
Silt: silt/minor clay couplets, thin down-core from 3-2 cm, mostly silt, lower contact sharp.	5,	1.5	45-50
Clay: very thinly laminated (<5 mm) clay-rich couplets, gradational lower contact.	2,	0.6	50-52
Clay/silt: 1-1.5 cm thick, clay-rich couplets, thicken downward to 3-4 cm, lower contact gradational.	5,	1.5	52-57
Clay/silt: 1-1.5 cm graded couplets, coarsen downward to more silty, sharp lower contact.	6,	1.8	57-63
Clay: <5 mm-1 cm thin clay laminae, grade downward into 1-2 cm, silt-poor rhythmites, lower contact gradational.	2,	0.6	63-65
Clay/silt: clay layers become progressively more ripped-up or convoluted downcore, couplets 3.5 cm clay/0.5 cm silt by 69 ft., grades down into thick beds of silt with clay clasts 69-79 ft., very soft, soupy core, one layer of contorted clay within planar laminated couplets at 67 ft., lower contact abrupt.	14,	4.3	65-79
Sand: coarse sand over cobble lag, lower contact sharp.	1,	0.3	79-80
Diamicton: 5Y5/2, sandy matrix, locally silty, 5-10% clasts, sharp lower contact	30,	9.1	80-110
Diamicton: silt matrix, very fissile, very cohesive, oxidized along contact and fractures below, local oxidation spots, 2.5Y6/4, interval of well sorted fine sand 115-116 ft., clast content variable through core 5-10%, mostly granules, rare large pebbles, increases down-core, blocky at base.	27,	8.2	110-137
Bedrock: abundant sulphide-rich stringers, pyrite, chalcopyrite.	5,	1.5	137-142

Borehole 58: 48°35'38", 81°37'12", Robb Township, NTS 42 A/12, depth drilled 145 feet (44.2 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: fine to medium sand, oxidized at top, sharp lower contact.	30.5,	9.3	0-30.5
Clay/silt: thinly laminated (<5 mm) clay-rich couplets, 10YR5/2, oxidized to 31 ft., lower contact sharp.	0.5,	0.2	30.5-31
Clay/silt: uniform couplets, 0.5-1 cm-thick, thickens downward to irregular, 2 cm rhythmites 33.5-35 ft., gradational lower contact.	4,	1.2	31-35
Clay/silt: uniform 1-1.5 cm rhythmites, convoluted rhythmites 35-36.5 ft., increase in silt content downcore, clay layers thicken to 3 cm by 39 ft., lower contact sharp.	4,	1.2,	35-39
Clay: thick clay beds with minor silt lenses, convoluted interbeds, clay-rich, lower contact abrupt.	1,	0.3	39-40

Borehole 58: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Silt/clay: highly contorted silt and clay, soft core, grades downward into silt inter-bedded with fine sand and rare clay rip-up clasts 42-46 ft., lower contact gradational.	5,	1.5	40-45
Sand: fine sand, disseminated organics, lower contact sharp.	10,	3	45-55
Sand: medium sand, minor coarser intervals, disseminated, mossy, organics, lense of organic-rich material at 63 ft., faint bedding with organics along bedding planes below 63 ft., more fine sand in lower part of unit.	31,	9.5	55-86
Boulder: crystalline.	5,	1.5	86-91
Sand: pebbly fine to medium sand, very clast-rich below boulder, abundant carbonates, locally clast-supported, gravelly, massive, fine sand at base, fines downward, lower contact sharp with large pebbles.	17,	5.2	91-108
Diamicton: sand/silt matrix, 10-15% small pebbles/granules, 5Y5/1, poorly cohesive, lower contact gradational.	11,	3.3	108-119
Diamicton: very cohesive, 15% clasts, small pebbles to cobbles, 5Y5/2, angular, local clasts at base, fresh pyrite, unoxidized, local oxidized lenses at edge of core, striated ultramafic cobble at 121 ft.	21,	6.4	119-140
Bedrock:	6,	1.8	140-146

Borehole 59: 48°49'15", 81°43'36", Geary Township, NTS 42 A/13, depth drilled 87 feet (26.5 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: medium- to coarse-grained, oxidized, surface may be road bed.	7,	2.1	0-7
Peat: sharp upper contact, gradational lower contact, massive.	1,	0.3	7-8
Clay/silt: thinly laminated clay and silt, interbeds up to 4 cm of peat/organics, unoxidized, sharp lower contact.	6,	1.8	8-14
Clay: massive, well sorted, sticky, some granules or rare pebbles at top, fines downward, lower contact sharp.	8.5,	2.6	14-22.5
Silt/clay: convoluted rhythmites, abundant clay rip-up clasts at top, grades downward to massive to laminated silt with rare pebble or clay clasts 23-30 ft., structureless, highly contorted silt 30-35 ft., coarsens downward to silt and fine sand at base, lower contact obscured by drilling.	17.5,	5.3	22.5-40
Diamicton: sand matrix, 5Y6/2, 10-15% clasts,mostly granule to small pebble, coarsens downward to very pebbly/sandy at base, lower contact sharp.	12,	3.7	40-52
Gravel/sand: gravel at top grades down to coarse pebbly sand, sharply bounded interval of clast-poor, fine sand 59-62 ft., lower contact sharp.	15.5,	4.7	52-67.5
Diamicton: green, highly variable, up to 45% clasts, borderline clast-supported, abundant carbonates, boulder at lower contact, matrix silty to granular sand.	4.5,	1.4	67.5-72
Sand: massive medium to coarse sand, well sorted, rare clasts, lower contact sharp.	6,	1.8	72-78
Diamicton: upper contact marked by several large cobbles, very compact, oxidized, greenish from incorporation of saprolite, carbonates evident, sand/silt matrix.	2,	0.6	78-80
Saprolite: highly weathered and soft, very thin slaty, micaceous layers of brown and green, no unaltered material recovered.	7,	2.1	80-87

Borehole 60: 48°49'10", 81°41'00", Wilhelmina Township, NTS 42 A/13, depth drilled 164 feet (50 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: coarse road bed material.	2.5,	0.8	0-2.5
Clay: massive, sticky, <2% granules, rare pebbles at top, no apparent structure, grades downward to weakly laminated/bedded clay with few clasts and local contorted beds 33-56 ft., <1% clasts, small disseminated organic fragments in upper beds, lower contact gradational.	53.5,	16.3	2.5-56
Silt/clay: highly turbated (convoluted) beds, predominantly clay, slightly more planar layers below 58 ft., some ripped-up silt beds, very soft, sticky core, lower contact sharp.	9,	2.7	56-65

Borehole 60: Continued

Lithology	Thickness (ft., m)	Interval (ft.)
Sand: very granular sand and pebbles, well sorted coarse sand (grains 0.5-1 mm) 95-110 ft.	45, 13.7	65-110
Silt: abruptly bounded, laminated silt and fine sand, 5Y5/1.	2, 0.6	110-112
Gravel: cobbly gravel to very coarse sand, coarse pebbly sand with no cobbles 115-118 ft., lower contact sharp.	9, 2.7	112-121
Sand: sorted fine sand at top coarsens down-ward to cobble gravel layer 141-142 ft., minor clay clasts and silt interbeds, small pebbly "lenses", irregular clast distribution, below 142 ft. sand coarsens downward to gravelly, medium sand at base of unit.	38, 11.6	121-159
Bedrock: greenish, slaty, fine grained metavolcanic with disseminated sulphides.	5, 1.5	159-164

Borehole 61: 48°49'00", 81°46'08", Wilhelmina Township, NTS 42 A/13, depth drilled 160 feet (48.8 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Sand: organic rich, may be road fill at top, peat 3-6 ft., lower contact gradational.	6, 1.8	0-6
Diamicton: clay-rich, fine sand matrix, 15% clasts, abundant cobbles/large pebbles, oxidized to 8 ft., 2.5Y4/2, brown bands to 19 ft., 5Y5/2, below 19 ft. appears to grade downward into fine sand and silt with fewer clasts, massive, slightly blocky, abundant carbonates, lower contact very gradational.	49, 15	6-55
Sand: fine sand, disseminated organics, rare clasts, similar to matrix material in upper diamicton, lower contact gradational.	2, 0.6	55-57
Sand/silt: fining downward, layered fine sand and silt, disseminated organics, lower contact sharp.	6, 1.8	57-63
Sand: sorted, massive, medium sand, sharply bounded.	0.5, 0.2	63-63.5
Sand/silt: 2.5-5 mm-thick silt/fine sand laminae, some laminae defined to <1 mm in thickness, organic-rich bands, thickening downward below 66 ft. to 1 cm, mostly silt, lower contact gradational.	12.5, 3.8	63.5-76
Silt/clay: stratified silt with clay rip-up clasts (probably former layers) to 83 ft., massive below 83 ft., organic-bearing, very cohesive, no pebbles or granules, sharp lower contact.	15, 4.6	76-91
Sand: massive, fine sand, coarsens downcore to medium sand at base, locally oxidized, lower contact sharp.	4, 1.2	91-95
Diamicton: clay matrix, extremely cohesive,blocky, 5% clasts, abundant carbonates, 5Y5/4, clasts are mostly small pebbles, lower contact gradational.	9, 2.7	95-104
Silt/clay: very thinly laminated.	0.5, 0.2	104-104.5
Sand: medium sand at top grades to fine sand with abundant finely divided organics, black, manganese-rich layer smelled of decomposition, fine to medium sand 105-108 ft., lower contact gradational.	3.5, 1.1	104.5-108
Silt/clay: mostly silt with clay-rich interbeds, 5Y4/2, finely disseminated organics, lower contact gradational.	5, 1.5	108-113
Silt/sand: interbedded silt/fine to medium sand, minor brown, organic-bearing, thinly laminated clay, sharp lower contact at organic-rich clay layer.	2, 0.6	113-115
Sand: coarse, granular, grades downward.	1, 0.3	115-116
Diamicton: sandy matrix, poorly cohesive, locally oxidized, 2.5Y5/4, sharp contact at cobble layer.		
Diamicton: silt matrix, very cohesive, 5Y5/1 to 5Y5/2, oxidized to 124 ft., 15% clasts, blocky, extremely rich in carbonates below 137 ft., very cohesive, some colour mottling at 150 ft.	39, 11.9	116-155
Bedrock: volcaniclastic rock, disseminated sulphides.	5, 1.5	155-160

Borehole 62: 48°48'55", 81°46'30", Wilhelmina Township, NTS 42 A/13, depth drilled 109 feet (33.2 metres)

Lithology	Thickness (ft., m)	Interval (ft.)
Sand: oxidized, organic-rich, top is road bed, lower contact sharp.	6, 1.8	0-6
Diamicton: fine sand/silt matrix, oxidized, 2.5Y6/4, 8-10% clasts, mostly granule, very cohesive, massive, lower contact sharp, at limit of oxidation.	5, 1.5	6-11

Borehole 62: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: fine sand/silt matrix, 10-15% clasts, massive, moderately cohesive, 5Y5/2, abundant carbonates, sandy matrix 18-32 ft., clast content and size decreases downcore to 5%, fissile 28-32 ft., lower contact gradational.	35,	10.7	11-46
Diamicton: silt matrix, massive, very cohesive, 5% granule clasts, 5Y5/1, organic rich layers, brown colour streaks, lower contact sharp.	6,	1.8	46-52
Sand: massive, medium sand, well sorted, locally oxidized, rare pebbles <3 cm, lower contact sharp.	9,	2.7	52-61
Diamicton: sand matrix, massive, 5-10% granule clasts, 5Y5/2, below 69 ft. matrix is silty, moderately cohesive, coarse sand layer 70-71 ft., gradational contacts, clast content decreases somewhat downcore, uniform soft, sandy diamicton toward base, lower contact gradational.	25,	7.6	61-86
Silt: fine sand/silt at top fines downward to laminated silt, brown organic streaks, 5Y5/2, lower contact sharp.	5,	1.5	86-91
Clay: massive, 5Y4/2, very compact, minor small pebbles/granules, sharply bounded.	1,	0.3	91-92
Sand: well sorted, medium sand, no clasts.	2,	0.6	92-94
Diamicton: upper contact very pebbly, almost clast-supported, medium to fine sand matrix, highly variable, matrix locally fine sand/silt, abundant carbonates, clast-supported large pebbles at 97 ft., 1 cm coarse, pebbly sand layer at 99 ft., oxidized streaks, very compact below 99 ft., locally stratified with thin silt laminae (0.25-0.5 cm) over 5 cm interval near base.	10,	3	94-104
Bedrock: fine grained chlorite schist, disseminated sulphides.	5,	1.5	104-109

Borehole 63: 48°49'50", 81°40'45", Geary Township, NTS 42 A/13, depth drilled 78 feet (23.8 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: fine sand, massive, oxidized, 2-3 cm-thick peat interbeds, top may be road bed, fine to medium, pebbly sand 5-6 ft., grades downward to fine sand with silt/clay interbeds 4-8 cm thick, minor clasts in clay, disseminated organics 18-30 ft., silty, diamicton-like bed at 21 ft., gradational contacts, fine sand/silt at base of unit with organic clots, lower contact sharp.	30,	9.1	0-30
Silt/clay: finely laminated (1 cm) clay and silt, coarsening downward to silt, laminae are contorted in upper 12 cm, planar below, unoxidized, lower contact sharp, 5Y5/2, few pebbles/granules.	17.5,	5.3	30-47.5
Diamicton: silt/sand matrix, massive, moderately cohesive, 10-15% clasts up to 7 cm, 5Y5/2, clast-supported at 54 ft., crystalline boulder 49-52 ft., sharp lower contact.	7.5,	2.3	47.5-55
Sand/silt: laminated fine sand/silt, rare clasts, disseminated organics, gradational lower contact.	1,	0.3	55-56
Sand: massive, fine sand, rare clay laminae, rare pebbles, disseminated organics, sharp lower contact.	5.5,	1.7	56-61.5
Silt/sand: interbedded (0.5-1 cm-thick), 5Y5/2, cohesive, <2% clasts up to granule-size, disseminated organics, grades to massive from 64-66 ft., sharp lower contact.	5.5,	1.7	61.5-66
Sand: fine to medium sand, minor clay/silt, 3% pebbles up to 5 cm, grades downward to fine sand/silt planar laminae with organic layers 70-72.5 ft., lower contact sharp.	6.5,	2	66-72.5
Diamicton: silt/sand matrix, abundant clasts up to 8 cm, green alteration around some clasts, cohesive.	0.5,	0.2	72.5-73
Bedrock:	5,	1.5	73-78

Borehole 64: 48°54'10", 81°35'47", Aubin Township, NTS 42 A/13, depth drilled 38 feet (11.6 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Clay: massive at top grades downward to laminated, oxidized, organics (roots, twigs), lower peaty layers, may be local road fill.	5,	1.5	0-5
Sand: coarse, cobbly, chunks of peat, may be bulldozed for built-up road, lower contact sharp.	1,	0.3	5-6
Clay: massive, rare silt lenses, 2.5Y6/4, mottled, <5% granules, minor organics at top, faintly laminated 8-10 ft., 5Y5/2 below 10 ft., structureless below 10 ft., fewer clasts, coarsens downward to silty, lower contact sharp.	16.5,	5	6-22.5
Silt: stratified silt/clay, <2% pebbles, laminations diminish downcore, lower contact gradational.	1.5,	0.5	22.5-24

Borehole 64: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: sand/silt matrix, poorly cohesive, massive, 10% clasts up to 6 cm, grades downward to more compact, sandy diamicton 29-33 ft., clasts decrease in size below 29 ft.	9,	2.7	24-33
Bedrock:	5,	1.5	33-38

Borehole 65: 48°49'35", 81°43'30", Geary Township, NTS 42 A/13, depth drilled 147 feet (44.8 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: pebbly, oxidized, abundant surface organics in top 0.2 m, grades downward to silty/fine sand, minor thinly laminated silt, gradational lower contact, upper part is road bed.	5,	1.5	0-5
Peat: organic peat with pebbles, granules, probably buried Sphagnum, lower contact sharp.	1,	0.3	5-6
Clay: massive to faintly laminated, rare pebbles/granules, disseminated organics, 5Y6/2, locally very sticky, lower contact gradational.	29.5,	9	6-35.5
Silt/clay: clasts up to 4 cm at top, thinly laminated silt/clay couplets (0.5 cm) thicken downward to 2 cm, rare fine sand beds up to 2 cm in normal and reverse graded couplets, couplets 3-4 cm 37-42 ft., 4-5 cm below 42 ft., massive fine sand with silt beds 46-47 ft., rhythmically laminated silt/clay up to 3 cm-thick below 47 ft., 5Y6/1 to 5Y5/2, coarsens downward to massive fine sand by 68 ft., lower contact sharp.	32.5,	9.9	35.5-68
Silt/sand: finely laminated silt, coarsens downward to silt/fine sand, interbedded clay layers to 3-4 cm, local cohesive, blocky texture, variable silt/sand couplet thickness throughout unit, fine sand with pebbles/minor cobbles below 130 ft., 5Y6/1, lower contact sharp.	65,	19.8	68-133
Diamicton: medium to fine sand matrix, clast content <5% increases downward, very cohesive, unoxidized, matrix is greenish, inclusions of brownish diamicton, clast supported 136-138 ft.	9,	2.7	133-142
Bedrock:	5,	1.5	142-147

Borehole 66: 48°47'25", 81°39'50", Thorburn Township, NTS 42 A/13, depth drilled 131 feet (40 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: coarse pebbly sand to gravel at top, wood chunks, road fill 0-4 ft., grades to fine to medium sand, oxidized, disseminated organics 4-6 ft., sharp lower contact.	6,	1.8	0-6
Clay/silt: massive clay, <2% clasts, 5Y5/2, organic material, thin sand layer at 7 ft., coarsens downward, interlayered 0.5-1 cm silt and minor clay below 19 ft., locally convoluted, no clasts, lower contact gradational.	28,	8.5	6-34
Sand: fine to medium sand, coarsens downward to coarse sand and gravel by 75 ft., well-rounded pebbles, gradational contact.	41,	12.5	34-75
Sand: very fine sand, disseminated organics, faint silty laminations, coarsens downward to medium to coarse, pebbly sand by 90 ft., coarse pebbly gravel 90-115 ft., coarsens to cobble gravel at base of unit, sharp lower contact.	45,	13.7	75-120
Diamicton: sand matrix, slightly oxidized, 2.5Y6/4, locally clast-supported, contains weathered saprolitic material, some carbonates.	4,	1.2	120-124
Bedrock: pulverized by drill, poor recovery.	7,	2.1	124-131

Borehole 67: 48°26'50", 81°39'00", Turnbull Township, NTS 42 A/5, depth drilled 131 feet (40 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: organic-bearing sand, road fill.	0.5,	0.2	0-0.5
Diamicton: sand matrix, soft, poorly cohesive, oxidized along parting planes at top, 5Y6/3, unoxidized below 11 ft., 5Y5/1, 5-10% clasts, lower contact sharp.	25.5,	7.8	0.5-26
Diamicton: silt matrix, very compact, 10% clasts, massive but locally blocky, 5Y5/2, oxidized spots at contact but may be core contamination, lower contact sharp.	19,	5.8	26-45
Sand: massive, medium sand.	0.5,	0.2	45-45.5
Diamicton: compact, silt/sand matrix, rich in crystalline clasts, 15% clasts, lower contact sharp.	4.5,	1.4	45.5-50

Borehole 67: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Diamicton: very soft, silt matrix, <10% clasts, 5Y5/1, gradational lower contact.	2,	0.6	50-52
Diamicton: very compact, locally oxidized at top, 15% clasts of all sizes, abundant carbonates.	13,	4	52-65
Sand: massive, fine sand, sharply bounded.	0.5,	0.2	65-65.5
Diamicton: large cobble at upper contact and at 82 ft., fine sand/silt matrix, fissile and blocky, 15-20% clasts, abundant carbonates, 5Y6/2, oxidized patches with gradational rims, locally broken up by drilling, large cobbles at lower, sharp contact.	19.5,	5.9	65.5-85
Diamicton: very cohesive, sand matrix, very pronounced increase in clast content, locally clast-supported, carbonate-rich, 5Y5/2, grades downward to silty above base, lower contact sharp.	20,	6.1	85-105
Gravel: coarse, pebbly, clasts up to 5 cm, lower contact sharp.	3,	0.9	105-108
Diamicton: sand matrix, moderately cohesive, 5Y5/1,10-15% clasts, lower contact sharp.	12,	3.6	108-120
Diamicton: very fissile, highly compact,minor silty stratification, 15% clasts, mostly local lithologies, 5Y5/2, oxidation along parting planes, inclusions of greenish saprolite.	5,	1.5	120-125
Bedrock: green, fine grained metavolcanic, minor sulphides.	6,	1.8	125-131

Borehole 68: 48°26'52", 81°31'50", Godfrey Township, NTS 42 A/5, depth drilled 50 feet (15.2 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Gravel: coarse, sandy, organic debris, poorly consolidated road bed, sharp lower contact.	0.75,	0.2	0-0.75
Diamicton: sand matrix, 5% clasts up to 4 cm, 5Y6/1, poorly cohesive, clast content decreases downcore, gradational lower contact.	4.25,	1.3	0.75-5
Sand/silt: interlayered fine sand and silt 0.75-5 ft., <2% clasts, grades to massive, medium sand below 5 ft., poorly sorted, cobbles up to 6 cm, 25% large clasts, 3 cm-thick diamicton layer at 20 ft., gradational lower contact.	15,	4.6	5-20
Diamicton: sandy, 5-10% clasts up to 5 cm, 5Y6/1, moderately cohesive, large cobble at lower contact, silty at base.	6,	1.8	20-26
Sand: massive, fine sand, coarsens downward to medium sand with pebbles/granules 30-38 ft., 3 cm silt layer at 30, 35 ft., pebble content increases downcore, coarse granular sand 38-40 ft., lower contact sharp.	14,	4.3	26-40
Diamicton: fine sand/silt matrix, moderately cohesive, 10% clasts up to 4 cm, 5Y6/3, clast size decreases to granule below 41 ft., very clast-rich with visible sulphides 44-45 ft., very compact at base, 5Y6/1.	5,	1.5	40-45
Bedrock:	5,	1.5	45-50

Borehole 69: 48°33'55", 81°37'00", Robb Township, NTS 42 A/12, depth drilled 110 feet (33.5 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Gravel: angular mine tailings used as road bed, lower contact abrupt.	3,	0.9	0-3
Sand: fine sand, unoxidized, lower contact sharp.	2,	0.6	3-5
Clay: massive to faintly laminated, 5Y6/2,grades to planar and convoluted laminae with organic debris along bedding planes 9-10 ft., lower contact sharp.	5,	1.5	5-10
Clay/sand: interbedded clay/very fine sand, 1-1.5 cm couplets, 5Y5/2, thickens below 11 ft. to 5 cm clay/1 cm silt at base, lower contact sharp.	4,	1.2	10-14
Clay/silt: graded clay laminae 1 cm-thick, minor silt, 2.5Y5/2, sharp contacts.	4,	1.2	14-18
Silt/clay: graded silt/clay rhythmites 1 cm-thick fines downward to mostly clay, clay laminae somewhat convoluted 21-23 ft., sharp lower contact.	6,	1.8	18-23
Clay/silt: uniform, well preserved graded silt/clay rhythmites, 1.5 cm, thicken slightly downward, fines downcore to clay laminae 26-27 ft., lower contact sharp.	4,	1.2	23-27
Silt/clay: silt with thin interbeds of clay at top, below 32 ft. massive to bedded silt with minor clay lenses or rip-up clasts, rare intact clay layers, fine silty laminae above lower, sharp contact.	6,	1.8	27-36
Diamicton: silty, 5% clasts, massive, soft, poorly cohesive, several large pebbles, 5Y6/1, lower contact sharp.	8,	2.4	36-44

Borehole 69: Continued

Lithology	Thickness (ft., m)		Interval (ft.)
Silt: layered silt with rare clay beds.	1,	0.3	44-45
Diamicton: pebbly, sand/silt matrix, clasts up to 5 cm, unoxidized, 5Y5/1, massive, sharply bounded.	3,	0.9	45-48
Silt: 1 cm-thick laminae, no clasts, lower contact gradational.	6,	1.8	48-54
Sand: fine to medium sand, minor pebbles or granules at top, fine, pebbly sand interbedded with thin diamicton beds 57-58 ft., contact gradational.	4,	1.2	54-58
Diamicton: massive, sandy, 5% clasts, mostly 1 cm pebbles, moderately cohesive, 5Y6/2 at top, 5Y5/2 at base, unoxidized, sharp lower contact.	10,	3	58-68
Diamicton: very cohesive, fissile, sand matrix, oxidized in top 5 ft. along parting planes, 5Y5/3, 5-10% clasts, not oxidized below 80 ft., clast content decreases downward, mostly small pebbles, sand/silt matrix at base, less cohesive, lower contact at large cobbles.	32,	9.8	68-100
Diamicton: clay-rich, blocky, 5% clasts, abundant local, mafic lithologies, minor carbonates, few large pebbles, unoxidized, 5Y5/2.	4,	1.2	100-104
Saprolite: green, weathered.	1,	0.3	104-105
Bedrock: green, fine grained volcanic, slaty.	5,	1.5	105-110

Borehole 70: 48°32'45", 81°35'50", Robb Township, NTS 42 A/12, depth drilled 55 feet (16.8 metres)

Lithology	Thickness (ft., m)		Interval (ft.)
Sand: oxidized, medium to coarse sand, upper 5 ft. is road fill from shoulder of highway, lower contact sharp.	6,	1.8	0-6
Silt/clay: massive, 5Y5/1, no clasts, lower contact sharp.	1,	0.3	6-7
Silt/clay: rhythmically laminated, thicken downward, lower contact gradational.	1,	0.3	7-8
Clay: <0.5-1.5 cm rhythmites, irregular thicknesses, not as planar as above, minor oxidation, grades down into evenly laminated silt (75%) and clay (25%), lower contact gradational.	3,	0.9	8-11
Clay: 5Y5/4, oxidized clay rhythmites with minor silt, <1-1.5 cm, thicken downcore, grade into thickly bedded clay (4-5 cm) below 18 ft., no clasts, very soft and sticky, minor silt lenses, lower contact gradational.	13,	4	11-24
Clay: poorly defined bedding, convoluted, ripped-up or convoluted silt layers, lenses, mostly clay, lower contact gradational.	8,	2.4	24-32
Clay/silt: planar-bedded rhythmites, thicken downward from 36-40 ft. from 2-2.5 cm to 4 cm, more silty at base, 5Y5/1, 5 cm-thick interval of very convoluted bedding at 40 ft., lower contact gradational.	8,	2.4	32-40
Clay/silt: minor silt, colour banding may indicate bedding in clay, coarsens downcore to silty with rare fine sand lenses, lower contact sharp.	7,	2.1	40-47
Silt: 1 cm-thick laminae, <1% sand, rare clay lenses along parting planes, sharp lower contact.	2,	0.6	47-49
Diamicton: sandy, 5% clasts, 5Y5/1, lower rontact obscured by drilling, poor recovery.	0.5,	0.2	49-49.5
Diamicton: 5Y5/2, clay/silt matrix, 10% clasts up to large pebbles, abundant carbonates and local lithologies, this unit is a thin veneer on bedrock, poorly recovered.	0.5,	0.2	49.5-50
Bedrock: pegmatite dyke, sulphide staining.	5,	1.5	50-55