# TH 0604

LATE QUATERNARY GEOLOGY, TEMISCAMIE AREA, CENTRAL QUEBEC

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*MICHEL A. BOUCHARD*

***Final geological report for the field seasons 1974 and 1975, submitted to the Ministère de l'Énergie et des Ressources du Québec***



***Décember 1980***
***Département de Géologie***
***Université de Montréal***

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# ABSTRACT

The Têmiscamie area, comprising about 4000 $km^2$ in central Quêbec, includes extensive drumlinized and fluted ground moraine, ribbed moraines, minor areas of hummocky moraine, ice-contact stratified drift with associated meltwater channels, and proglacial deposits which include outwash and glacial-lake sediments with related glacial-lake strandlines. Recent deposits include alluvium, peat, and organic mud in modern lake basins.

Three distinct types of till are recognized, namely basal till, melt-out till, and ablation till. They differ in their textural, structural, compositional, and geomorphic attributes. Melt-out till is associated with ribbed moraines; it is the equivalent of the Kalix and Sveg tills of northern Europe.

The deglaciation of the area occurred between 7,200 years ago, based on the history of Glacial Lake Ojibway, and 6,600 years ago, based on a local radiocarbon date. Glacial Lake Ojibway extended partly into the Mistassini area and drained completely when the ice margin was at the Opataca ice frontal position, 100 km south of the Têmiscamie area, and 20 to 35 km south of the Sakami moraine. Glacial Lake Mistassini succeeded Glacial Lake Ojibway in the Lac Waconichi basin and also extended to the basins of Lac Mistassini and Lac Albanel. Its complex history involved the successive uncovering of outlets to the west as the ice retreated north-northeastward. Rates of frontal recession are estimated as 220 to 260 m/year based on varve counts. Strandlines in the Têmiscamie area formed while the final outlet, in the head area of the present Rupert River, controlled the water level, and their positions suggest an average uplift gradient of 0.55 m/km in the direction of glacial retreat.

Ribbed moraines, a type of minor moraines of problematic origin that occurs extensively on the Canadian and the Baltic Shields, are formed subglacially, possibly as far as 3 to 5 km back from the margin of the receding ice sheet, as a consequence of an obstruction to glacier flow which results in shearing and stacking of slices of near-base englacial debris. Interstitial ice in the debris melts under a protective and confining cover of stagnant glacier ice. Although the trend of the ridges closely approximates that of the receding ice margin, the spacing between successive ridges has no chronological significance for the rate of recession of the ice sheet.

# RESUME

La région de Témiscamie occupe environ 4,000 $km^2$ au nord-est du Lac Mistassini, dans la partie centrale du Québec. Les dépôts meubles y sont principalement du till surmonté de sédiments stratifiées de contact glaciaire et de dépôts proglaciaires dont une partie s'est accumulée dans un lac glaciaire auquel sont associées des lignes de plage émergées. Les sédiments récents sont les alluvions, la tourbe, et la boue organique des fonds de lacs actuels.

Le till dans la région compose la moraine de fond à surface intensément fuselée, des moraines mineures de type ribbed moraine, et des moraines à butte et dépressions. Trois types de till sont reconnus; ils se distinguent les uns des autres par leurs propriétés texturales, structurales, morphologiques, ainsi que par leurs caractéristiques de composition lithologique. Il s'agit du till de fond, du till d'ablation, et du till de type melt-out. Ce dernier est associé aux moraines mineures; de par ces différentes propriétés, il est, croit-on, l'équivalent des tills de Kalix et de Sveg connus et décrits en Suède.

La région a été découverte de glaçe entre 7,200 ans A.A., tel que déduit à partir de l'histoire du Lac Glaciaire Ojibway, et 6,600 ans A.A., tel qu'indiqué par une date radiocarbone dans la région. Le Lac Ojibway a inondé en partie la région de Mistassini et fut drainé lorsque la marge glaciaire en retrait était à la position frontale d'Opataca, à quelques 100 km au sud de la région de Témiscamie et de 20 à 35 km au sud de la moraine de Sakami. Par suite de la vidange du Lac Ojibway, le Lac Glaciaire Mistassini s'est étendu depuis le bassin du Lac Waconichi à ceux des lacs Mistassini et Albanel. Son évolution fut le jeu du dégagement successif de déversoirs vers l'ouest par suite du retrait progressif de la glaçe vers le nord-nord-est. Le recul du front glaciaire s'est effectué à un rythme de 220 à 260 m/an, tel qu'indiqué par des comptages de varves. Les lignes de plage émergées de la région de Témiscamie se sont développées alors que le déversoir actuel, la Rivière Rupert, controlait déjà le niveau de l'eau dans le lac. L'altitude et la localisation de ces lignes de plage indiquent un gradient de gauchissement de l'ordre de 0.55 m/km dans la direction du retrait glaciaire.

Les moraines mineures de type ribbed moraine, qui sont très abondantes sur les Boucliers Canadien et Scandinave, se sont formées sous la glaçe

encore en mouvement, à quelques kilomètres de la marge. Elles sont le résultat d'une obstruction à l'écoulement glaciaire dans la zone frontale, obstruction qui provoque la formation de plans de décollement et l'empilement de tranches de débris infra-glaciaires. Bien que l'orientation des crêtes de ces moraines mineures reproduise à peu près l'orientation du front de la glaçe en retrait, l'espacement des crêtes n'a pas de signification chronologique en terme de taux de retrait de la glaçe.

# ACKNOWLEDGEMENTS

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I am indebted to Dr. Claude Hubert who reviewed the part of the report on bedrock geology. I wish also to thank in a very special way Dr. Peter P. David who helped me in so many ways that it is impossible to list them all here. He critically reviewed substantial parts of the manuscript, and from this, it benefited greatly. None of the least of his help was from the stimulating discussions he animated with serenity, and from his encouragement .

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# CHAPTER 1
# INTRODUCTION

## 1.1 Setting and objectives

This report is the result of a detailed study of the Quaternary geology of an area, approximately 4,000 $km^2$ in size and here referred to as the Témiscamie area, located northeast of Lac Mistassini in central Québec (Fig. 1). The project started as part of the exploration program of the Division du Quaternaire, Service de l'Exploration Géologique, Ministère des Richesses Naturelles du Québec[1]. The area was selected for us by Dr. Pierre LaSalle of the Division, with the intention of gathering much needed basic information on the nature and distribution of the surficial deposits for the purpose of supporting mineral exploration in the region.

The area assigned was mapped during the field season of 1974 (Bouchard et al. 1974). The preliminary field work revealed the presence of a number of problematical glacial features in the area, among which are ribbed moraines,strandlines, meltwater channels, and still other minor features. Ribbed moraines are common in the Témiscamie area and are also known to be widespread on the Canadian Shield, both in

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[1] Now called Ministère de l'Energie et des Ressources du Québec.

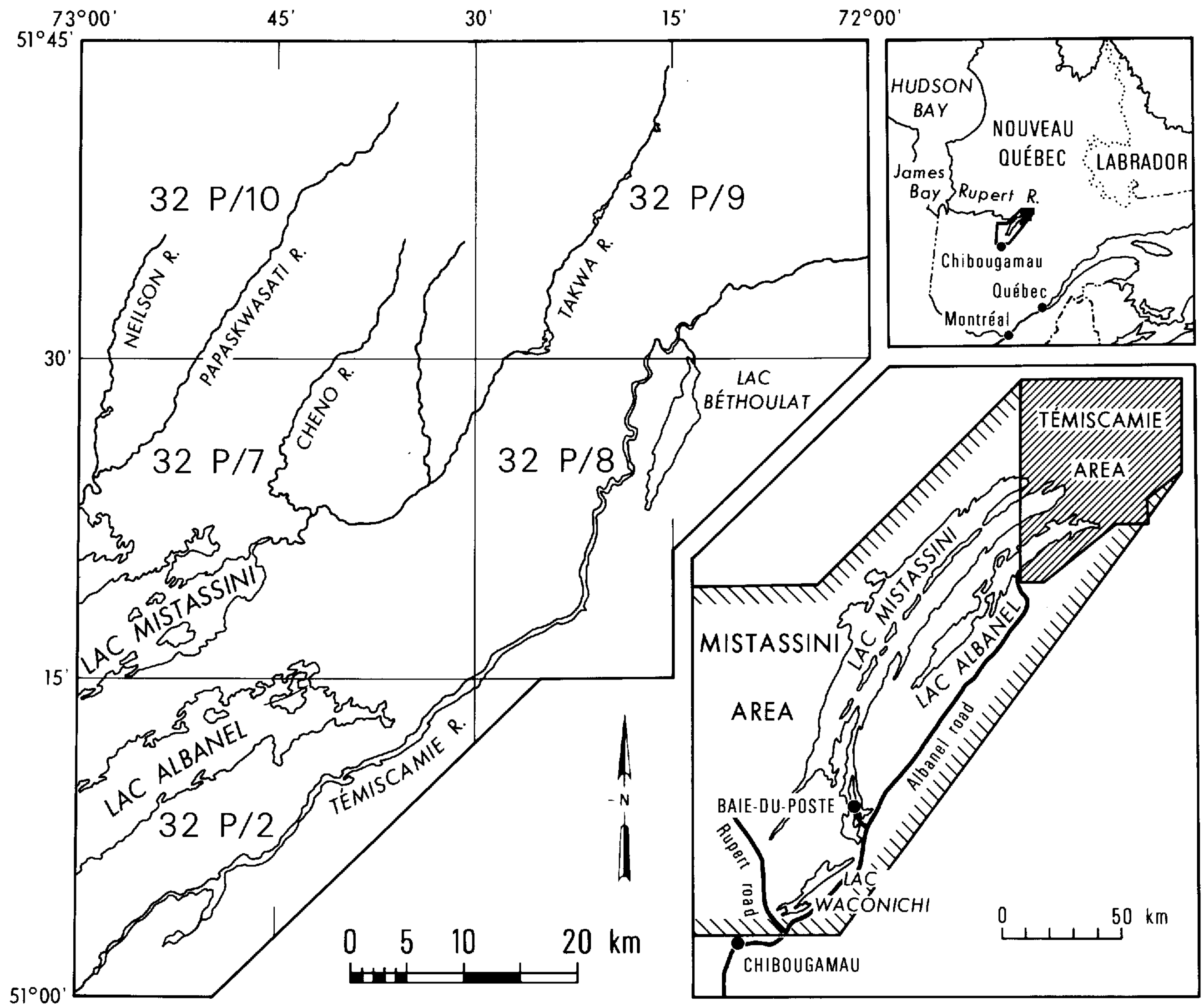


FIGURE 1. GENERAL LOCATION, BOUNDARIES AND TOPOGRAPHIC MAP COVERAGE (N.T.S. 1:50,000), TÉMISCAMIE AREA.

Nouveau-Québec[2] and in Keewatin (Prest et al. 1968). Their genesis and significance are not fully understood as yet (Prest 1968).

Strandlines which are less common in the study area, occur around the north shore of Lac Mistassini. Since previous studies by other authors in the areas south of our region have demonstrated that Glacial Lake Ojibway extended over parts of the Mistassini basin, the relationship of the strandlines to Glacial Lake Ojibway had to be established.

Finally, the Témiscamie area is located in that part of Québec (central Québec and Nouveau-Québec) where detailed investigations of surficial deposits and landforms are very scarce. Excluding the studies conducted in the coastal regions and dealing principally with the reconstruction of sea-level fluctuations and land emergence (Løken 1962, Matthews 1967, Hillaire-Marcel 1976, Lauriol et al. 1979), detailed investigations have been concentrated mainly around Shefferville and Labrador (Ives 1956, 1959, 1960, Derbyshire 1958, 1962, Harrison 1963, Morrison 1966, Fulton et al. 1971, Fulton and Hodgson 1979). Other studies include the works done by Vincent (1974) in the area around Rivière La Grande and by Liard (1977) on the glacial lake phases in the Caniapiscau River area. Small-scale reconnaissance works include those done by Low (1896), Douglas and Drummond (1955), Hare (1959), Henderson (1959), and Hughes (1964) all of which have been summarized and added to by Prest et al. (1968). However, due largely to the

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[2] The name Nouveau-Québec has been officially approved by the Assemblée Nationale du Québec, in December 1972, to designate that part of the province which lies north of Eastman River in the west and north of latitude 52° North, elsewhere.

general scarcity of adequate exposures of glacial drift and especially of till in these undeveloped parts of the country (see Fulton et al. 1974), most of these previous quaternary studies concentrated on landforms and provided only a few quantitative descriptions of till from central and northern Québec the same way as other studies did from elsewhere on the Canadian Shield, in general (Scott 1976).

Owing to the presence of the problematical features in the Témiscamie area and because there is a dearth of detailed studies of surficial deposits in central and northern Québec, it was decided to continue and extend our research in the study area with the following primary objectives:

(1) to establish the history of deglaciation of the region with particular emphasis on the reconstruction of the history of the glacial lake phases in the Mistassini basin;

(2) to contribute to the understanding of the genesis and the significance of ribbed moraines; and

(3) to provide quantitative petrographic description of the tills and suggest means of recognition of their genetic types.

An additionnal objective was to revise and improve upon the post-glacial pollen stratigraphy previously established in the region by Ignatius (1956). This objective was not satisfactorily fulfilled for reasons explained below and, consequently, it is omitted from the report. Three pollen diagrams were produced from the region, two of which are from within the Témiscamie area and the third one from the Otish Mountains, situated about 200 km to the northeast.

According to our plans, improvements in the pollen stratigraphy were to come from the use of pollen influx data rather than pollen percentage values as the basis for drawing the diagrams (Davis 1965, 1967, Davis et al. 1973). The method of pollen influx is based on measurements of pollen concentrations and on radiocarbon dating of successive levels in the core. For the purpose of the latter a number of core samples were submitted to the Laboratoire de Datation of the Ministère des Richesses Naturelles. That laboratory uses a benzene counting technique which requires a minimum of 3,0 g of carbon for dating. As it turned out, most of our samples contained insufficient quantities of carbon and could not be dated. Unfortunately, the samples were not recoverable. As a result of these difficulties, the diagrams from the Témiscamie area could not be established in terms of pollen influx, while the per cent pollen diagrams simply duplicate the stratigraphy established earlier by Ignatius (1956). In the mean time, a second core taken from the Otish Mountain site was successfully dated at another laboratory which uses a gas counting technique requiring less carbon. However, without correlative diagrams from the Témiscamie area, the diagram from the Otish Mountain site becomes a separate and distinct project. Furthermore, since 1974, when this project was undertaken, many new pollen profiles have been published (McAndrews and Samson 1976, Short and Nichols 1977, Richard 1979) from central and northern Québec. For these reasons our work on pollen stratigraphy is not included in the present work.

This report is an original contribution to knowledge as it provides a surficial geological map and descriptions of the surficial deposits of a previously unknown area; it contributes to our knowledge of the history of final deglaciation of central Québec in late Wisconsin time, and provides a new reconstruction of the glacial lake phases in the Lac Mistassini area. Furthermore, it is a contribution to glacial geomorphology because it contains the first description of the internal composition and structure of ribbed moraines in North America and an original model for its formation. Finally, the Report provides quantitative petrographic descriptions of the tills in the area, it suggests criteria for differentiating among the different types of tills, and gives the first report and description of basal melt-out till in the Canadian Shield. It is hoped that all this information can find useful application in mineral exploration in this and other parts of central Québec.

## 1.2 Access and methods

The Témiscamie area is located about 200 km north of Chibougamau, the nearest large settlement (Fig. 1). An all-weather gravel road, the Albanel road, leads from Chibougamau north to Lac Albanel at the south boundary of the study area.

Access to the Témiscamie area proper is limited to canoes or aircraft. Canoes may be used along the Témiscamie River and, with some caution and difficulty, on the other large rivers of the region draining into Lac Mistassini, namely the Papaskwasati and Takwa Rivers

(Fig. 5, Chap. 2). The shores of Lac Mistassini and Lac Albanel are accessible by canoe. Aerial support was provided by fixed-wing aircraft which may be chartered at the hydroplane base of Lac Caché in Chibougamau or, more conveniently, at the hydroplane base of Témiscamie located in the south part of the study area. The aircraft used were mostly Beaver equiped with floats; consequently, access was limited to water bodies with at least 1 km of open landing and take-off space. There are 29 such lakes in the area. From these points, travel was done by foot or by canoe.

Mapping of the Témiscamie area is based on aerial photographic interpretation with ground checking. Complete aerial photographic coverage is available at scales of 1:15,840 and 1:62,360. Aerial photographs at a scale of 1:31,680 are available for the north half of the study area. Topographic map sheets 32 P/7, 32 P/9 and 32 P/10 (Fig. 1) were mapped during the field season of 1974. Sheet 32 P/8 was mapped in 1975. Both are based on examination of air photos at a scale of 1:15,840. Units were reported on base maps at a scale of 1:50,000. Additionnal mapping (32 P/2) is based on examination of aerial photographs at a scale of 1:62,360.

Field work was organized with a base camp from which fly camps lasting 2 to 5 days each were set up at different accessible localities. Natural cuts along the rivers which exposed exclusively fluvio-glacial sediments were described. Selected sections are described in Appendix C. Till was examined in manually dug excavations ranging from 0,5 to 1,5 m in depth. Considerable difficulty was encountered in digging in many places where an ortstein has developed in the podsolic soils of the area. Descriptions include mass properties of the till such as color and compaction , textural properties, such as particle size distribution,structural properties such as fissility, bedding, and orientation of the long axis of included pebbles, and finally lithologic composition of the clast fraction of selected samples.

The descriptions were done by four different observers, including this author. No one observer saw all the exposures. Color is given in reference to Munsell Colour Chart and applies to the matrix of the dry sample. Compactness was evaluated qualitatively in three classes, namely "loose", "compact", and "very compact". Cobble and pebble content of the till was visually estimated in the field using a comparative density chart (Terry and Chilingar 1955). Charts were carried as mobile flaps in the notebooks of all observers. The two dimensional orientation of the long axis of 50 pebbles included in the till was measured at 12 sites. Fabric analyses were intended as a descriptive means as it was hoped that they could be useful in discriminating between till types.

The reconstruction of glacial lake phases is based on reconnaissance work in the Mistassini area (inset, Fig. 1). This involved the examination of aerial photographs at a scale of 1:62,360, of all the area, and field traverses along all the available roads, namely the Albanel and the Rupert road. Methods used for this part of the project are discussed in Chapter 4.

Cuts in ribbed moraine area available only south of the study area, along the northernmost 10 Km of Albanel road. The sections were examined in 1975 and were revisited in 1977 and 1978. Methods of description of till exposed along Albanel road differ slightly from those of the till observed in excavations in the main of the study area. They are stated in the appropriate section of the (Chap. 5).

Additional work involves particle size analysis of samples of the surficial deposits of the area, statistical evaluation of till fabric analysis and examination of the lithology of the clast fraction of selected samples of till. Particle size distributions were analysed by conventionnal sieving methods.The Wentworth grade scale is used. The silt and clay fraction was analysed by hydrometer method. Grain size analysis of till is of the matrix only, defined as that fraction of grains of a diameter smaller than 4 mm. A statistical parameter of the particle size distribution of till which is used in this work is the graphic sorting index ($\sigma_G$) (Folk and Ward 1957). This was measured on grain-size curves plotted on probability paper. Tabulated results of particle size analysis of till samples are given in Appendix A. Results of till fabric analyses are reported as mirror-image rose diagrams. Resulting trend, vector strength, as well as a "p" factor evaluating the randomness of the vectoral distribution in reference to a Rayleigh test were calculated using Curray's (1956) method. Data are tabulated in Appendix B. Lithologic composition of the clast fraction of selected till samples is based on identification of clasts retained on the 4 mm sieve, and on examination of additional 150 to 200 grains in the 2 to 4 mm fraction.

## 1.3 Previous work

Since part of this report is concerned with regional deglaciation, all previous works pertaining to the Pleistocene geology of the whole of the Mistassini region are reviewed even though only a few of them are directly pertinent to the Témiscamie area. A more detailed review of previous works on glacial lake phases in the region is given in Chapter 4, and a review of the literature on ribbed moraines is presented in Chapter 5.

The history of the opening up of the Mistassini area and accounts of the early explorations therein are summarized by Rousseau (1948, 1949, 1950, 1954, 1970) and Rogers (1963).

The first geological observations are those of Richardson (1871) while the earliest observations on the Pleistocene geology of the region are made by Low (1885-86) who notes the pattern of dispersal of dolomite boulders and correctly infers the northeast-southwest direction of glacial movement in the area.

Mawdsley (1936), mapping the bedrock geology around Lac Chibougamau, describes the peculiar topography he observed from air: "of closely spaced ridges with a remarkably uniform trend in a southeasterly direction, at right angles of the known movement of the last Pleistocene ice sheet" (Mawdsley 1936, p. 9). He named these features "wash-board moraines", and associated their origin with the presence of glacial lakes in front of the ice margin.

Norman (1938) who continued the work that Mawdsley began in the Chibougamau area also became interested in the Pleistocene geology of the region, and published his observations obtained partly in the field but mostly from aerial photographs, in an area around Lac Opemisca. In that publication he suggests that Lake Barlow-Ojibway extended north to the south part of the Mistassini area; he disagrees with Mawdsley's (1936) explanation of the origin of the wash-board moraines, he considers them to be of annual deposition, and, consequently, calls them "annual moraines". This interpretation allows him to calculate annual rates of retreat of the waning ice sheet. Currently, these moraines are recognized as the De Geer moraines (Elson 1968). In addition to the moraines, Norman (1938) also describes the various types of eskers found in the region and discusses their mode of formation.

Later, travelling north to the lower reaches of the Témiscamie River, Norman (1939) erroneously identifies a frontal moraine on the west bank of the river, which, according to him, was formed by ice flowing northwestward (sic.). He extends the northern limit of Glacial Lake Barlow-Ojibway into the Témiscamie River valley on the basis of a series of small annual moraines located north of Lac Albanel, and of a large deltaic type of esker grading northward into outwash.

It is clear that Norman did not have aerial photographs for the Témiscamie River area or he would not have misinterpreted the direction of glacial flow that is so conspicuous on air photo. Furthermore, the end moraine identified by Norman is really an area of hummocky and ground moraine left by ice retreating to the northeast. In addition, the small annual moraines are most likely the elongate and short drumlins that are clearly visible on air photos at that location. It is Shaw (1944) who, a few years later, established in the region the northern limit of the "annual moraines" at about the latitude of Lac Waconichi, about 100 km south of Témiscamie area (Fig. 1).

Ignatius (1956, 1958) contributed additional information on the Presqu'Ile area southwest of Chibougamau where, while he agrees with Norman's views on the history of deglaciation of the area, he finds further evidence on Glacial Lake Barlow-Ojibway. He also accepts the hypothesis of annual formation for Norman's minor moraines.

A second area studied by Ignatius is located around Lac Béthoulat and is included in the present work. There, Ignatius (1956) published a surficial geology map at a scale of 1:63,360 showing undifferentiated drift, drumlinoid topography, stagnant ice topography, outwash, peat, and other features, such as striations, glacial drainage channels, and stream terraces. He disputes Norman's (1939) frontal moraine on the basis of lack of any evidence. Though Ignatius does not discuss the matter at length, it appears that he does not find any supporting evidence of a deep proglacial lake north of Lac Albanel, and, consequently, he considers that deglaciation in the Béthoulat area proceeded in "superaqueous" conditions, as opposed to the "subaqueous" conditions that prevailed in the areas around Chibougamau and Opemisca. He also describes a "lobate morainic field" in the Béthoulat area which is interpreted by the present author as a field of ribbed moraines. He recognizes that, although this group of ridges present some analogies to the "annual moraines" of the Opemisca area, they are significantly different and constitute a distinct type of minor moraines. He suggests no particular name for the moraines, nor a mechanism for their formation even though he clearly implies that their genesis did not require a proglacial lake but that their formation was associated with a stagnant ice margin and with subglacial meltwater channels.

At around the same time, Ermengen (1957) studied the surficial deposits of the Chibougamau area and provides textural data on the tills of that region. For many years little work is done in the area. In 1971, Laverdière commented on the dispersal of erratics in the Mistassini area. Later, Warren (1974) mapped the surficial geology of the Baie-du-Poste area at a scale of 1:50,000. His map shows eskers, outwash, drumlins fluted ground moraine, and hummocky moraine. Allard and Cimon (1974) comment on the amount of glacial erosion in the Chibougamau district which they believe to have been minimal owing to the preservation of lateritized anorthosite near Lac Doré.

A comprehensive study of the glacial dispersion of rocks and minerals in the Lac Waconichi area was done by DiLabio (1976). He establishes the local glacial stratigraphy and recognizes a short readvance of the ice front near Lac Waconichi. His work includes textural and fabric analyses of the tills and distinguishes lodgement and ablation types.

Laverdière and Guimont (1977a) studied the drumlinoid landforms of the Lac Mistassini area, and the various shore types around Lac Mistassini and Lac Albanel (1977b). Later, they described the physical geography of the area around Einer and Kallio Lakes which lies within our study area (Guimont and Laverdière 1978).

From about 1950, numerous physiographic observations pertaining to the glacial geology of the Témiscamie area were made by geologists mapping the bedrock in the area, the most common being on striations. Wahl (1953) reports karstic features on the dolomite around Lac Albanel, mentions the association of drumlins and dolomitic bedrock, and reports the occurrence of wave-cut terraces ca. 12 m above the present level of Lac Albanel. Neilson (1953) describes drumlins and also comments on their association with dolomitic rocks. Chown (1960) suggests that glacial erosion has been minimal in the Tichégamie Mountains situated at the north end of the Témiscamie area, and that the pre-Pleistocene surface had considerable relief. Neale (1965) includes in his report on the Béthoulat area many of the observations made by his field assistant, Ignatius. Neilson (1966) in his report on the Takwa area comments on the morainic landforms, on the minimal distance of glacial transport, and reports beach ridges from the north end of Lac Mistassini.

# CHAPTER 2

# GENERAL DESCRIPTION OF THE AREA

## 2.1 Bedrock geology

All the rocks of the Témiscamie area are Precambrian in age. Geologically, the region straddles parts of the Superior Province, the Mistassini Subprovince, and the Grenville Province in the central part of the Canadian Shield in Québec (Fig. 2).

The Superior Province comprises those rocks which are Archean in age (ca. 2.4 b.y.) and which have a predominantly east-west structural trend. The commonest rock types are quartzo-feldspathic gneisses and granites with intercalated greenstone belts of metavolcanic and metasedimentary rocks. They are cut by diabase dykes.

One narrow greenstone belt, 10 km wide, extends from about the center of the region eastward to the fault which separates rocks belonging to the Superior Province from those of the Grenville Province (Mistassini Fault). This belt is composed of paragneiss, schist, and amphibolite (Neilson 1950, 1951, 1966; Neale 1952, 1965) which have been assigned to the Toqueco Group (Neilson 1950). The rocks in this belt are folded into a major anticlinal structure.

Another belt, 20 km wide, consisting of amphibolite with minor meta-ultrabasic rocks is in the northwest part of the area. The rocks are assigned to the Tichégami Group (Chown 1961). The belt continues

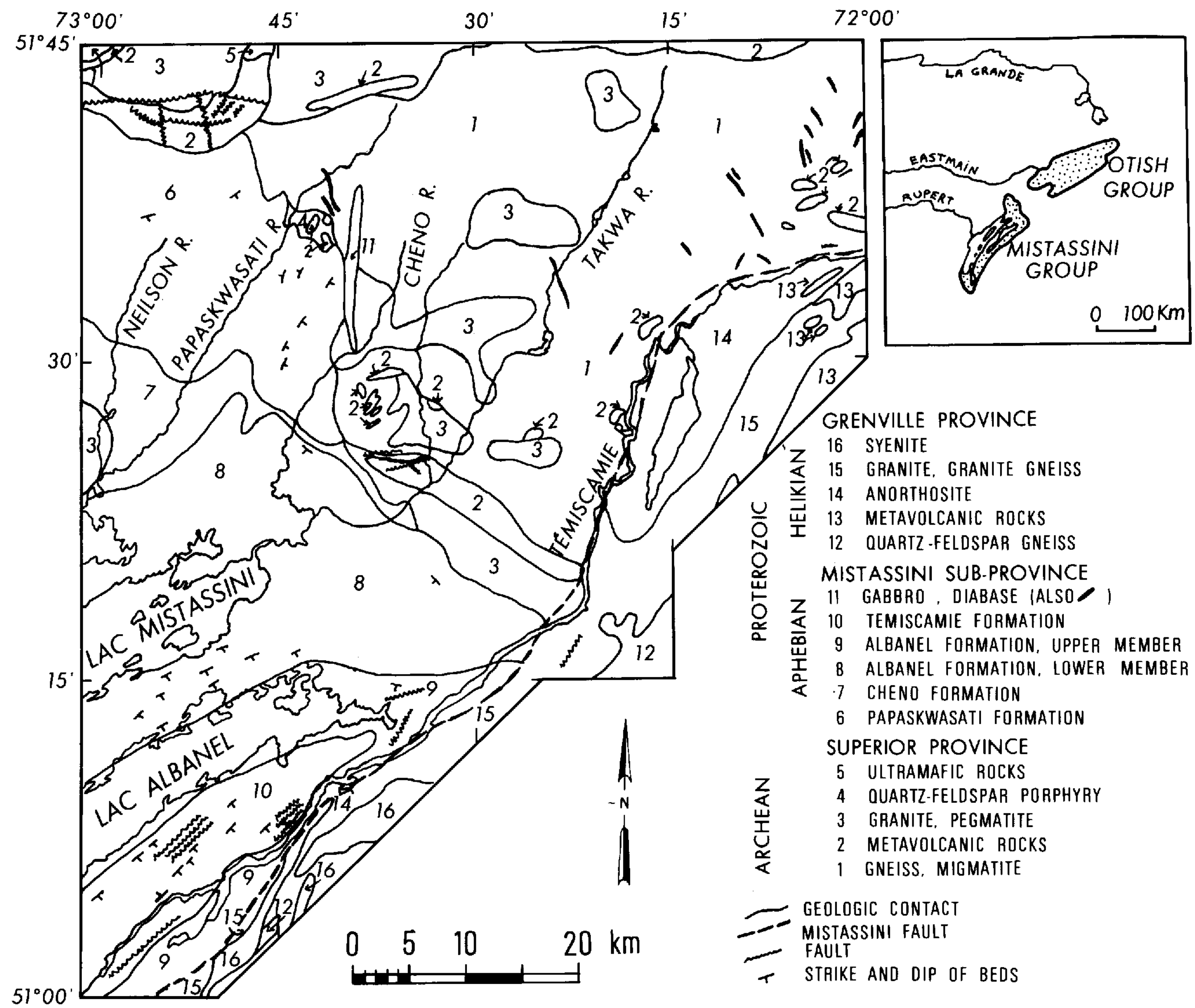



FIGURE 2. BEDROCK GEOLOGY OF THE STUDY AREA, FROM CATY, 1976.

eastward into an area where Bérard (1965) has mapped paragneiss, schist, and minor quartzite. Most of the area between these two belts is underlain by quartzo-feldspathic gneiss. Granite occurs as masses with gradational migmatite boundaries within the gneiss.

The Mistassini Subprovince includes clastic and chemical sedimentary rocks assigned to the Mistassini Group (Bergeron 1957) which is Aphebian in age (ca. 1.7 b.y.); the rocks lie unconformably over the Archean basement. The Mistassini Group is divided into four formations, from oldest to youngest, the Papaskwasati, Cheno, Albanel, and Témiscamie Formations.

The Papaskwasati Formation occurs in the Témiscamie area, in a northwest elliptical apophysis of the Proterozoic sedimentary basin (Fig. 2, inset). It has two members from base to top, the Holton and Neilson Members. Each one of these members is a fining upward sequence of detrital sedimentary rocks, passing from coarse quartz conglomerate at the base to quartzitic sandstone with intervening argillite interbeds at the top (Chown 1960, Neilson 1966, Chown and Caty 1973, Caty 1976). Strata dip southward, though in the north part of the subcrop area of this formation north-south trending folds have deformed the sediments.

The Cheno Formation, consisting of dark quartzitic sandstone and dolomitic sandstone (Chown 1960, Chown and Caty 1973, Caty 1976), occurs as a narrow belt, 2 to 15 km wide, south from the Papaskwasati Formation. The dark color is caused by disseminated sericite, iron oxides, and graphite (Caty 1976). The strata dip south and at their northern margins form low south sloping monoclinal ridges, notably near Lac Brideau (Fig. 5).

The Albanel Formation occupies the rest of the sedimentary basin. It can be divided into a Lower and Upper Member. The Lower Member underlies and surrounds the whole of Lac Mistassini. It comprises a number of mappable units of stromatolitic dolomite, massive and bedded dolomite, and brecciated and cherty dolomite, with intervening graphitic shale interbeds (Caty and Chown 1973). The Upper Member underlies and surrounds the whole of Lac Albanel and is also composed of several mappable units including stromatolitic massive and sandy dolomite (Wahl 1953, Neilson 1953). Throughout most of the area of the Albanel Formation the strata dip 10 to 60 degrees eastward (Bergeron 1957); in the Témiscamie area however, at the northern edge of the subcrop area of Albanel Formation, the strike of the beds turns to east-west and strata dip south.

The Témiscamie Formation (Wahl 1953, Neilson 1953, Quirke 1960) overlies unconformably the Upper Member of the Albanel Formation and is restricted to east of Lac Albanel and west of Mistassini Fault. Only the northern half of the subcrop area of this formation is in the Témiscamie area. The formation comprises a number of stratigraphic units, without formal names, which are from bottom to top, quartzite and chert, "slate", "iron-formation", and siltstone. The quartzite and cherts, referred to informally by Wahl (1953) as the Boulder Bay quartzite, outcrops as a thin band east of Lac Albanel and as patches along the Témiscamie River. The "slate", still according to

Wahl (1953), would be better described as argillite, as it lacks a slaty cleavage. The "iron-formation" is a potentially exploitable iron ore deposit; it is estimated that it could yield about 350 millions of tons of concentrate with an average content of 67% of Fe (Min. Rich. Naturelles 1974 in St-Jacques and D'Aragon 1976).

Northeast of the Témiscamie area (Fig. 2, inset), sedimentary rocks assigned to the Otish Group (Caty and Chown 1973) are divided into the Indicator and the Péribonca Formations. Rocks of the Indicator Formation are homotaxial equivalents of those of the Papaskwasati Formation (Caty 1976). The Péribonca Formation comprises sandstone, clayey sandstone, and petromict conglomerates; the rocks commonly have a pinkish to reddish tint caused by disseminated hematite. These formations do not outcrop in the Témiscamie area but they lie within 20 km northeast of the north border of the region, "upstream" relative to the direction of glacial flow in the area (Chapter 3).

There are a few outliers or patches of rocks which are assigned either to the Papaskwasati or Indicator Formations and which occur in the intervening region between the subcrop areas of both formations (Caty and Chown 1973). One of them, the Mantouchiche outlier, is located within 5 km north of the northwest corner of the Témiscamie region. Another one is found in the fault-bounded depression occupied by Holton Lake (Fig. 5).

The Grenville Province comprises rocks which are Helikian in age (ca. 0.9 b.y.) and have a predominantly northeast-southwest structural trend. The most common rock types are gneiss, granite, syenite, anorthosite, and metasedimentary and metavolcanic rocks. These rocks underlie all the area east of the Mistassini Fault which was interpreted as representing the Grenville Front in this region.

## 2.2 Physiography

According to Bostock (1970), the Lac Mistassini area is the southern part of the Mistassini Hills physiographic region (Fig. 3, inset). In an earlier classification, Hare (1959) considered the area of Lac Mistassini as part of the Lake Plateau, a gently rolling mostly drift-covered plateau strewn with myriads of lakes. Douglas and Drummond (1955) described the Mistassini area as part of a physiographic unit called "drumlinized till". The Témiscamie area represents a transition between the elevated part of the Mistassini Hills, in the north, and the lowland section, in the south, where Lakes Mistassini and Albanel are found. The main topographic features of the region area are shown on Figure 3, and compiled data on the thickness and distribution of the drift cover appear on Figure 4.

The Tichégami Uplands, so named in this work, form the north part of the Témiscamie area and rise above 600 m altitude. The west part of these uplands is occupied by the Tichégami Mountains where altitudes, at least within the Témiscamie area, may reach 830 m. The topography is irregular, exposed bedrock is abundant, and drift is found mostly in valleys. The local relief, defined as the maximum relief within a 100 $km^2$ quadrat, ranges from 190 to 380 m.

The east part of the Tichégami Uplands is formed by the Hippocampe Plateau. Local relief is in the order of 50 m and decreases northward where it is less than 30 m. The drift cover is continuous (more than

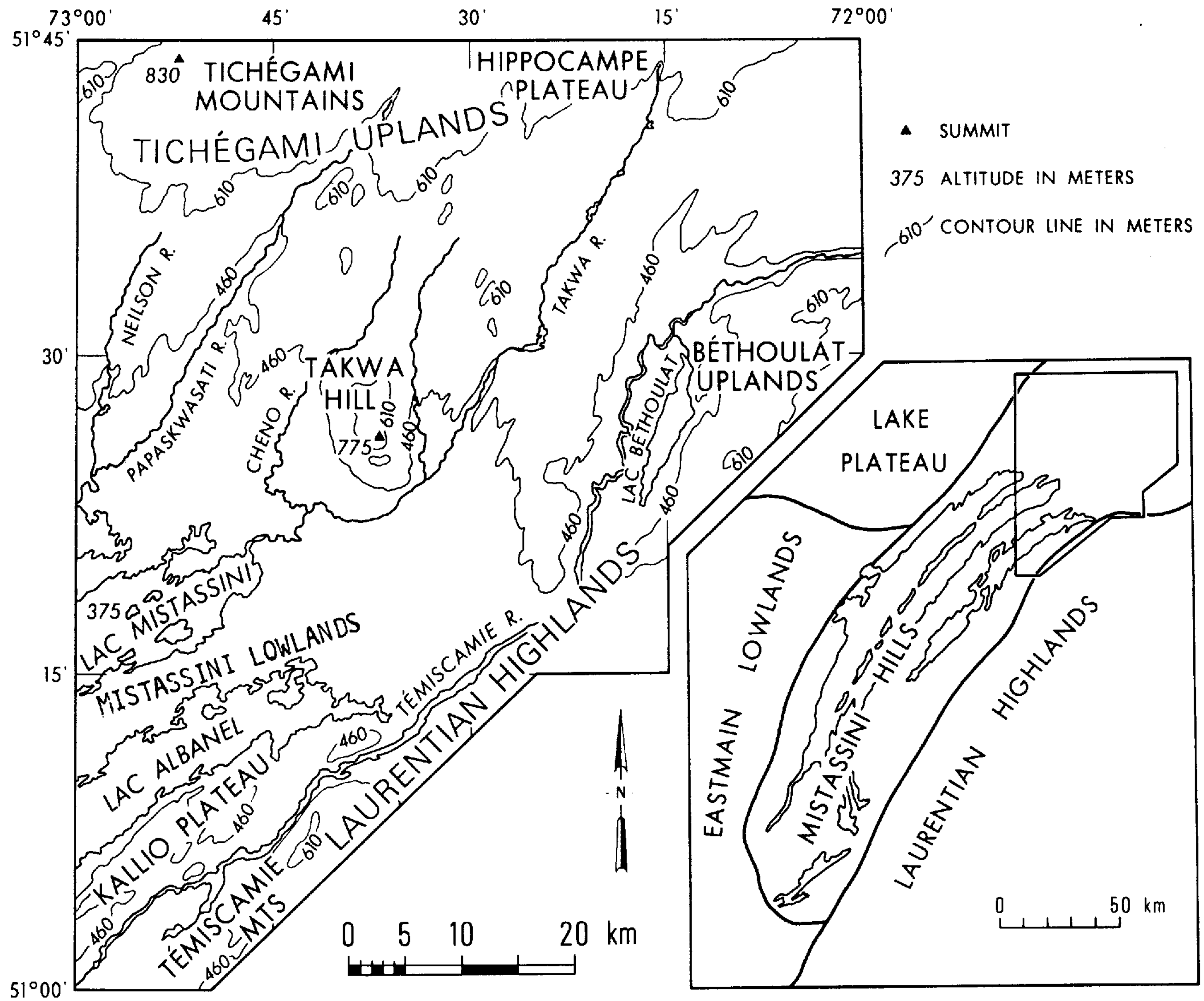



FIGURE 3. MAIN TOPOGRAPHIC FEATURES OF TÉMISCAMIE AREA AND REGIONAL PHYSIOGRAPHIC DIVISIONS.

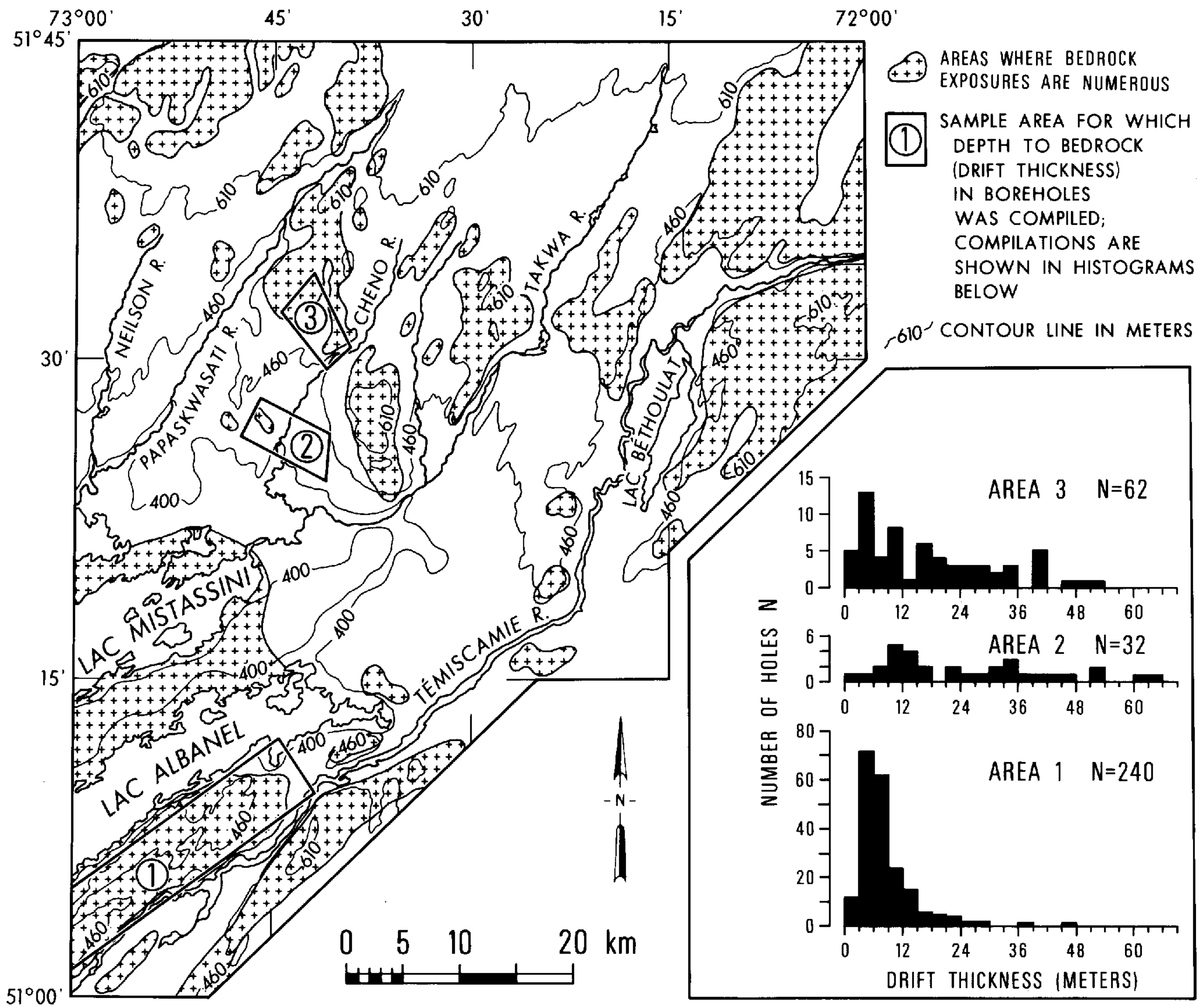



FIGURE 4. OUTCROP AREAS AND THICKNESS OF THE DRIFT, TÉMISCAMIE AREA.
Data for histograms are compilation of recorded drift thickness in boreholes effectuated by various mining exploration companies.

90% of the surficial cover) and is presumably thick, possibly from 3 to 12 m. The area is underlain predominantly by rocks of the Indicator Formation (Hashimoto 1961) (Fig. 2, inset). These rocks are separated from the northern boundary of the Témiscamie area by a belt of metasedimentary and metavolcanic rocks which have a more irregular topography. The thick and continuous drift cover appears to extend some 15 km southwest from the edge of the Hippocampe Plateau as a tongue onto the lower-lying parts of the Témiscamie area.

South of the Tichégami Uplands, between 450 and 600 m elevations, the local relief ranges from 150 to 180 m and decreases eastward to less than 75 m. There are numerous bedrock outcrops south of the uplands with drift covering only about 30% of the surface. Judging from sample area 3 shown in Figure 4, drift thickness is generally from 3 to 6 m but may reach 54 m in depressions. East of the Témiscamie River, the region is referred to as the Béthoulat Upland. There, the maximum altitude is 650 m, drift is found mostly in valleys, and local relief is in the order of 200 m.

Near the center of the region, the 460 m elevation countour loops southward to encircle Takwa Hill, a prominent relief which rises 350 m above the surroundings to the south and reaches a maximum altitude of 775 m.

Below ca. 450 m elevation, the region is characterized by a gently rolling topography with a local relief of about 30 m, and by a continuous and thick drift cover extending over 95% of the area. The drift is generally from 9 to 12 m thick but may reach 66 m locally (area 2 in Fig. 4). The western part of this region coincides with the subcrop area of the Papaskwasati and Cheno Formations. Eastward, the drift is thinner, outcrops are more numerous, and east of the Témiscamie River, in the area around Lac Cawachigamau (Fig. 5), the local relief is in the order of 120 m and the drift cover is discontinuous.

The Mistassini Lowlands occupy the southwest part of the Témiscamie area and extend more than 100 km farther to the south-southwest. Mean altitude is around 400 m. Local relief is 30 m or less. Drift cover is discontinuous (about 50% of the surface) and the thickness appears to be very variable in short distances from 0 to 30 m. The lowlands coincide with the subcrop area of the dolomitic rocks of the Albanel Formation.

Kallio Plateau stands above the lowlands between Lac Albanel and the lower course of the Témiscamie River. Altitude may reach 520 m. Drift cover is discontinuous; its thickness is approximately 3 to 6 m but may be more than 30 m in depressions (area 1 in Fig. 4). This plateau is underlain by rocks of the Témiscamie Formation.

East of the Témiscamie River, in the south part of the region, the Témiscamie Mountains form parts of the Laurentian Highlands. The altitude reaches 672 m and the drift cover is thin and discontinuous.

The overall regional slope in the Témiscamie area is 3 to 3.5$^{o}$ in a south but locally southwest or southeast direction. The maximum relief for the whole region is 455 m, between the highest point in the Tichégami Mountains (830 m) and the water level of Lac Mistassini (375 m).

A rough estimate of the overall average thickness of the drift as if it were spread evenly as a layer over the entire Témiscamie area is in the order of 3.5 m, having an estimated total volume of about 48 $km^3$. This value gives an indication of the amount of erosion caused by the last glacier which left the drift sheet, notwithstanding the assumption that about as much drift was imported into the area from the northeast as there was exported to the southwest.

## 2.3 Drainage

The Témiscamie area is part of the James Bay drainage system (Fig. 5, inset). While most of the area forms part of the Rupert River drainage basin, the northwest corner of the area drains into the Eastmain River (Fig. 5).

The main rivers are the Témiscamie, the Takwa and the Papaskwasati Rivers. The Témiscamie River flows southwestward into Lac Albanel. Its source is outside the area in the Tichégami Uplands. Three tributaries join the Témiscamie River with barbed junctions, such as the outlet stream of Lac Béthoulat, Rivière Perdue, and Tournemine River (Fig. 4). Témiscamie River flows in a gorge in the northeastern part of the area. In the vicinity of Lac Béthoulat, the valley becomes wider and the river flows through abundant sandy alluvium. There the channel meanders and the river is incised about 20 m into a proglacial valley fill.

Takwa River rises on the Hippocampe Plateau and flows into the northeast end of Lac Mistassini. Its main tributaries are the

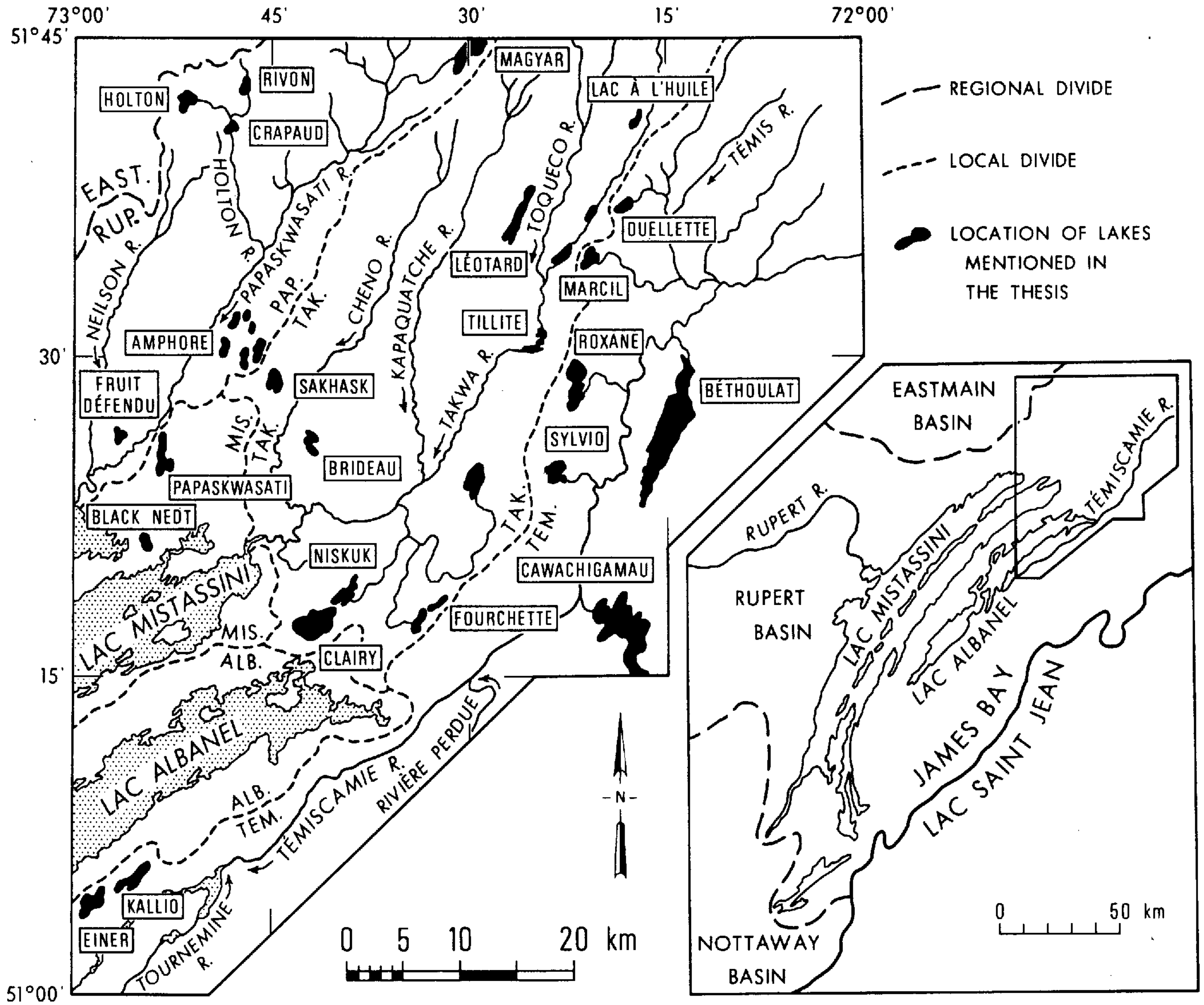



FIGURE 5. LOCAL AND REGIONAL DRAINAGE SYSTEM. Names of some lakes are not official.

Toqueco, Kapaquatche and Cheno Rivers. The Papaskwasati River which rises in the Tichégami Mountains, drains into the western part of Lac Mistassini. Its main tributaries are the Holton and Neilson Rivers. In all these rivers, numerous rapids are created by boulder accumulations derived from eskers in the valleys. Bedrock floor is seen exposed in the channels of Takwa and Papaskwasati Rivers only, and in the Takwa River, it gives rise to a falls, about 3 m high, east of Takwa Hill.

## 2.4 Climate and vegetation

The closest meteorological stations are Baie-du-Poste and Nitchequon, respectively about 100 km southwest and 200 km northeast of the region. A compilation of monthly mean air temperature and precipitation is presented in Table 1. The means applicable to the Témiscamie area are probably intermediate between those at these two stations. Data for winds are available for Nitchequon and Manouan stations; the latter is about 200 km east from the Témiscamie area. Dominant summer wind directions at Nitchequon are SSW, SW, W, WNW, whereas at Manouan, winds from NW and SE predominate. Westerly winds predominate during the winter at both stations (Gagnon and Ferland 1967).

According to Ducruc et al. (1976), the Témiscamie area is part of the Mistassini Ecological Region; it lies within the Low Subartic subzone of the James Bay area. The southern limit of the subzone coincides with the isoline representing the 1400 annual degree-days for the growing season.

The forest cover in Témiscamie area may be described according to various author's terminology as Taiga (Hustich 1949), Open Boreal Woodland (Hare 1950, Grayson 1956), as Boreal Forest (Rowe 1972), and as Open Forests (Ducruc et al. 1976). Open Forests represent an arboreal cover with 40 to 80% of the surface populated with trees that range in height from 9 to 21 m. In fact, in the Témiscamie area tree density does not exceed 60% and tree heights are in the order of 10 to 15 m according to Forest Inventory Maps available for parts of the region (Min. Terres et Forêts, Québec). Forest cover is absent only from the summits of the Tichégami Mountains.

The dominant arboreal species is black spruce (Picea mariana) with subordinate amounts of fir (Abies balsamea). Locally birch (Betula sp.) and aspen (Populus tremuloides) form stands of mixed coniferous and deciduous forest. Jack pine (Pinus divaricata) occupies well drained sites, mainly the wide fluvioglacial sandy deposits along parts of the main valleys. Tamarak (Larix laricina) occupies poorly drained sites.

The lower carpet throughout the forest is composed predominantly of mosses (mainly Cladonia sp.) as well as of varieties of herbs (Ducruc et al. 1976). The moss cover that predominates in places produces light tones on aerial photographs.

Extensive fires have destroyed the forest cover over large parts of the Témiscamie area. Regeneration must be slow, because in areas where some of the fires occurred more than 20 years ago (Min. Terres et Forêts, Québec, pers. comm.), second growth has not progressed significantly.

Soils in the region are dominantly podsolic (Clayton et al. 1977). On well drained sites, especially on fluvioglacial sand or sandy till, the B-horizon of the podsols is so strongly indurated with iron oxide that it resists pick blows. The eluviated horizon is generally very well developed and appears as a white or light gray layer, from 1 to more than 15 cm thick.

According to Brown (1967) the southern limit of the discontinuous sporadic permafrost zone is at Lat. 50°30' N in the Mistassini region, about 50 km south of the Témiscamie area. Laverdière and Guimont (1977) reported sorted nets of boulders along the shores of Lakes Mistassini and Albanel between Lat. 50°30' and Lat. 51°30' N which they attributed (referring to Dionne 1974) to seasonal frost.

| | MEAN AIR TEMPERATURE °C | | | MEAN PRECIPITATION rain (mm)/snow (cm) | |
|---|---|---|---|---|---|
| | B*1 | N*2 | | B*1 | N*2 |
| J | -20.5 | -22.9 | | 0/53.1 | 0.3/36.6 |
| F | -18.0 | -20.9 | | 2.5/54.1 | 0.3/34.3 |
| M | -11.2 | -14.4 | | 7.9/49.0 | 2.5/31.5 |
| A | - 2.1 | - 5.8 | | 17.5/17.0 | 6.9/27.2 |
| M | 5.9 | 1.7 | | 51.3/4.3 | 38.1/20.1 |
| J | 12.9 | 9.6 | | 87.8/0.8 | 87.1/1.8 |
| J | 16.0 | 13.6 | | 99.8/0 | 101.1/trace |
| A | 14.6 | 12.0 | | 107.2/0 | 107.7/1.0 |
| S | 9.6 | 6.9 | | 95.3/0.5 | 83.3/6.9 |
| O | 3.5 | 0.5 | | 45.7/11.4 | 46.7/34.3 |
| N | - 4.5 | - 7.9 | | 20.3/49.0 | 13.2/48.3 |
| D | -15.6 | -18.3 | | 3.8/55.4 | 3.0/42.9 |
| Mean | - 0.8 | - 3.8 | total | 536.1/294.6 | 487.2/284.9 |

B*[1] Baie-du-Poste; record since 1914.

N*[2] Nitchequon; record since 1942.

Table 1. Compilation of monthly mean air temperature and precipitation at two meteorological stations situated closest to the Témiscamie area from Environnement Canada 1975, Normales climatiques Si; vols. 1 and 2.

# CHAPTER
# 3
# SURFICIAL GEOLOGY

The main features of the surficial geology of the Témiscamie area include a pronounced glacial linear topography, transversally ridged topography, abundant meltwater erosional and depositional landforms, and evidence of a glacial lake that flooded parts of the area below 398 m altitude. Linear topography with a northeast-southwest trend shows well on Landsat imagery (Fig. 6). Its orientation is discordant with the main Archean structural direction which is east-west. This topography is formed of large-scale streamlined glacial landforms such as drumlinoid ridges and crag-and-tail hills; the latter together with smaller forms indicate that ice flowed southwestward. Ridged topography consists of ribbed moraines which occupy valleys, swales, basins, or depressions in the region. The purpose of this chapter is to describe these and other aspects of the surficial geology of the area with emphasis on ribbed moraines and on glacial lake features.

## 3.1 Surficial deposits

Surficial deposits are chiefly glacigenic sediments overlain locally by non-glacial deposits such as alluvium, peat, and organic rich mud found in modern lake basins (Table 2). Glacigenic sediments are mostly undifferentiated till, ice-contact stratified drift, and

Figure 6. Landsat image illustrating the glacial linear topography of the Témiscamie area.

Image no. B17-24-12, 253-45, Band 7. August 31, 1975.


W72-30
W74- 0
N
10 km

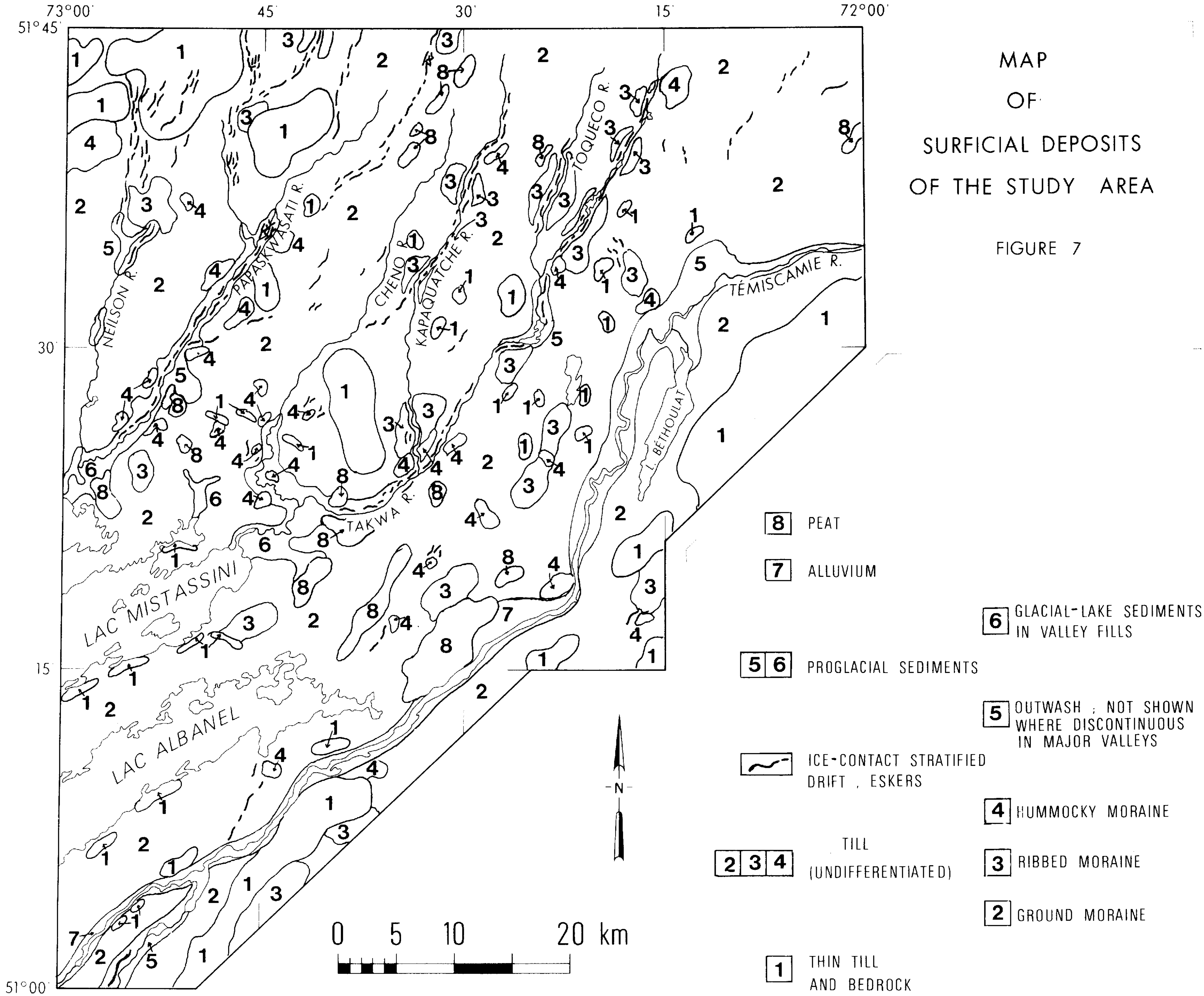
| ERA | EPOCH | STAGE | | | UNIT | MATERIAL | MAXIMUM THICKNESS | OCCURRENCE | LANDFORMS |
|---|---|---|---|---|---|---|---|---|---|
| QUATERNARY | HOLOCENE | POST-GLACIAL | NON-GLACIAL | | GYTTJA | Organic rich mud | 3,8 | scattered | modern lake basins |
| QUATERNARY | HOLOCENE | POST-GLACIAL | NON-GLACIAL | | PEAT | *Sphagnum* peat mostly | 3,1 | scattered | bogs |
| QUATERNARY | HOLOCENE | POST-GLACIAL | NON-GLACIAL | | ALLUVIUM | Boulders, gravel, sand and silt | 4,0 | valleys | modern streams; cap terraces in valley fills ; |
| QUATERNARY | HOLOCENE | WISCONSIN | GLACIGENIC | PROGLACIAL SED. / GLACIAL-LAKE SED. | EOLIAN | Sand | 7,0 | mouth of Papaskwasati River | chains of parabolic dunes |
| QUATERNARY | HOLOCENE | WISCONSIN | GLACIGENIC | PROGLACIAL SED. / GLACIAL-LAKE SED. | BEACH | Sand, minor gravel | 2,0 | north shore, Lac Mistassini | beach ridges |
| QUATERNARY | HOLOCENE | WISCONSIN | GLACIGENIC | PROGLACIAL SED. / GLACIAL-LAKE SED. | DELTAIC AND LAKE FLOOR | Sand, silt, clay | 20,0 | Papaskwasati, Takwa and Cheno Rivers | valley fill |
| QUATERNARY | HOLOCENE | WISCONSIN | GLACIGENIC | PROGLACIAL SED. | OUTWASH | Sand, minor gravel | 10,0 | valleys | discontinuous patches, valley fill (Témiscamie) |
| QUATERNARY | HOLOCENE | WISCONSIN | GLACIGENIC | | ICE-CONTACT STRATIFIED DRIFT | Boulder, gravel, sand | 22,0 | valleys | eskers |
| QUATERNARY | LATE PLEISTOCENE TO HOLOCENE | WISCONSIN | GLACIGENIC | | TILL (UNDIFF.) | Bouldery sandy diamicton | 60,0(?) | widespread regional | as a sheet; underlies ground moraine, ribbed moraine and patches of hummocky moraine |
| PRECAMB. | | | | | BEDROCK | | | | |

TABLE 2 . SURFICIAL DEPOSITS OF THE STUDY AREA.

proglacial sediments. The latter comprise outwash and glacial-lake sediments. The distribution of the various units is shown on a map (Fig. 7).

Till is by far the most abundant unconsolidated deposit in the area. It extends as a sheet of variable thickness throughout the region and it underlies ground moraine, ribbed moraine, and patches of hummocky moraine. Most of the earlier statements (Chap. 2) about drift thickness and continuity apply to the till sheet. Although abundant, it is very poorly exposed as all the natural cuts, which are scarce, are largely covered by moss, shrub, or even forest vegetation. This has limited observations to the shallow surficial zone of the till sheet in the upper part of cuts and in more than 50 manually dug excavations. From these, a set of 31 surface samples were selected from 28 different sites.

The sedimentary characteristics of the till are determined by the lithology of the bedrock from which glacial debris is derived and by the mode of transport and sedimentation of this debris. The predominance of granite, gneiss, and coarse-grained sedimentary rocks in the study area has led to the formation of predominantly sandy till, similar to most till from the Canadian Shield (Scott 1976). The till is a bouldery sandy diamicton with clast content ranging from 5% to 20%. Its color ranges from pale yellow (2.5 Y 7/4) to, more commonly, light yellowish brown (2.5 Y 6/4). In reference to Elson's (1961) classification, it is mainly sand till with subordinate sandy silt and sandy loam till (Fig. 8). Cumulative curves of the




MAP OF SURFICIAL DEPOSITS OF THE STUDY AREA

FIGURE 7

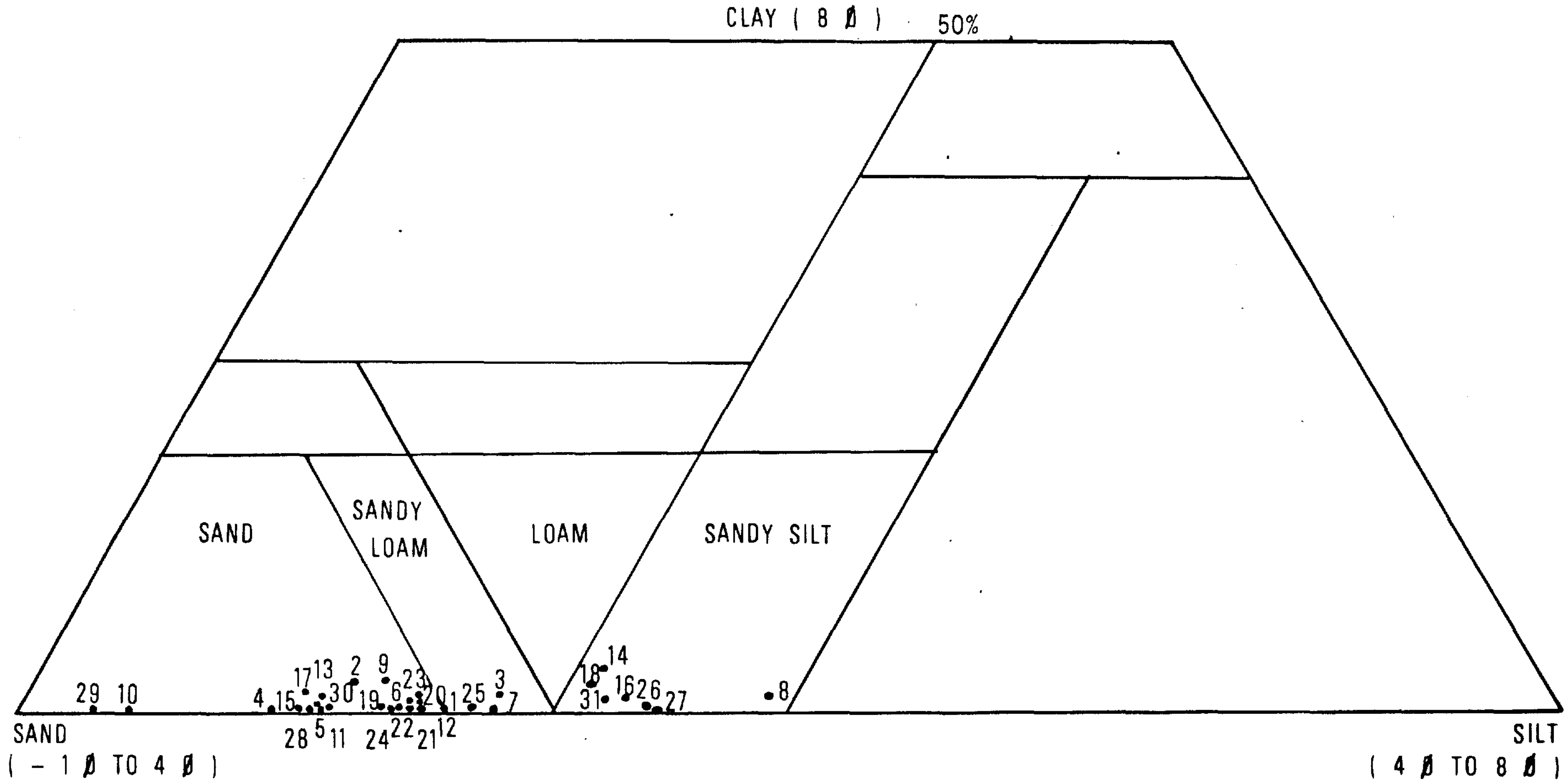



FIGURE 8 . TERNARY PLOT OF THE PARTICLE SIZE DISTRIBUTION OF TILL MATRIX.

BOUNDARIES AND END MEMBERS ARE FROM ELSON (1961).

grain size distribution of the till matrix show that most samples have their modal size in the fine sand fraction (2 to 4 Ø) (Fig. 9). Clay content is generally less than 1% reaching 4% in sandy silt till.

A comparison of the particle size distribution of till from Témiscamie area with that of till from Waconichi (Dilabio 1976) and Chibougamau (Ermengen 1957) regions illustrates the strong influence of bedrock lithology on the texture of till (Fig. 10). Till from Waconichi area is predominantly sandy silt with subordinate silt till; it was deposited on and derived mainly from dolomite of the Albanel Formation which extends about 80 km up-ice from the sampling area. Till from Chibougamau is mostly sandy loam to loam till with subordinate sand till; it was deposited on mainly mafic and anorthositic rocks, down-ice from the dolomitic rocks of the Mistassini Group with an intervening belt about 20 km wide of Archean granite and gneiss.

Ice-contact stratified drift forms esker ridges which occur almost exclusively in the main valleys of the area. As in the case of till, the material is poorly exposed, the slopes of the eskers being mantled by bouldery and cobbly colluvium. Limited observation has shown that the deposits range from mainly bouldery gravel, with rounded to sub-rounded clasts, to stratified medium- and fine-grained sand, with numerous normal faults affecting the sediments. The maximum thickness reported in Table 2 (22 m) is the maximum height of eskers in the area. Ice-contact stratified drift is probably interdigitated with till in areas of hummocky moraine.

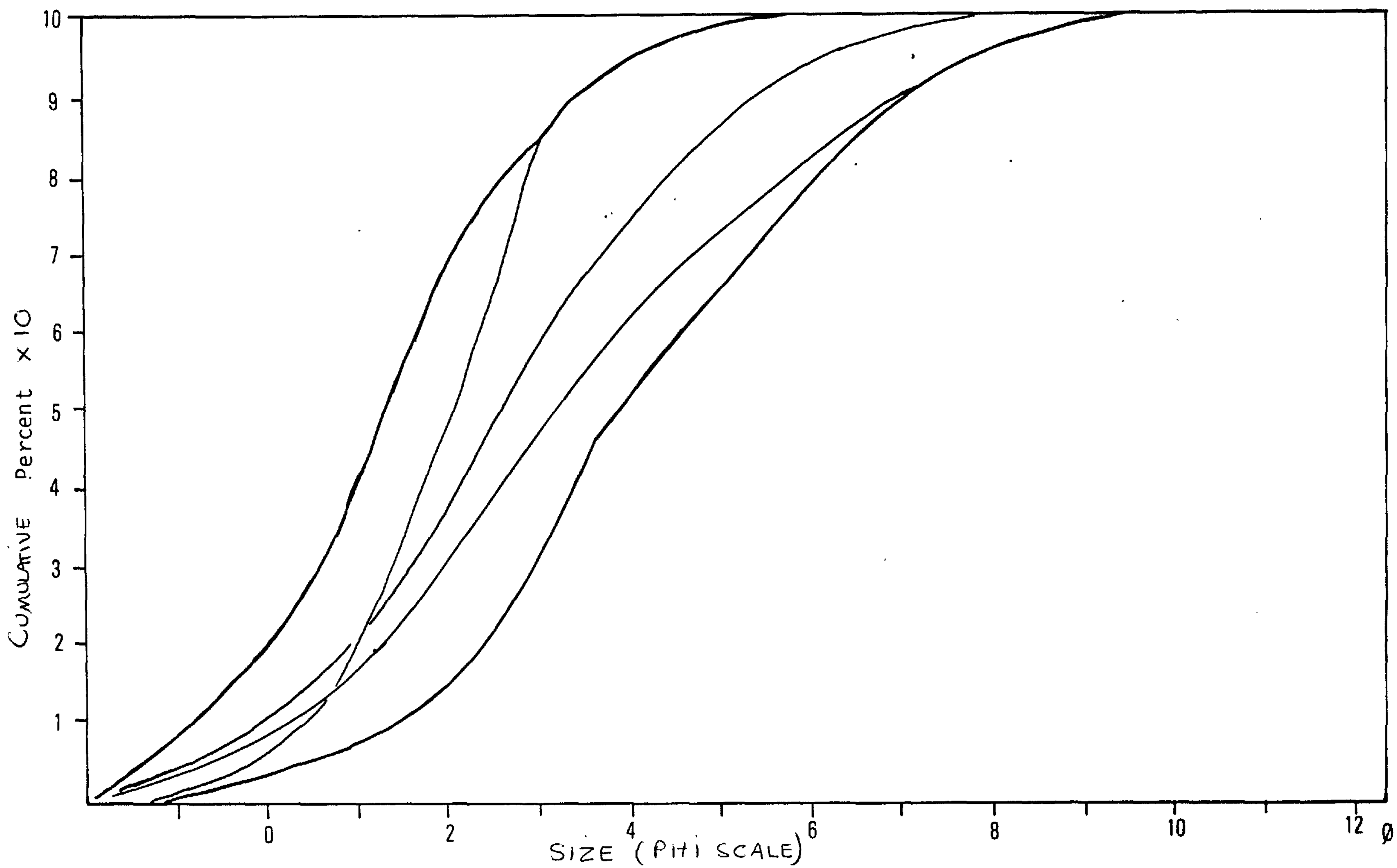



FIGURE 9 . PARTICLE SIZE DISTRIBUTION OF THE LESS THAN −2Ø (4mm) FRACTION OF TILL. ONLY FEW REPRESENTATIVE CUMULATIVE CURVES ARE SHOWN . THE OUTERMOST CURVES ARE ENVELOPPES OF CURVES OF ALL SAMPLES.

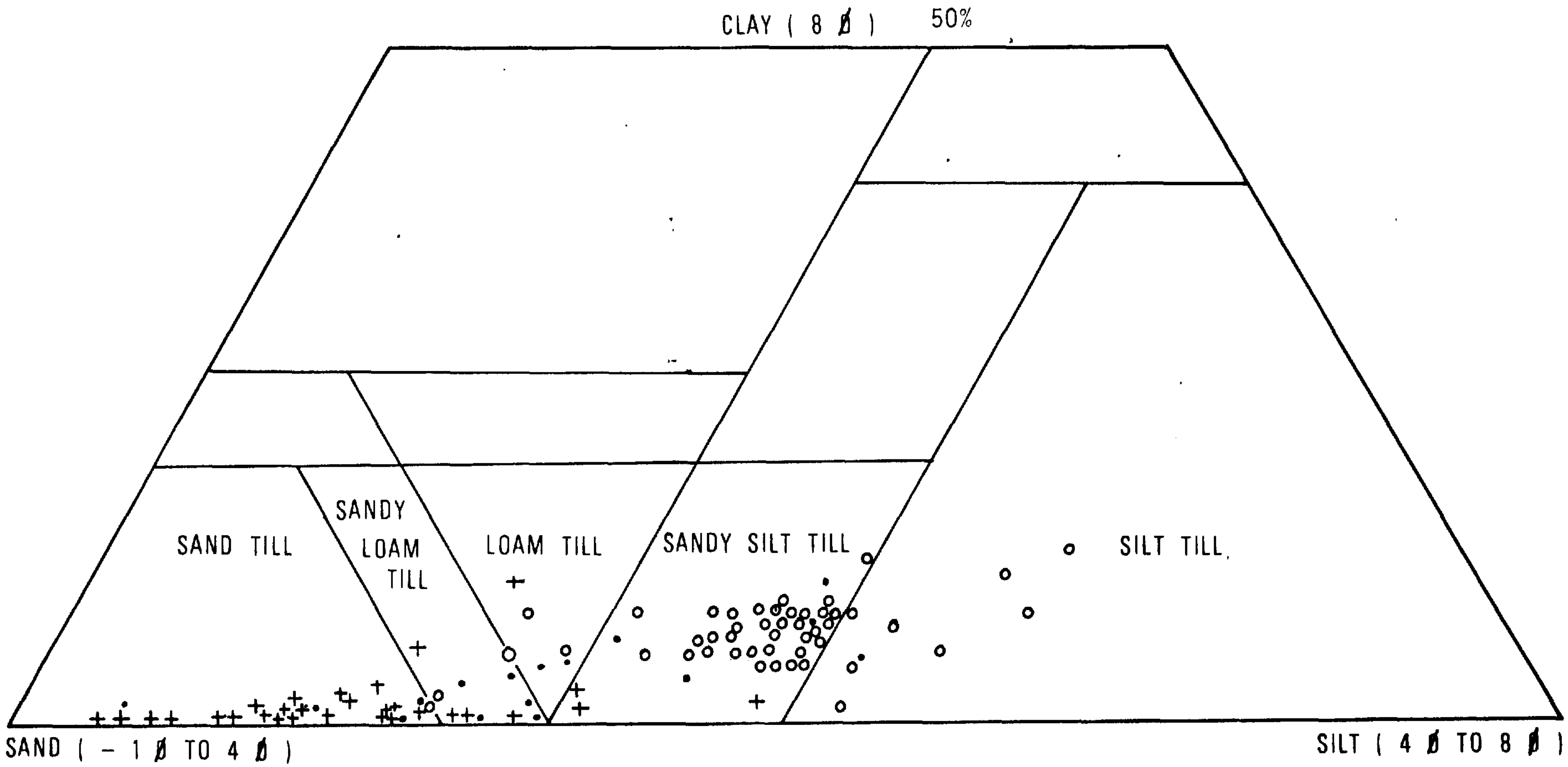



FIGURE 10. COMPARISON OF THE PARTICLE SIZE DISTRIBUTION OF THE TILL MATRIX FROM DIFFERENT AREAS OF THE MISTASSINI REGION. SAMPLES FROM THE TEMISCAMIE AREA ARE SHOWN AS PLUS SIGNS. SAMPLES SHOWN AS OPEN DOTS ARE FROM THE WACONICHI AREA (DILABIO 1976). SAMPLES SHOWN AS BLACK DOTS ARE FROM THE CHIBOUGAMAU AREA ( ERMENGEN 1957 ).

Proglacial sediments are those that are deposited beyond the ice margin when part or all the sediment load from heavily laden meltwater streams, issuing from the snout area of the glacier, is abandoned (Flint 1971). The characteristics and morphology of these sediments are strongly dependent on the type of environment at the glacier margin. When ice retreats across land, as was the case throughout most of the area, proglacial sediments are deposited as outwash. When the ice margin is in a glacial lake, or when proglacial streams debouch into a large body of standing water, as was the case in the southwest part of the area, proglacial sediments are deposited as glacial-lake sediments that range from deltaic sandy deposits to finer-grained lake-floor sediments.

Outwash ranges from well sorted plane- and cross-bedded medium- to coarse-grained sand with minor gravel to thinly bedded fine-grained sand and silt. It occurs discontinuously in all the main valleys where it commonly laps onto the sides of eskers. Maximum thickness of outwash is around 10 m. Extensive patches which extend the full width of valleys for lengths of more than 3 km are found in the Tichégami Mountains and at places along Neilson, Papaskwasati, Takwa, and Kapaquatche Rivers. The most extensive accumulation of outwash is in Papaskwasati valley where numerous kettles indicate that it was largely deposited on stagnant ice or else that it buried blocks of ice left in the valley.

Glacial-lake sediments range from rhythmically bedded silt and clayey silt to medium- and coarse-grained sand. They form extensive valley fills, more than 20 m thick, in the mouth area of rivers tributary to Lac Mistassini, namely the Papaskwasati and Takwa-Cheno Rivers. In the Papaskwasati valley, a coarsening upward sequence from clay to sand records the filling of the valley mouth during a falling water level while the ice front was retreating northeastward. Strandlines on the north shore of Lac Mistassini indicate that this valley was submerged under more than 20 m of glacial lake waters when the sediments started to accumulate. In Cheno valley, the proglacial sediments were deposited as deltaic sand with prominent foreset beds. As the water level fell in the lower ends of valleys, streams cut down into the sediments accumulated previously and this has created paired terraces in the valley fills. The material is well exposed in river cuts, where erosion maintains actively retreating faces.

Sediments associated with strandlines of the glacial lake form beach ridges composed mainly of sand, with minor gravel, and chains of parabolic sand dunes. They occur exclusively around the north shore of Lac Mistassini and the dunes are restricted to the vicinity of the mouth of Papaskwasati River.

The proglacial sediments also form an extensive valley fill in Témiscamie valley between Lat. 51°24' N and 51°32' N. Maximum thickness is around 22 m (exposed above present river level) in the north part of the valley. It is mainly plane- and cross-bedded medium-grained sand. The surface is kettled in the part where the thickness is maximum. Part of this valley fill was undoubtedly deposited as outwash but strandlines around Lac Albanel, and the presence of rhythmically bedded silt and clay at Lat. 51°24' N in the valley indicate that outwash accumulated with little gradient as the south part of the valley was flooded under as much as 20 m of water.

Alluvium ranges from boulders, to cobble gravel, to sand and silt, because it is derived mainly from ice-contact stratified drift and outwash. At places, it includes organic matter. The paired terraces in the valley fills are capped by 1 to 3 m of gravelly and coarse sandy alluvial deposits. There is no sharp distinction between these and outwash, inasmuch as the latter is also an alluvial deposit.

Peat occurs in bogs, which are numerous. More than half of them are of the string bog type (Allington 1961). Most average 0.5 $km^2$ or less in area; the largest in the region covers 3 $km^2$ and is located west of Témiscamie River at Lat. 51°18' N, Long. 72°28' W. Bogs may be found at all altitudes but the largest sizes and greatest number of them are in a belt of about 400 m altitude at the north ends of Lakes Mistassini and Albanel (Fig. 7). The peat is generally thin; over 30 rod measurements have yielded values ranging from 75 to 310 cm for depth to solid ground. Two samples from Einer bog, at Lat. 51°02' N, Long. 72°58' W, were found to be predominantly slightly decomposed *Sphagnum* peat with ash content from 7% to 14% (cited in St-Jacques and D'Aragon 1976).

The sediments at the bottom of modern lakes (exclusive of Lac Mistassini and Lac Albanel) generally are thin layers of mineral deposits that grade upward into organic rich mud, or gyttja. The thickness of the sediment column ranges from 1,1 to 3,8 m in five selected lake basins. The sediments from one of these lakes are used for dating the minimum age of deglaciation of the area (see 3.5., this chapter).

Only one drift sheet is present in the area as nowhere were non-glacial deposits found buried under or interstratified with glacial sediments. Deep exposures are limited however, and there is a possibility that such a stratigraphy might be found in deeper depressions of the bedrock, notably where recorded drift thickness exceeds 60 m. The drift sheet was undoubtedly deposited during the last glaciation (Wisconsin) of the Pleistocene Epoch. Since deglaciation of the area occured between about 7,500 and 6,600 years ago (Chapter 4), part of the till which was deposited during deglaciation as well as ice-contact stratified drift and proglacial sediments, and all the post-glacial deposits, are Holocene in age (defined as the geologic time having its lower limit at 10,000 years B.P., Hageman 1971). The till is assigned an age no more precise than Late Pleistocene (Wisconsin) to Holocene (Table 2) because part of it may have been deposited during glacial advance.

## 3.2 Glacial landforms

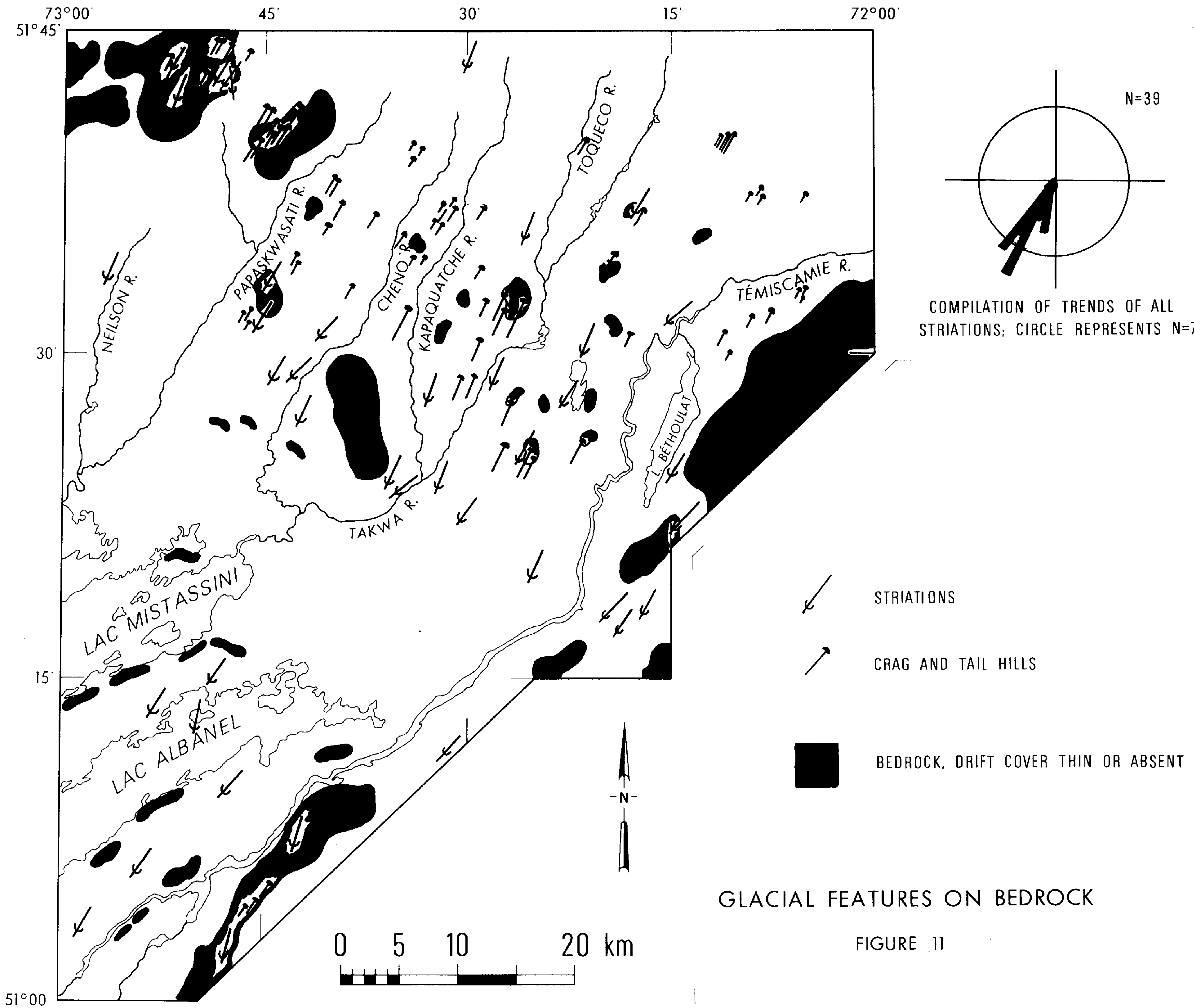
The different glacial landforms are grouped under features involving mainly bedrock, which are essentially erosional in nature, and depositional features which involve till.

3.2.1 Bedrock surface features

These range in size from millimeter to centimeter scale, such as striations and grooves, to larger features such as whaleback forms and crag-and-tail hills, which are tens of meters high and may exceed 1 km in length. All these have in common an elongation in the direction of glacial flow. Although striations in themselves do not indicate in which of two directions the ice was flowing, they are stated as indicating southwestward flow; this is based on the general context indicated by the other directional features.

Trends of striations were measured at 32 locations in the area (Fig. 11). Seven additional striations shown on the map are compiled from Wahl (1953) and Neilson (1966). Among the different rock types in the region, metavolcanic and metasedimentary rocks, as well as fine-grained sedimentary rocks of the Témiscamie Formation, appear to be the most prone to develop and preserve a smooth polished surface from glacial abrasion. Striations are relatively scarce on granite, gneiss and coarse-grained clastic Aphebian rocks. Dolomitic rocks of the Albanel Formation are readily attacked and weathered by surface run-off, consequently glacial polish is seldom preserved on this rock type.

The mean trend of all measured striations is S 29.7$^{\circ}$ W ranging from S 5$^{\circ}$ E to S 53$^{\circ}$ W, a total variation in orientation of 58$^{\circ}$. In general, no striations systematically overlap others or significantly diverge from others nearby so as to suggest more than one flow system in the region. Cross-cutting striations were observed at only one




GLACIAL FEATURES ON BEDROCK

FIGURE 11

location, at an altitude of 820 m in Tichégamie Mountains, west of Lac Rivon. The smooth polished surface of greenstone there shows a set of striations trending S 35° W cut by an apparently younger set oriented at S 5° E. This is an isolated occurrence in an area of high relief where local deflections during deglaciation could cause overlapping relationships.

The relatively large range of orientation (58°) of the limited number of striations measured in the area contrasts with the very consistent trend indicated by other features such as crag-and-tail hills and drumlinoid ridges; this suggests that striations were inscribed at a late stage of deglaciation under thin ice, the flow of which was increasingly influenced by underlying topography. In addition to the local deflections within the Tichégamie Mountains, the map (Fig. 11) shows that the Témiscamie Mountains diverted the flow eastward, and that the massif of the Béthoulat Upland deflected the flow westward. Striations both east and west of Takwa Hill indicate a westward deviation of the flow direction there. This could have been caused by topographic deflection or by the changing outline of the ice margin as this hill became uncovered.

Non glacial striations were observed at Lat. 51°32 ' N along Papaskwasati River. There, an outcrop of Aphebian sandstone forms a tabular surface about 0,5 to 1 m above river level on the convex west side of a bend in the river. Striations range in length from 20 to 50 cm and change in width from 1 to 3 mm over that distance. Many sets of these may be followed along the outcrop where they curve to conform to the path of the river bend. It is likely that these features were produced by river ice in spring time. Similarly, some striations recorded along Takwa and Témiscamie Rivers may have had a similar origin, although the trends of these was not seen to vary within short distances. Drifting lake ice might also produce comparable features. Striations on the shore of an island in Lac Albanel, on an outcrop the surface of which is 1,5 m above water level, indicate a trend which is 25° more easterly than that indicated by other striations nearby and which is approximately at right angles to the trend of the shoreline at this location. Although they appeared as a good set of parallel glacial striae, these perhaps were formed by lake ice.

In addition to striations, grooves, ranging from 15 to 35 cm wide, and 5 to 15 cm deep, were observed on fine-grained metasedimentary rocks near Takwa Falls, and on anorthosite near Témiscamie River. The inner parts of the grooves bear striations which conform in orientation to that of the groove. Crescentic marks were observed over fine-grained rocks of the Témiscamie Formation along Albanel road, at the south limit of the study area. Similar features were noted on granite in the vicinity of Lac Léotard and were reported by Neale (1952) from around Lac Cawachigamau, on gneiss.

Whaleback forms are small individual bedrock bosses which show a gentle, occasionally smooth and abraded, stoss slope leading to an irregular, quarried, lee slope. They range in size from 2 to 45 m long, less than 1 to 3 m high, and 1 to 15 m wide. Smaller examples occur in succession and create small-scale stepped stoss and lee topography in some localities. These features are not readily observed on aerial photographs and are not shown on the map (Fig. 11). However they appear to be very abundant and widespread on hard crystalline rocks and to be concealed under drift over the larger part of the area. Particularly good examples of such features were described by Ignatius (1956) from around Lac Béthoulat, where drift was washed away on the east side of the lake. Other examples of individual knobs are found near Lac Cawachigamau where bedrock islands in the lake show remarkably well the stoss and lee asymmetry. In those two localities, east-trending joint systems in anorthositic and gneissic rocks respectively appear to have favored the development of quarried faces. Near Lac Marcil, whaleback knobs outcrop in an area of ribbed moraine, and down-ice from the stoss and lee features the terrain is littered with a profusion of joint blocks of the same lithology as that of the knobs. Elsewhere in the region, stepped stoss and lee topography was commonly observed on lee sides of larger bedrock hills, the best example being west of Lac Roxane (Fig. 12). There, a prominent hill of gneiss, about 800 to 1200 m long, 30 m high and 150 to 220 m wide, trends S 22$^{o}$ W. On the down-ice slope of this hill, stepped stoss and lee topography extends continuously for about 500 m in length. The steps are 1 to 3 m high and spaced 15 to 20 m apart; quarrying was controlled by joints and quartz veinlets in the gneiss, striking transverse to the trend of the hill. At the stoss end of this hill, which is a large rock drumlin, small quarried block scars, 30 cm deep, 150 cm wide, and spaced about 60 cm apart, are common.

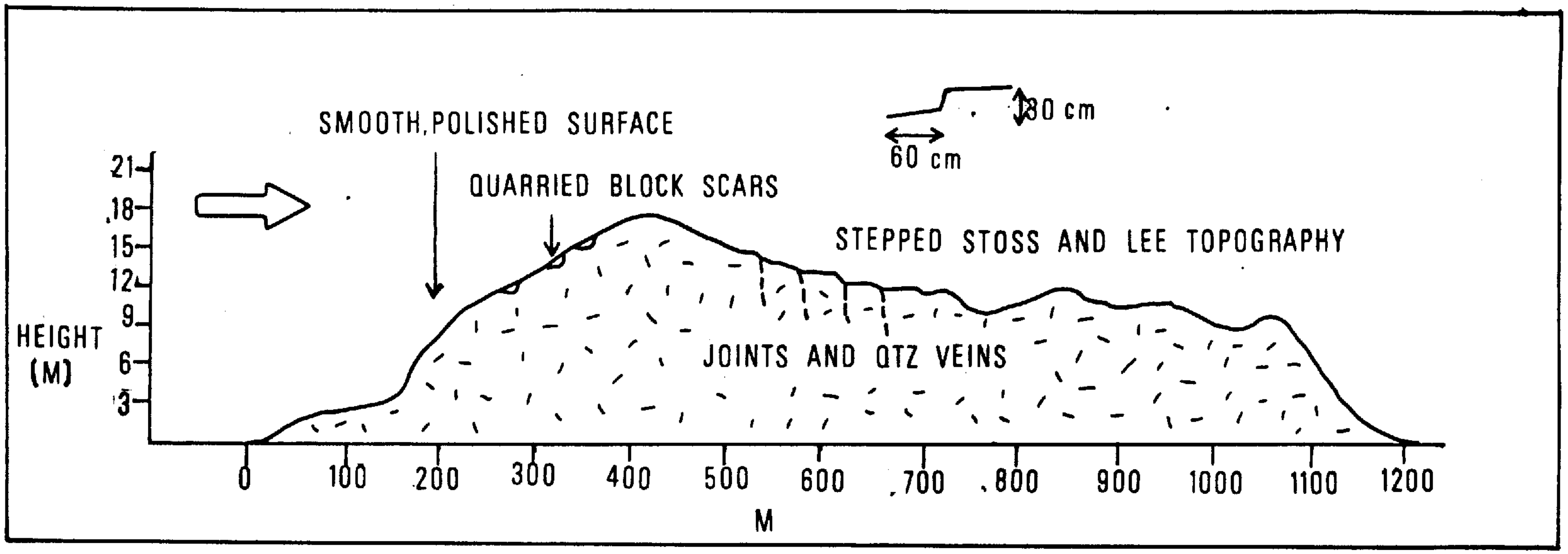



FIGURE 12 . ROCK DRUMLIN, WEST OF LAC ROXANE. OPEN ARROW INDICATES THE GLACIAL FLOW DIRECTION. THE PROFILE WAS ESTABLISHED WITH HAND LEVEL AND TAPE.

Crag-and-tail hills are glacially streamlined landforms which have a hill of bedrock (crag) with a long sloping tail of drift streaming behind it (Flint 1971). The size of features shown on the map (Fig. 11) range from 100 m to more than 2 km in length, 50 to 600 m in width, and 10 to over 50 m in height. Such landforms are particularly abundant in the belt of land between 450 and 600 m altitude which crosses the area in a northwest-southeast direction between Tichégamie Mountains and Béthoulat Upland, and in Témiscamie Mountains, in the south part of the area.

The tail is at places largely bedrock protected from glacial erosion by the crag. An exceptionally large feature of this type is found east of Lac Ouellette reaching 75 m in height and exceeding 5 km in length. In the lee of the prominent crag of gneiss, the bedrock surface is mantled by thin and patchy drift with abundant boulders of the same rock type as the resistant knob.

Granite, gneiss, gabbro, as well as resistant beds of Papaskwasati Formation, all may form crags at places. Granite and gabbro appear however, proportionally, most prone to develop these features. Pre-glacial bedrock topography and differences in joint density within and between the various rock types most likely controlled as well the distribution of crag-and-tail.

Average orientation of the crag-and-tail hills is S 29$^{o}$ W and this varies slightly. The crag-and-tail features that diverge most both east and west from the mean trend are found above 800 m altitude in the Tichégamie Mountains.

### 3.2.2 Till landforms

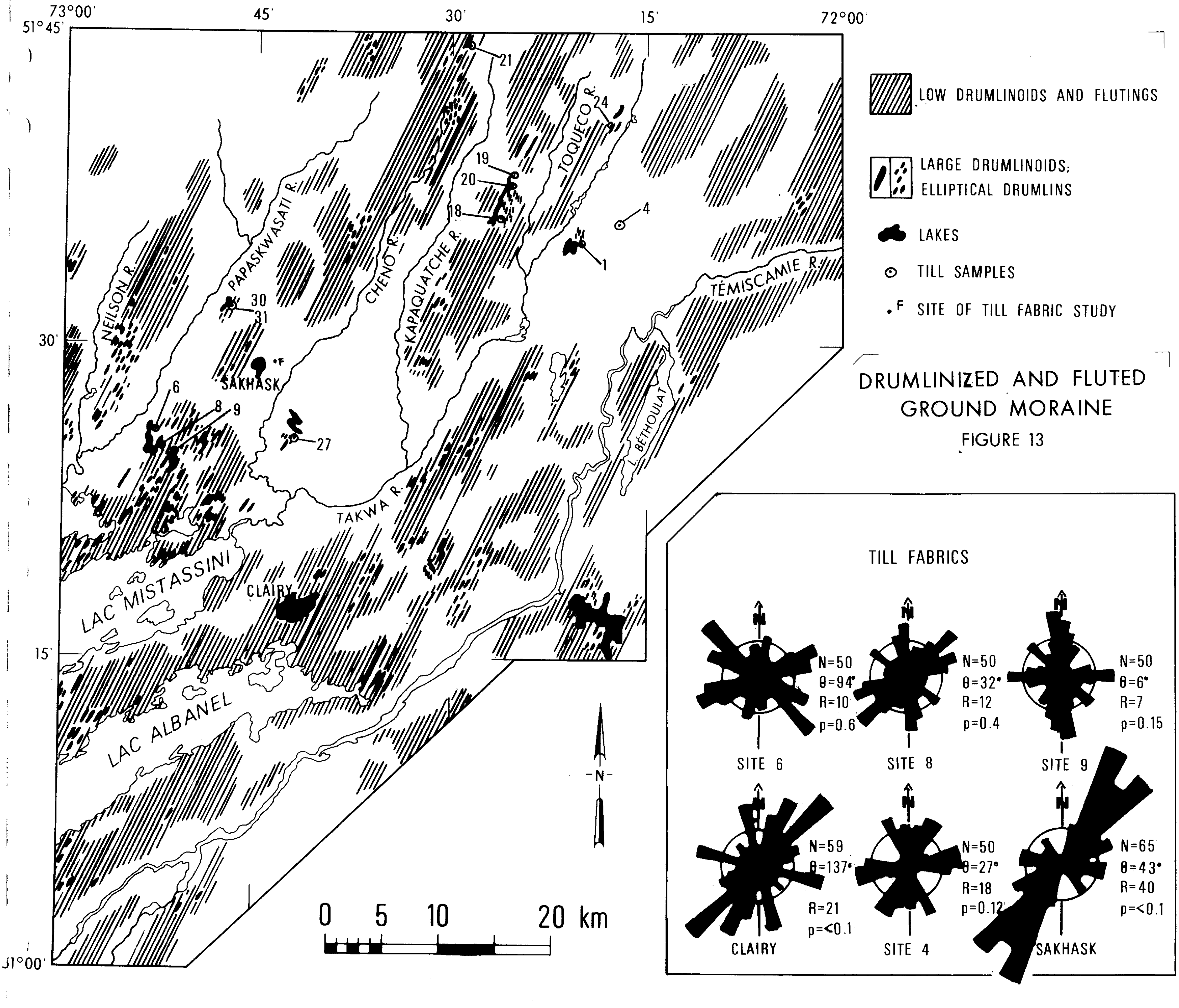
#### 3.2.2.1 Ground moraine

About 80 per cent of the drift covered parts of the area is ground moraine (Fig. 7). More than 80 per cent of the ground moraine are drumlinized or fluted (Fig. 13). This ice flow lineation occurs mainly in the higher central parts of interfluvial areas.

Glacial streamlined landforms range from (1) large, very elongated, distinct drumlinoid ridges to (2) shorter elliptical drumlins to (3) low relief ridges and grooves which produce a background trend of flow lineation (Fig. 14). All types are transitional. Collectively these ice-flow features indicate a very consistent flow direction which averages S 29$^{o}$ W. Local discrepancies however between features of different types suggest that all were not formed simultaneously, and that for instance , shorter drumlins were probably formed later in a late stage of deglaciation.

(1) Large drumlinoid ridges range in length from 100 to more than 3 km and are 10 to 25 m high across widths of 30 to 600 m. With few exceptions, large elongate distinct ridges that exceed 500 m in length occur in the south part of the region overlying dolomitic rocks. Similar ridges are found south of the Témiscamie area in the Mistassini drumlin field which extends for a distance of over 100 km southward, covering the whole dolomitic Mistassini basin.

Within the Témiscamie area, the drumlinoid ridges have a haphazard pattern as some overlap others on sides or on ends. The majority




DRUMLINIZED AND FLUTED GROUND MORAINE

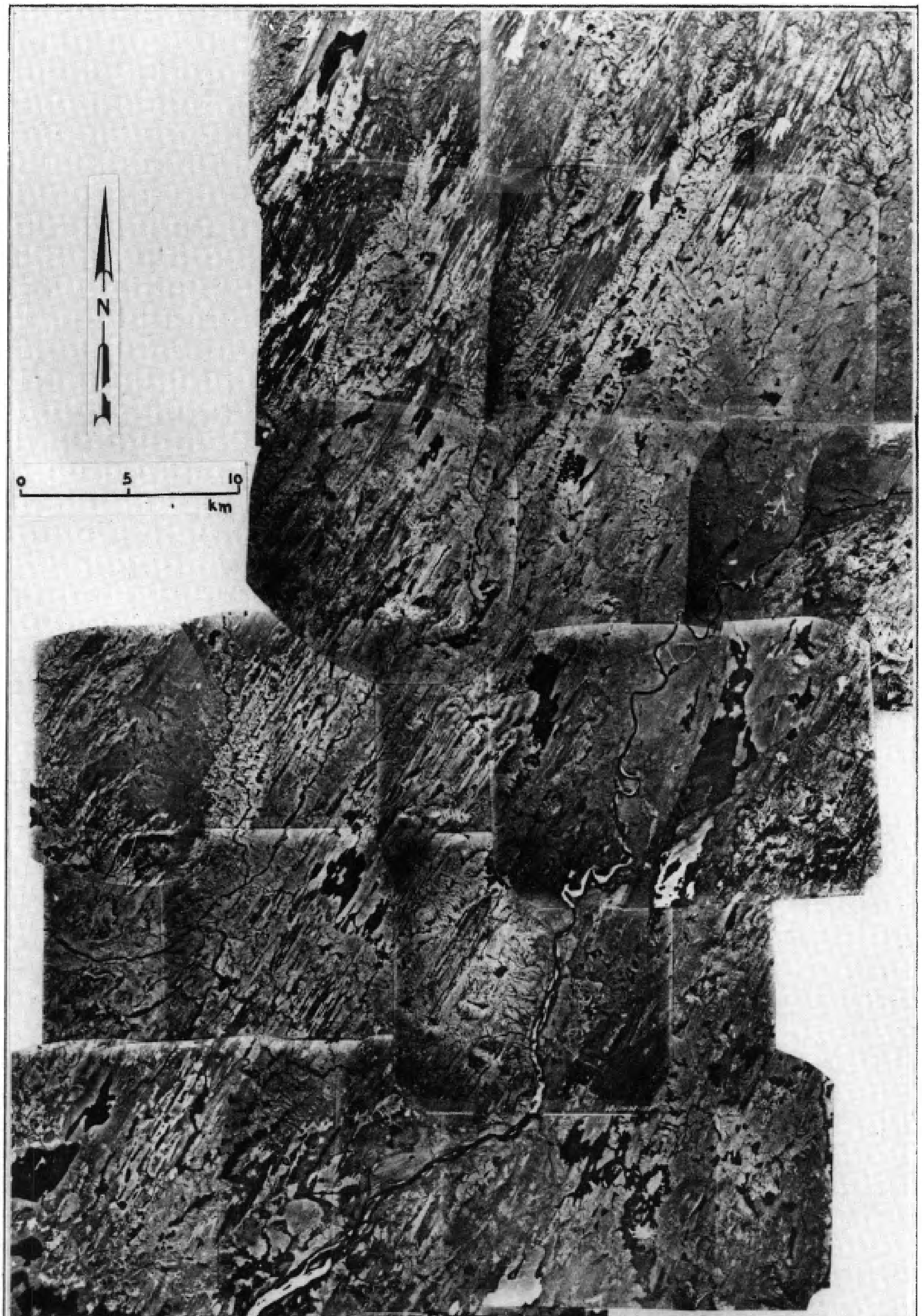
FIGURE 13

presumably are composed entirely of drift as they occur in areas of thick drift. This is shown by a channel, more than 7 m deep, cutting one ridge at Lat. 51° 25' N, Long. 72°33' W.

(2) Shorter drumlins resemble more the classical description of the "inverted bowl of a spoon" (Flint 1957). They are elliptical in shape, 50 to 350 m long, 5 to 10 m high and 25 to 120 m wide, and occur in swarms covering many square kilometers. Most of these are in the north part of the area; major fields are southeast of Lac Magyar, east of Lac Léotard and northeast of Lac Marcil. In these areas, drumlins are en échelon. Both Magyar and Léotard drumlin fields grade laterally into ribbed moraine. The group of drumlins north of Lac Marcil, and others in the vicinity of Lakes Cawachigamau and Fourchette grade down-ice into ribbed moraine. Although this is not apparent on any single aerial photograph the trend of these smaller drumlins, at least in the Léotard, Marcil, and Fourchette fields, does not conform to that of the low drumlinoid ridges or crag-and-tail hills in the vicinity, but diverges by more than 10 degrees.

(3) Low relief ridges and grooves are spaced from 15 to over 200 meters from trough to trough. When closely spaced they form a fluted surface. Flutings may be found superposed on larger drumlinoid ridges or crag-and-tail hills where their trends may be at angles of a few degrees to that of the larger feature. More widely spaced ridges (see Fig.49 , Chapter 5) resemble low drumlinoids.

Figure 14. Uncontrolled photomosaic of the east half of the study area showing the consistent trend of glacial flow lineation and abundance of glacial streamlined landforms.


N
0
5
10
km

They are common in areas of thin drift but also occur intermixed with higher ridges in areas where drift is thicker.

Parts of the region mapped as undifferentiated ground moraine (Fig. 7) include areas where the flow lineation pattern of the till sheet is either absent or highly discontinuous because of dissection by meltwater or post-glacial streams.

Till underlying ground moraine was sampled at 12 sites (Fig. 13, Table 3); eleven of these samples are from drumlinized or fluted ground moraine. The orientation of the long axes of pebbles in the till was measured at five locations.

Hard massive sandy silt till was encountered at sample sites 8, 18, 27, and 31. At site 8, at the south end of large drumlinoid ridge east of Lac Papaskwasati, the till has a well developed fissility, and the pebble orientation has a predominant mode parallel to the axis of the drumlinoid. Similar material underlying low drumlinoid ridges west of Lac Clairy and northeast of Lac Sakhask also have orientations with strongly developed modes parallel to flow (Fig. 13). Compact massive sandy loam till underlies fluted ground moraine east of Lac Marcil (Sample 1). Massive sand till (Samples 6 and 9) underlies fluted ground moraine and a large drumlinoid ridge east of Lac Papaskwasati. At the site of sample 6, pebbles have a preferred orientation of the long axes in a direction tranverse to that of the topographic trends. At sample site 9, the pebble orientation mode is oblique to the trend of the drumlinoid

| SAMPLE | Location (Lake) | Map unit or landform | Structure | Fabric*[2] | Textural name |
|---|---|---|---|---|---|
| 1 | Marcil | fluted GM*[1] | compact, massive | - | sandy loam |
| 4 | Ouellette | unpatterned GM | compact, layered (?) | parallel and oblique | sand |
| 6 | Papaskwasati | low drumlinoid | compact, massive | transverse | sand |
| 8 | " | large drumlinoid | compact, fissile | parallel | sandy silt |
| 9 | " | " | compact, fissile | - | sand |
| 18 | Léotard | elliptical drumlin | loose, massive | - | sandy silt |
| 19 | " | " | modified*[3] | - | sand |
| 20 | " | " | " | - | sand |
| 21 | Magyar | large drumlinoid | " | - | sand |
| 24 | Lac à l'Huile | " | " | - | sand |
| 27 | Brideau | " | compact, massive | - | sandy silt |
| 30 | Amphore | " | loose, layered | - | sand |
| 31 | " | " | compact, massive | - | sandy silt |
| - | Sakhask | " | compact, massive | parallel | - |
| - | Clairy | low drumlinoids | compact, massive | parallel | - |

*[1] GM: ground moraine.

*[2] Trend of mode(s) relative to glacial flow direction.

*[3] E horizon of soil.

Table 3. Summary of till samples in ground moraine, Témiscamie area. See Fig. 13 for sample location.

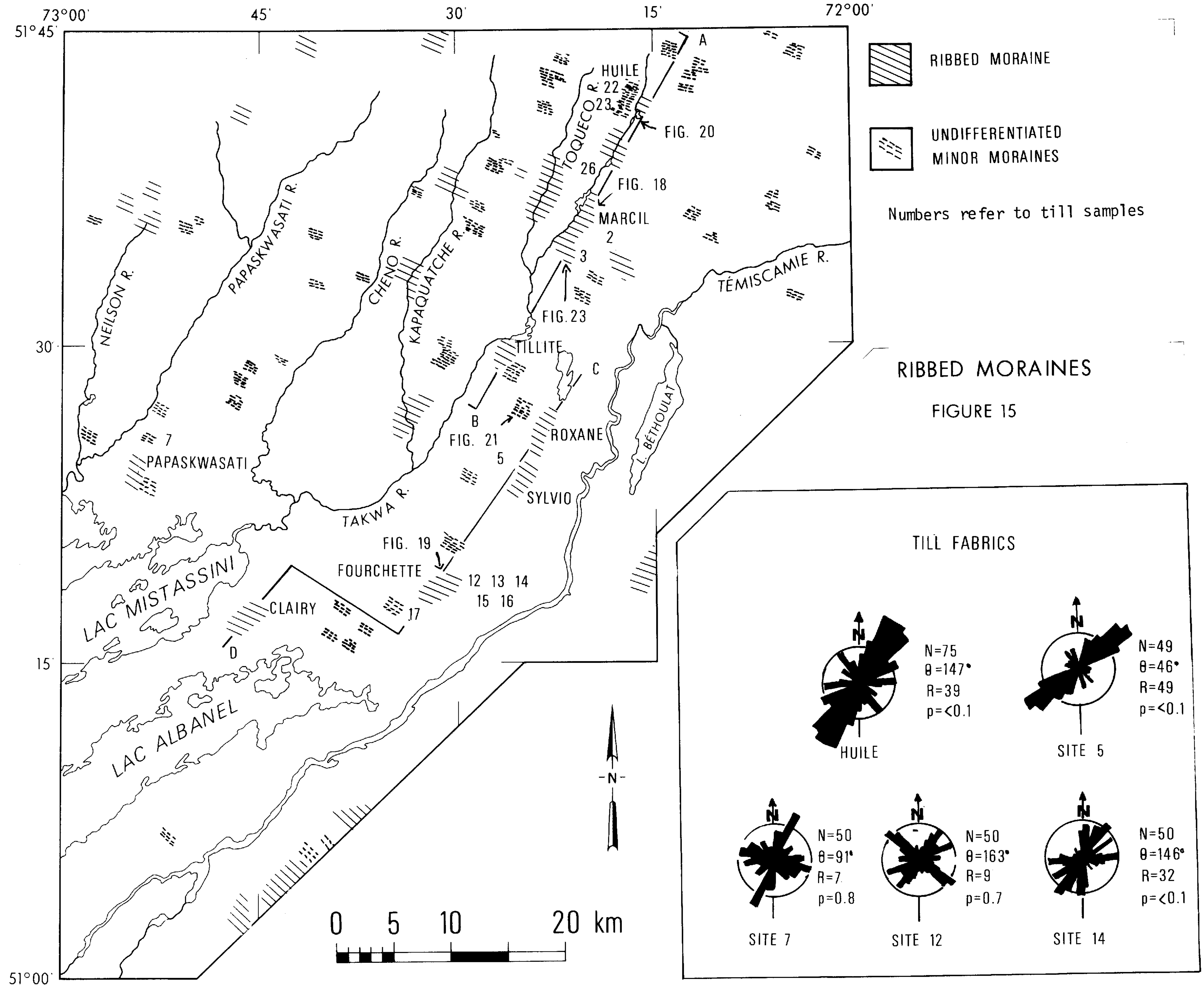
ridge; both trends converge in a down-ice direction. East of Lac de l'Amphore, a layer, 1,2 m thick, of loose cobbly sand till with pockets of well sorted gravel overlies compact sandy silt till (Samples 30 and 31). Samples 19, 20, 21, and 24 were taken in drumlins but above indurated soil horizons so that structural and textural modifications are likely to have occurred from the eluviation processes of soil formation.

Sample 4 is from an area northeast of Lac Ouellette where the flow lineation of the till sheet is largely masked below a patternless cover, and where deep meltwater channels are cut in the ground moraine (see 3.3.2, this chapter). The till was observed in the upper part of a wall of one of these channels. The material is a bouldery sand till, with a suggestion of layering from concentration of small boulders and pebbles at a depth of 25 cm below the surface. The orientation of pebbles in this material, in the zone where pebbles are concentrated, shows two modes, one parallel and one oblique to the flow direction (Fig. 13).

#### 3.2.2.2 Ribbed moraine

According to Prest (1968), "ribbed moraine is a descriptive term used to refer to moraine areas where relatively large scale transverse lineaments give a 'ribbed' pattern to the land surface". The adjective "ribbed" was coined by Lee (1959) and evidently was chosen in reference to similarity of the pattern of the ridges to a rib cage. The ribbed pattern results from broad arcuate morainic ridges which in the study area are 50 to 200 m wide, 5 to 20 m high, and spaced irregularly from 90 to more than 200 m apart. "Ribbed moraine" refers collectively to a set of ridges in a more or less distinct field (Hughes 1964). An extensive patch of ribbed moraine occurs just north of Témiscamie area and covers pratically all of Hippocampe Plateau (Prest _et al_. 1968).

There are about 30 discrete fields of ribbed moraine in the study area (Fig. 15); they range in size from a few to about 15 $km^2$. The largest is at Lat. 51°40' N, on the east side of Takwa River, along Lakes Marcil and Ouellette. Ribbed moraines occupy valleys or basins. The greatest concentration of ribbed moraines occurs in a zone extending northeast-southwest in the east part of the area. Generalized topographic profiles (Fig. 16) show that most occur up-ice from bedrock obstructions closing bedrock basins or concavities. Most ribbed moraine fields are elongate with their long axis oriented in the main direction of glacial flow. The maximum length of any field is 6,5 km for Marcil-Ouellette ribbed moraine. This particular moraine might be composed of two or three separated but closely spaced fields. If the extent of all ribbed moraines in the area is projected as segments on a line oriented in the direction of glacial retreat, they collectively occupy almost all the available space on the line. In other words, although in separate basins or valleys, they together form an almost continuous sequence in the direction of glacial retreat. Finally, ribbed moraine occurs at all altitudes and over all types of rocks in the region, although in the study area they appear to be more common in gneissic terrain.




RIBBED MORAINES

FIGURE 15

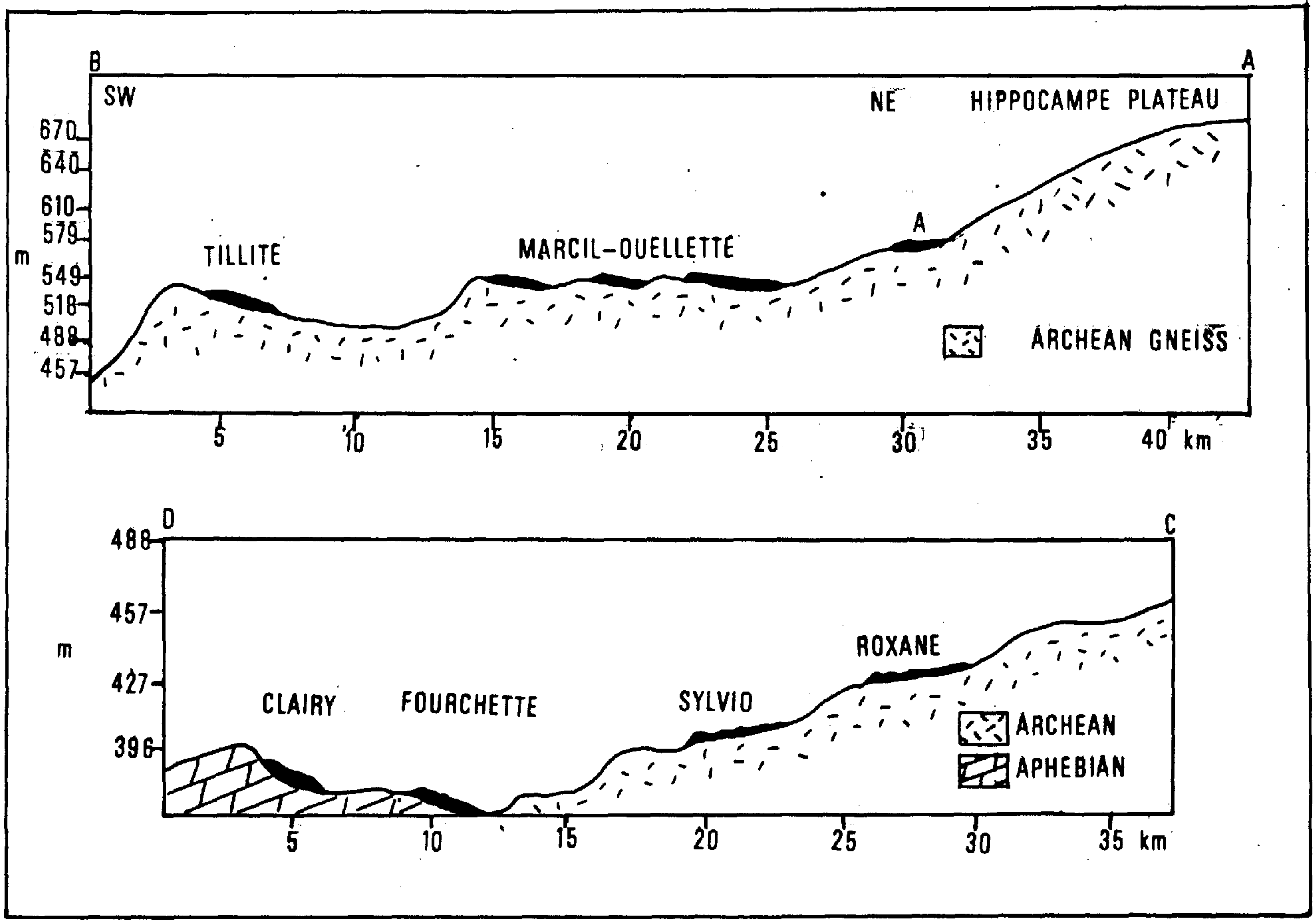



FIGURE 16 . GENERALIZED TOPOGRAPHIC PROFILE SHOWING THE LOCATION OF SELECTED FIELDS OF RIBBED MORAINE . POINT A IS THE LOCATION OF MINOR MORAINE OF LAC A L'HUILE. SEE FIG. 15 FOR LOCATION OF PROFILES.

Within any one field, the plan of the ridges is generally arcuate, slightly concave down-ice. Individual ridges are commonly sinuous, composed of several arcuate segments with smaller wave lengths. This confers to any one ridge a cuspate margin down-ice and a lobate margin up-ice,the pattern resembling that of advancing ripples. A common impression is that the opposing margins of two ridges could be fitted together as pieces of a jigsaw puzzle; this is particularly noticeable in Clairy field. There are however numerous exceptions and at places, opposing margins diverge from each other with a widening intervening trough. In the Marcil and Ouellette ribbed moraines the pattern is enhanced by innumerable bays and arms of lakes, which in turn are strewn with innumerable islands that are mostly isolated segments of submerged rib ridges. The altitude of the crest is commonly variable laterally along any one ridge and relief may reach 10 m at places where there are superposed hillocks or mounds on the ridge.

A longitudinal theodolite topographic profile perpendicular to the trend of ridges in part of the Fourchette ribbed moraine (Fig. 17) shows the following features: the proximal slopes range from 7 to 23 degrees but the steeper of these are obviously related to post-formation modifications and trough deepening by channel erosion. A common slope would be in the range of 7 to 12 degrees. Distal slopes range from 7 to 25 degrees, the larger figure may possibly be attributed similarly to channel erosion in the troughs. There is no statistically evident asymmetry but examination of ridges in the north part of the profile suggest that unmodified ridges have a gentler proximal slope.

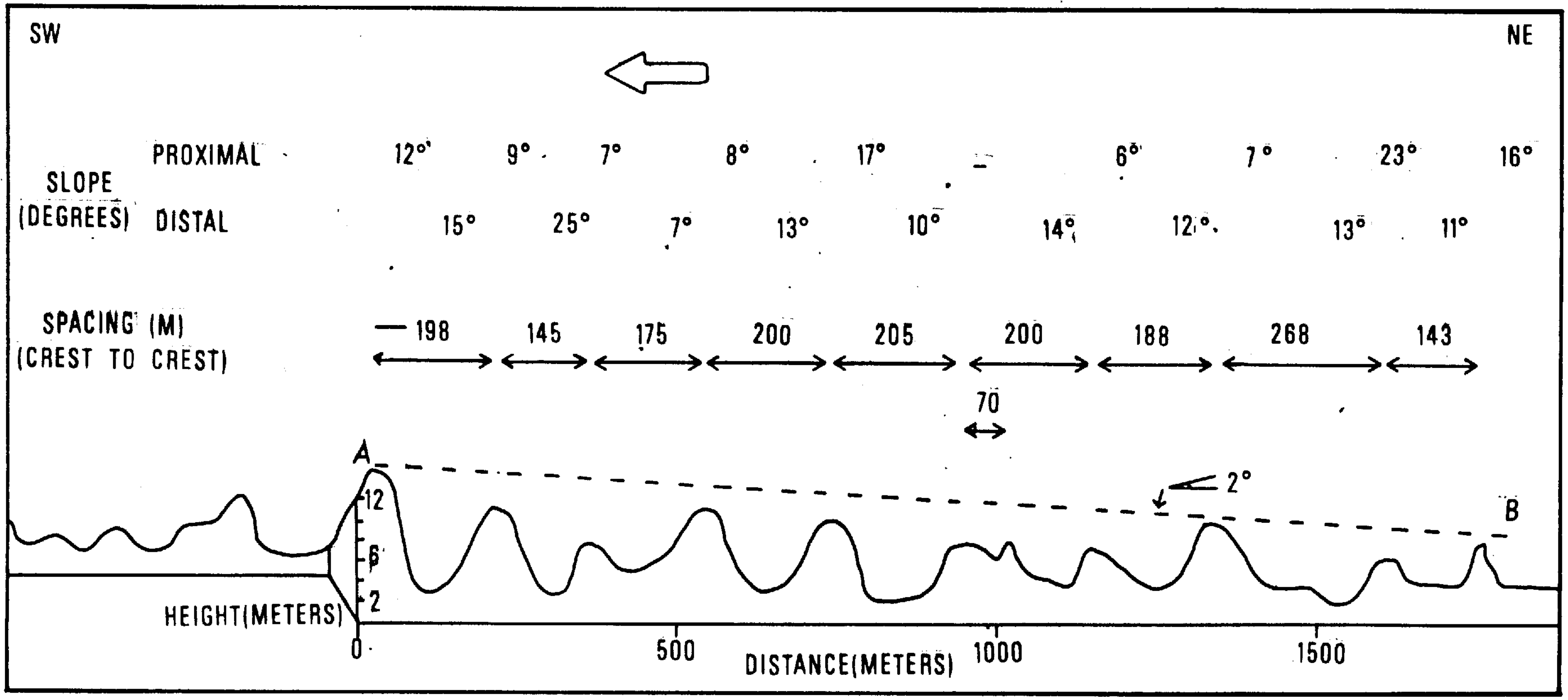



FIGURE 17 . TOPOGRAPHIC PROFILE PERPENDICULAR TO RIDGE AXES, PART OF FOURCHETTE RIBBED MORAINE. THE PROFILE WAS ESTABLISHED FROM A THEODOLITE SURVEY. HEIGHT (IN METERS) IS RELATIVE TO WATER LEVEL OF LAC FOURCHETTE, SEE FIG. 19 FOR LOCATION OF PROFILE. ARROW INDICATES GLACIAL FLOW DIRECTION.

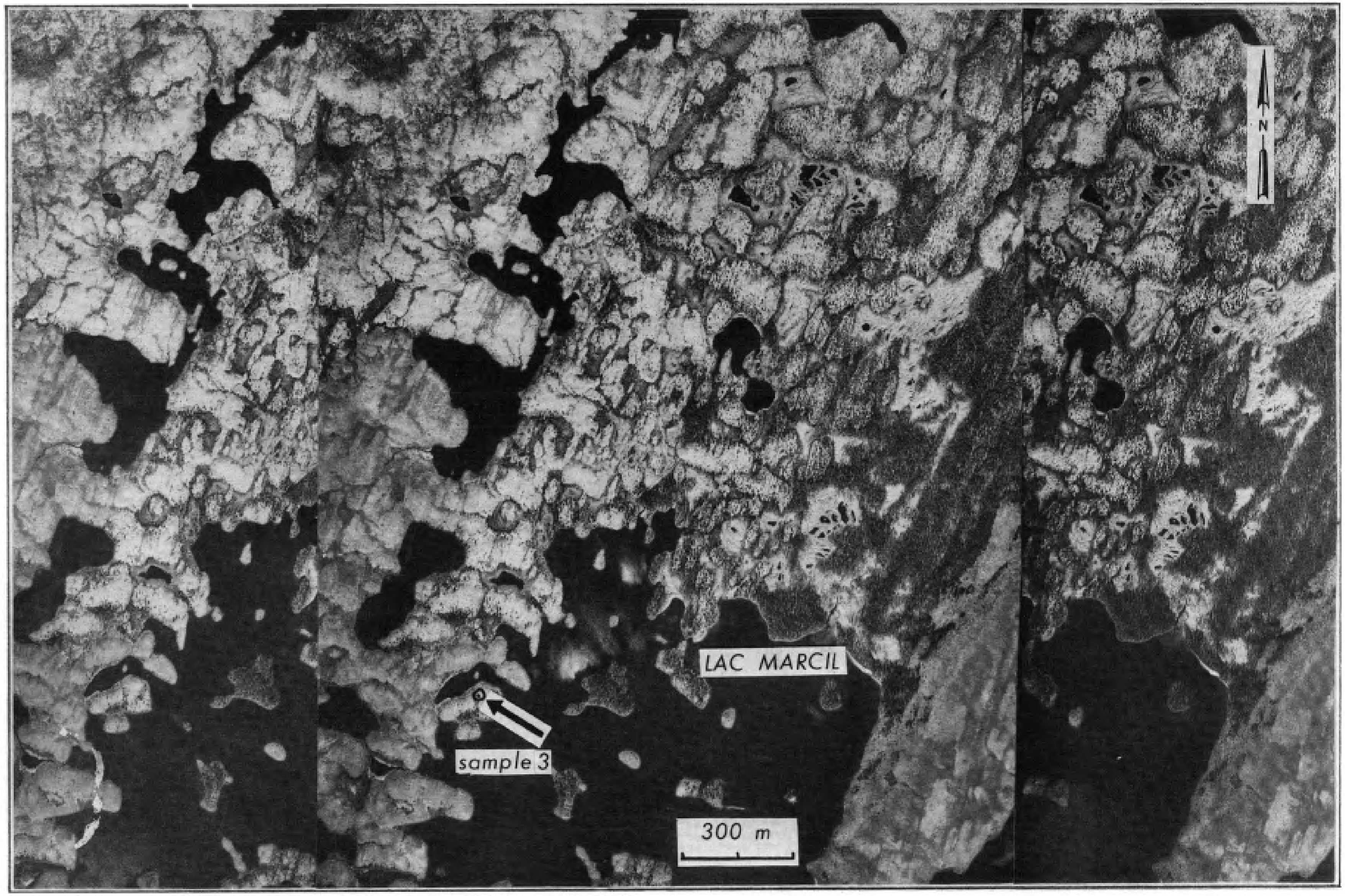
This is more pronounced in other fields notably in the Roxane ribbed moraine ridges. Spacing in the Fourchette field varies from 145 to 268 meters from crest to crest. One ridge is double with two crests 70 m apart.

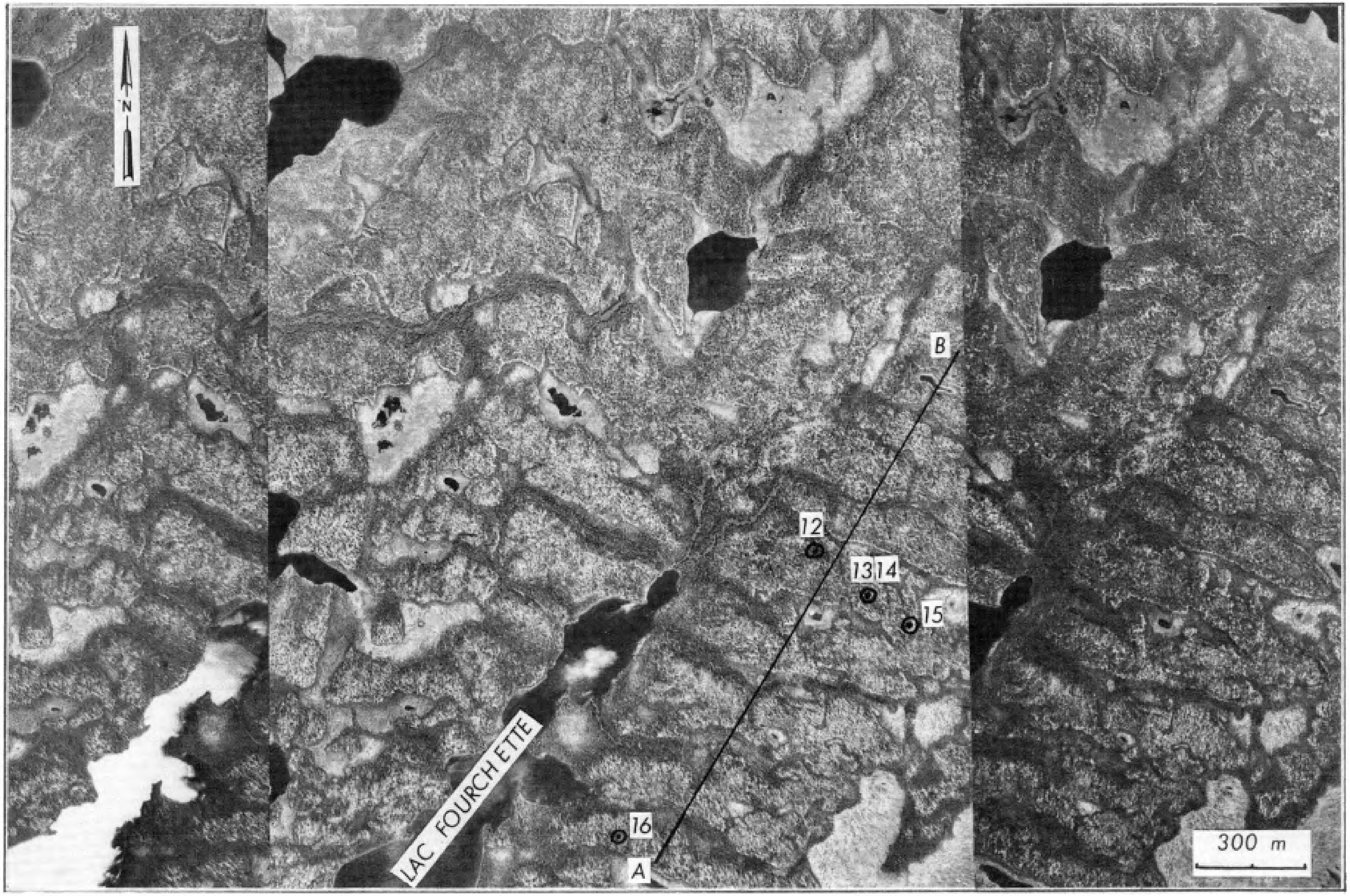
An imaginary surface that would join the top of the successive ridges would be a rather smooth, gently undulating plane with a relief of about 3 meters over a distance of more than 1 km, gently sloping up-ice (Fig. 17).

The lateral boundaries of ribbed moraine fields are not sharp. Lateral gradation of drumlin swarms into ribbed moraines was already noted previously. In addition, the surfaces of the ridges bear distinct flow lineations. This is seen in parts of ridges that are elliptical in shape with the long axis of the ellipse transverse to the ridge axis in the direction of glacial flow. Elsewhere, and this is so common as to almost be the general case, the surface of the ridges is distinctly fluted or grooved. This lineation is readily visible from air photos, but is indistinct on the ground. These, together with the shape and segmentation, and imbrication of successive ridges, combine to give the impression that the features were formed under active ice, a conclusion which was reached by Hughes (1964) on the basis of similar observations.

Gradation from drumlins to ribbed moraine is shown (Fig. 18, 19) in the Marcil and Fourchette fields. The trend indicated both by transitional drumlins and by flow lineations on the ridges does not necessarily, in fact seldom, conforms to the direction of glacial flow

Figure 18. Stereogram showing part of Marcil ribbed moraine and illustrating the transition from drumlins ( northeast part of the stereogram) to ribbed moraine ( southwest part of the stereogram). Note the higher hummocky moraine devoid of flow lineation in the northwest corner of the stereogram. See Fig. 15 for location.


N
LAC MARCIL
sample 3
300 m


N
B
12
13
14
15
16
A
LAC FOURCHETTE
300 m

indicated by larger features such as drumlinoid ridges and crag-and-tail hills in the vicinity. In figure 18, the flow direction indicated by the transitional drumlins is S 17$^{o}$ W; the large crag-and-tail (not shown) immediately southeast from the border of the stereogram trends S 30$^{o}$ W. The more southerly trend is also in the opposite direction to the expected flow deflection if the ice had been channeled into the adjacent Takwa valley. Similar divergences and in the same southward direction, are noted in the Tillite, Roxane, Sylvio and Fourchette ribbed moraines (Fig. 15). A group of ill-defined streamlined drumlin-like hills grading into the ridges of the Fourchette ribbed moraine (Fig. 19) indicate a flow direction which not only diverges from that indicated by adjacent larger features but also is at an angle not perpendicular to the ridge axis, suggesting that these flow features might have originated after the ridges were originally formed.

Not all ridged topography of the area was mapped as ribbed moraine. Other groups of ridges lack the distinctive character of broad, irregular, arcuate ridges, and consequently were considered to be other forms. They are mapped as undifferentiated minor moraines (Fig. 15). This may not be justified as many of these do resemble "typical" ribbed moraine on the basis of occuring in the same type of topographic situation, in the same areas, often in longitudinal or lateral continuity with ribbed moraine. They differ in that that the individual ridges are generally shorter, lower, and much more closely spaced. One example of these morainic ridges is around Lac à l'Huile (Fig. 20).

On the west side of the lake a succession of 9 to 10 ridges, spaced on the average 75 to 80 m apart, extend over a lateral length of 350 m, perpendicular to glacial flow direction. Relief is about 8 m and ridges are 60 m wide. Apart from smaller dimensions, they are in all other ways comparable to larger ridges of ribbed moraine, including the arcuate segmentation and sinuosity of ridges, and fine surface fluting across the ridges. On the topographic profile (Fig. 16) this particular short field is at point A, in a shallower depression than other ribbed moraines further south. The ridges west of Lac à l'Huile are easily seen on air photos because of clearing by forest fire. Elsewhere in the area, under continuous forest cover, other ridged features having similar or lower relief, might be indicated only by the serrated lake or bog margins, as observed west of Lac à l'Huile (Fig. 20). However wavelength of these serrations does not reflect faithfully the true spacing between individual ridges because only every second or third ridge produces a point and a re-entrant at the lake margin; consequently, spacing may easily be overestimated where these features are poorly displayed.

In the vicinity of Lac Roxane west from the ribbed moraine, a fine pattern of minor morainic ridges appear on air photos as a zebra-toned pattern on a low drumlinoid ridge (Fig. 21 and 22).

Figure 20. Stereo-pair showing the minor morainic ridges west of Lac à l'Huile

See Fig. 15 for location

Numbers are till samples.

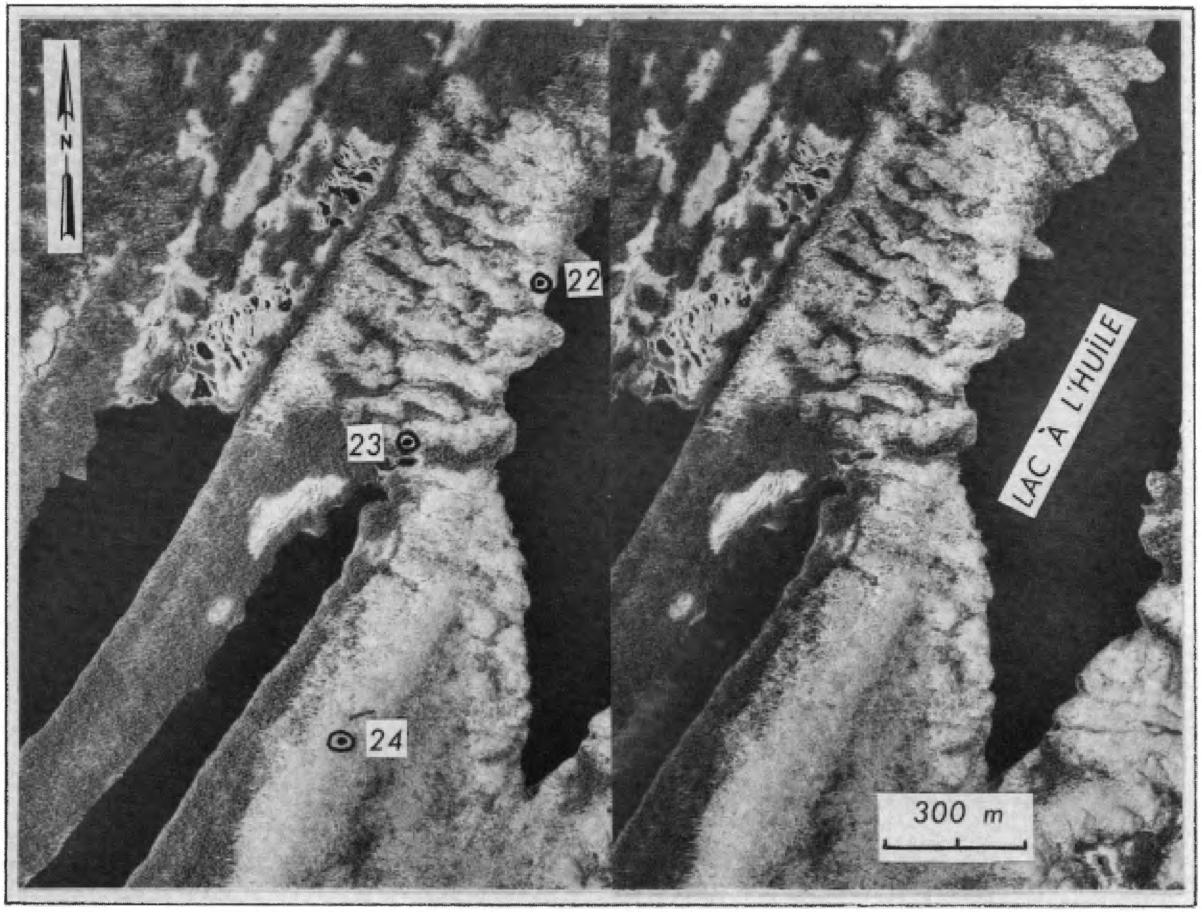

N
22
23
24
LAC À L'HUILE
300 m

Figure 21. Stereo-pair showing minor morainic ridges, west of Lac Roxane. Low altitude oblique aerial view of parts of same area appears as Fig. 22. See Fig. 15 for location.

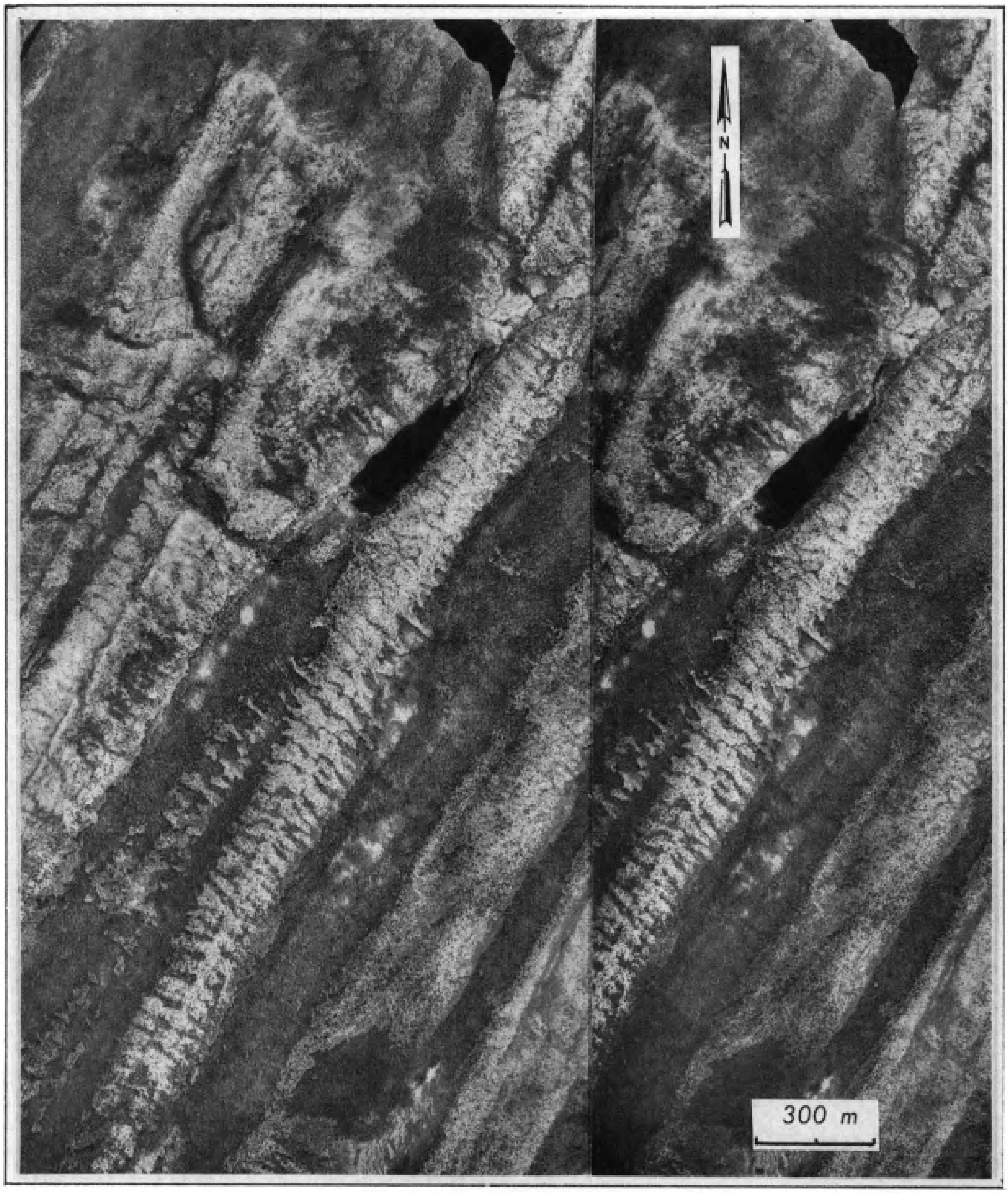

N
300 m

Fig. 22a - Low altitude oblique aerial view of part of the area shown in Figure 21. View is to the southwest. Glacial flow direction is from left to right. Length of view is about 1 km.

Fig. 22b - Low altitude oblique aerial view of the same area shown in Figure 22a. Spruce trees are about 10 m high. Glacial flow direction from left to right. Note the arcuate nature of the minor morainic ridges which appear as chevrons, pointing in the up-ice direction.

These small ridges are spaced only 45 to 60 m apart (crest to crest), extend across the drumlinoid which itself has very low relief, and the succession extends for nearly 1,5 km in the direction of glacial flow. Relief or height or individual ridges is no more that 2 m. The shape and outline of individual ridges bear some resemblance, in miniature, to the ribs of ribbed moraine. Margins of successive ridges appear to fit into each other, some parts of ridges show a down-ice concavity or arcuate segmentation, and on close inspection a faint flow lineation appears to be present on them (Fig. 22b).

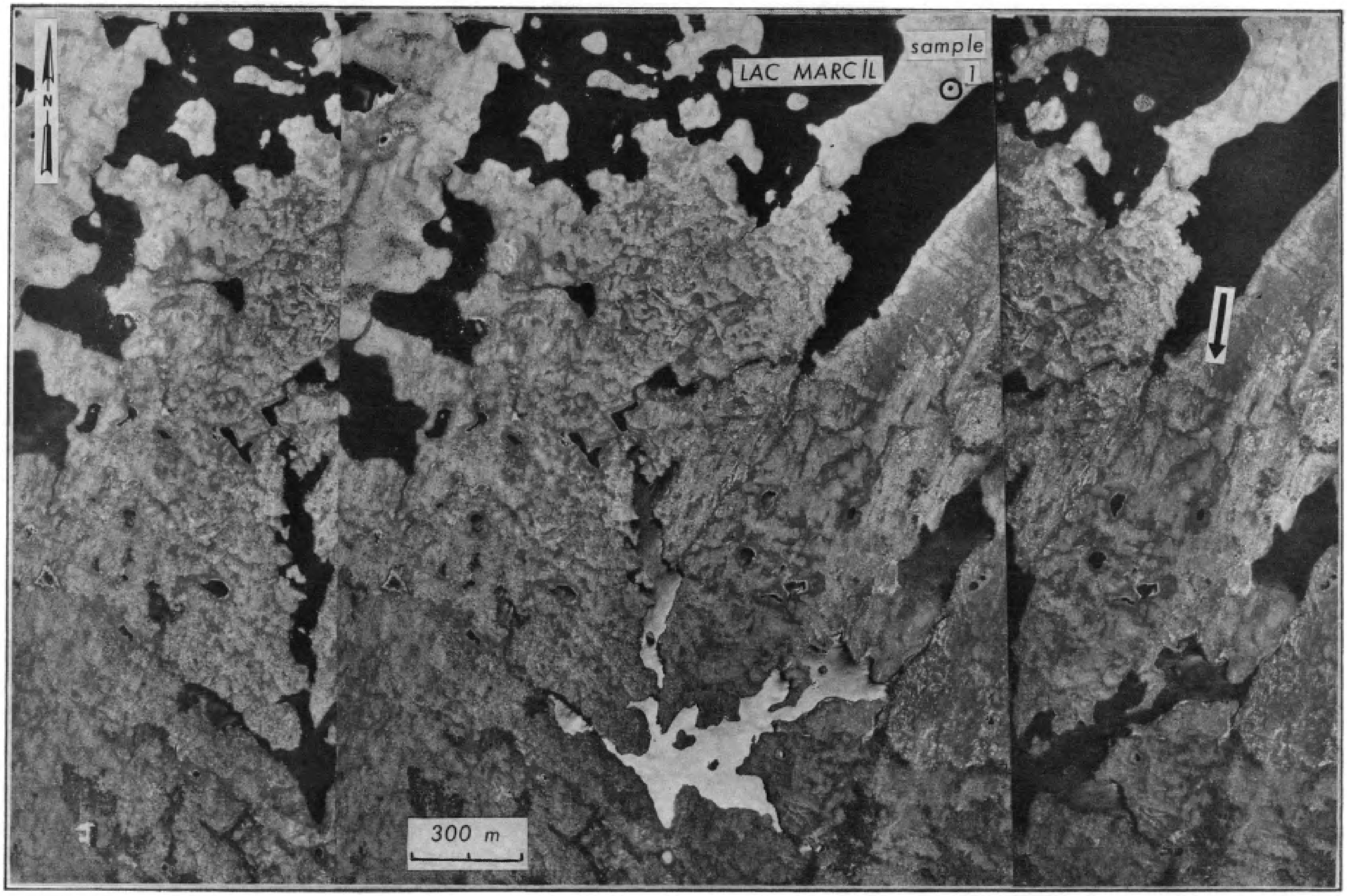
Similar features are seen elsewhere in the area although not with the same clarity. They frequently appear as faint transverse ridges in the lower parts of drumlinoid ridges having higher relief. When they occur on both sides of the ridges, the whole resembles a centipede with the body extending in the direction of glacial flow and short numerous "legs" streching out for a short distance transversally from the trunk.

All the various types of transverse ridged topography in the study area appear to belong to a family of features ranging from broad ridges, up to 20 m high formed in deeper depressions and basins, to closely spaced ridges about half as high, formed in shallower depressions, and finally, to small ridges, 2 m or less in height, even more closely spaced, that occur in the low swales between drumlinoid ridges. The shape and outline of all these features suggest a common subglacial origin under actively flowing ice.

The surface of ribbed moraines is commonly but not always littered with a profusion of generally angular boulders derived locally. This was studied in the south part of the Marcil ribbed moraine, and was observed also in the Roxane and Sylvio fields. The part of the Marcil field which is literally covered with boulders is shown in Figure 23. The boulders are of huge dimension and some exceed 8 $m^3$ in volume. Individual boulders can be seen on the stereogram. The area of boulder concentration has a very sharp western edge on one rib of the moraine. This edge trends in the direction of glacial flow. The up-glacier end of the bouldery area is at the south end of Lac Marcil, where numerous whaleback shaped bedrock knobs pierce the thin drift cover. Numerous outcrops showing irregular quarried lee slopes are found over the width of the lake and extend south within the boulder field itself. East and northeast of this region there are prominent outcrops of jointed gray-weathered gneiss with pegmatite injections. The joints trend roughly northwest-southeast. At three locations within the field, counts of 100 boulders revealed only 12 blocks in 300 that were not gneiss with occasional pegmatite injections. The allochtonous boulders are light gray fine-grained quartz sandstone derived from the Indicator Formation which underlies Hippocampe Plateau, about 25 km northeast from this location.

The topography in the area of abundant boulders is very irregular, with relief as great as 15 m, and apparently random hills. Part of this topography is produced by the irregular bedrock surface underlying the thin drift. Close examination reveals that the topography is not

Figure 23. Stereogram showing the south part of Marcil ribbed moraine, with the surface littered with boulders.


LAC MARCIL
sample
1
N
300 m

so chaotic and individual small hills are elongated in the direction of glacial flow, suggesting some streamlining under actively flowing ice. In the west and east parts of the stereogram flute ridges extend down-ice from individual boulders (Fig. 23). These are not wider than the boulder at the head and extend for roughly 10 to 20 m, occasionally up to 75 m, in a southwest direction. Obviously the boulders were carried subglacially and were deposited at the base of actively flowing ice. This particular field extends a further 3,5 km down to Lac de la Tillite where the boulders are widely dispersed and merge with the scattered blocks at the surface of the ground moraine.

Similar boulder fields associated with Sylvio and Roxane ribbed moraines extend 5 km in a down-ice direction. The short distance of dispersal of the boulders suggests that they were quarried at a late stage of deglaciation (see also Henderson 1959).

Till underlying ribbed and other minor moraines was sampled at 13 locations; 8 samples are from ribbed moraine (Fig. 15, Table 4). The orientation of the long axis of clasts in the till was measured at five locations, two in smaller ridges and three on proximal slopes of ribbed moraine ridges (Fig. 15).

The material most commonly observed in ribbed moraine was compact, massive, commonly cobbly to bouldery, sand till, with local occurrences of sandy loam and sandy silt till. The till was mostly indistinct, as judged in the field, from that underlying ground moraine. At sample

| Sample | Location (Lake) | Landform*[1] | Structure | Fabric*[2] | Textural name |
|---|---|---|---|---|---|
| 3 | Marcil | R.M. | compact, massive | - | sandy loam |
| 5 | Sylvio | R.M. | compact, massive | parallel | sand |
| 7 | Papaskwasati | U.M.M. | very compact, massive | - | sandy loam |
| 12 | Fourchette | R.M. | compact, massive | parallel and transverse | bouldery sand |
| 13 | " | " | compact, massive | - | pebbly sand |
| 14 | " | " | very compact, massive | parallel | sandy silt |
| 15 | " | " | compact, stratified | - | sand |
| 16 | " | " | compact, massive | - | sand |
| 17 | " | U.M.M. | loose, massive | - | sand |
| 22 | Lac à l'Huile | " | compact, massive | - | sand |
| 23 | " | " | compact, massive | - | sand |
| 25 | " | " | compact, massive | - | sandy loam |
| 26 | Takwa River | R.M. | very compact, massive | - | sandy silt |
| - | Cawachigamau | " | compact, stratified | - | - |

*[1] R.M.: Ribbed moraine; U.M.M.: undifferentiated minor moraine.

*[2] trend of mode(s) relative to glacial flow direction.

Table 4. Summary of till samples and observations in ribbed moraine and undifferentiated minor moraine.

See Figure 15 for location of samples.

site 15 (Fig. 15), on the top part of a ridge, a pit was excavated into very compact stratified till. Individual beds in it ranged from 0,5 to 3 cm in thickness and consisted of alternating layers of medium-grained and fine-grained sand matrix, with gradationnal contacts. A similar occurrence was found on the proximal slope of a ridge in ribbed moraine north of Lac Cawachigamau.

In minor morainic ridges, such as those near Lac à l'Huile, and in the smaller type of minor moraines, such as those observed west of Lac Papaskwasati, excavations penetrated very compact to compact, relatively well sorted, massive sand to sandy loam till. Pebble fabric at these two locations show a well developed mode parallel to flow, with a secondary transverse mode also present in the till at Lac Papaskwasati. The three pebble fabrics measured in ribbed moraine, one in the Sylvio moraine and the two others along a single ridge in the Fourchette moraine, had well developed modes parallel to flow. Till in both excavations on the Fourchette moraine showed in addition secondary modes transverse to flow direction.

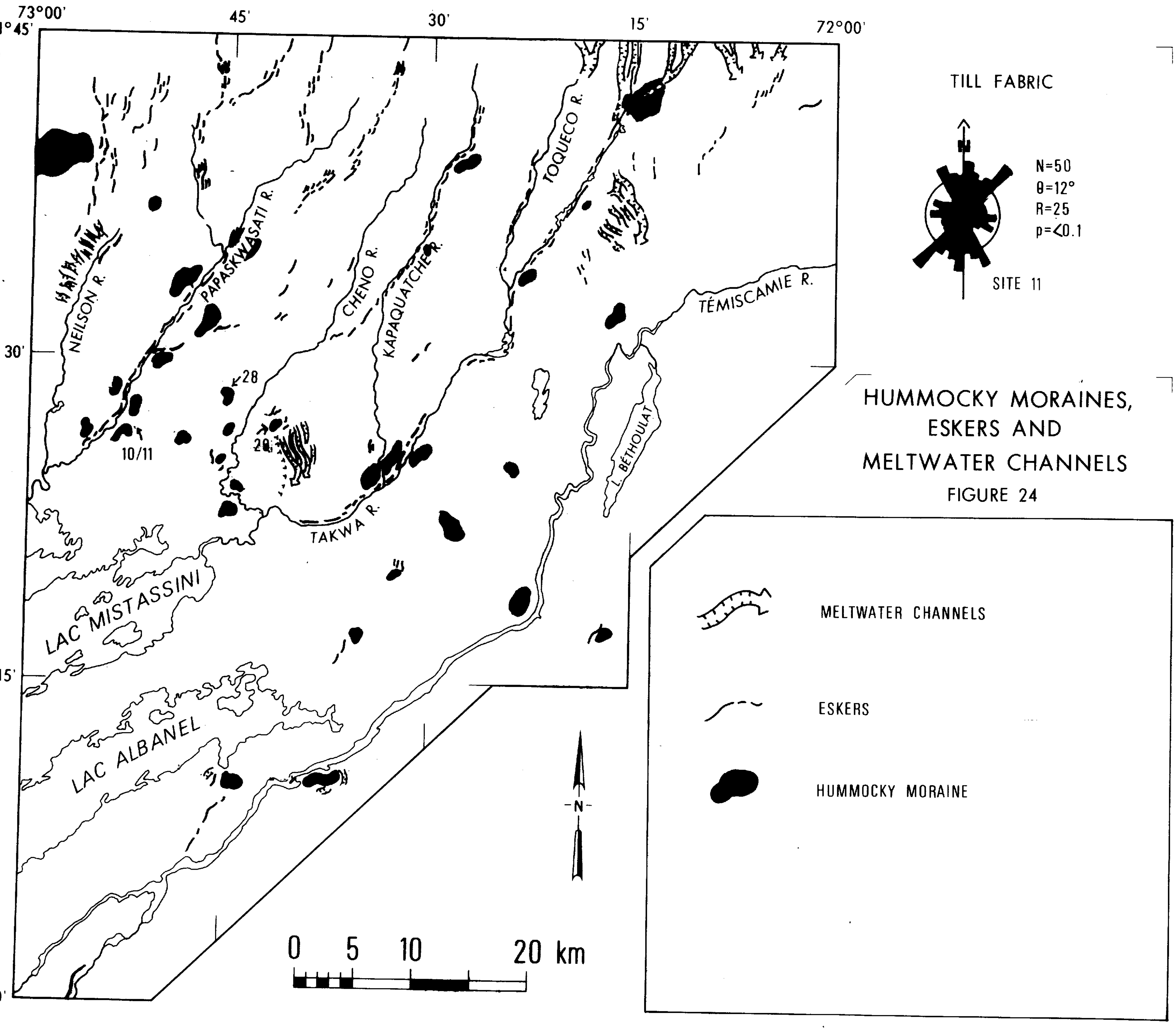
#### 3.2.2.3 Hummocky moraine

Hummocky moraine is used primarily in a descriptive sense for areas of mainly till with topography devoid of flow lineation and comprising irregularly shaped to circular closely spaced mounds, 5 to 25 m high, and 20 to more than 200 m in diameter. The absence of flow lineation, distinguishes hummocky moraine from dissected lineated ground moraine, and the minimum relief of 5 m for positive features distinguishes hummocky moraine from unpatterned ground moraine.

The map unit is interpreted on geomorphological basis as an ice stagnation landform; consequently its distribution is shown on a map (Fig. 24) along with other features of deglaciation, such as eskers and meltwater channels.

The mounds have steep slopes, generally between 20 and 30 degrees and there is no apparent pattern, such as alignment or elongation of relief features, except at few locations, namely near Lac Papaskwasati, where a faint pattern transverse to ice flow is discernible. Depressions around and between the hummocks are commonly deepened in the form of channels which are often littered with boulders. The tops and sides of some hills also are covered with bouldery debris. Larger hills may have a relatively flat summit; in hummocky moraine adjoining Takwa River in the northeast part of the area (Fig. 24), some hills 20 to 25 m high and 150 to 250 m in diameter have at their top a central depression, of a diameter smaller than that of the hill, and as deep as 2 to 3 m below the rounded crests of the side slopes (see Fig. 18). In some cases a bog occupies this flat central depression. These hills are analogous in aspect to some "ice-disintegration" features (Gravenor and Kupsh 1959) known as moraine plateaux (Hoppe 1952, 1957) or rim-ridged plateaux (Parizek 1969).

Elsewhere in the area, such as in the vicinity of Lakes Roxane and Sylvio, the hills are smaller in diameter and conical in shape, suggestive of a series of kames. Similar topography near Lac Brideau, and at another location west of Cheno River, about 7 km southwest from Lac Brideau, shows in addition to hills small winding esker-like




HUMMOCKY MORAINES, ESKERS AND MELTWATER CHANNELS

FIGURE 24

ice-contact ridges, 3 to 5 m high, and tens to few hundred meters long. In the patch of hummocky moraine at the northeast end of Lac Papaskwasati, instead of hills, the topography shows closely spaced circular hollows, some of which coalesce leaving intervening irregularly shaped steep-sided ridges and hummocks. The diameter of these kettle-lake hollows is 110 to 240 m and their flat floors are often occupied by lakes or bogs. The morphology is suggestive of "glacial karst topography" (Clayton 1966) which results from collapse of thick super-glacial debris due to melting of underlying stagnant ice (Clayton 1966, Clayton and Moran 1974)

In the south part of the area, east of Lac Albanel, two patches of thick drift rising about 10 m above adjacent ground moraine and about 2 $km^2$ in diameter are found up-ice from and abutting on Kallio Plateau and Témiscamie Mountains (Fig. 24). These accumulations lack the distinctive hillocky character of other patches of hummocky moraine but are similarly devoid of flow lineation, and are deeply dissected by numerous flat-floored and steep-sided meltwater channels, about 10 to 15 m deep.

The material underlying hummocky moraine was observed in surficial excavations at three locations (Fig. 24, Table 5). Samples 10 and 11 are from one excavation northeast of Lac Papaskwasati: loose, cobbly to bouldery sand till, 1,0 m thick, overlies compact sand till which includes pockets of well sorted gravel with rounded clasts. Pebble fabric in the lower till shows a poorly developed mode parallel to ice

| Sample | Location (Lake) | Structure | Fabric | Textural name |
|---|---|---|---|---|
| 10 | Papaskwasati | loose, sorted | - | sand till |
| 11 | " | compact, sorted lenses | faint mode parallel to ice flow direction | sand till |
| 28 | Sakhask | loose, sorted lenses | - | sand till |
| 29 | Brideau | loose, sorted lenses | - | sand till |

Table 5. Summary of till samples from hummocky moraine.

flow direction. Samples 28 and 29 were collected respectively near Lac Sakhask and Lac Brideau; they both are loose cobbly sand till with inclusions of sorted material.

There are no extensive areas of hummocky moraine in the region but patches, 2 to 10 $km^2$ in extent, are widespread. They occur preferentially in the low parts of the topography and the hummocks are seldom higher than the surface of the adjacent ground moraine. In some depressions, hummocky moraine occurs with ribbed moraine (e.g. at Lakes Roxane, Sylvio, and Marcil, Fig. 18); there, the hummocks are always higher than the surface of the ribbed moraine, and, unlike the ribbed moraine, the surface of the hummocky moraine is devoid of any flow lineation. The higher topographic position and the lack of lineations suggest hummocky moraine is a younger accumulation formed partly on ribbed moraine (see also Chap. 5).

Since the hummocky moraine patches are interpreted as ice stagnation landform, their distribution might be indicative of successive ice marginal stagnation zones, formed as the ice front receded across the region.

#### 3.2.2.4 Differentiation of till types

The Témiscamie area, as well as nearby regions, is currently the site of mineral exploration, mostly for uranium deposits. Part of these exploration programs use till as a sampling medium; drift samples are generally collected either at the surface or from drill holes.

Differentiation of genetic types of till, namely the recognition of basal and ablation till (Dreimanis 1976), is of primary importance to mineral exploration (Shilts 1976) because the compositional characteristics of each type may vary and their source areas may differ. Recognition of till types is rendered the more difficult in those areas where most tills are of a rather sandy nature, such as in the study area as well as in many other regions of the Shield.

The criteria used for differentiating till types should be of practical application in order to be useful in an exploration program. For surface samples, a tempting criterion is to rely on the form of the deposit and to infer from this the genetic type of till. The purpose of this section is to assess the usefulness of such practices in the study area and to suggest criteria based mostly on grain-size distribution and verified from surface forms, which may be applicable equally well to either surface or drill-hole till samples.

Basal till, on the one hand, is mainly derived from subglacial debris and is deposited directly underneath ice. It is commonly compact and massive, and embedded clasts seem to be aligned in some predictable fashion, transverse or parallel to the glacial flow direction. Ablation till, on the other hand, is mainly derived from englacial debris and is deposited from the ice during ice wastage. It is generally remobilized and washed to varying degrees by meltwater (Goldthwait 1971, Dreimanis 1976, Shilts 1976). Consequently, ablation till is expected to be coarser than its associated basal till, and is also likely to be better sorted.

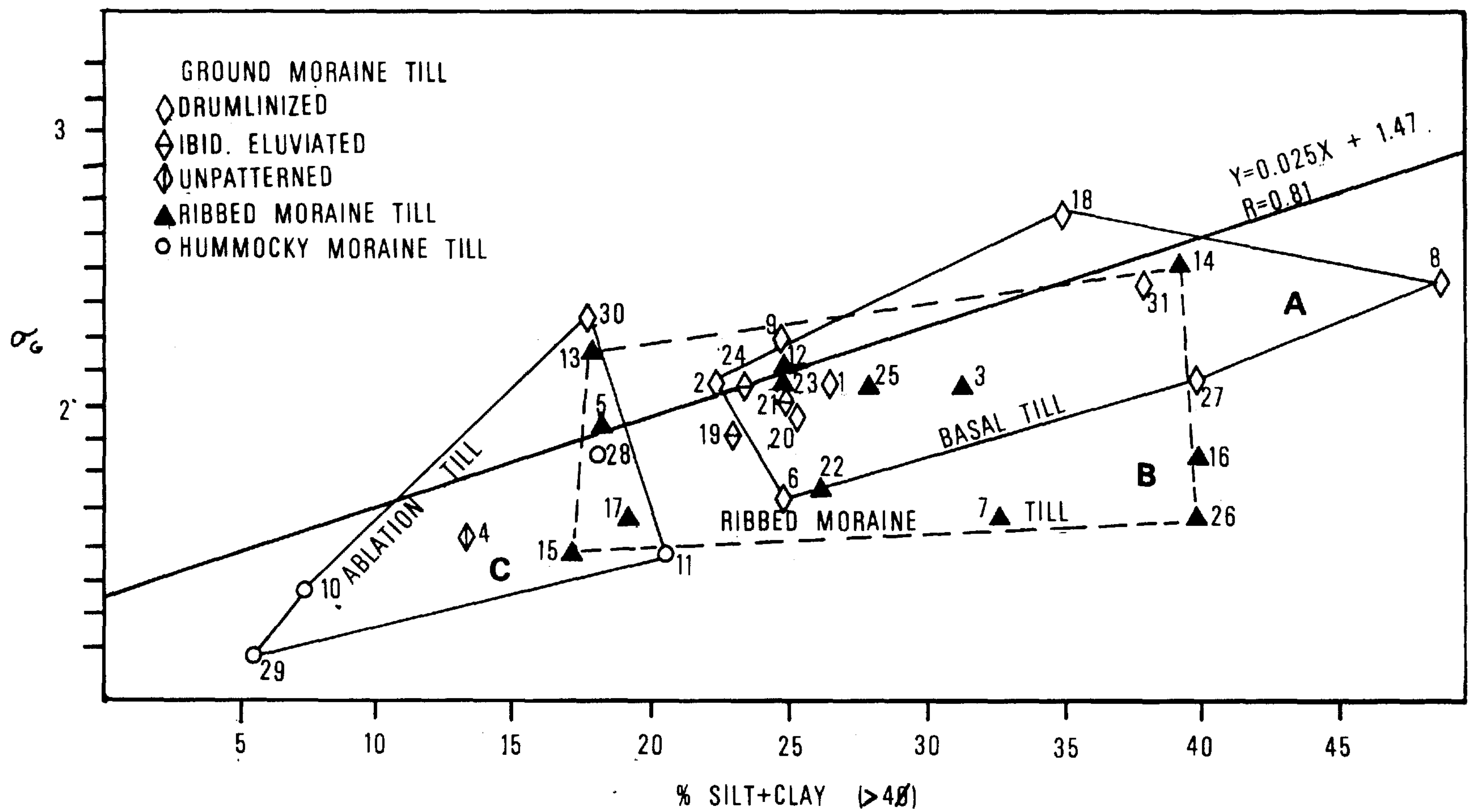



FIGURE 25. DIAGRAM SHOWING THE SORTING ($\sigma_G$) AND THE TOTAL PER CENT CONTENT OF SILT AND CLAY OF THE MATRIX, FOR TILLS SAMPLED IN VARIOUS TYPES OF MORAINIC TERRAINS IN THE TEMISCAMIE AREA. SOLID LINE IS THE REGRESSION LINE CALCULATED FOR THE SAMPLES IN FIELDS A AND C ONLY.

All the till samples, obtained from shallow excavations in various types of morainic terrains in the area, are plotted on a diagram (Fig. 25) which shows the sorting ($\sigma_G$) plotted against the total per cent content of silt and clay (> 4 Ø) of the matrix. On that diagram, according to theoretical considerations, basal till should plot in the upper right corner as opposed to ablation till which should plot in the lower left corner.

The till samples collected from drumlinized and fluted ground moraine (Table 3) are from predominantly compact, massive, and locally fissile sandy till which, as measured at five locations, show well developed preferential orientations of the long axis of clasts trending either parallel or transverse to the glacial flow direction. One sample (No. 30, Table 3) is from a loose bouldery sand till with pockets of sorted material, which has a poorly developed pebble fabric, and overlies compact sandy silt till (No. 31, Table 3). Ignoring the plot of this sample (No. 30 in Fig. 25), till from drumlinized and fluted ground moraine lies within the field identified by the letter A, (Fig. 25) that occupies the upper right hand side of the diagram. Samples from this map unit that were collected from eluviated horizons of the soil plot nevertheless within field A with the exception of one (No. 19) which is just off the better sorted end of the field.

The till samples, one from unpatterned ground moraine (No. 4, Table 3), the others from hummocky moraine (Table 5), together with sample 30 from drumlinized ground moraine, lie within another field (C, Fig. 25) which occupies the lower left hand side of the diagram.

All these samples are from mainly loose, cobbly to bouldery sand till with common inclusions of sorted material.

The tills represented by the samples in fields A and C, are interpreted respectively as basal and ablation tills. Fields A and C lie without overlapping one another along a common axis which is defined by the regression line calculated for the samples enclosed in the two fields (Fig. 25). In summary, basal till in the area is a compact, massive sand to sandy silt till; sorting ($\sigma_G$) of the matrix ranges from 1,65 to 2,80 and the content of fines (silt and clay) varies from 23 to 49%. Ablation till in the area is a loose, cobbly to bouldery sand till; sorting of the matrix ranges from 1,30 to 2,30 and the content of fines varies from 5 to 21%.

The diagram (Fig. 25) shows that the plot of the sorting index against the per cent content of fines is a simple discriminant criterion to distinguish basal from ablation till in the type of area under consideration. In addition, it shows that landforms (map units) are indeed useful guides in identifying till types in the region. And, if landforms are correctly identified, basal till will be found in ground moraine and ablation till in hummocky moraine or as a cover over ground moraine. Once the relationship between sorting index and content of fines has been identified for the surface samples of a particular region, the results can easily be extrapolated to samples taken from drill holes.

The till samples derived from ribbed moraine (Table 4) represent a particular group of tills as their field (B in Fig. 25) is seen overlapping the fields of both ablation and basal tills. This would indicate that ribbed moraine till is really intermediate in grain size between ablation and basal tills and that it is relatively well sorted irrespective of its silt and clay content. It may be that ribbed moraine till is a distinct and particular form of either ablation or basal type till. The nature and origin of this till is discussed in more detail in Chapter 5.

In order to provide a preliminary assessment of the lithological characteristics of the different types of till in the area, the lithology of the 2 to 64 mm size-fraction of tills was analysed at two selected locations (Table 6).

Locations 1 is around Marcil and Ouellette Lakes, 21 km down-ice from and about 100 m lower than the south edge of the subcrop of Indicator Formation composed of quartz sandstone. The underlying bedrock at the sampling site is Archean gneiss; granite and greenstone occur in the intervening area between Lac Ouellette and the edge of Indicator Formation. The results of the analysis show that basal till contains predominantly locally derived clasts ("local" meaning a travel distance of less than 21 km) in contrast to ribbed moraine till and ablation till which contain predominantly Indicator rocks (Table 6). The high proportion of distant lithologies in both the ribbed moraine and ablation tills is interpreted as the result of predominantly englacial transport of the debris from which the two till types were derived. The results also indicate that the clast composition of ribbed moraine till is in great contrast to the predominantly locally derived nature of the boulders which overly the ribbed moraine at this location (section 3.2.2.2, this chapter).

Location 1: Marcil and Ouellette Lakes.

Local bedrock: Archean gneiss.

| Sample | Type | N*[1] | Indicator Fm. % | Greenstone % | Granite and gneiss % | Local (< 20 km ) | Distant (> 20 km) |
|---|---|---|---|---|---|---|---|
| 1 + 2 | Basal | 179 | 37 | 6 | 57 | 57 | 43 |
| 3 | R.M.*[2] | 210 | 70 | 8 | 22 | 22 | 78 |
| 4 | Ablation | 223 | 67 | 12 | 21 | 21 | 79 |

Location 2: Lac Papaskwasati

Local bedrock: Cheno Formation

| Sample | Type | N | Cheno Fm. % | Papaskwasati Fm. % | Archean % | Local (< 8 km) | (< 20 km) | Distant (> 20 km) |
|---|---|---|---|---|---|---|---|---|
| 6+8+9 | Basal | 414 | 28 | 60 | 12 | 28 | 88 | 12 |
| 7 | R.M.*[2] | 169 | 23 | 67 | 10 | 23 | 90 | 10 |
| 10 + 11 | Ablation | 382 | 25 | 73 | 2 | 25 | 98 | 2 |

*[1] number of clast counted.

*[2] ribbed moraine till.

Table 6. Lithology of the 2 to 64 mm fraction of selected samples of till in the study area.

Location 2 is around Lac Papaskwasati in the south west part of the area. There, the underlying bedrock is the Cheno Formation, composed mainly of dark colored quartz sandstone. Location 2 is 20 km down-ice from and about 30 m lower than the south edge of the subcrop of Archean rocks (Fig. 2). Rocks of the Papaskwasati Formation (quartz sandstone) occur in the intervening area between the sampling site and the edge of the Archean rocks. The results of the analysis (Table 6) show that basal till contains a very high proportion of quartz sandstone clasts and close to 30% of the clasts is from the Cheno Formation. Ribbed moraine and ablation till also contain 90% or more of clastic Aphebian rocks. Assuming that all the quartz sandstone is derived from the Papaskwasati Formation and not from the Indicator Formation which lies about 50 to 60 km to the northeast, all till types contain predominantly locally derived clasts ("local" meaning here a travel distance of less than 20 km). This is interpreted as a reflection of the high erodibility and susceptibility to glacial plucking of the rocks of the Papaskwasati Formation resulting in the subglacial as well as the englacial debris to be predominantly composed of quartz sandstone.

## 3.3 Eskers and meltwater channels

### 3.3.1 Eskers

The eskers range from 5 to 22 m in height and about 10 to 75 m in width. The largest and most continuous eskers follow the major valleys (Fig. 24). Practically all of them are the single ridge type, although at places the ridges divide and rejoin enclosing an elongate depression, generally not longer than 75 to 150 m. Heights are variable along the length; no systematic regularity is apparent in these height variations, which amount to as much as 5 m. Although an esker may be mapped along a given valley for more than 30 km, it consists of a series of aligned segments separated by numerous gaps. In upper Takwa valley the longest segment is only 4 km. The crests of the eskers are generally rounded and side slopes are steep.

At two locations, north of Lac Rivon, and at the juction of Papaskwasati and Holton Rivers, triangular-shaped areas, about 3 $km^2$ in extent, show anastomosing patterns of esker ridges. In the field, this type of terrain appears to be very chaotic; the surface is very bouldery. There are numerous closed, steep-sided depressions formed by ridges that diverge and rejoin in a complex manner, and the height of the ridges varies considerably. North of Lac Rivon, the highest surface of this network is an estimated 15 m higher than the top of an esker ridge immediately downstream. Henderson (1959) studied similar esker networks in the vicinity of Shefferville. He suggested that those might have been formed in a zone of fractured, stagnant ice at the margin of the retreating ice sheet, in channels open to the air and fed by water from subglacial tunnels.

In upper Takwa valley, the two sides of the valley, where adjacent to eskers, have steep scarp-like slopes. The top of the scarps are at the same level slightly above the crests of the esker ridges. With these steep slopes the valley may be considered as an "esker valley" (Henderson 1959), 150 to 200 meters wide.

The development of such features is not fully understood but two hypotheses can be postulated. One is that the steep-sided "esker valley" represents an early erosional phase of subglacial water flow, followed by a depositional episode in a smaller tunnel. A second, more likely hypothesis is that the valley may have been occupied by stagnant ice in the late stages of deglaciation; in that situation the valley-side scarps could have been cut by channels open to the air flowing and situated between the ice and the valley sides, while, at the same time, englacial, sub-ice, or ice-walled channels also open to the air but situated in the central part of the valley could have formed the esker.

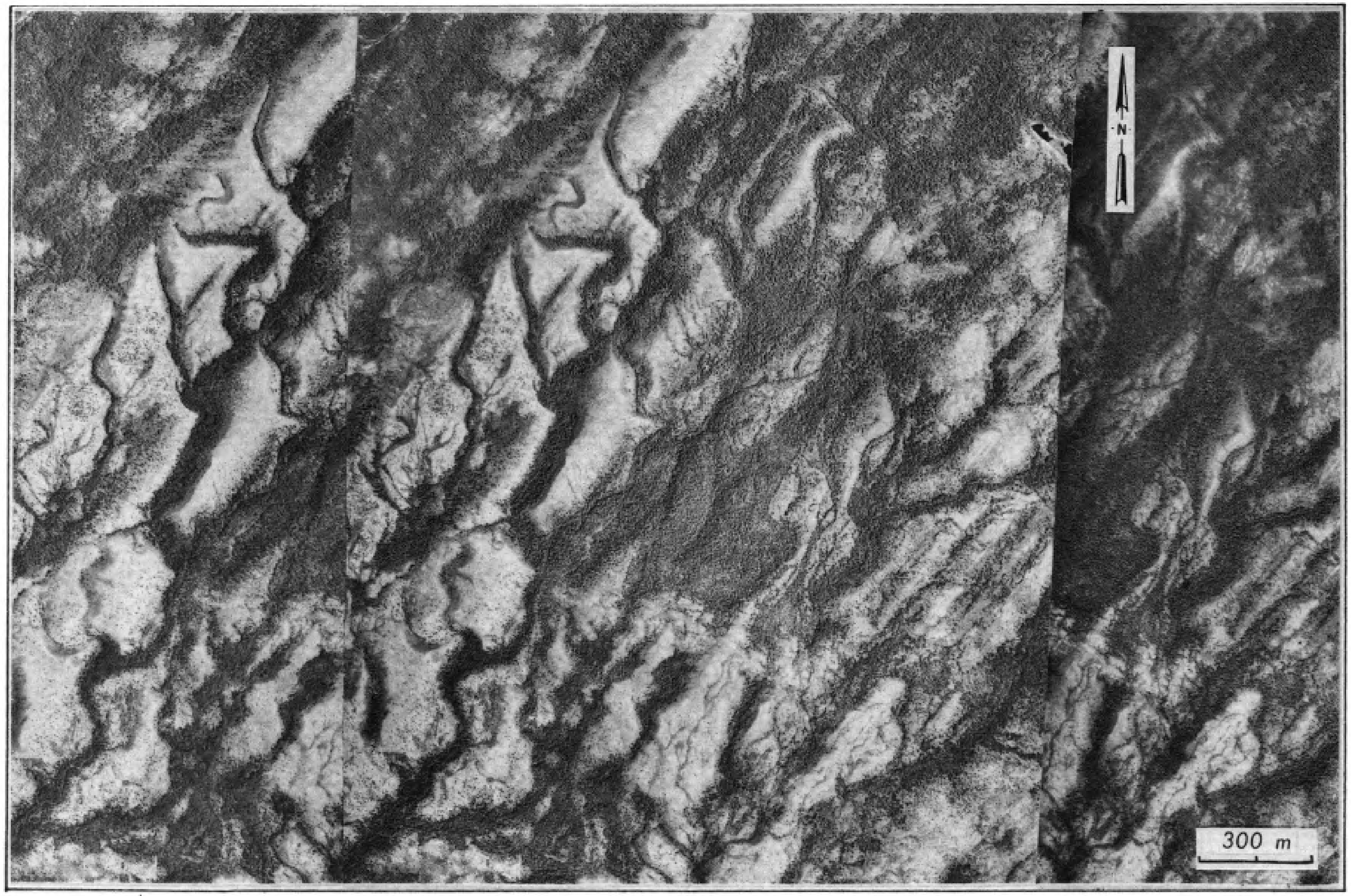
Ice-contact stratified drift in eskers ranges from fine-grained sand to bouldery gravel. Limited observations suggest a tendency for coarser material to occur near the top of sections. In the vicinity of Lac Rivon, ripple-laminated fine-grained sand overlain by fine gravel and pebbly sand was observed in the upper meter of an esker ridge. Near Lake Jules, the upper 2 m of slumped cuts in eskers, 16 m high, show mostly coarse-grained sand and pebble gravel. The stones are well rounded. In Papaskwasati River valley, at Lat. $51^{o}35'$ N, a cut, 10,5 m high, shows 4,0 m of cobble and boulder gravel with faint north-dipping imbrication of the clasts overlying pebble gravel and coarse- and medium-grained sand with numerous cut-and-fill lenses. Minor normal faults with displacements of a few centimeters have affected both units.

### 3.3.2 Meltwater channels

Meltwater channels were not studied in detail and no elaborate attempt was made to classify the various features according to their mode of origin. Nevertheless, three different features are described under this heading. First are channels following contour lines on the side of Takwa Hill. Second are channels which occur in succession parallel to the ice margin and third are channels trending away from the ice margin.

A network of channels occurs on the southwest side of Takwa Hill (Figs. 24 and 26). There, the ground moraine is deeply dissected by the channels which are 65 to 75 m wide, 7 to 10 m deep, with generally steep sides. The channels trend mostly south and southeast. At the northwest end, the intake channels hang above the low land of Cheno valley. At the other end they lead into the valley fill above the mouth of Takwa valley. The channels have winding courses across drumlinoid features and trend obliquely to the present slope of the terrain for some distance and then along the present slope. Parts of the channels have both sides sharply defined, but at places one side is missing. In the northwest, near the intake area, the channels are spaced 120 to more than 250 m apart. Their vertical separation is not known.

The formation of these channels requires that the ice margin stood against the side of the hill. They developed at successively lower positions on the slope as the ice melted. They are equivalent to the "marginal channels" first recognized by Tarr (1909) and

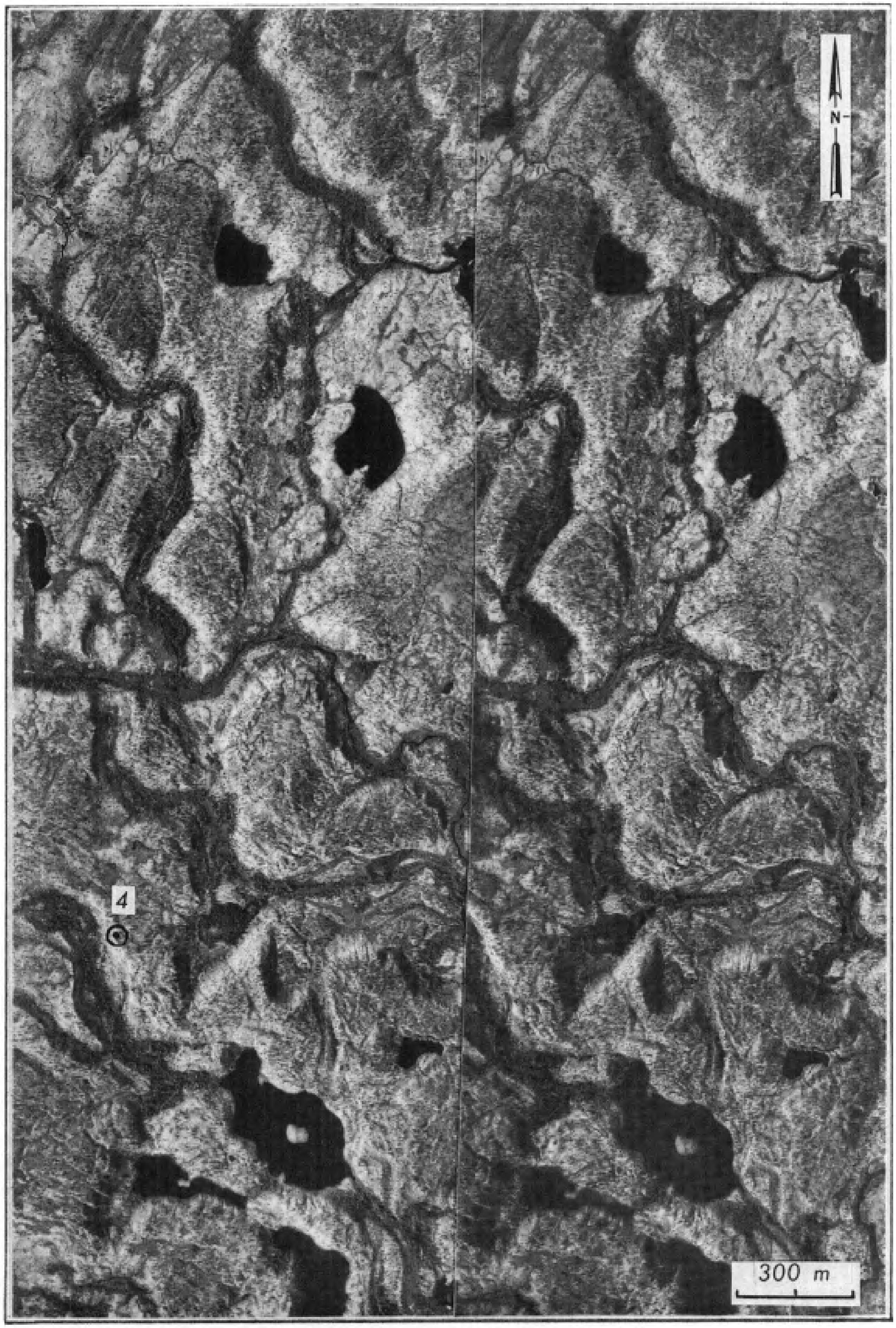

N
300 m

described from Labrador by Derbyshire (1958). It is reasonable to suppose that as Takwa Hill became uncovered by downwasting ice, heat reflection from the rocky slopes would cause more rapid melting of the ice close to the hill, leaving a depression between the ice margin and the slope. Thus, ice-marginal channels would develop along the uncovered slope. It is generally assumed that the ice margin was that of active ice, as fractured or pitted stagnant ice would not act as an impervious wall keeping the channels on the valley side.

The location of the channels on the southwest side of the hill however poses a difficulty in interpretation as that is the lee side. The location of the ice margin, at the time when channels formed, is shown in Figure 37c.

Between Takwa and Témiscamie Rivers, east of Lakes Marcil and Ouellette, a series of prominent flat-floored channels (Fig. 27), 50 to more than 150 m wide, and about 20 m deep, extend northwest-southeast for a maximum of about 3 km and join a valley discharging southward into Témiscamie River. These channels were most likely feeders to the streams that deposited the thick fill deposits in the Témiscamie valley. The trend of the channels is roughly parallel to the local slope gradient, but is also transverse to the glacial flow direction. The series of channels extend for nearly 7 km northeast-southwest and their spacing ranges from 200 to more than 800 m. The floor of some of them extend into basins now occupied by elongate lakes. The north-facing sides are consistently sharp,

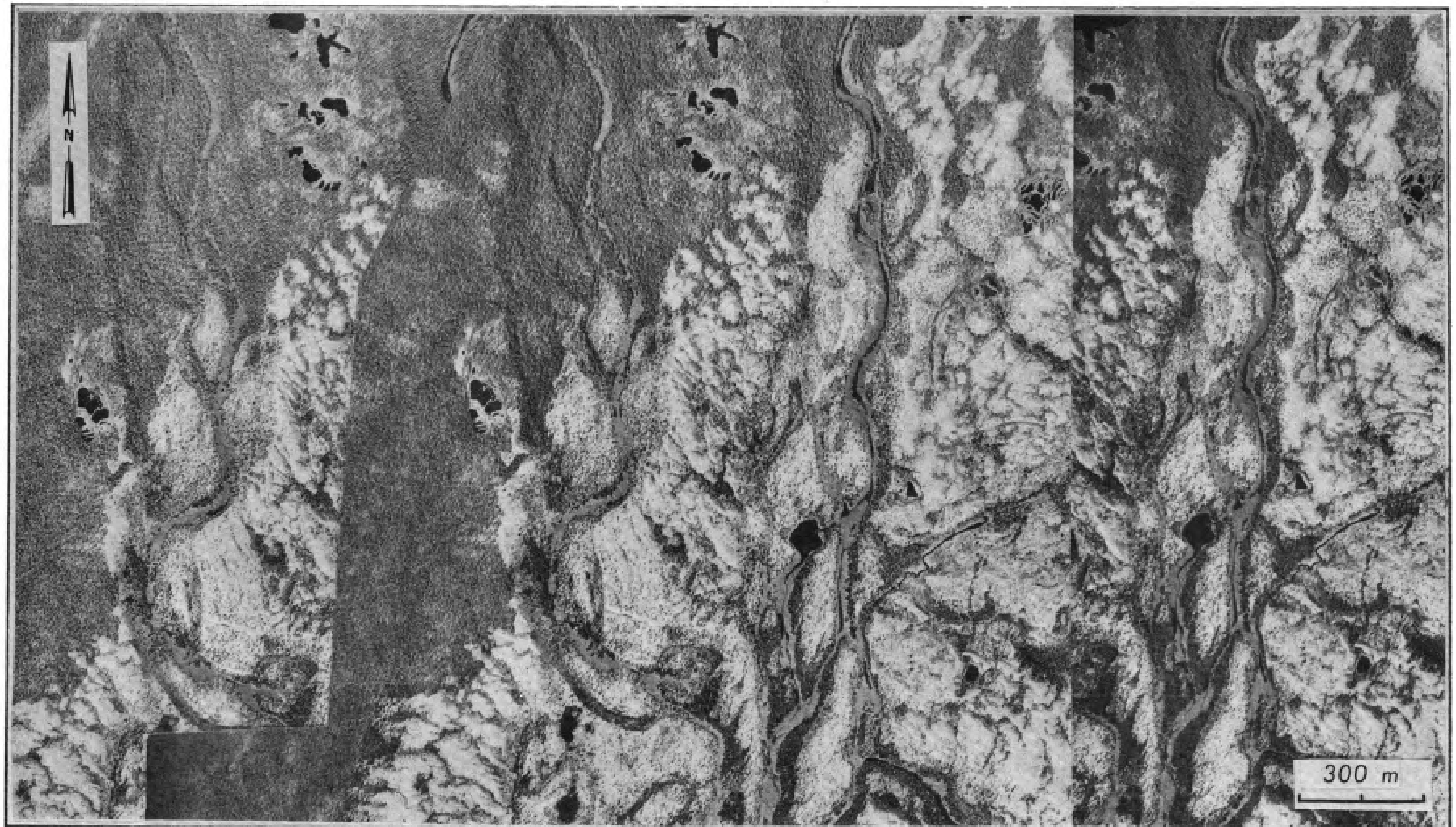
Figure 27. Stereogram showing meltwater channels northeast of Lac Ouellette. Note the channel leading in and out of a lake in the south part of the area shown. Number is till sample


N
4
300 m

and are marked by very steep slopes, whereas the south-facing slopes are often irregular and gentler. It is suggested that these channels were formed successively from south to north, at or near the ice margin, perhaps associated with belts of stagnant ice parallel to the ice margin. Two or more could have formed at any one time. A comparable succession of smaller channels is found on the west side of Neilson River valley, in the west part of the area (Fig. 24).

Larger channels in the northeast part of the area (Figs 24, and 28) link up with the heads of the Kapaquatche, Toqueco, and Takwa River valleys. Others are found to the east. The channels are as wide as 400 m and 26 m deep. They have flat floors occupied by braided streams, and sharply defined steep sides. Terrace remnants occur at places in these channels. In the channel north of Takwa River, terraces occur at four different levels; 8,5, 11,0, 16,0 and 18,5 m above the valley floor. At least one of the terrace levels can be traced on both sides of the valley. The origin of the channels is not known. It is unlikely that they are segments of subglacial tunnels (the Nye channels of Weertman 1972) because they are about 20 times as wide as eskers to the south. Equally, it is unlikely that they were formed on ice stagnating in the valley, with subaerial channels cutting the sides and leaving kame terraces, since the terraces are quite level, and some are paired. The shape, size, and location of these features suggest rather that they were formed as spillways of a lake that was situated just north of the

Figure 28. Stereogram showing spillways at the head of Takwa River valley. Note that the channels cut minor morainic ridges in the southwest part of the area shown. The morainic ridges are part of the minor moraine of Lac à l'Huile (see Fig. 20)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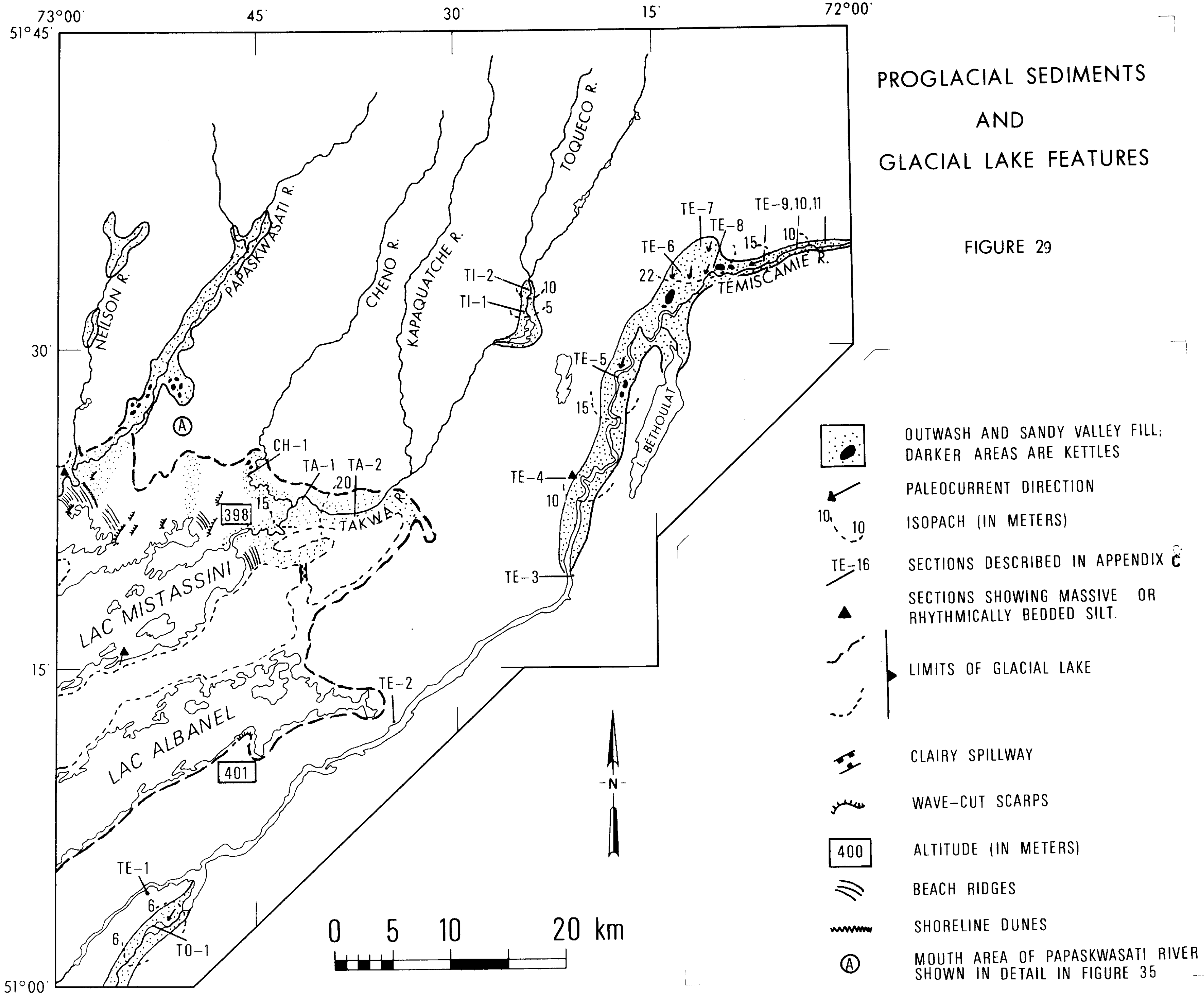



PROGLACIAL SEDIMENTS AND GLACIAL LAKE FEATURES

FIGURE 29

study area. There, ice retreating across Hippocampe Plateau would have uncovered first a terrain sloping up-glacier and a proglacial lake could have easily been formed on parts of the Plateau, discharging southward into the Témiscamie area. The terraces in the spillways could have formed as a result of changes in the local base level in the main valleys of the Témiscamie area due to the effect of stagnating ice there. Confirmation of these ideas requires more information on the region north of the Témiscamie area.

## 3.4 Glacial lake features and proglacial sediments

Strandlines associated with a glacial lake in the basins of Lakes Mistassini and Albanel are described first. Proglacial sediments, including those deposited in the flooded valley mouths, are described further on.

### 3.4.1 Strandlines

Strandlines comprising wave-cut scarps, beach ridges and shoreline dunes are found mainly around the northeast shore of Lac Mistassini (Fig. 29) and at only one occurrence along the shore of Lac Albanel. Following a detailed description of each of the individual strandline types, some comments are made on the absence of similar features elsewhere around the north ends of Lakes Mistassini and Albanel.

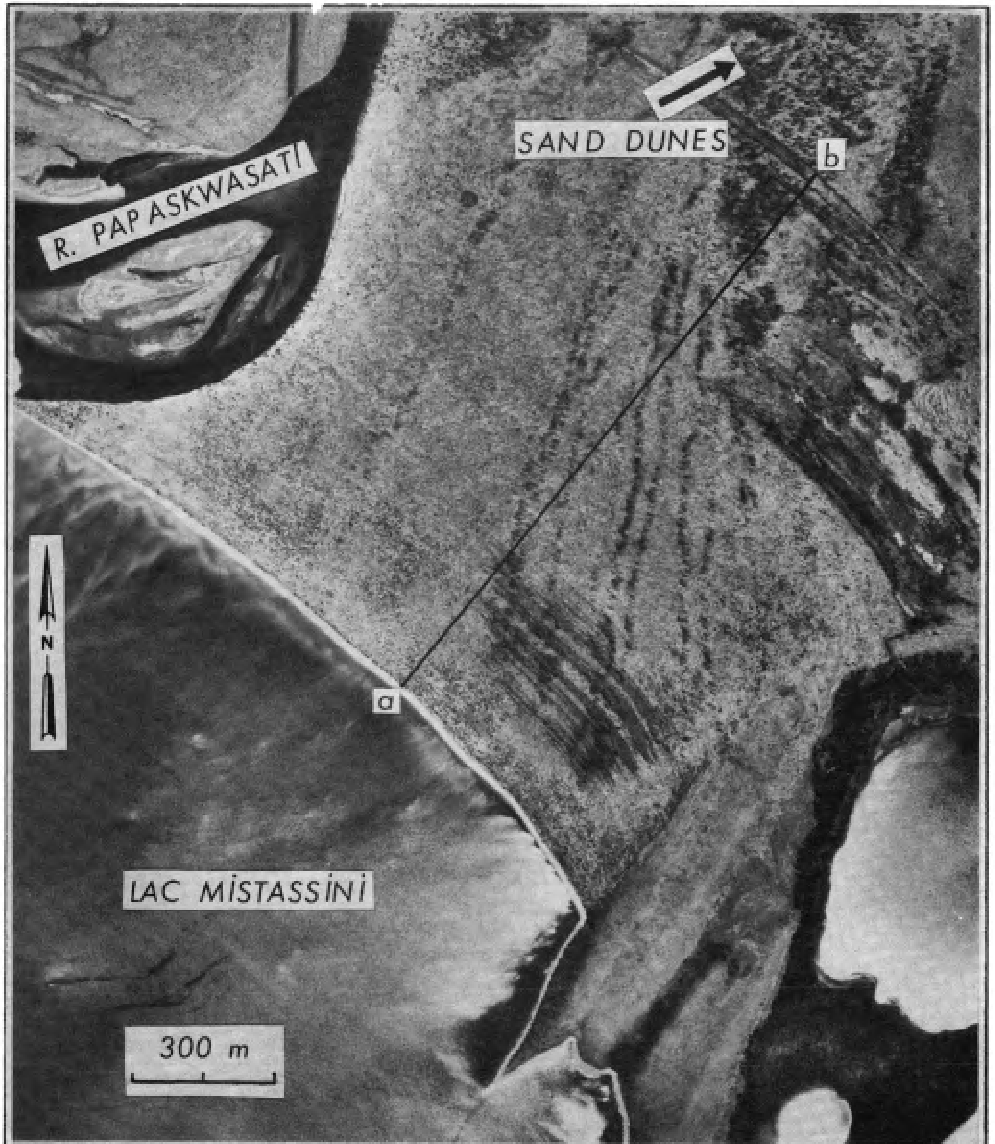
Wave-cut scarps are erosional features cut on the sides of drumlins or till hills, within about 7 km from the northern shore of Lac Mistassini (Fig. 30). The scarps range in height from 1 to 3 m. No berms or benches are well developed below the steep scarp

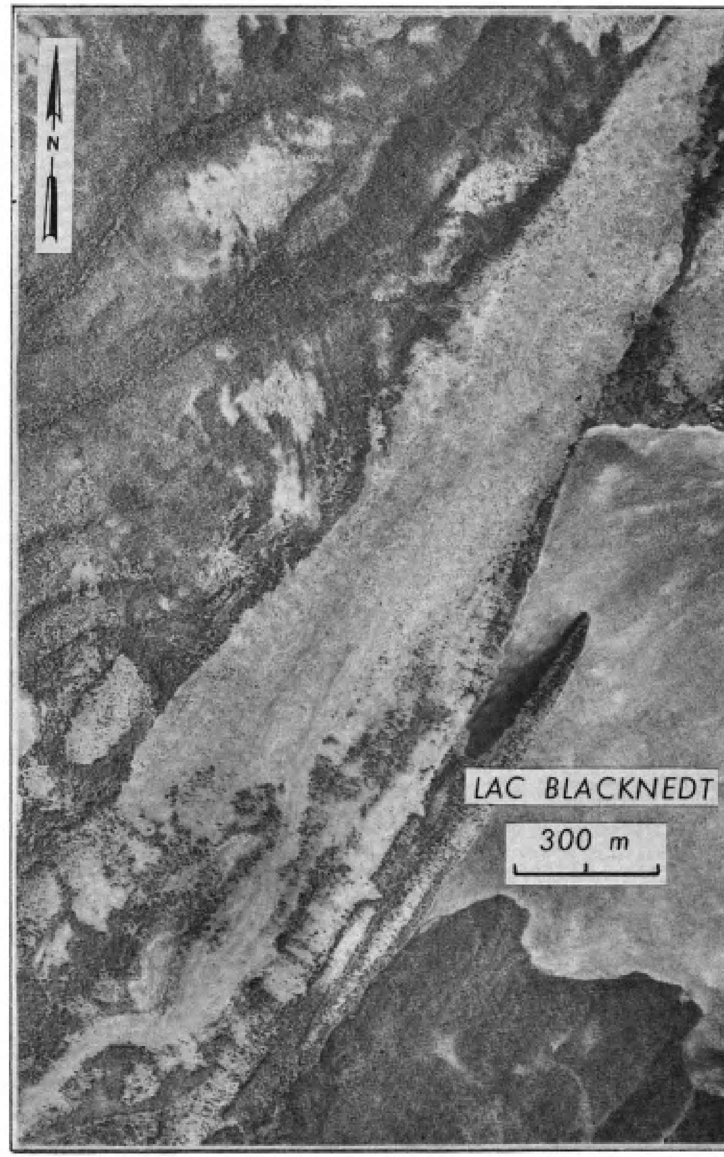
Figure 30. Aerial photographs showing strandlines around the northeast shore of Lac Mistassini.

A) beach ridges and shoreline dunes;

line a-b is a surveyed profile of beach ridges shown in Figure 31;

B) wave-cut scarps on a drumlinoid ridge.


R. PAPASKWASATI
SAND DUNES
b
a
N
LAC MISTASSINI
300 m


N
LAC BLACKNEDT
300 m

faces. The scarps occur consistently on the west or south sides of the hills suggesting wave erosion on the shore of a former deeper water body in which winds from the southwest generated waves of great energy.

The wave-cut scarps are the highest strandlines in the Témiscamie area, ranging up to 398 m altitude. Their elevations were measured in the field, using a Brunton compass as a level and the present level (375 m) of Lac Mistassini as the datum. The precision of measurements is estimated to be ± 3 m. The altitude of 398 m (±3 m) is considered to be the highest water level of a glacial lake in the north part of the Lac Mistassini basin.

Wahl (1953) reported a "wave-cut terrace" on the southeast shore of Lac Albanel. This feature is on the east shore of Baie du Canso, at Lat. 51°10' N, about 12 m above the present water level of 389 m. The resulting altitude of 401 m (± 3 m) is considered to be the highest glacial-lake level in the north part of the Lac Albanel basin.

Beach ridges are small constructional features particularly well developed on the surface of the sandy proglacial sediments near the mouth of the Papaskwasati and Takwa Rivers. The ridges are conspicuous on aerial photographs (Fig. 30) but in the field some of them are barely discernible. The majority of them cannot be followed laterally for more than a few tens of meters. They occur in series, more or less well developed at different locations, between the present lake level and a maximum altitude of approximately 390 m.

A transverse profile of a continuous series of ridges, located at the mouth of the Papaskwasati River, was surveyed from the lake shore to a point 1,6 km inland (Fig. 31). The surface over which the ridges are developed slopes gently toward the lake with a uniform gradient of 0.008 ($0.45^o$).

A total of 58 ridges were traversed to a maximum altitude of 387 m. The traverse ends at a scarp about 2 m high beyond which shoreline dunes are found. The ridges are composed predominantly of sand, with sparse pockets of fine gravel. The profile (Fig. 31) shows berms as well as the ridges and swales. The berms are flat steps, about 10 to 15 m wide, extending lakeward from the base of ridges, they are uncommon features as only three occur in the profile. They are quite analogous to, though narrower than, the modern nearly-flat beach surface in this part of Lac Mistassini. Inter-ridge swales are particularly apparent on aerial photographs (Fig. 30) where dense vegetation on them enhances a marked tonal contrast.

Heights of the ridges, measured from the foot of the lakeward slopes to the crests, range from 15 to 190 cm, with the majority of the ridges being between 30 and 40 cm high. Widths, measured from the base of the lakeward and landward slopes of each ridge, range from 8 to slightly over 100 m, with most being 15 to 25 m wide. For the purpose of simple comparison of the size of the various ridges a so-called volume index has been defined for them. This index is obtained by multiplying the height of a ridge by its width

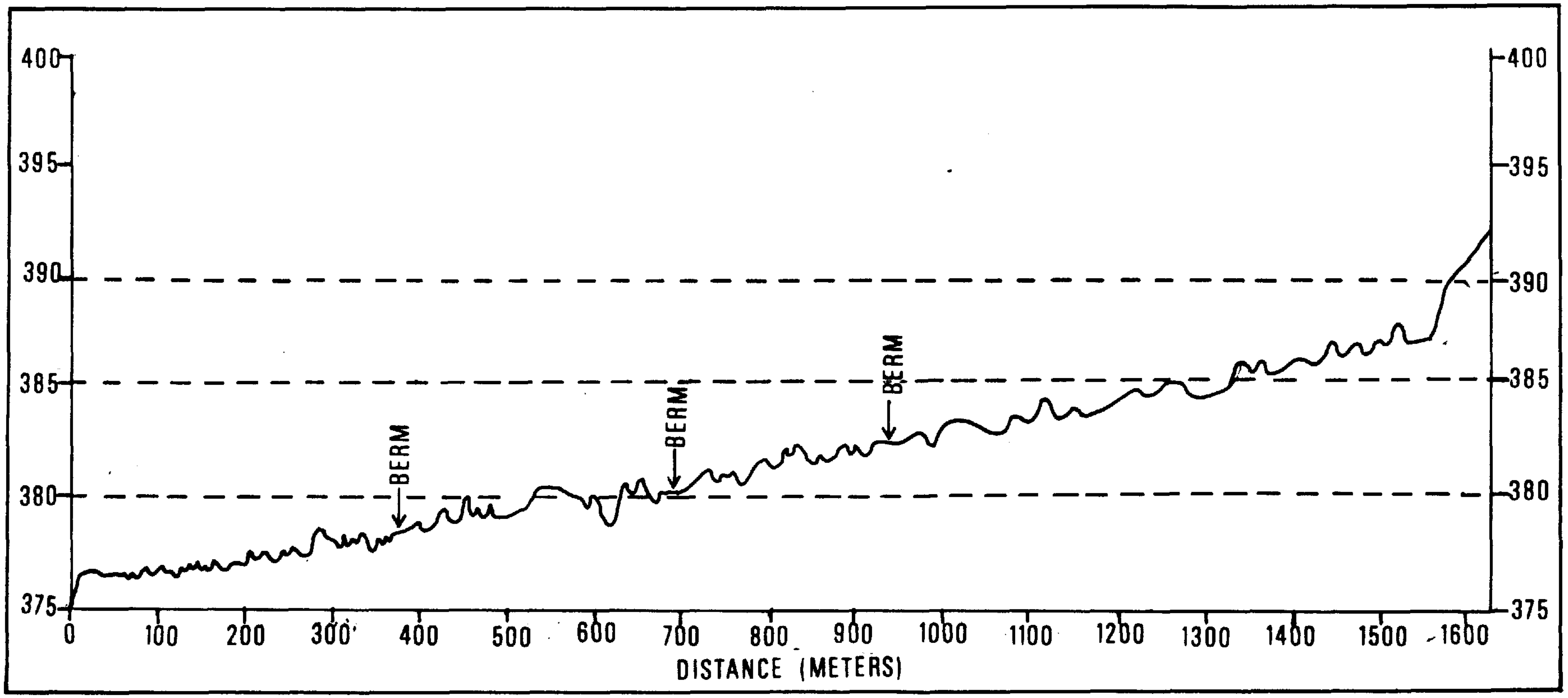



FIGURE 31. SURVEYED PROFILE ACCROSS A SUCCESSION OF BEACH RIDGES, MOUTH OF PAPASKWASATI RIVER. SEE FIG. 30a FOR LOCATION OF PROFILE. DATUM IS LAC MISTASSINI WATER LEVEL (AUGUST 1975) TAKEN AS 375m ALTITUDE.

as measured along the transverse profile and taking that value for the unit distance of one meter in the third direction, perpendicular to the profile. Even though the resulting values are not precise calculations of the true volume of the ridges, they may still be used to quantify the differences in size among them. In fact, the indices show a large variation from about 1 $m^3$ to over 80 $m^3$. There is a general tendency for ridges at higher altitudes to be larger than those found at lower positions. Spacing, measured from crest to crest, varies from 8 to 75 meters, with most crests being between 11 to 20 meters apart. Vertical spacing, as expressed by the number of ridges per unit interval of altitude, varies systematically with elevation from lower values at higher elevation and vice versa, (Fig. 32) indicating that the lower ridges are more closely spaced. The best-fit curve shown in Figure 31 is in the form $A = Ce^{-KN}$, where A = altitude, N = number of ridges per unit of altitude, C = 389.1, and K = 0.18. Since the surface over which the ridges are developed has a uniform gradient, the shape of the curve indicates either a progressive decrease in the recurrence interval for the formation of each ridge or else a decrease in the rate of lowering of the water level, or a combination of both. The curve (Fig. 32) is very similar to uplift curves of northern Canada (Andrews 1968) but with different parameters.

The ridges are interpreted as storm beach ridges, based on the observation of the present-day shore morphology in this part of Lac Mistassini (Fig. 33). The modern shore in the area of the mouth

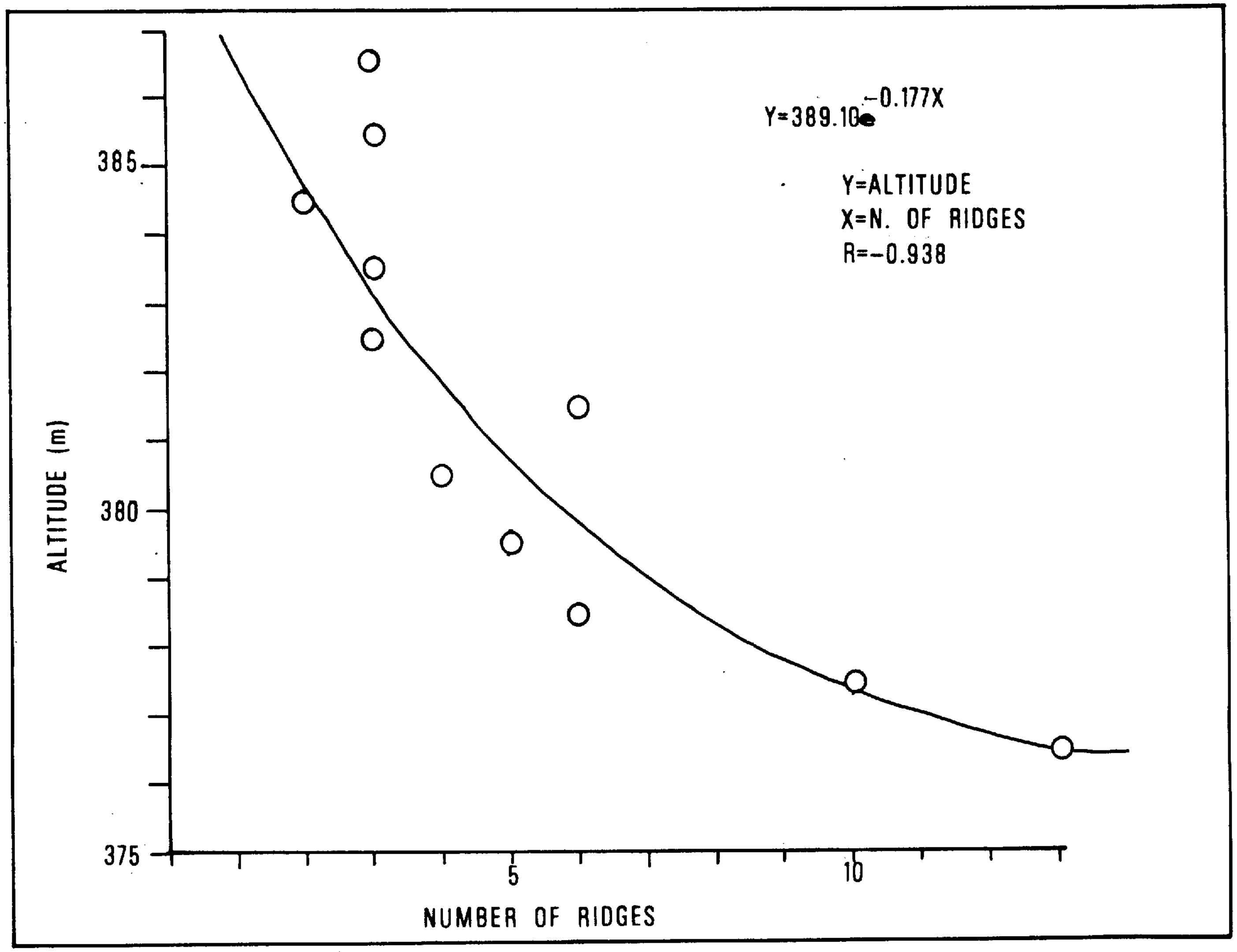



FIGURE **32**. DIAGRAM SHOWING THE NUMBER OF BEACH RIDGES PER UNIT METER OF ALTITUDE. THE BEST-FIT CURVE IS SIMILAR TO UPLIFT CURVES OF NORTHERN CANADA (ANDREWS 1968) BUT WITH DIFFERENT PARAMETERS.

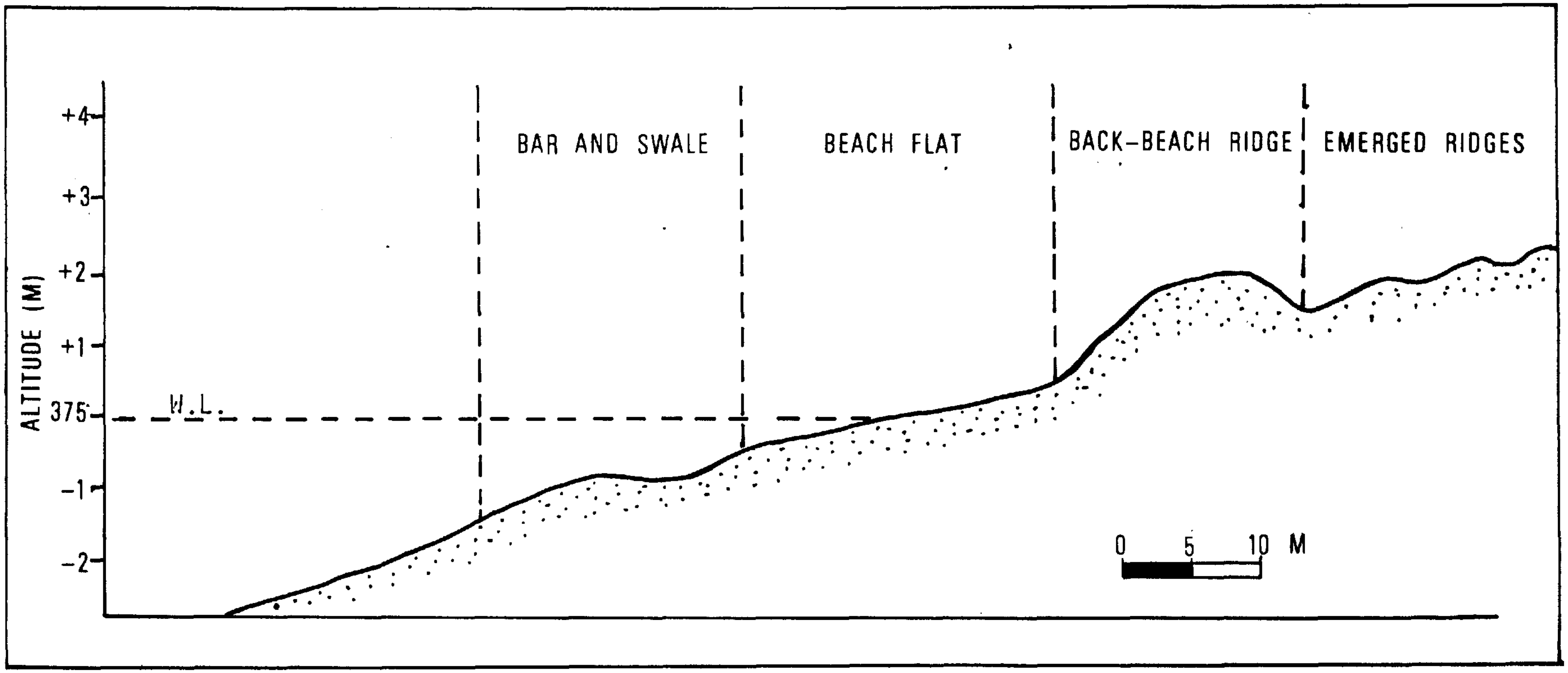



FIGURE 33. IDEALIZED DIAGRAM SHOWING THE PRESENT-DAY SHORE MORPHOLOGY AROUND LAC MISTASSINI, MOUTH OF PAPASKWASATI RIVER.

of the Papaskwasati River is a gently sloping sandy beach surface, about 20 to 25 m wide, bordered landward by a back-beach ridge partly covered by vegetation. Below the late summer water level, a bar, separated from the shoreline by a swale, may be noted in front of the beach (see Fig. 30a).

The back-beach ridge is higher and wider than most of the emerged ridges (ca. 39 $m^3$). The foot of its lakeward slope is approximately 1 m above the August (1975) water level. The mean of present annual amplitude of fluctuation of water level in Lac Mistassini is about 1,2 m (Table 7) with the highest level occurring in late summer months. The back-beach ridge is, therefore, formed about one meter above the annual high water level of that season (1975) and above the highest level for the 26 years on record. From that, it is deduced that the back-beach ridge was built by exceptionally high water levels, most likely related to storm events involving strong and persistent winds from the southwest.

The submerged bar and swale couple has some similarity with features described as "low and ball" elsewhere, notably by Evens (1940) around Lake Michigan. There, according to Evans (1940), these features are associated with the breaking point(s) of the incoming waves. They are always formed below a sandy beach, and generally occur in sets of 3 or 4. In Lac Mistassini, only one set is observed below the sandy beach. The bar is estimated to be about 16 to 20 m wide, a width that is comparable to that of one of the smaller emerged ridges. The swale is 20 to 35 meters wide.

| YEAR | FLUCTUATION (M) | MONTH OF HIGH | MONTH OF LOW |
|---|---|---|---|
| 1974-72 | 1.17 | August | March |
| 1973-74 | 1.80 | July | May |
| 1973 | 1.44 | July | May |
| 1972 | 0.83 | July | May |
| 1971 | 0.76 | October | February |
| 1970 | 0.86 | June | December |
| 1969 | 1.09 | - | - * |
| 1968 | 1.13 | - | - * |
| 1967 | 1.14 | August | April |
| 1966 | 1.48 | August | March |
| [illegible] | | | |
| 1963 | 1.03 | August | April |
| 1962 | 1.07 | June | April |
| 1961 | 0.78 | July | April |
| 1960 | 0.99 | August | April |
| 1959 | 1.20 | July | May |
| 1958 | 1.44 | July | April |
| 1957 | 1.57 | July | April |
| 1956 | 1.68 | October | May |
| 1955 | 1.16 | June | April |
| 1954 | 1.10 | June | April |
| 1953 | 0.93 | July | March |
| 1952 | 1.38 | September | April |
| 1951 | 0.90 | June | April |
| 1950 | 1.66 | July | April |
| 1949 | 0.63 | - | - * |

Maximum yearly fluctuation: 1.80 meter (1973-1974)

Maximum in 20 year (1949-1970): 1.98 meter with highest July 1950
and lowest April 1963

* few data only

Source : Annuaires Hydrologiques du Québec,
Ministère des Richesses Naturelles, Québec.

Table 7. Amplitude of annual water level fluctuations in Lac Mistassini since 1949; water level measured at Baie-du-Poste.

Because these features are subaqueous, they would require a rapid rate of lowering of water level in order to be preserved during emergence, otherwise they would likely be reworked, and consequently destroyed by wave action.

Other ridge-like features presently visible along the north shore of Lac Mistassini are subaqueous ripples. These are developed below sandy beaches, in heads of narrow bays. The features are about 1 m high, approximately 10 to 20 m apart, they commonly branch out laterally, and may occur in a series of 8 or 9 at any one location. Since their geometry, location, and size do not compare with the emerged ridges, they are not considered to be modern analogs of them. Furthermore, similarly to bars and swales, they are unlikely to be preserved during emergence.

The irregular relief of the emerged beach ridges might be attributed to some syn- or post-depositional processes associated with winds or perhaps floating lake-ice. On windy days, some of the sand in the present-day back-beach ridge may be seen to deflate away. However, no dune-like landforms were observed in the main area of the ridges, so that wind reworking may be considered inconsequential on a large scale. The action of floating lake-ice during spring and early summer is believed to be an active shore process around Lac Mistassini and Lac Albanel, at least in terms of boulders being rafted and redistributed along the shoreline (Laverdière and Guimont 1977b). However, no traces of grooving, scouring, or of ice-shove ridges were observed on the present beach in July or August. These phenomena, which are formed in late spring time, are probably not preserved throughout the year.

The variable size of the emerged ridges must be due to variable intensity and duration of storm events. It is suggested here that the ridges were abandoned at an exponentially decreasing rate, suggestive of a rate of differential post-glacial rebound. The larger size of the present back-beach ridge indicates that the present water level may have been attained long ago.

Shoreline dunes are associated with and are at higher altitudes than the beach ridges near Papaskwasati River (Fig. 30) and form chains of coalesced parabolic dunes (David 1977). All the dunes are now stabilized by vegetation.

Three dune chains are present, spaced a few hundred meters apart, between about 389 and 392 m altitude. Those at higher altitudes are not continuous for more than a couple of hundred meters, they have subdued forms with a relief of 1,5 to 2 m, and the parabolic shape of the individual dunes is not well developed. One of them merges into tracts of string bogs. The third lowest dune chain has the best eolian landforms. In that chain, the individual parabolic dunes are concave to the southwest, and have a strong curvature. The transverse width of each dune does not exceed about 20 m. Length is in the order of 25 m with a maximum of about 150 m. Height of the dunes may reach 5 m in their apical zones, with steep frontal slopes facing northeast. This dune chain can be followed for more than 3 km laterally, and the chain has a low sinuosity.

The dunes are interpreted as having resulted from wind action on the shore of the former higher level lake that occupied Lac Mistassini basin. The wings point in the direction of greatest fetch in the north part of modern Lac Mistassini. Maximum horizontal landward displacement of sand was approximately 150 m. The parabolic shape suggests that the features developed under the stabilizing effect of abundant soil moisture (David 1978). Dune chains are found only in the higher zone of emerged strandlines suggesting that an active sand source, essential for their development, existed only in early post-glacial time. The active sand source may have been a wide sandy beach, produced by a high rate of lowering of the water level.

The absence of strandlines elsewhere on the shore of Lac Albanel and Lac Mistassini is a striking phenomenon. It is best explained by examining the processes which produce shoreline features. The formation of strandlines is a result of a combination of a number of factors, notably the size and shape of the lake, its orientation in respect to the winds, and, finally, the nature of the material at the coastline. Lac Mistassini, as well as Lac Albanel, is a long but narrow expanse of water (Fig. 34). The maximum width of Lac Mistassini is about 20 km. However, because it is separated along its length by an almost continuous series of elongate islands which link up with long peninsulas projecting from the land, the maximum effective width, that is, the maximum transverse length of continuous open water , is only about 10 km. In comparison, Lac Albanel has a maximum width of only 5 km.

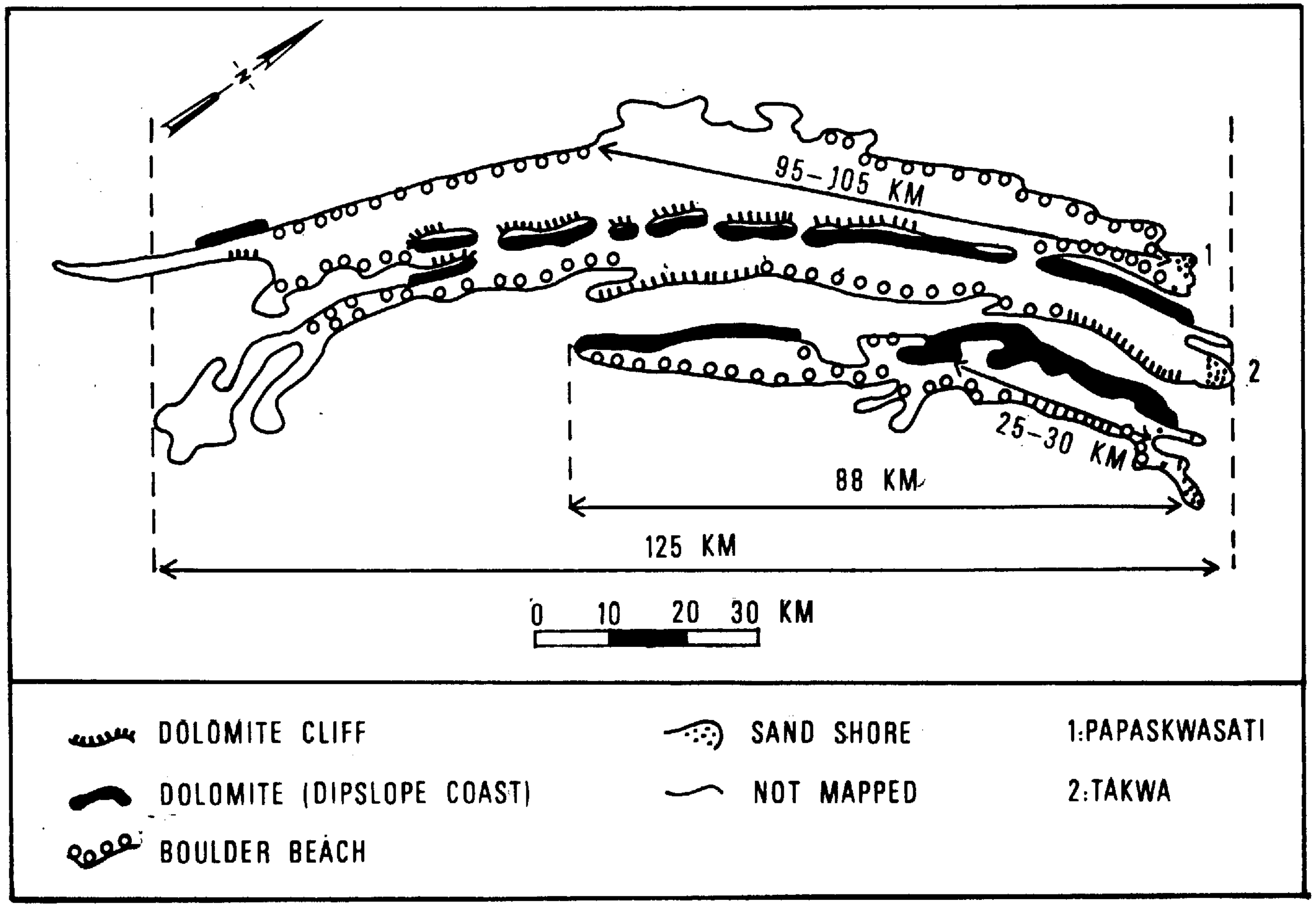



FIGURE 34. LENGHT OF FETCH AND TYPE OF COASTLINE AROUND LAC MISTASSINI AND LAC ALBANEL. COASTLINE TYPES ARE FROM LAVERDIERE AND GUIMONT (1977).

The overall length of Lac Mistassini is slightly more than 120 km. Because it is curved, the longest straight line that can be fitted within its perimeter is 95 to 105 km long and joins a point in the southwest, south of the Rupert outlet to a point in the northeast near the mouth of the Papaskwasati River. In the eastern part of Lac Mistassini, east of the dividing islands and peninsulas, the longest fetch is 85 km and points north to the mouth of the Takwa River. In comparison, the northern extremity of Lac Albanel is exposed to a maximum fetch of only about 25 to 30 km from a southwest direction. Consequently, from the simple criteria of exposure and wind fetch in the two lakes, the area of the mouth of the Papaskwasati River is the only expectable region where wave action should be powerful. However, data for the wind regime of the area (Chap. 2) indicates that southwest winds are not the most frequent winds and occur for only about 10% of the time. Nevertheless, Rogers (1963) in his ethnographic account among the Crees of the Lac Mistassini area, concludes from both personal experience and reports from local inhabitants, that southwesterly winds do predominate during the summer months.

A considerable part of the shore of Lakes Mistassini and Albanel are formed either by dolomite cliffs (cuesta front) or platforms (cuesta dipslope) which accounts for the very irregular shoreline on the west side of Lac Albanel. The other equally common type of material forming the coastlines is coarse morainic sediments (Fig. 34). Only a small portion of the coastline in the northern ends of the lakes. is developed on sandy deposits conducive to beach formation.

On the present coasts which developed in morainic material, the shore is characterized by a narrow boulder beach. No raised equivalent of this beach type was noted anywhere along the lakes, suggesting that water level did not stabilize at any given altitude for any considerable length of time to permit the development of such beach types. On the coasts where dolomite outcrops, very little wave erosion is to be expected. However, in some parts of Lac Mistassini, and at a few places along the Témiscamie River, dissolution cavities along dolomite outcrops were observed at the water level or slightly above it. The cavities are small, 4 to 7 cm deep, 14 to 18 cm long, and 10 to 14 cm wide, and most of them appear to have developed along bedding planes or joints enlarged by dissolution (Fig. 35). A few other cavities developed along intra-bed inhomogeneities associated with stromatolitic structures (Fig. 35) while still others appeared to be unrelated to any particular structure in the rock. At first it was thought that solution features might prove to be useful criteria for identifying former water levels on higher parts of the dolomite cliffs and, consequently, a search for similar features was undertaken at one location on the southeast shore of Lac Mistassini. The cliff face examined is 10 m high and, thus is entirely below the maximum glacial water level. Other faces at higher elevation were only cursorily examined. Numerous solution features were found at all levels of the exposure. At one site, even a patch of glacial-lake silt, massive, composed of 71,3% silt and 11,4% of clay, was found below the cliff and 2 m above present water level. Even so, the findings

Figure 35. Dissolution cavities about 1 m above present water level, shore of Lac Mistassini. Nuphar sp., for scale, are about 25 cm in diameter.

were inconclusive because of several complicating factors. Firstly, none of the features located were of sizes comparable to those noted near the present water level. Secondly, the level of carbon dioxide concentration in the air, measured along the cliff at that location and found to be 1,2 mg/l, indicates that runoff and seepage together appear to be sufficiently capable of producing the bedding plane and joint enlargement by dissolution (C. Ek, pers comm.) so that any one of these features may have developed in quite recent times. Nevertheless, a more detailed systematic search for similar features in a larger area might prove to be one way of locating former water levels along the cliffy shores of Lakes Mistassini and Albanel.

### 3.4.2 Proglacial sediments

Proglacial sediments are described systematically from south to north and from west to east in successive valleys. Representative sections are numbered with two letters and a number. The letters identify the valleys while the numbers designate the individual sections in a particular valley. The sections are numbered in increasing order from the mouth upstream. The sections are described in Appendix C.

#### Papaskwasati valley

The proglacial sediments form a valley fill that extends from the mouth of the valley to a point about 30 km upstream (Fig. 29). The width of the fill varies from more than 2 km in the mouth area to about 200 m in a narrow section of the valley west of Lac

Papaskwasati and increases again to nearly 2 km further upstream. The lower 10 km of the valley is shown on a detailed map in figure 36. The maximum thickness of the fill exposed above river level is 22 m. An esker ridge extends down the valley to a point about 5 km upstream from the mouth. The esker cannot be traced further downstream but it probably continues, buried beneath the valley-fill sediments, as suggested by a chain of kettles on the west bank of the river.

The surface of the valley fill lies between 392 and 394 m elevation and has a very low downstream gradient of about 0.0002. Extensive bogs have formed on this gently-inclined surface of the fill (Fig. 36). The low gradient extends down valley to about 1,5 km from the mouth where the slope becomes steeper (0.008) and leads all the way down to present water level of Lac Mistassini. The beach ridge sequence,discussed earlier, is developed over that steeper surface (Fig. 31), while the shoreline dunes are developed at the junction of the two slopes.

Kettles which may reach 25 to 30 m in diameter and as much as 3 to 5 m in depth, are numerous only in a zone extending from about 8 to 13 km from the mouth. In this zone, there are patches of hummocky moraine on both sides of the valley (Fig. 24). The sections situated along the axis of the valley show a sequence of sediments coarsening both upward and upstream, ranging from rhythmically bedded (PA-2) silts to thinly bedded silt and fine sand (PA-5 and PA-6). Upstream, this sequence grades further into coarser sediments which are mainly stratified medium- and

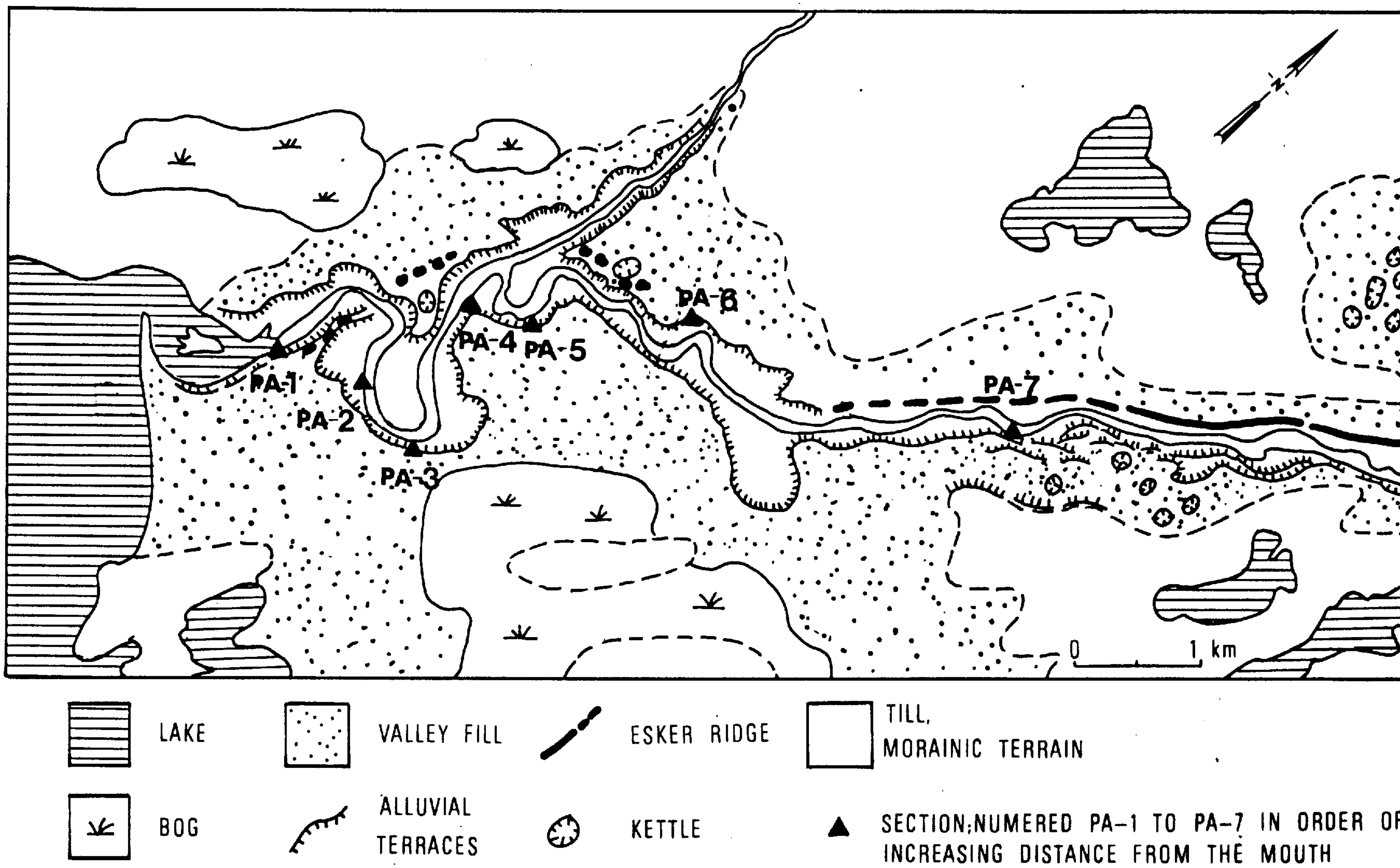



FIGURE 36. MAP OF VALLEY FILL, MOUTH AREA OF PAPASKWASATI RIVER.

coarse-grained sands. In section PA-7, a layer of very poorly sorted silty gravel, 1,0 m thick, is interbedded with the well sorted medium- to coarse-grained outwash. This section is in the narrow part of the valley where the stratified sediments occur adjacent to hummocky moraine and their surface is pitted with kettles. The layer of gravel is presumed to have accumulated when debris from the melting stagnant ice slumped into the valley where it became interbedded with outwash.

The stratigraphic sequence in the valley, downstream from section PA-7, is interpreted as an offlapping deltaic sequence which formed as a result of shoaling in the flooded mouth of the valley. Based on the maximum altitude of strandlines in the vicinity of the valley, the depths at which the sediments were deposited, changed from 23 to 6 m. The presence of laminated silt as well as the relative fineness of the deltaic sediments suggest that at the time when they accumulated the glacier margin must have been some distance up the valley beyond the limit of Figure 36. The coarser load of the proglacial streams was deposited closer to the glacier partly on stagnant ice as suggested by the numerous kettles in the vicinity of section PA-7. Further up the Papaskwasati valley, proglacial sediments accumulated as outwash which is mainly cross-bedded medium sand with layers of fine gravel.

### Takwa-Cheno valleys

Examination of few exposures near the mouth of Takwa River suggest that a deltaic valley fill similar to that described in

Papaskwasati valley was also formed in this valley. The deltaic accumulation is a minimum of 20 m in thickness and the main mass of the deltaic sediments is found between the confluence of the Cheno River upstream to a point about 11 km from the mouth. Rhythmically bedded silts were not observed and the sediments range from stratified very fine sand and silt to cross-bedded fine grained sand and silt to cross-bedded fine and medium grained sand.

Along the Cheno River, the valley fill extends north to a point just west of Lac Brideau. Its maximum thickness above river level is 10 m. At section CH-1 (Fig. 29), fine-grained sand, 6 m thick, occurs in foreset beds inclined at 25 degrees southeast, overlying thinly-bedded silty sand. The north part of this deltaic accumulation adjoins patches of hummocky moraine northwest of Lac Brideau (Fig. 24).

Further north in Takwa valley, proglacial sediments form an extensive patch of outwash in the vicinity of Lac de la Tillite (Fig. 29). The formation of these sediments is related to the presence of a bedrock sill downstream from Lac de la Tillite. There, prominent bedrock hills project through the ground moraine on both sides of the valley (see Fig. 11), and a series of cascades are formed in the river where it flows over the bedrock exposed in the channel between the hills. The outwash occurs upstream from the bedrock sill for a distance of 7 km. At its upstream end the outwash has a maximum thickness of 10 m and is mainly well-sorted medium-grained sand with interbeds of coarse-grained sand and sandy gravel (section TI-1) overlying fine-grained sand (section TI-2). Its thickness decreases southward to 3 m near the south end of Lac de la Tillite, ca. 1 km upstream from the rapids. There, loose, well-sorted very fine sand is seen in the lower 1,5 m of the sections.

Témiscamie valley

Proglacial sediments form a continuous thick valley fill in that segment of the valley which lies between Lat. 51°20' and Lat 51°33' N (Fig. 29). The maximum thickness of the sediments, exposed above river level, at the junction with two unnamed tributaries flowing southward from Hippocampe Plateau is 25 m. Thickness decreases both upstream and downstream from this point; it is less than 10 m at Lat. 51°22' N.

The surface of the valley fill lies between 400 and 420 m altitude, and slopes southward with a gradient of approximately 0,0005. Paleoccurents measured at various locations in the thicker part of the deposit indicate that most of the sediments came from the two unnamed tributaries, and not from upstream in the mainly valley (Fig. 29). Today, outwash is not seen in either one of these tributary valleys and bedrock is exposed at numerous locations.

In the Témiscamie valley, large kettles are seen around Lat. 51°32' N. In nearby sections (TE-6 and TE-7), long and shallow undulations characterize the beds, which presumably developed due to subsidence during sedimentation. These observations suggest that part of the valley fill accumulated on stagnant ice or buried blocks of ice.

About 22 km downstream from the above localities, at Lat. 51°24' N, where the outlet of Lac Sylvio discharges into the Témiscamie River, a section, 12 m high (TE-4), exposes over 4 m of rhythmically-bedded silt and silty clay. Couplets are on the average 5 to 9 cm thick. The unit rises 8,6 m above the river level and contains perhaps a hundred couplets. All these sediments lie below 400 m altitude in the valley and suggest that the Témiscamie valley must have been flooded as a result of high water levels in the Lac Albanel basin and that river flow velocity was checked in this part of the valley. Downstream from section TE-4, the river has deposited a layer of alluvium, about 4 m thick (sections TE-1, 2, 3), derived from the main outwash mass upstream.

Tournemine River presently flows northward into Témiscamie River, in the south part of the area. Its valley is occupied by a continuous accumulation of fine-grained sand about 6,0 m thick, (section TO-1). Cross-laminations in the sand indicate a southward flow, that is sedimentation in the upvalley direction. This is best explained by presuming that the valley fill was probably deposited in front of the retreating ice margin before the Témiscamie valley was uncovered.

## 3.5 Deglaciation

### 3.5.1 Recession of the ice front

The history of deglaciation of the area is given as a summary to this section. For clarity deglaciation is condensed into five phases

(Figs. 37a to 37e). Since there are no end moraines within the study area, the position of the retreating ice front during the various phases is based entirely on other features such as patches of hummocky moraine, ice-marginal meltwater channels, and anastomosing esker ridges. In those parts of the area, where these indicators are absent, the ice frontal positions are speculative. In addition, the tracing of the ice front at the successive positions is based on the assumption that the ice always maintained its margin approximately orthogonal to the last glacial flow direction at the various locations. Consequently, the ice front at the various positions is shown perpendicular to the trends indicated by striations, short drumlins, and flow lineations on ribbed moraines. The glacial lakes and associated features, mentioned in this review of deglaciation, are deliberately not named here since they are discussed in detail in Chapter 4.

Phase 1. Prior to this phase the ice front was south of the area and glacial lakes occupied the ice-free portions of the Lac Mistassini and Lac Albanel basins. During Phase 1 (Fig. 37a) the ice front was north of Kallio Plateau and Témiscamie Mountains. The trend of the ice margin at this position is based on the southward flow direction indicated by striations in Témiscamie Mountains and by flow lineation on the Clairy ribbed moraine. During this phase the glacial lake in the Lac Albanel basin extended into the area, while that part of the Lac Mistassini basin which lies within the Témiscamie area, was still under ice. Meltwater channels north of

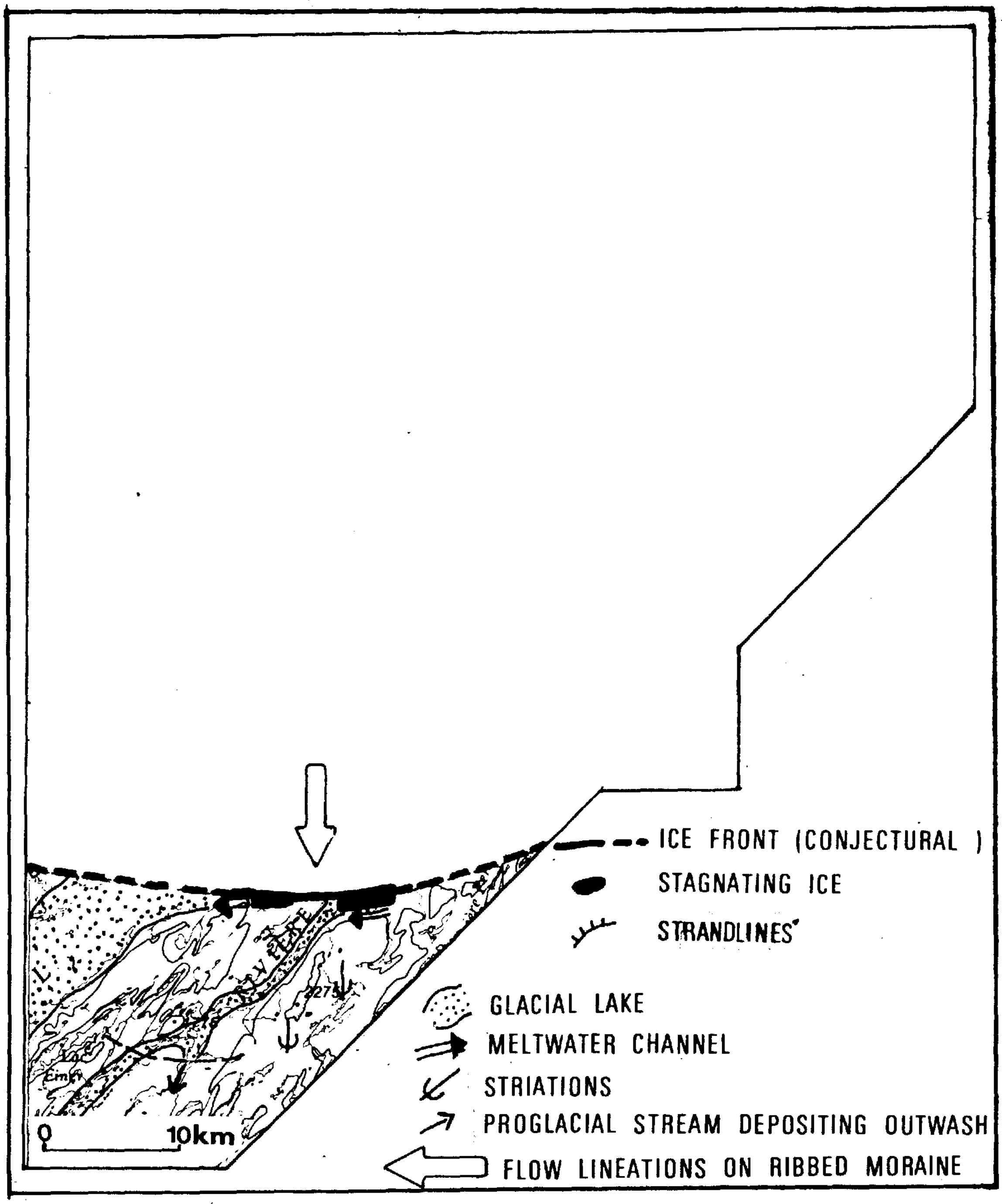



FIGURE 37 a. DEGLACIATION OF THE TEMISCAMIE AREA. PHASE 1. DIAGRAM INCLUDES AN EARLIER POSITION OF THE ICE FRONT.

Kallio Plateau indicate that the water level in the glacial lake was near 400 m altitude. The Témiscamie River valley was also flooded to a level of more than 10 m above the present river level. Figure 37a shows also an earlier recessional position of the ice front from which a southward flowing proglacial stream deposited outwash in the Tournemine valley.

During Phase 2 (Fig. 37b) the ice front is ca. 15 km north of its former position. The ice front has been drawn based on the trend of flow lineations on the Fourchette and Cawachigamau ribbed moraines and on minor moraines near Lac Papaskwasati. It connects patches of hummocky moraines east of Lac Clairy and west of Témiscamie River. During this phase, the glacial lake in the Lac Albanel basin extended further northeast. At the same time, parts of the Lac Mistassini basin became also ice-free within the Témiscamie area and became flooded by glacial lake waters. Massive silts were deposited in this glacial lake. During the retreat between Phases 1 and 2, a spillway located west of Lac Clairy opened up establishing communication between the two lake basins.

During Phase 3 (Fig. 37c) Takwa Hill formed a re-entrant on the ice front and the ice-marginal channels along its southwest slope were eroded. The ice front is drawn through patches of hummocky moraine near Lac du Fruit Défendu and near Cheno River. East of Takwa Hill, the ice front extends eastward from the patches of hummocky moraine located at the confluence of Kapaquatche and Takwa Rivers to other patches south of Lac Sylvio west of Témiscamie

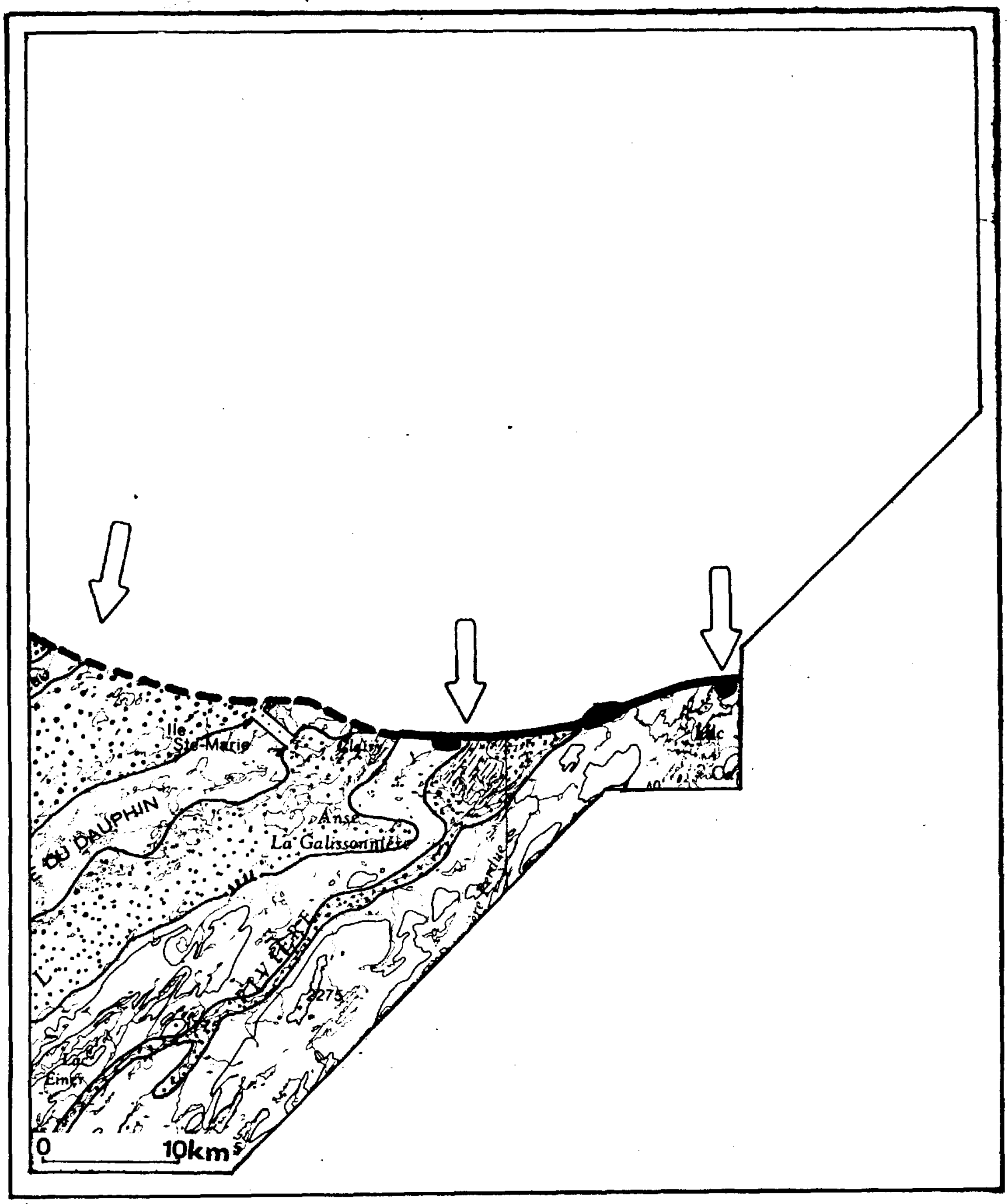



FIGURE 37 b. DEGLACIATION OF THE TEMISCAMIE AREA. PHASE 2.
FOR LEGEND SEE FIGURE 37 a.

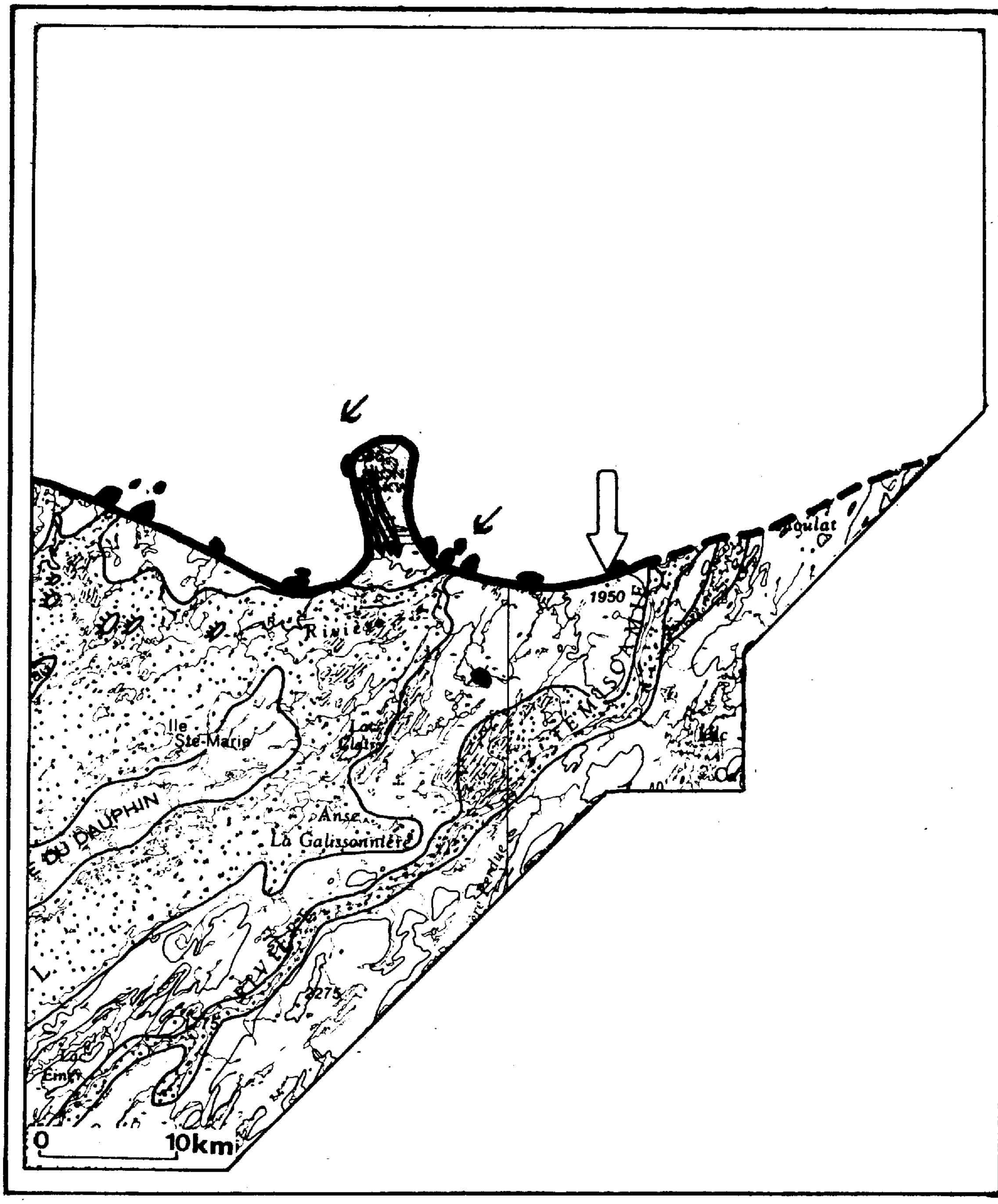



FIGURE 37 c. DEGLATIATION OF THE TEMISCAMIE AREA. PHASE 3.
FOR LEGEND SEE FIGURE 37 a.

River. The ice margin northwest and east of Takwa Hill is based on the trend of local striations and near Témiscamie River, it is based on the trend of the flow lineations on the Sylvio ribbed moraine. The water level in the glacial lakes was at 398 m altitude as shown by wave-cut scarps formed around till hills and drumlins at the northeast end of Lac Mistassini. Fine-grained deltaic sediments accumulated in the mouth of the Papaskwasati and Takwa valleys under a minimum of 23 m of water. In the flooded Témiscamie valley, the fine-grained rhythmically-bedded silt and clay occurring west of Lac Béthoulat were deposited. The height of water level in this valley is not known but if it reached 400 m altitude, Lac Béthoulat basin was flooded.

Phase 4 (fig. 37d). As the ice front retreated between Phases 3 and 4 to the position north of Takwa Hill, stagnant ice was left in the vicinity of the Neilson, Papaskwasati, and Cheno valleys, and near Lac Brideau. The trend of the ice-margin in the east part of the area is based on the direction of the flow lineations on the Tillite ribbed moraines. Water level in the glacial lakes started to recede as a result of post-glacial uplift and, consequently, coarser deltaic sediments accumulated in the mouth areas of Papaskwasati and Takwa valleys. The foreset-bedded deltaic accumulation in Cheno valley formed presumably at the same time. In the Témiscamie valley, proglacial sediments may have started to accumulate in the form of outwash partly deposited on stagnant ice left in the valley.

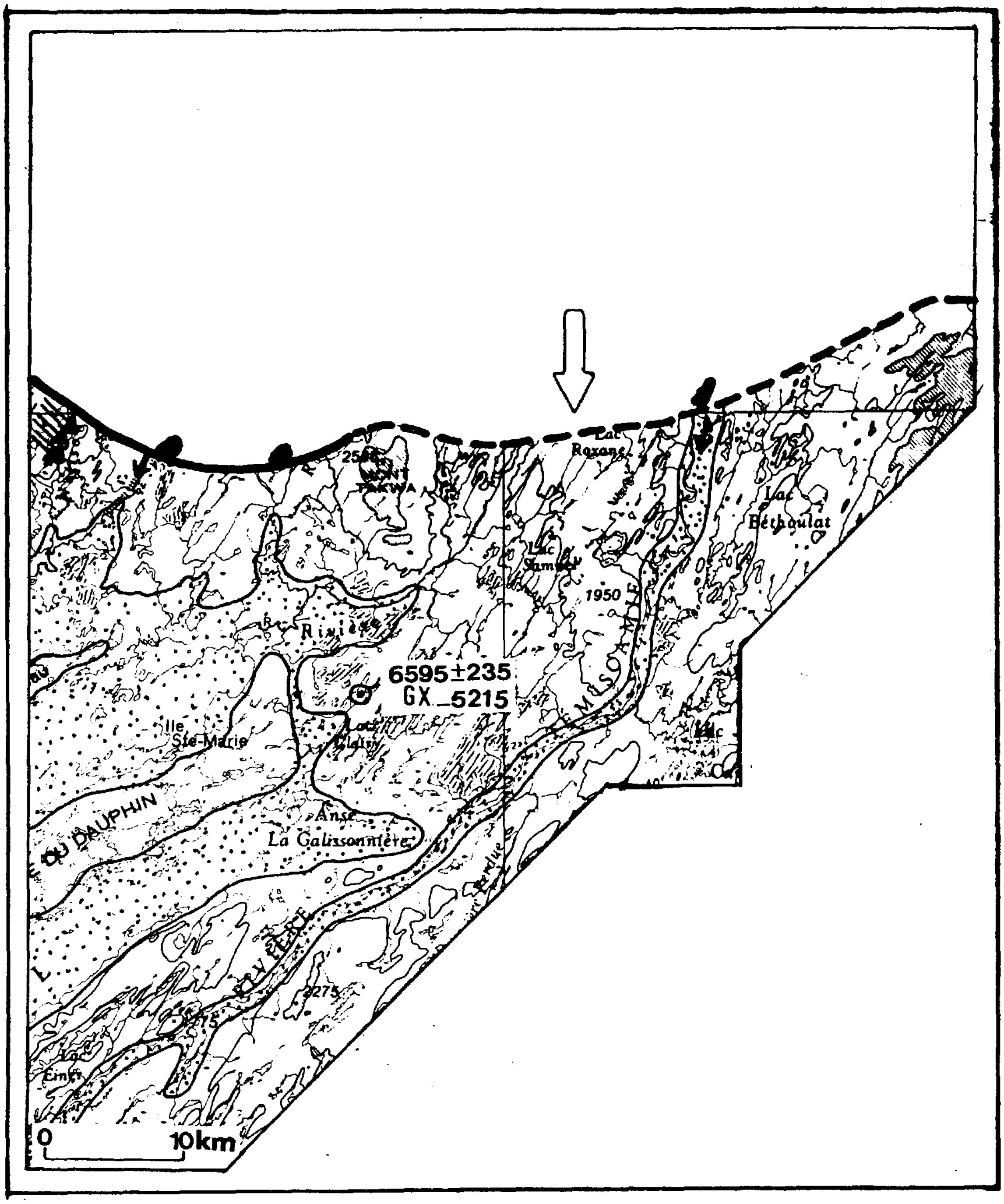



FIGURE 37 d. DEGLACIATION OF THE TEMISCAMIE AREA. PHASE 4.
FOR LEGEND SEE FIGURE 37 a.

During Phase 5 (Fig. 37e) the ice front is in the north part of the area joining anastomosing esker ridges at the confluence of Papaskwasati and Holton Rivers to a patch of hummocky moraine in Takwa valley. The trend of the ice front near Takwa valley reflects the trend of the flow lineation on the Marcil and Ouellette ribbed moraines. In the west, west of Papaskwasati River, an extensive occurrence of hummocky moraine indicates that substantial parts of the ice stagnated in the lee of the prominent Tichégami Mountains. Everywhere, meltwater released from the ice front discharged into the main valleys and eventually reached the glacial lakes in the Mistassini and Albanel basins. Water level continued to drop in the lakes which, consequently, became separated from one another, at least, within the Témiscamie area. Beach ridges formed around the northeast end of Lac Mistassini, at successively lower positions and closer vertical intervals owing to a decrease in the rate of uplift.

As the ice retreated further north following Phase 5, stagnating masses were left in the Kapaquatche and Takwa valleys. Meltwater released from the ice front east of the Takwa-Témiscamie divide cut the channels northeast of Lac Ouellette and deposited the thick outwash fill in the Témiscamie valley. When the ice front retreated outside the study area, a glacial lake formed over parts of Hippocampe Plateau and spillways from it became eroded in the head areas of Takwa and Kapaquatche Rivers. Stagnating ice left in these valleys acted as temporary base levels for the spillways.

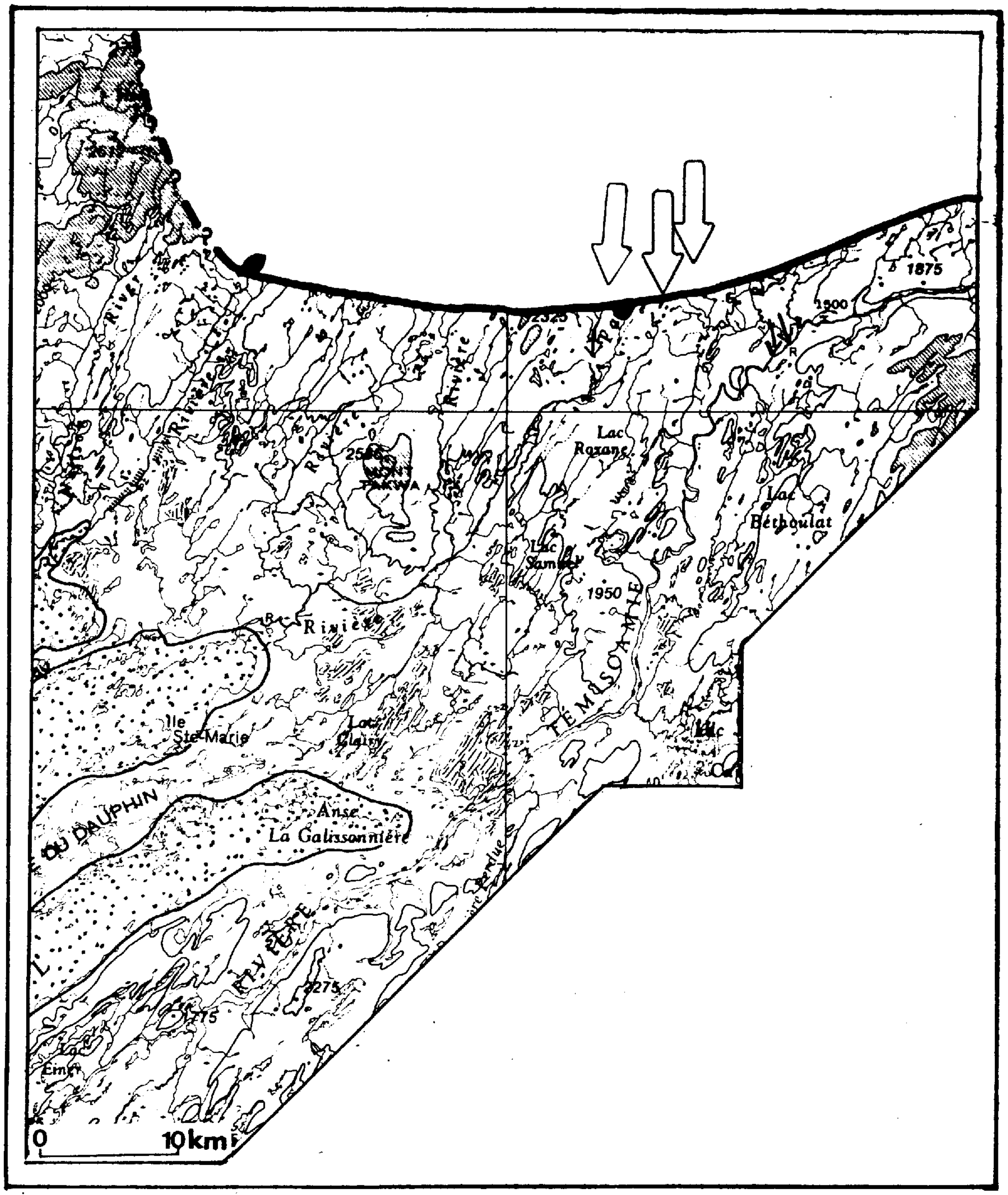



FIGURE 37 e. DEGLACIATION OF THE TEMISCAMIE AREA. PHASE 5.
FOR LEGEND SEE FIGURE 37 a.

Later events following complete deglaciation of the area include erosion and alluvial sedimentation in the main valleys, and accumulation of organic detritus in lakes and bogs elsewhere.

The absence of end moraines in an area may be due to one of the following reasons: 1) the ice front retreats without any halt for any extended period of time, 2) there is insufficient quantity of debris in the ice to build prominent end moraines at stable positions of the ice front or 3) the ice sheet wanes principally by down wasting and this leads to widespread stagnation of the glacier margin. The second explanation is not applicable to the area since relatively large amounts of ice contact stratified drift have accumulated in the area indicating that considerable drift was present in the ice during deglaciation. The two other possibilities are not mutually exclusive and, in fact, they both apply to the area. As it has been shown, large patches of stagnant ice were left in most of the valleys during deglaciation. Furthermore, the width of the stagnating marginal zones at successive locations is estimated to be in the order of 4 km, based on the greatest northeast-southwest extent of patches of hummocky moraine and on the maximum length of continuous esker segments.

3.5.2 Chronology

The Témiscamie area was deglaciated prior to 6,600 years B.P. The minimum age of deglaciation is inferred from a radiocarbon date (6595 ± 235 C14 years B.P., GX-5215), obtained on lowest 10 cm of a core of gyttja (limnic organic-rich deposit) sampled in Lac Niskuk, Lat. 51°18'47" N, Long. 72°39'10" W, within the study area (Fig. 37d).

Lac Niskuk is situated at an altitude of 390 m in that part of the region which was submerged under glacial-lake waters to a maximum altitude of 398 m. Therefore, the date should indicate the minimum age at which the glacial-lake waters receded and the organic detritus could have accumulated in the small isolated lake basin. Consequently, the minimum age involves a time-gap of unknown magnitude relative to the time of deglaciation.

Two other samples of gyttja collected in the study area could not be dated for reasons explained in Chapter 1. An additional sample from Otish Mountains, 140 km northeast of the Témiscamie area, at Lat. 52°26'37" N, Long. 70°57'10" N, and at an altitude of 770 m yielded a date of 6270 ± 350 C14 years B.P. (GX-5675). Another pertinent date on comparable material is reported by Prest (1970) from a peat bog in the vicinity of Chibougamau, about 180 km southwest of the Témiscamie area. The date is 6960 ± 90 C14 years B.P. According to Prest (1970), this date is several hundred years younger than the presumed true age of deglaciation in that area.

# CHAPTER 4
# GLACIAL LAKE PHASES IN MISTASSINI AREA

The purpose of this chapter is to provide a regional framework for the understanding of the strandline evidence of the Témiscamie area, and subsequently, to present an outline of the history of the glacial lake phases in the Mistassini area (inset, Fig. 1, and Fig. 38).

## 4.1 Previous ideas

The different ideas on the nature and the extent of successive water bodies in the Mistassini area are summarized in Figure 39. The presence of one or more proglacial lakes in front of the retreating ice sheet has been known since the work of Mawdsley (1936) in the area around Lac Opémisca, southwest of the Mistassini area, as defined in this work.

Norman (1938) considered that the proglacial lake in the Opémisca area was the extension of Glacial Lake Barlow-Ojibway. The latter was known from the previous works of Coleman (1909), Wilson (1918), and Antevs (1925, 1928) in the Témiscamingue area, and was thought to extend northeast at least to the head of Bell River. The original correlation by Norman (1938) was based on the nature and location

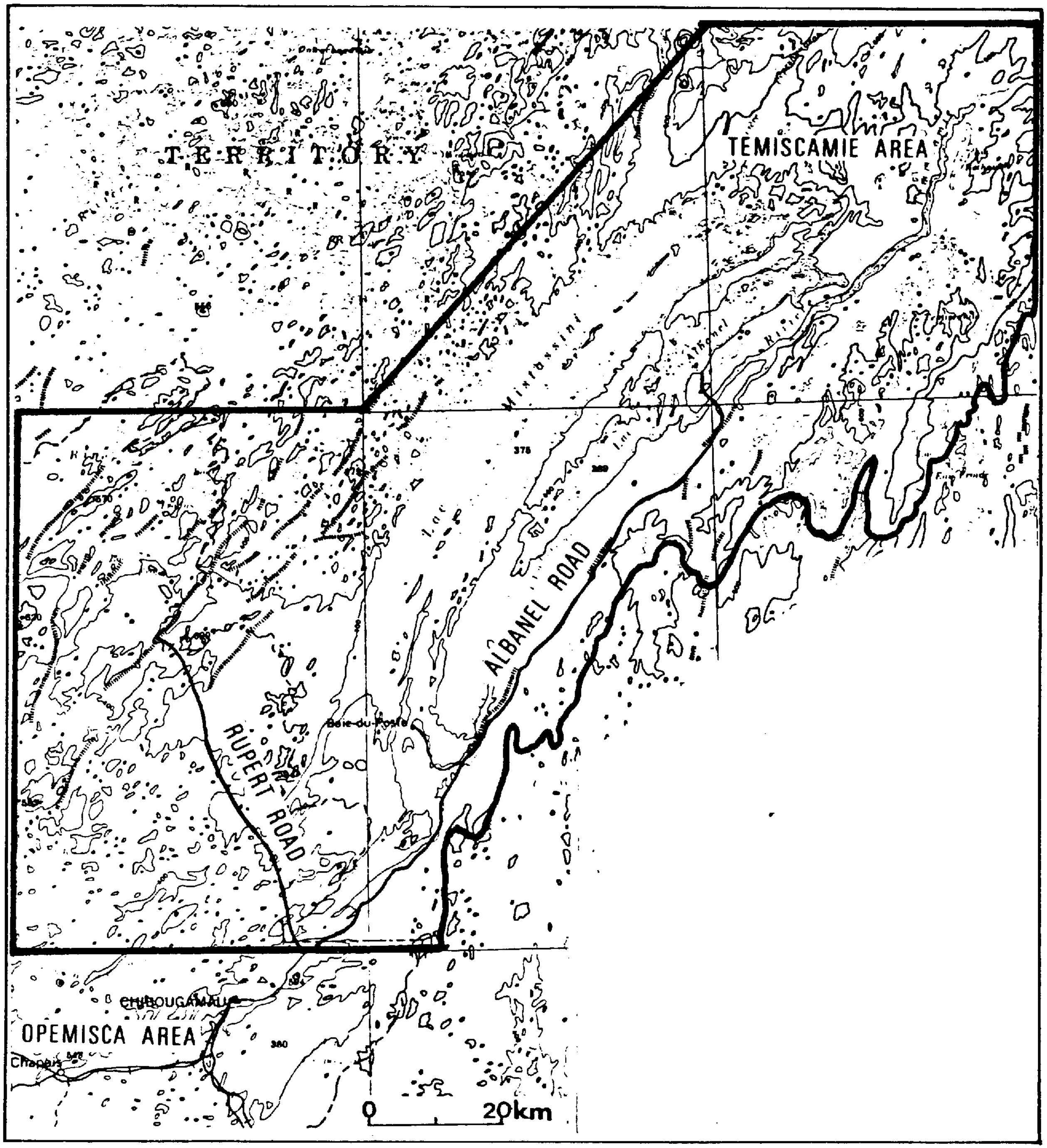



FIGURE 38. LOCATION MAP, MISTASSINI AREA.

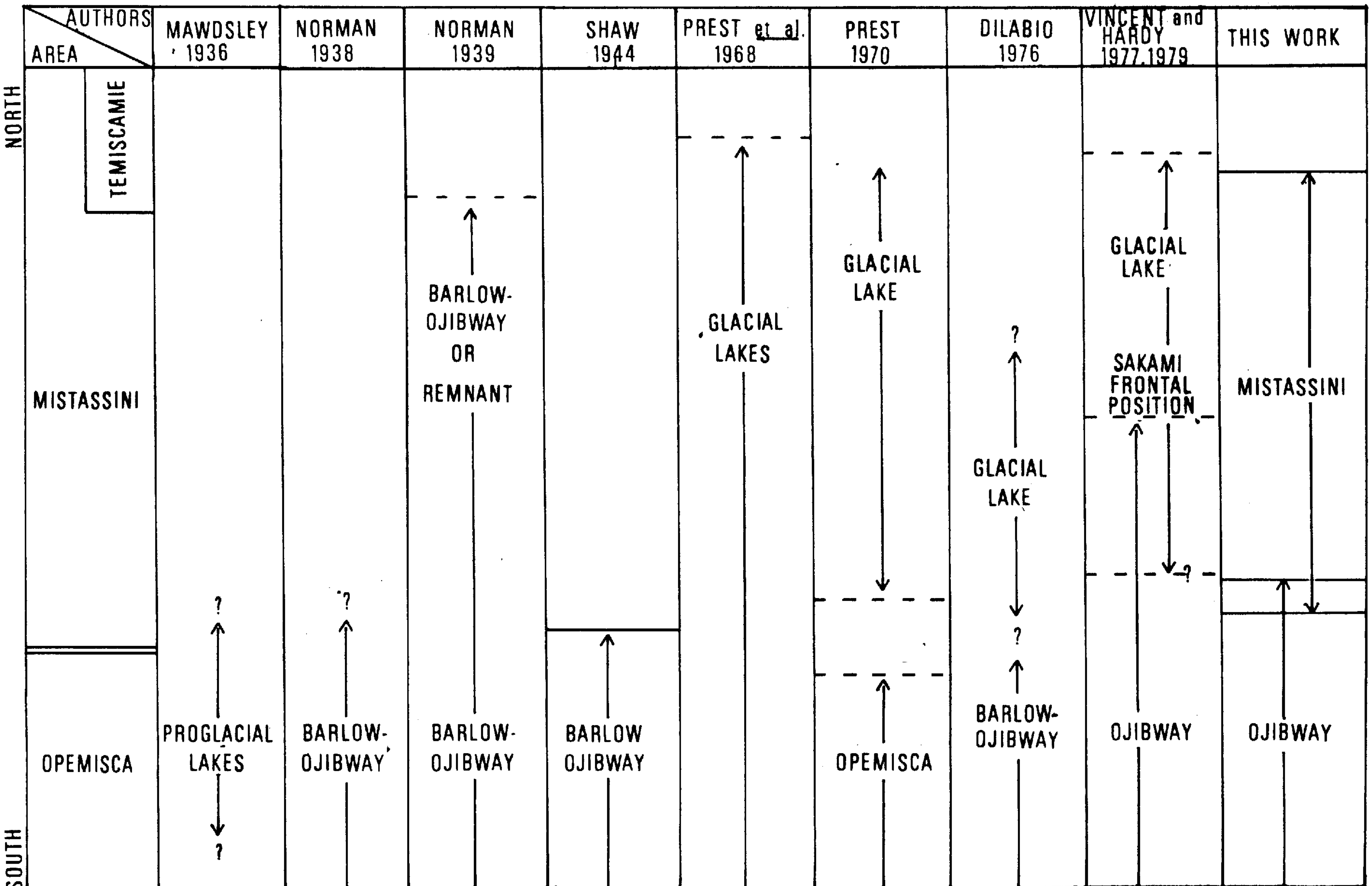



FIGURE 39. VARIOUS IDEAS ON THE NATURE AND EXTENT OF WATER BODIES IN THE MISTASSINI AREA. DASHED LINES INDICATES APPROXIMATE LOCATIONS.

of the strandlines which suggest wave action in a large lake and on the absence of any topographic barrier, which would have prevented a large proglacial lake in the Opémisca area to be contiguous to Glacial Lake Barlow-Ojibway in the Bell River region. In 1939, Norman suggested that Glacial Lake Barlow-Ojibway, or a remnant of it, had extended into the Mistassini region as far north as the latitude of the mouth of the Témiscamie River.

For the history of the terms "Glacial Lake Barlow-Ojibway" and "Glacial Lake Ojibway", as well as for the most recent accounts of the history and extent of these water bodies, the reader is referred to Hardy (1976), and Vincent and Hardy (1977, 1979).

Shaw (1944) traced northward the distribution of minor moraines which according to Norman (1938) are characteristics of the recession of the ice margin into a body of standing water in the Opémisca area. He inferred from the northern limit of the moraines that Glacial Lake Barlow-Ojibway extended northward into the Mistassini area at about the latitude of Lac Waconichi.

The Glacial Map of Canada (Prest et al. 1968) shows the areas which were flooded by glacial lake waters. The Mistassini area is shown to have been covered by an extensive proglacial lake. Even allowing for the small scale, the extent of the flooding is drawn so as to suggest that the water level in the Mistassini area, though not indicated, was quite high above the present water level.

Prest (1970) summarized in a series of maps the succession of glacial lake phases in northern Ontario and western Québec, including the Mistassini region. According to him, Glacial Lake Opémisca, a remnant of Glacial Lake Ojibway, formed at the ice margin that was south of the Mistassini region about 8,100 years ago. He thought that this lake drained completely before the ice retreated further north into the Mistassini area, and that a new proglacial lake formed in the Mistassini basin, around 7,500 years ago.

Dilabio (1976) reported varves in the Waconichi area, within Mistassini region (Fig. 38). He suggested that the lake in which the varves were deposited was most likely younger and lower than Glacial Lake Barlow-Ojibway, which did not extended into the Mistassini region. He based his interpretation on the absence of high level strandlines in the Waconichi area.

Part of the history of Glacial Lake Ojibway established elsewhere, particularly the determination of the time and of the events related to its final drainage, have implications to the story in the Mistassini region. Skinner (1973) and Hardy (1976) suggested that Glacial Lake Ojibway in the James Bay Lowlands drained northward into the Tyrell Sea. According to Hardy (1976), final drainage occurred at a time when the receding ice front was at the Sakami moraine, which marks the inception of a separate residual ice sheet over central and northern Québec. Shells from the Tyrell Sea, found in material overlying the Sakami moraine, indicate a minimum age of ca 7,900 B.P. for the drainage of Glacial Lake Ojibway. Vincent and Hardy (1977, 1979), summarizing the evolution of Glacial Lakes Barlow and Ojibway in Ontario and Québec, incorporated the suggestion of Hardy (1976) and further postulated that Glacial Lake Ojibway drained completely when the ice margin was at the "Sakami Frontal Position". Afterwards a smaller proglacial lake was left and extended northward in the basin of Lake Mistassini.

The Sakami moraine is a prominent feature, which extends discontinuously for nearly 600 km from near Poste-de-la-Baleine at James Bay, to the west side of Lac Mistassini. It was first mapped by Prest et al (1968). Parts of the moraine, where it is well developed near James Bay, have been described by Vincent (1974) and Hardy (1976). In the vicinity of Lac Mistassini, however, the moraine is very discontinuous, and within the Mistassini area, only two small patches of drift, each less than about 2 $km^2$ in extent, have been mapped as part of the moraine (Prest, pers. comm.) (Fig. 40). The moraine was not traced across the Mistassini basin.

In summary, the reconstruction of the glacial lake phases in the Mistassini basin involves the determination of the limit of Glacial Lake Ojibway in the region which, according to the views of the various authors, may have been south of or within the Mistassini area as far north as the Témiscamie River, or at the Sakami frontal position which is not well defined in the area; the evolution of the glacial lake that formed, or succeeded Lake Ojibway, in the Mistassini region remains also to be established. The reconstruction as proposed in this work is shown for comparison in Figure 39.

## 4.2 Setting and method

Lac Mistassini is drained presently westward by Rupert River which flows into James Bay (Fig. 40). Leaving from Lac Mistassini, the river follows a course northward to Woolett Lake and then westward. It has a well-incised single channel only about 100 km west from Lac Mistassini. In the intervening area, the river flows through a series of interconnected lakes of various sizes and outlines which suggest a strong structural control by the underlying Archean rocks. Near Lac Mistassini, the outlet is a maze of irregular channels flowing around and between islands. The present intake of the outlet is at Lat. $51^{\circ}05'$ N.

Lac Waconichi and Lac Albanel presently drain into Lac Mistassini. Lac Waconichi drains northward into the Baie-du-Poste of Lac Mistassini via the short Waconichi River. The lake level is held at around 381 m by a bedrock sill located at the first (southernmost) rapids, the so-called "Foam Falls". The sill is a resistant outcrop of the Lower Albanel Formation.

Lac Albanel drains westward into the eastern part of Lac Mistassini by a short obsequent stream (Fig. 40). The level of the lake is held at around 389 m, 14 m higher than Lac Mistassini, by a sill at the Opitchouan Rapids, which are, in fact, low falls, created there also by a resistant bed of the Lower Albanel Formation.

Lac Waconichi, Lac Mistassini, and Lac Albanel occupy separate basins within a low area, below 400 m altitude, which is enclosed on

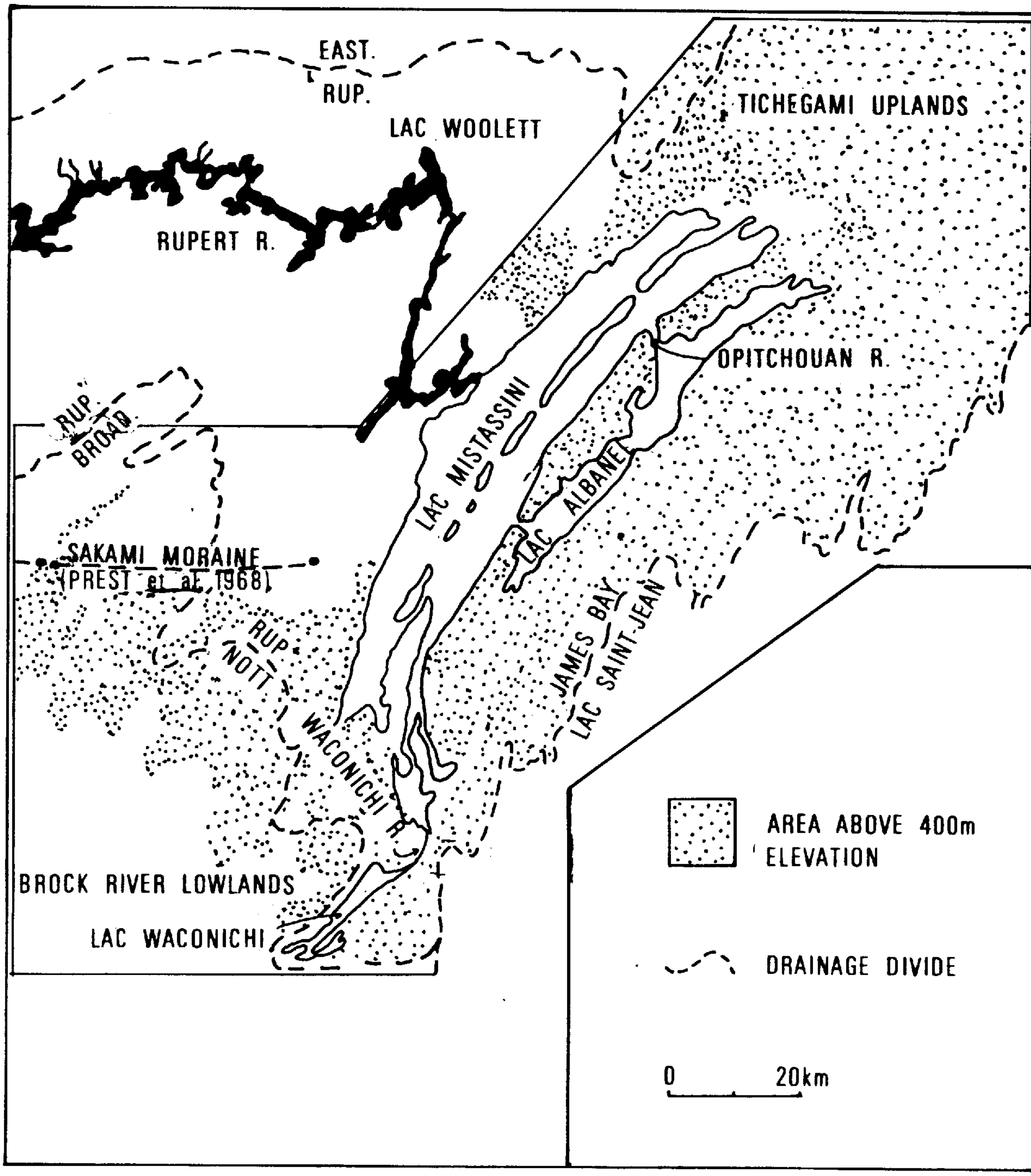



FIGURE 40. DRAINAGE SYSTEMS AND GENERALISED PHISIOGRAPHY OF THE MISTASSINI AREA.

three sides by land at higher elevation (Fig. 40). Eastward the land rises to the divide separating the James Bay and Lac Saint-Jean drainage basins. The altitude of this divide rises from 450 m in the southwest to more than 500 m in the northeast. Southward, the closure of the Mistassini basin is formed by a hilly terrain above 400 m altitude, located at the north edge of a lowland area.

The divide separating the Nottaway and Broadback drainage basins from the Rupert drainage basin winds across this hilly terrain and joins the continental divide southeast of Lac Waconichi. Northward from Lac Mistassini, the land rises to the Tichégami Uplands. The divide separating Eastmain and Rupert drainage basins extends westward from these uplands.

For convenience, the southwest part of the Mistassini area, below 400 m elevation, is referred to as the Brock River Lowlands. The main glacial flow direction in the Mistassini area is southwestward as indicated by the numerous drumlinoid ridges in the region.

The reconstruction which is presented in this work is based on a compilation of previously available data pertaining to glacial lake phases in the area, and on new evidence gathered from a reconnaissance study in the region. Reconnaissance work was effected through the examination of aerial photographs at a scale of 1:62,350 and by field traverses along the available roads, namely the Albanel and Rupert roads (Fig. 38).

The altitudes of the features along the road were measured with a pocket aneroid altimeter, calibrated either to the level of Lac

Mistassini or Lac Albanel. The precision of these altitude determinations is within 5 m corresponding to the total drift due to atmospheric pressure changes during the measurements. The altitudes of unaccessible features were read from 1:50,000 topographic maps with a contour interval of 16 m. The elevations are stated to the nearest contour line with a plus or minus qualification depending on whether the feature is located above or below that contour line. Assuming that the position of the contour lines on the map is accurate, the precision is in order of 8 m. For instance, an altitude of 396 (+) m means that the feature is between 396 and 404 m elevation. These altitude determinations have only indicative values and cannot be used for close correlation of water planes.

## 4.3 Evidences of glacial lakes

Direct evidence of glacial lakes in the area is provided by such features as strandlines and varved lacustrine sediments. Indirect evidences is provided by features from which either the presence, the extent, or the level, of glacial lakes may be inferred with a reasonable degree of confidence. Such features are glacial landforms built at the margin of the glacier retreating in a body of standing water, namely the De Geer moraines. Indirect evidence is also provided by biogeographic data, namely the present distribution of "relict" organisms presently inhabiting modern lakes in the region, as surveyed by Dadswell (1974).

4.3.1 Strandlines

Strandlines were previously reported from the Opémisca area by Mawdsley (1936), Norman (1938), and Ignatius (1956). Norman (1938), identified, surveyed, and mapped the strandlines of an area enclosing Lac Opémisca and extending partly into the Brock River Lowlands of the Mistassini region. The strandlines are boulder beach ridges, the upper limit of wave-swept rocks, and terraces. The highest strandline is a boulder beach ridge at 438 m elevation just north of Lac Opémisca (Fig. 40). Other ridges are found all the way down to 395 m elevation. This suggested to Norman that the lake level had dropped a total of 43 m before final, sudden, drainage of the lake occurred. Ignatius (1956) reported strandlines at ca. 427 m in the Presqu'Ile area, west of Chibougamau. The strandlines of the Opémisca area, as measured by Norman (1938), are well integrated into the reconstruction of the tilted water planes of Glacial Lake Ojibway (Vincent and Hardy 1977, 1979).

Within the Mistassini region, excluding the Témiscamie area, strandlines were previously reported by Low (1896) and Neilson (1953), respectively around Lac Waconichi, and around Lac Albanel. Those around Lac Waconichi are about 12 m above present lake level, that is, at an altitude of about 393 m. Those around Lac Albanel are about 14 m above present lake level, that is, at an altitude of about 403 m.

During the present reconnaissance work, strandlines, yet unreported, were identified in the Brock River Lowlands, but no additional strandlines were found around Lakes Waconichi, Mistassini, and Albanel

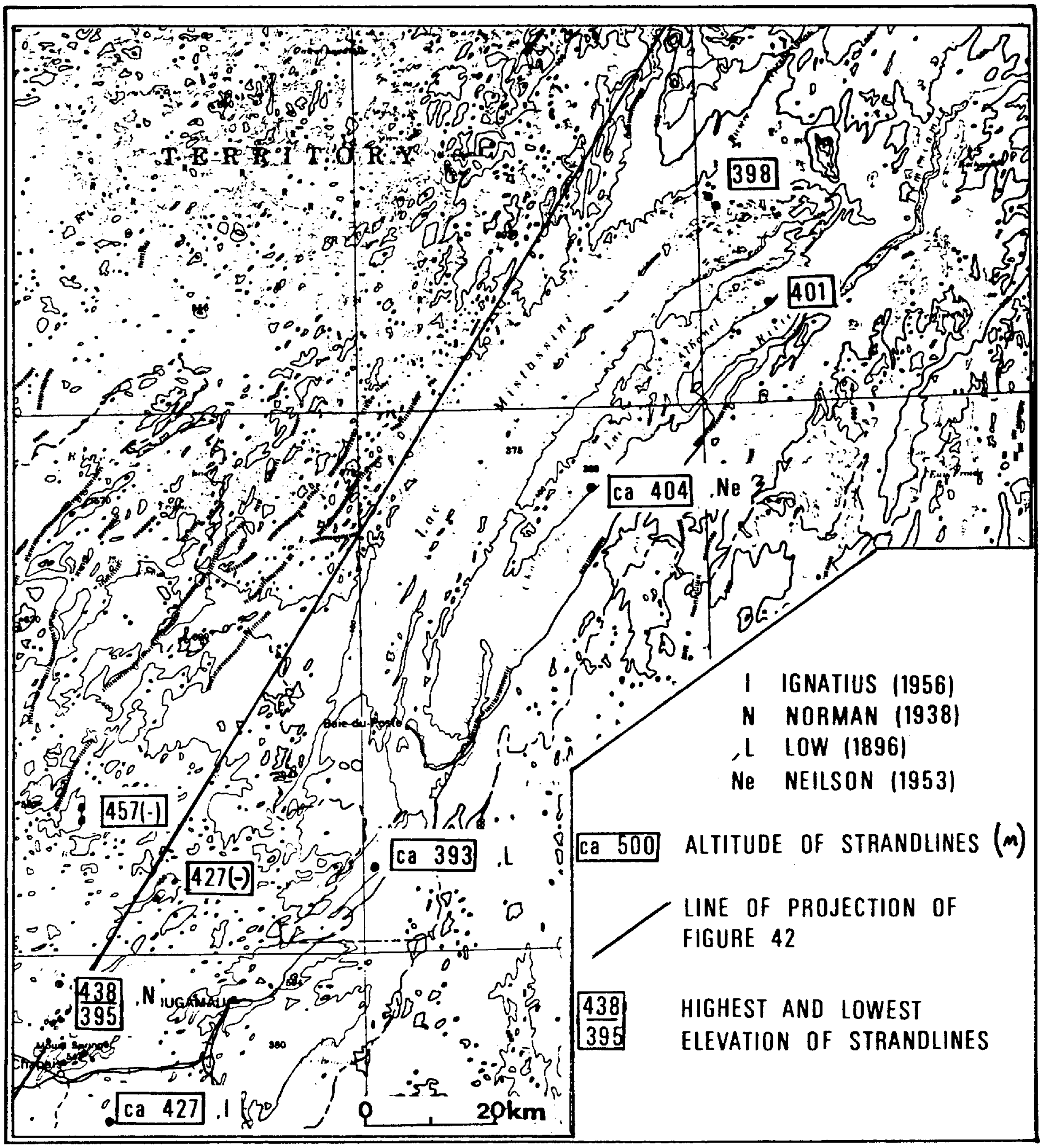



FIGURE 41. STRANDLINES IN THE MISTASSINI AND OPEMISCA AREAS.

(Fig. 41). Strandlines identified from aerial photographs are of two types. The first type appears as faint lines on bedrock hills mantled by till, following the topographic contours. They are interpreted as either wave-cut scarps or beach ridges. The highest feature of this type is at an altitude of 457 (-) m (Fig. 41). The second type appears as narrow benches on the flanks of large esker ridges in the Lowlands. Generally, several of them occur at different levels at any one location. The altitude of the highest of these features is around 427 (+) m.

In order to see how the high water level of Glacial Lake Ojibway in the Opémisca area compares with those recorded further north, the altitude of the strandlines measured by Norman (1938) is projected northeastward using the isostatic uplift gradient established from the isobases on the water plane of Glacial Lake Ojibway (Vincent and Hardy 1977, 1979); this gradient is about 0,48 m/km and is assumed to be linear. The projection (Fig. 42) shows that the newly mapped features in the Brock River Lowlands are, in general, in good agreement with the Ojibway water level but that the strandlines around Lac Waconichi and Lac Albanel, and those of the Témiscamie area, are considerably lower. Strandlines around Lac Waconichi are more than 70 m below the projected (high) level of Glacial Lake Ojibway, whereas strandlines around Lac Albanel and those of the Témiscamie area are more than 100 m below that level.

The general agreement of the elevation of the strandlines in the Brock River Lowlands with the projected Ojibway water level suggests

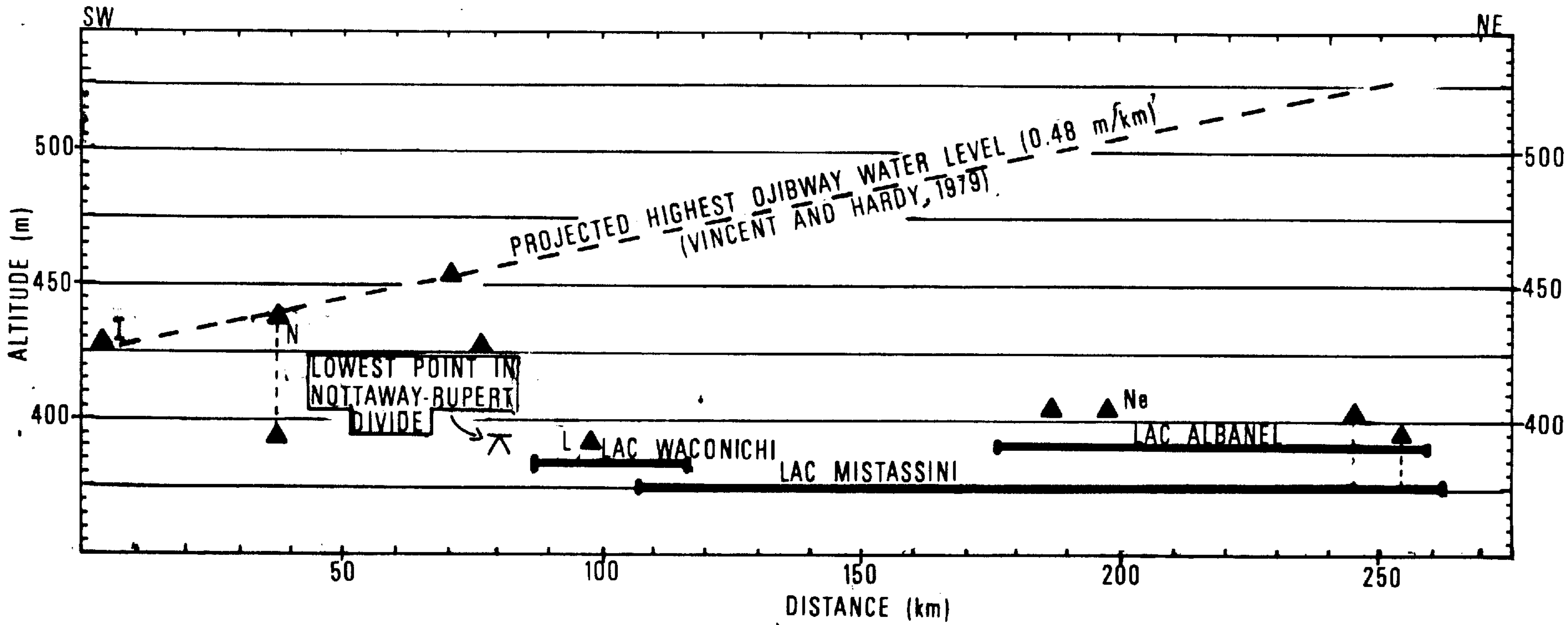



FIGURE 42 . NORTH EASTWARD PROJECTION INTO THE MISTASSINI AREA OF THE ELEVATION OF THE HIGHEST STRANDLINES OF GLACIAL LAKE OJIBWAY AS MEASURED BY NORMAN (1938) IN THE OPEMISCA AREA. PLANE OF PROJECTION ORIENTED ALONG THE LINE SHOWN IN FIGURE 41. I FOR IGNATIUS (1956); N, FOR NORMAN (1938); L, FOR LOW (1896) AND Ne, FOR NEILSON (1953). VERTICAL DASHED LINES INDICATE RANGES OF ALTITUDE OF STRANDLINES.

that Glacial Lake Ojibway extended within the Mistassini region as far north as the Brock River Lowlands. The lower elevations of the other strandlines around the lakes within the Mistassini basin suggest that these were formed later in a lower proglacial lake within the main part of the Mistassini area.

The absence of high level strandlines within much of the Mistassini area, and particularly in the hilly terrain above 400 m altitude north of the Brock River Lowlands, is strongly suggestive that either Glacial Lake Ojibway had drained before this terrain was deglaciated, or that its level had dropped to lower elevations and did not stabilize at any one level long enough for strandlines to develop.

4.3.2. Varved sediments

Lacustrine sediments in the Opémisca area, most likely associated with Glacial Lake Ojibway, have been cursorily reported by Mawdsley (1936) who noted the silty and clayey deposits at places in the sand plain of the area. Varved sediments are known to occur near Lac Obatagamau, west of Chibougamau (J. Cimon, resident geol., pers. comm.) but have not been described yet.

Within the Mistassini area, lacustrine sediments have been reported by Warren (1974) and by Dilabio (1976) (Fig. 43). Warren (1974) mapped scattered occurrences of lacustrine very fine sand, silt, and clay, near the present water level of Lac Mistassini, in the vicinity of Baie-du-Poste. Dilabio (1976) reported varves in the Waconichi River valley at an altitude of 380 m (Site 1, Fig. 43).

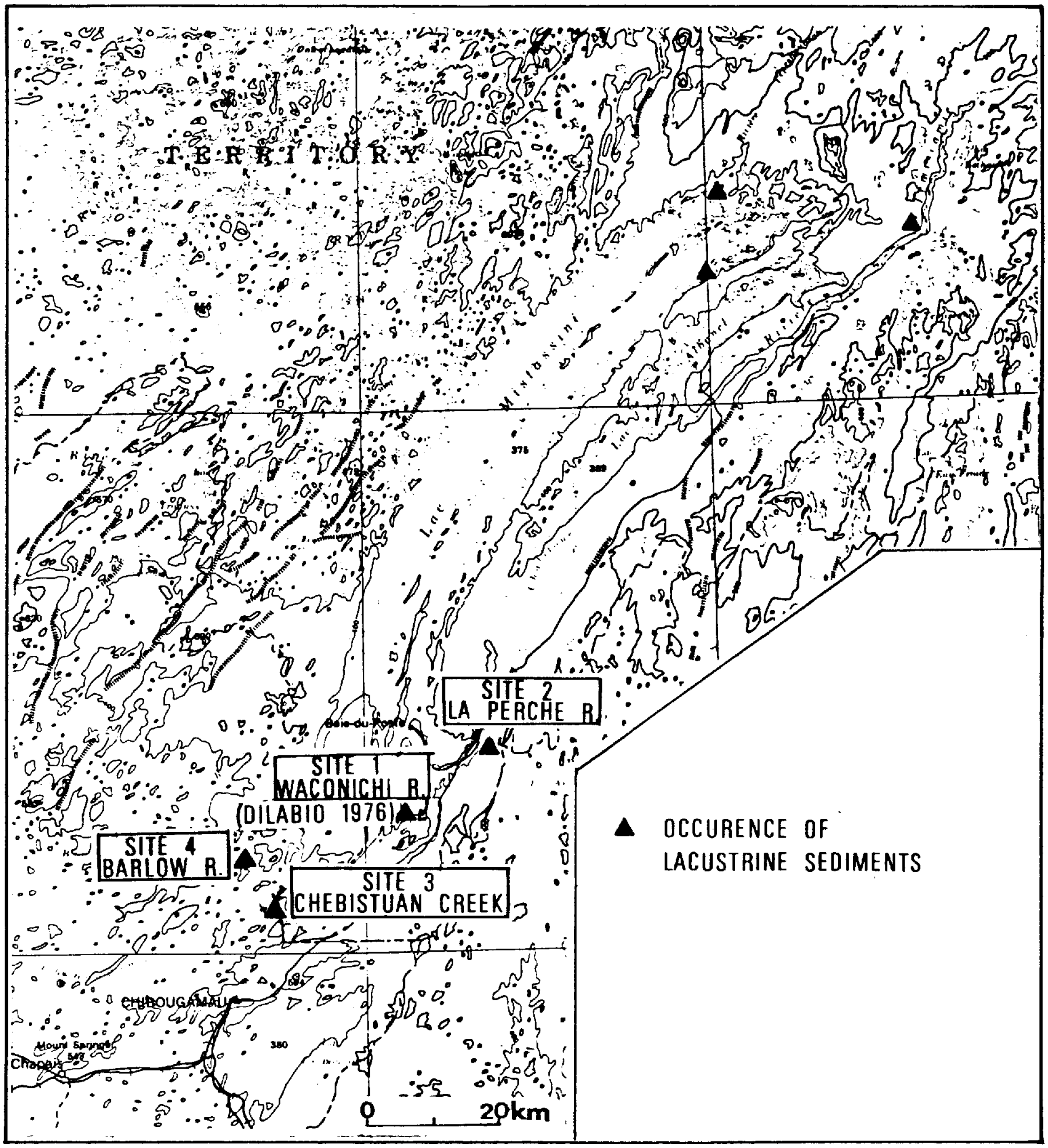



FIGURE 43. LACUSTRINE SEDIMENTS IN THE MISTASSINI AREA.

He described the sediments as "varves, usually about 1 cm thick, dominated by the silty (summer) layer. In a section ... 210 varves were counted in an interval 2,0 m thick. Because of their thinness, and their lack of dropstone, current bedding, and sand, they are interpreted as distal varves." (Dilabio 1976, p. 73). Most of the sections examined by Dilabio (1976) were in excavations of a mining operation in the Waconichi River valley. The mine was closed in 1976, and the pits were either filled or flooded so that the sections are no longer accessible and could not be re-visited by the present author.

During the reconnaissance work in the Mistassini area, the best exposures of lacustrine sediments of the Baie-du-Poste area were examined, and new exposures of varved sediments were observed along the recently opened Rupert road in the Brock River Lowlands.

In the Baie-du-Poste area, the best exposures of varves are in the north part of the Gauvin Township (Warren, pers. comm.), in the La Perche River valley (Site 2, Fig. 43). Access to the sections is provided by a small road leading east from Albanel road 4,5 km north of the Baie-du-Poste road junction. Rhythmites, 4,0 m thick, are exposed on both the north and south sides of the road at an altitude of 381 m. The beds show a general dip of 5 to $15^{o}$ toward the center of the valley (Fig. 44).

The lower 1,10 m of the sequence is exposed on the north side of the road. The deposit is mainly chocolate brown silt with thick sand interbeds. The base of the exposure is a 33 cm thick sand layer.

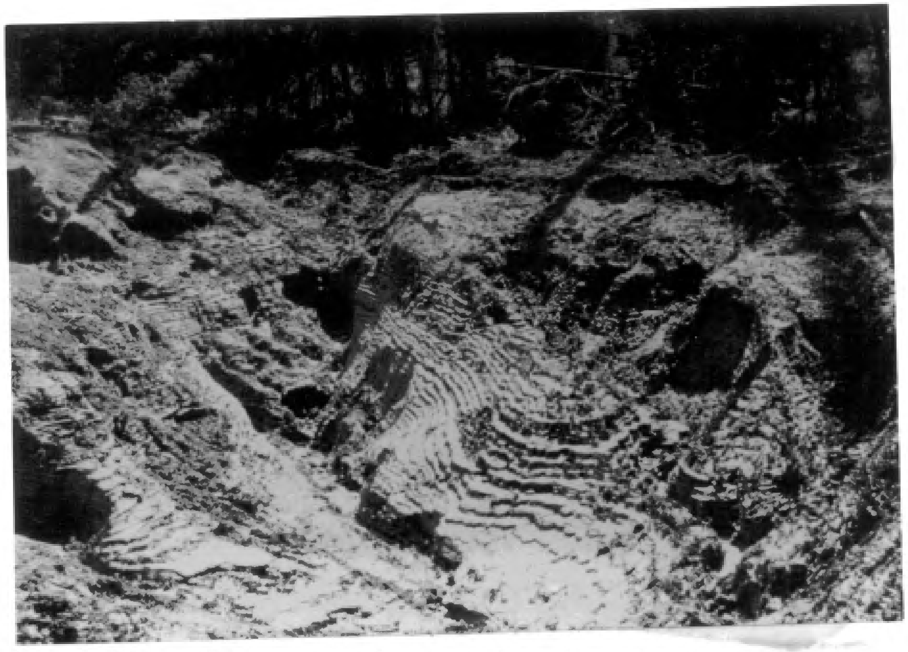


Figure 44a. Exposure of varved sediments in the La Perche River valley, north part of Gauvin Township (Site 2 on Figure 43).

Figure 44b. Close-up view of the lower part of the sequence of the varved sediments shown in Figure 44a. Exposure on the north side of the access road. Note the cross-bedding in the sand layers.

The next upper 32 cm are laminated silt with 6 sand interbeds ranging in thickness from 5 to 40 mm (Fig. 44b). In the next upper 45 cm, the deposit is a regular succession of couplets consisting of sand, few centimeters thick, which grades upward into laminated silt, overlain by clay, 1 to 2 mm thick. The thickness of the couplets ranges from 3 to 9 cm. The thicker sand interbeds show cross-bedding indicating a current flow direction toward the south. In comparison with the varves described by Dilabio (1976) in the Waconichi River valley, the lower part of the sequence in the La Perche River valley is interpreted as proximal varves.

The upper 3 m of the sequence are exposed on the south side of the road. There, the cross-bedded sand interbeds are absent; the couplets are on the average 4 cm thick in the lower half of the section (Fig. 44a) and decrease to less than 1 cm thick in the uppermost part. An estimated total of 160 to 170 couplets are present in this 3 m interval. The upward decreasing thickness of the couplets in the section is interpreted as recording the increasing distance of the ice margin, retreating northeastward through the Mistassini area.

The varved sediments in the Waconichi and La Perche River valleys are not in themselves straightforward indicators of either a given water level or a certain lake. They, in fact, may have been déposited in Glacial Lake Ojibway or in a lower and later proglacial lake in the Mistassini basin. If, however, they represent annual rhythmic deposition, then they indicate that a certain glacial lake lasted in the Mistassini basin a minimum of 160 years at the La Perche River site and 210 years at the Waconichi River site.

Lacustrine sediments in the Brock River Lowlands consist of rhythmically bedded silt and fine sand, occuring throughout the Lowlands at altitudes below 400 m. They were observed at five locations within the first 22 km of the Rupert road, namely at 8,7, 10,1, 12,9, 20,3, and 21,2 km. Kilometers are measured from the junction of this road with Albanel road. Most of the exposures are low cuts along the roadside ditch and show the layered silt below a sand cover of variable thickness. Best exposures are at 8,7 and 20,3 km, respectively near Chebistuan Creek (Site 3, Fig. 43) and Barlow River (Site 4, Fig. 43).

Near Chebistuan Creek, at about 400 m elevation, the ditch on the north side of the road exposes about one meter of rhythmically bedded very fine sand and silt. Within any one layer, the sand grades upward into brownish silt and the upper contact of the silt with the next overlying sand layer is sharp. The sand-silt couplets are about 16 mm thick. An estimated 60 couplets are exposed. A layer of medium sand 70 to 80 cm thick overlies the sequence.

Near Barlow River, at around 395 m elevation, 1,5 m of rhythmically bedded silt and clay are exposed in the ditch on the northwest side of the road, just north of the bridge across the river. The exposure is about 150 m long. The upper 20 to 80 cm of the section is oxidized. The couplets which are on the average 2 cm thick, consist of light-toned silty layers which grade upward into laminated, darker-colored clay layers. An estimated 75 varves are exposed.

The exposures of lacustrine sediments along the Rupert road discussed in the foregoing paragraphs, are well below the altitude of the Glacial Lake Ojibway strandlines (Fig. 41) in the Brock River Lowlands indicating that the sediments were deposited in Glacial Lake Ojibway under a water depth of 55 to 60 m. If the sediments represent annual rhythmic deposition, then they indicate that Glacial Lake Ojibway occupied the Lowlands during a minimum of 75 years.

Numerous low bare bedrock outcrops occur in the sand plain of that part of the Brock River Lowlands where the lacustrine sediments are found. The sand cover and the bare bedrock knobs are additional indications that a glacial lake once covered this region. Along the Rupert road, the continuous sand cover and the bare bedrock knobs are not found north of about km 35, at ca. 425 m altitude. North of this point, the terrain is covered mostly by till, outcrops are scarce, and sand occurs only in the valleys associated with eskers. The relatively sharp limit between the two contrasting landscapes along the Rupert Road, as well as the previously noted absence of strandlines in the hilly terrain north of the Lowlands, suggest that Glacial Lake Ojibway water level at least below ca. 425 m altitude receded while the ice margin was around or slightly north of km 35 along the Rupert road.

4.3.3. De Geer moraines

De Geer moraines are small morainic ridges which are generally thought of having been formed at the margin of a glacier retreating

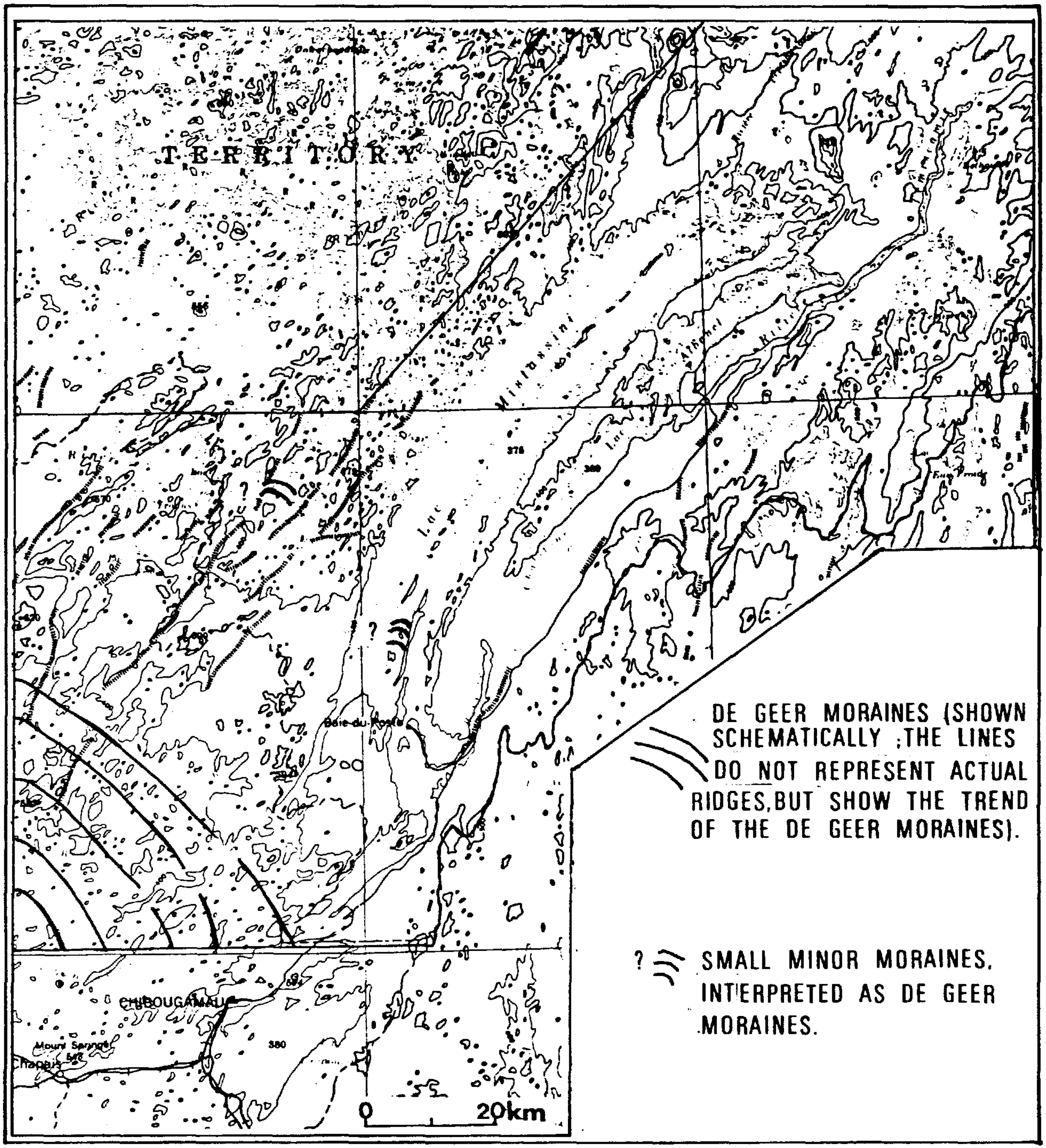



FIGURE 45. DISTRIBUTION OF THE DE GEER MORAINES, MISTASSINI AREA.

in a body of standing water (Elson 1968, Mickelson and Berkson 1974, Barnett and Holdsworth 1974). They have been known under various names since they were first described by De Geer (1889) in Sweden. The name De Geer moraine was suggested by Hoppe (1959). The ridges are small features, generally 1 to 10 m high, 5 to 40 m wide, extending laterally for several hundred meters, and occurring in succession, spaced 100 to 300 m apart (Elson 1968).

De Geer moraines are well known from the Opémisca area where they were described under different names by Mawdsley (1936) and Norman (1938) (see Previous works, Chapter 1). Ignatius (1956) mapped a tract of these moraines in an area west of Chibougamau. All these moraines are found in the low parts of the Opémisca area, well below the strandlines of Glacial Lake Ojibway. Shaw (1944) mapped the northern limit of the distribution of the moraines in the Mistassini area and concluded from it that Glacial Lake Barlow-Ojibway did not extend northward into a good part of the Mistassini basin.

During the present reconnaissance work, the De Geer moraines of the Mistassini area were mapped from aerial photographs (Fig. 45). On aerial photographs, these features are readily distinguished from ribbed moraine on the basis of their smaller size, regular spacing, lateral continuity, and lack of sinuosity in detail. However, on small scale aerial photographs, such as those used in the reconnaissance study, some other types of minor moraines described in the Témiscamie area could not be easily distinguished from short De Geer moraines. Consequently, the present map (Fig. 45) applies to the well developed, easily identifiable De Geer moraines only. The small short, morainic ridges observed in the lowlands west of the Lac Mistassini north of the Broadback-Rupert divide, and other minor moraines in the Baie-du-Poste area (Fig. 45) might also be De Geer moraines.

The map in Figure 45 shows that most of the well-developed De Geer moraines are located in the Brock River Lowlands. Their limit of occurrence, as mapped in the present work, corresponds to the limit established earlier by Shaw (1944).

In the Lowlands, the ridges are about 20 m or less wide, and individual segments may be as long as 800 m. A single ridge may be traced with gaps over lengths of a few kilometers. The ridges are better developed, more continuous, and more closely spaced below about 365 m altitude in the extreme southwest part of the area, but occur up to about 425 m farther north in the Lowlands. Spacing, defined as the number of ridges encountered in a given interval on selected aerial photographs, ranges from 130 to 240 m. Based on the elevation of the Glacial Lake Ojibway strandlines in the Lowlands, the De Geer moraines were formed under depths of water of about 30 to more than 100 m.

The northern limit of the well-developed De Geer moraines (Fig. 45) is not in itself a conclusive evidence for the maximum northern extent of Glacial Lake Ojibway in the area, since other factors, such as water depth, ice thickness, activity at the ice margin and amount of debris in the ice, are also likely to be involved in the formation of these ridges (see Vincent 1974). Similarly, the presence of De Geer moraines in the lowlands west of Lac Mistassini cannot be considered either as evidence that Glacial Lake Ojibway extended to that location since the ridges there could have been formed just as well in a later water body. However, the lack of widespread development of De Geer moraines in most of the Mistassini basin, where water depth in Glacial Lake Ojibway would have exceeded 30 m, as well as the absence of high level strandlines in the same area, suggest that the lake did not extend into much of the Mistassini area.

#### 4.3.4. Biogeographic evidence

Dadswell (1974) sampled over 700 lakes in eastern North America in order to establish the distribution of a group of "relict" organisms that he refers to as the "postglacial opportunists". The group is composed of the following crustaceans: *Mysis relicta*, *Pontoporeia* "*affinis*", *Limnocalanus macrurus*, and *Senecella calanoides*. In the words of Dadswell (1974, p. 3) "certain characteristics of these animals limit their dispersal to movement primarily through bodies of standing water". The characteristics are as follows: a) they swim poorly against current, b) they show a pronounced light-avoiding tendency and, therefore, tend to occupy deep water (*Pontoporeia* is completely benthic), and c) they do not have a long larval stage in their life cycle. For these reasons, the animals are considered incapable of active dispersal up-current, and passive dispersal by wind or waterfowl is considered very unlikely. If the latter was the case, adults would be subjected to it, and it is improbable that they could resist dessication during long distance dispersal (Dadswell 1974).

The distribution of these organisms in eastern North America shows an excellent correlation, on a large scale, with the areas formerly covered by proglacial lakes, as established on geological evidence. Martin and Chapman (1965) demonstrated the exact relationship between the distribution of a group of "relict" forms and the extent of Glacial Lake Algonquin, in Ontario. Part of the data from Dadswell (1974) were used by Vincent and Hardy (1977, 1979) in their reconstruction of the successive phases of Glacial Lakes Barlow and Ojibway and they found a perfect correlation between the distribution of the organisms and the extent and water levels of the different phases of the lakes.

Seventeen of the lakes examined by Dadswell (1974) are located within the Opémisca and Mistassini areas (Fig. 46). The lakes in which one or more of the organism were found will be referred to here as "positive" lakes; and those devoid of any organisms as "negative" lakes. In his work, Dadswell (1974) used a number of physical parameters in order to establish the ecologically favorable conditions for the establishment of the crustaceans in the limnic fauna. According to him, even the negative lakes can be shown, with reasonable

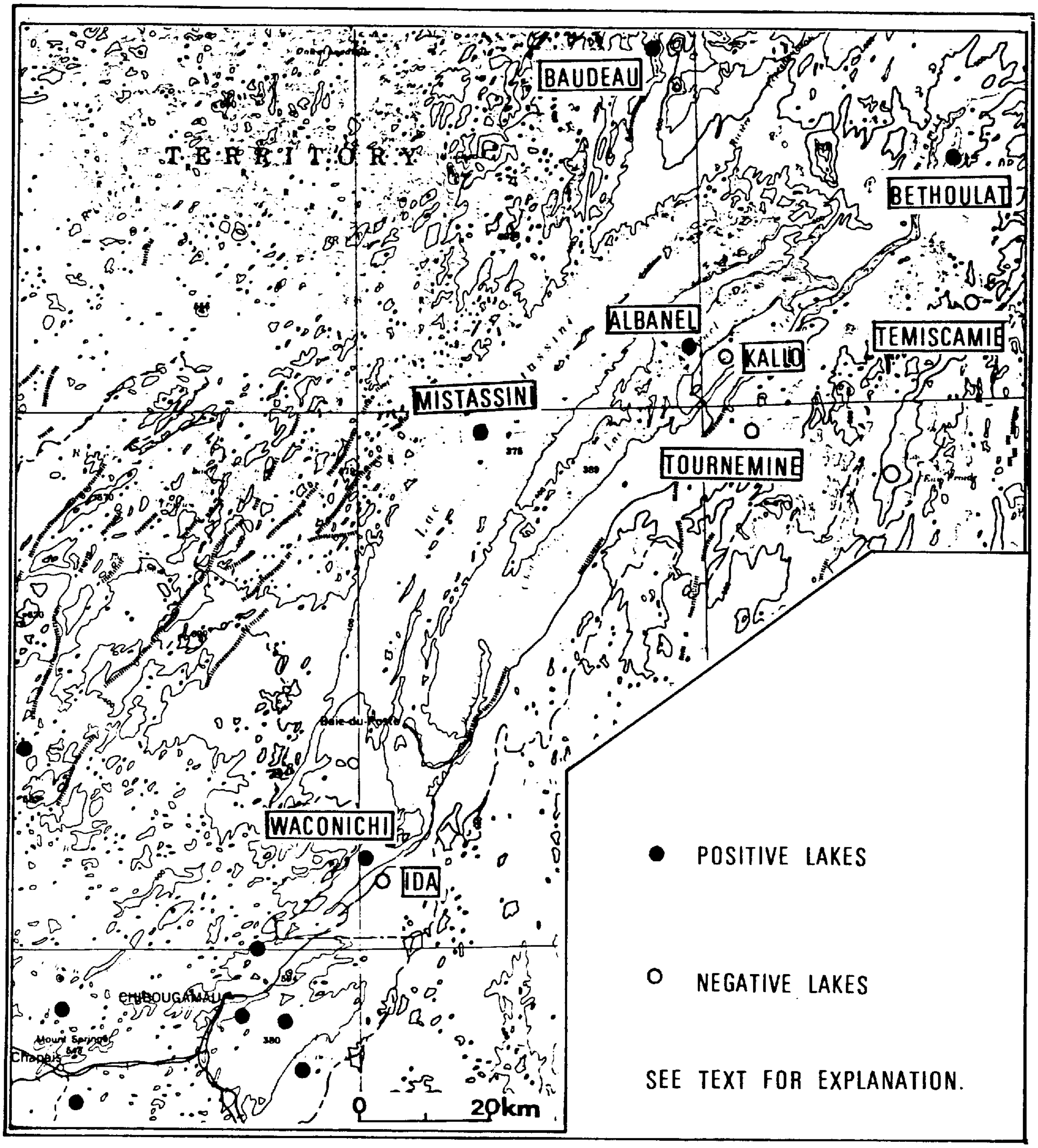



FIGURE 46. DISTRIBUTION OF "RELICT" CRUSTACEANS IN THE MODERN LAKES OF THE MISTASSINI AREA. FROM DADSWELL (1974).

confidence, to offer favorable conditions for the crustaceans and are therefore indicative that the basins which they now occupy were never submerged under a proglacial lake.

Of the seventeen lakes examined by Dadswell (1974) in the Mistassini and Opémisca areas, those that are south of the Nottaway-Rupert divide were all found to be positive. Since these lakes are well below the highest water level of Glacial Lake Ojibway, and were at one time inundated by it, Dadswell's biogeographic evidence from them is in perfect agreement with the geological evidence.

North of the Nottaway-Rupert divide, only five lakes were found to be positive, namely Waconichi, Mistassini, Albanel, Béthoulat, and Baudeau Lakes (Fig. 46). Of these, however, only the Waconichi basin could have been clearly under Glacial Lake Ojibway which then must have extended over and north of Nottaway-Rupert divide. This is the more likely, since the lowest point on the divide south of Lac Waconichi is at an altitude of 396 (-) m which is well below the levels of Glacial Lake Ojibway. The presence of relict species in the other four lakes farther north does not necessarily mean that Glacial Lake Ojibway extended into their basins. The various species in these may have originated in another lower proglacial lake. For example, the "relicts" in Lac Albanel as well as in Lac Mistassini, simply imply that the level of the proglacial lake in the Mistassini basin was at least as high as the present elevation of Lac Albanel, which is 389 m.

Of the remaining lakes the biogeographic evidence in Lac Béthoulat, which lies entirely within the Témiscamie area, is compatible with the geological evidence of flooding of the Témiscamie River valley (see Fig. 37c, Chapter 3). The fifth lake, Lac Baudeau, is located in the head area of the Eastmain drainage basin just outside the Témiscamie area. The biogeographic evidence from that lake would suggest that the proglacial lake in the Mistassini basin may have extended a long arm north along one of the valleys and may have come in contact with the basin of Lac Baudeau over a threshold on the divide which is at 396 (-) m altitude.

Several of the negative lakes which lie north of the Nottaway-Rupert divide may be used to delimit the maximum water level for the proglacial lake that occupied parts of the Mistassini area. One of these, Lac Ida, is just east of Lac Waconichi, at approximately 427 m elevation (Dadswell 1974), roughly 30 m below the projected high water levels of Glacial Lake Ojibway. This must indicate that at the time when Glacial Lake Ojibway extended into the Waconichi Lake basin the water level in it had already dropped by about 30 m.

The other negative lakes further north namely Témiscamie, Kallio, and Tournemine Lakes, suggest that the water level of the proglacial lake never reached 421 m elevation in the north part of the Mistassini area.

In summary, the biogeographic evidence indicates that Glacial Lake Ojibway extended partly into the Mistassini basin but that it did not extend to the north part of the Mistassini area. The level of the lower glacial lake in the Mistassini basin was at a minimum of 389 m altitude at the latitude of the south end of Lac Albanel, and between 396 (-) and 421 m in the north part of the area. The biogeographic evidence therefore is compatible with the geological evidence.

## 4.4. The northern limit of Glacial Lake Ojibway

Strandlines, De Geer moraines, and biogeographic data, indicate that Glacial Lake Ojibway extended as far north as the Brock River Lowlands and partly into the Mistassini basin. The general lack of features which could be related to Glacial Lake Ojibway farther north in the Mistassini area, strongly suggests that Glacial Lake Ojibway had drained before most of the Mistassini area became ice free.

Critical evidence of the northern limit of Glacial Lake Ojibway is found near North Brock Lake, at Lat 50°25' N, Long. 74°35' W, at the north edge of the Brock River Lowlands (Fig. 47). Since the site is not accessible in the field, it was examined from aerial photographs. In the vicinity of the lake, west from it, a series of four well defined drift ridges are seen on the photos, aligned in a northwest-southeast direction. The westernmost ridge is about 2 km long, more than 500 m wide, and rises approximately 30 m above the surrounding terrain. The other ridges line up with this ridge and together they extend for a total length of about 12 km in a

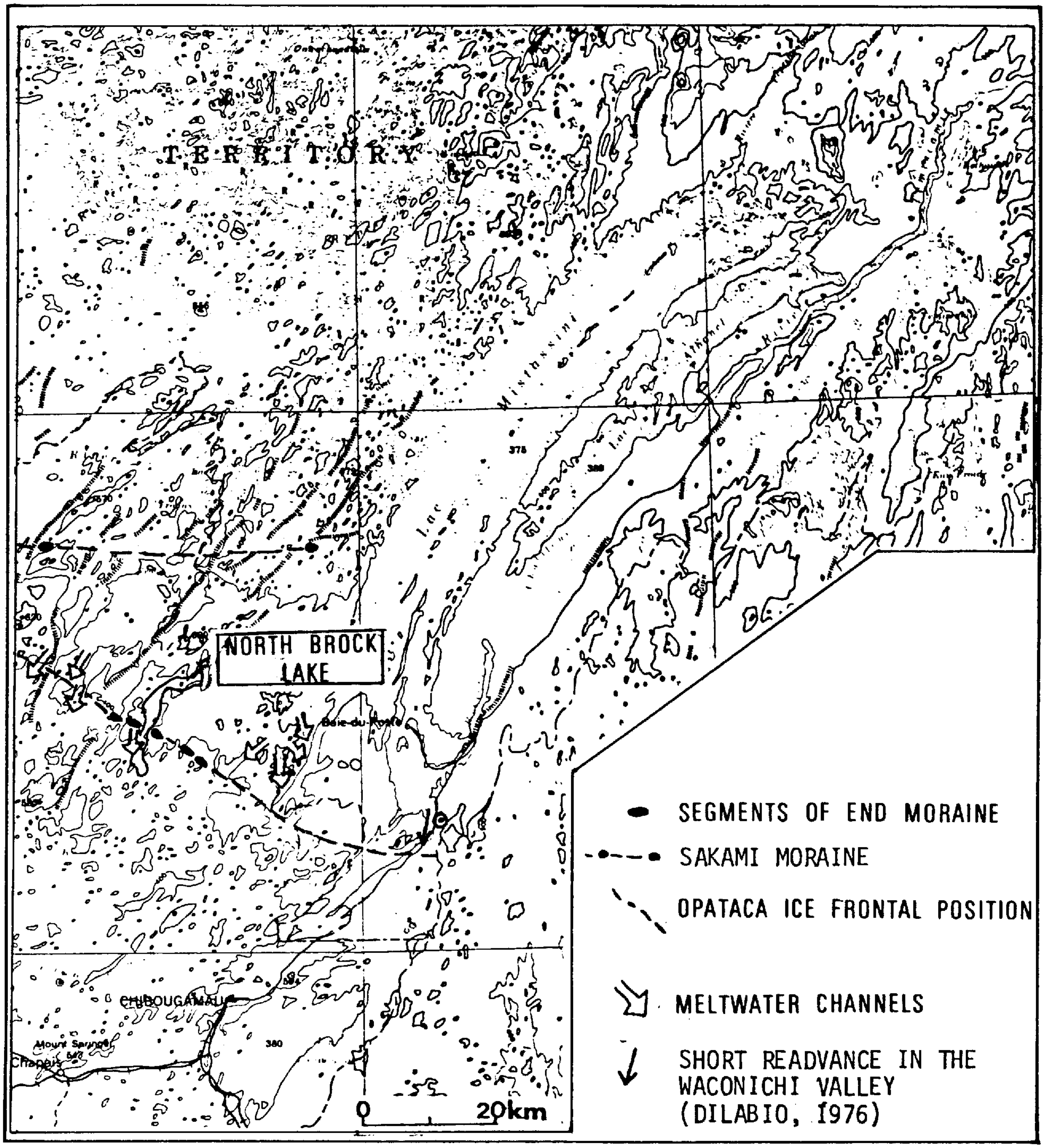



FIGURE 47. OPATACA ICE FRONTAL POSITION AND THE NORTHERN LIMIT OF GLACIAL LAKE OJIBWAY.

pattern slightly concave to the southwest. On the east side of North Brock Lake, a patch of hillocky drift lies in line with the ridges to the west. Further southeast, approximately 15 km from North Brock Lake, other comparable ridges are found on both the northwest and southeast sides of an unnamed lake at Lat. $50^{o}20'$ N, Long $74^{o}30'$ W (Fig. 47). These ridges are less than 1 km long each, they also trend in a northwest-southeast direction, and line up with the ridges near North Brock Lake. The imaginary lines which connect the two sets of ridges are conformable to the pattern of the De Geer moraines about 10 km southwest of this location. Based on the morphology, position, and configuration of the ridges at the two lakes, they are interpreted as segments of an end moraine which, although discontinuous, is relatively well defined over a total length of 30 km. Since this end moraine could not be described from field observations, it is not named here.

Southwest from the moraine and lying adjacent to it in the vicinity of North Brock Lake, a series of deeply incised meltwater channels are observed on the west side of North Brock Lake. The channels are box-shaped, more than 10 m deep, extend over short distances, and lie at a general altitude of 396 (-) m. The channels do not line up with the major valley, and are conspicuously larger in size than would be expected from post-glacial run-off. Their shape and location relative to the end moraine suggest that these channels discharged water released from the glacier when the ice front was at the end moraine. They also clearly indicate that meltwater was free to flow overland and cut the channels at elevations around 396 (-) m. Since the channels occur at the north edge of the Brock River Lowlands over which strandlines of Glacial Lake Ojibway developed at 457 (-) m altitude, the implication is that the lake must have drained prior to the ice-frontal position at the moraine near North Brock Lake.

Northwestward extension of the ice front from its position at the end moraine shows that it would pass northeast of Lac Opataca where other prominent deeply-incised channels are observed. In the intervening area, between North Brock Lake, and Lac Opataca, the ice frontal position is defined by other similarly prominent channels situated near Lac Oubliette.

Southeastward from North Brock Lake, the trend suggested by the pattern of the De Geer moraines south of this position, would bring the ice front across the Rupert road at about km 35-40, where a relatively sharp limit between contrasting landscapes was noted. Further southeastward, the ice frontal position projects across Lac Waconichi (Fig. 47). Owing to the importance of this ice frontal position as defined in the foregoing paragraphs, it is informally named here the Opataca ice frontal position.

Other examples of steep-sided channels cut by free overland flow are widespread in the hilly terrain west of Lac Mistassini and north of the Opataca ice frontal position. Particularly good examples are found west of the Baie Pénichouane of Lac Mistassini at Lat. 50°30' N.

Based on the evidence given by the meltwater channels, it is suggested that Glacial Lake Ojibway drained completely just before the ice front retreated to the Opataca position. That the northern limit of Glacial Lake Ojibway coincides more or less with the Opataca ice frontal position is further confirmed by all the other available evidence in the area. For example, the Opataca ice frontal position is 5 km north of the location where the northernmost strandlines of Glacial Lake Ojibway are recorded. It is about 10 km north of the northern limit of the well-developed De Geer moraines, and approximately 15 to 20 km north of the varve occurrences along the Rupert road. Furthermore, it is in complete agreement with the biogeographic evidence obtained from the present water bodies. Finally, there are no features north of the Opataca ice frontal position which could be related to Glacial Lake Ojibway.

The development of an end moraine at the ice margin just after the final drainage of Glacial Lake Ojibway is unlikely to be a coincidence. Prior to the drainage of the lake, the retreating ice front stood in a large body of water and the rates of frontal ablation had to be high due to the buoyancy effect leading to calving of the ice margin. Flow velocities within the ice were probably adjusted to this condition of mass-balance. Following the drainage of the lake, however, the ice margin was land-based, rates of frontal ablation were drastically reduced, and during the time while flow within the ice re-adjusted to the new condition of mass balance, the ice front may have come to a halt or even perhaps readvanced (Andrews 1973).

It was shown that the ice front at the end moraine near North Brock Lake may be projected southeastward across the Waconichi lake basin parallel with the trend of the De Geer moraines which occur to the south in the Brock River Lowlands. In the Waconichi River valley, north of the projected ice frontal position, Dilabio (1976) found stratigraphic evidence for a minor readvance of the ice margin over a distance of approximately 3 km. According to him, the readvance was restricted to the valley and involved a local ice lobe, ca. 2 Km wide. A new exposure at mile 36,2 along Albanel road (mile 0 is at Chibougamau), 2 km east of the Waconichi valley, shows about 3 m of till overlying more than 2 m of stratified sand and gravel. The till is brownish gray (5 Y 5/1), hard and compact, fissile, silty to clayey, and contains deformed inclusions of the underlying sand. The sand is well bedded, includes pockets of gravel, and is complexly deformed. While the section was only cursorily examined and would require further study, still, it is tentatively interpreted here as indicating a readvance of the ice, the same that occurred in the Waconichi valley. This readvance of the ice in the Waconichi valley area, based on stratigraphic evidence and affecting at least a four kilometer long section of the ice front, is interpreted as being correlative with the Opataca ice frontal position in the Mistassini basin. The readvance occurred as a result of a change in mass balance of the ice sheet following the drainage of Glacial Lake Ojibway.

According to various authors (Hughes 1965, Lee 1968, Prest 1970, Skinner 1973, Hardy 1976), Glacial Lake Ojibway drained completely at around 7,700 to 7,900 years B.P. This is a minimum age inferred from radiocarbon dates on shells from the Tyrrell Sea which succeeded the lacustrine inundation in the James Bay Lowlands. From that an age of ca. 7,700 to 7,900 years B.P. is assumed as a minimum age for the Opataca ice frontal position in the Mistassini area.

According to Hardy (1976, p. 244), Glacial Lake Ojibway drained when the ice front was at the Sakami moraine near James Bay. However, at that location, the moraine was largely built in marine waters of the Tyrrell Sea (Hardy 1976, p. 118) and consist mainly of chains of prominent ice-contact deltas at various altitudes of the marine transgression (Vincent 1974, Hardy 1976). The implication is that since marine transgression followed the lacustrine phase in the James Bay Lowlands, Glacial Lake Ojibway must have had drained before the Sakami moraine was built. Indeed, the present work shows that Glacial Lake Ojibway had drained before the ice retreated to the Sakami moraine within the Mistassini area, where the moraine, as mapped by Prest et al. (1968), lies from 20 to 45 km north of the Opataca ice frontal position (Fig. 47).

The determination of the northern limit of Glacial Lake Ojibway in the Mistassini area allows an interesting calculation to be made on the probable rate of recession of the ice front in the Glacial Lake Ojibway basin. This calculation is based on varve counts at two sites. At the Chebistuan Creek site, a minimum of 60 varves were counted while at the Barlow River site, a minimum of 75 varves were observed. The two sites are about 20 and 15 km south of the limit of Glacial Lake Ojibway, respectively. Assuming that the varves represent annual deposition, that varve deposition began as soon as flooding occurred, and that the ice front retreated without a halt from the two sites to the Opataca frontal position, maximum rates of 330 and 200 m/year are indicated for the frontal recession. It is interesting to note that these figures are of the same order of magnitude as the spacing of the De Geer moraine ridges, that is 130 to 240 m, in the Brock River Lowlands.

### 4.5 Glacial Lake Mistassini

Following the final drainage of Glacial Lake Ojibway, a remnant lake was left in the Waconichi lake basin between the ice front at the Opataca position and the Nottaway-Rupert divide. As the ice retreated from that position, the lake extended northeastward into the Mistassini basin and, eventually, into the Albanel basin. This lake is here referred to as Glacial Lake Mistassini.

The history of Glacial Lake Mistassini is outlined in a series of schematic maps (Figs. 48a to 48c) which show the position of the retreating ice front and the extent of the glacial lake at the successive stages of its evolution. The reconstruction presented here, is based on all the evidences of glacial lakes described earlier from the area north of the northern limit of Glacial Lake Ojibway. However, due to the scarcity of strandline occurrences in the three basins within the Mistassini area, the water levels at the various stages could not be reconstructed in detail, and, consequently, the extent of the lakes shown on the maps (Figs. 48a to 48c) is somewhat conjectural. Additional indications of the water levels are provided by the elevations of the various outlets of the glacial lake. When the water level is known from only one location, it is extrapolated from there to other parts of the basin, assuming an isostatic uplift gradient of 0,5 m/km, rising linearly in the direction of glacial retreat (NNE). This gradient is taken from that which was established on the isobases of the water planes of Glacial Lake Ojibway (Vincent and Hardy 1979). As it will be seen in Phase 3, the gradient is corroborated by independent evidence.

The history of Glacial Lake Mistassini is divided into three phases based on changes in the direction of drainage.

Phase I

During Phase 1, the lake covered, as a single body of water, the Lac Waconichi and parts of the Lac Mistassini basins (Fig. 48a). Drainage was southward into the Nottaway River system *via* an outlet located at the southwest end of the Baie Pénichouane. Presently, the outlet is a prominent channel, more than 300 m wide and approximately 10 m deep, and appears as a breach across a large esker which extends from the shore of the bay southwestward into the Brock River Lowlands. The channel is sharply defined and steep-sided where it crosses the esker. Upstream from the esker, it is not so well-defined but lines up with a series of scarps which occur discontinuously for a distance of 7 km along the west side of Baie Pénichouane. The channel leads across the divide into the head of the Barlow River which discharges into the Chibougamau River. The floor of the channel where it crosses the divide is at 396 (-) m elevation.

During Phase 1, varves were deposited in the Waconichi and La Perche River valleys at elevations of ca. 380 m. De Geer moraines were formed in the vicinity of Baie-du-Poste. Strandlines around Lac Waconichi situated at ca. 393 m altitude, were formed either during this phase,

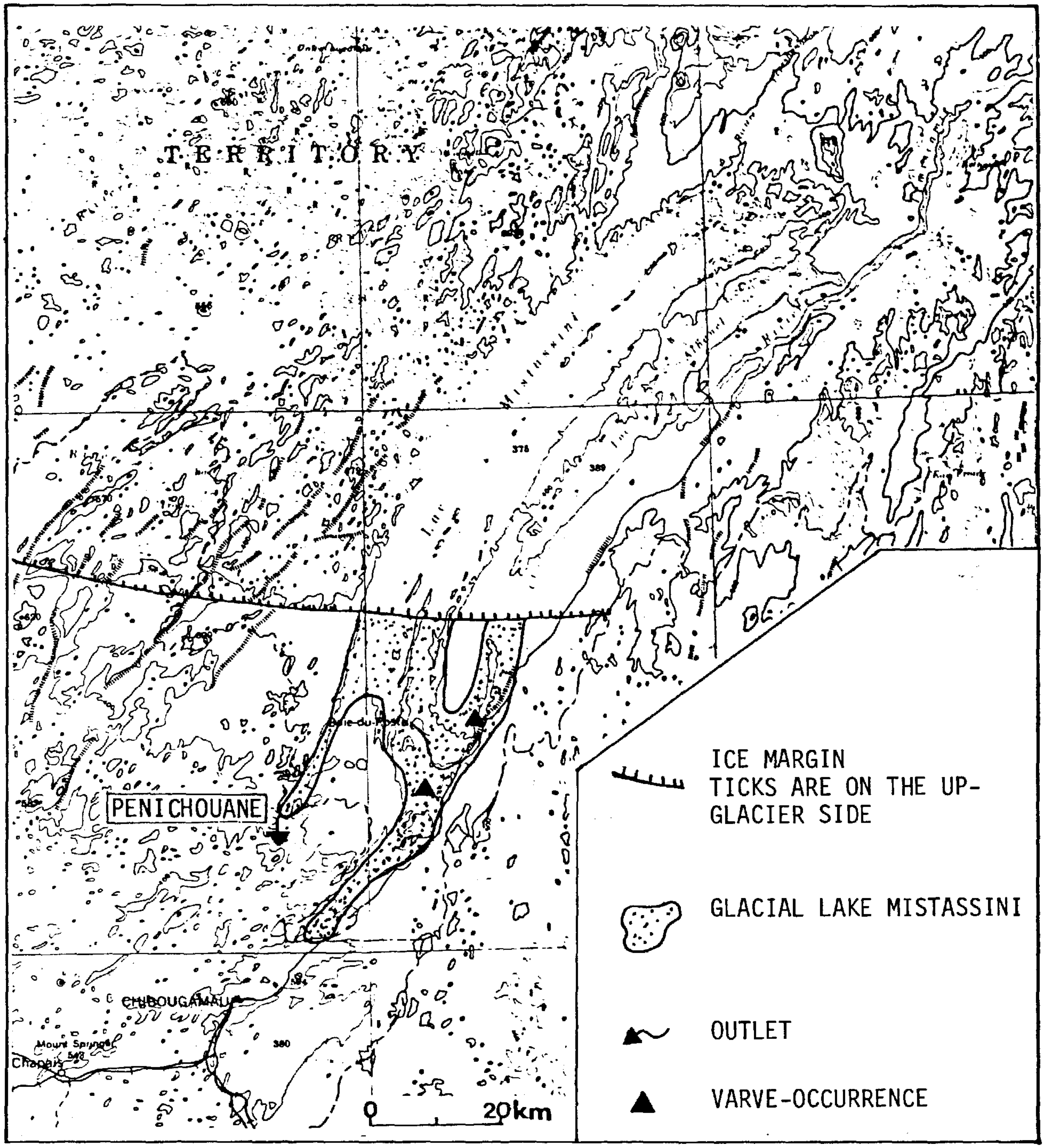



FIGURE 48 a. HYPOTHETICAL RECONSTRUCTION OF GLACIAL LAKE MISTASSINI. PHASE I.

or earlier in the remnant lake that was left behind in the Waconichi basin following the disappearance of Glacial Lake Ojibway. This remnant lake is presumed to have been in existence, however, for only a short period of time since no outlet can be seen anywhere at the south end of present Lac Waconichi.

The absence of strandlines elsewhere in the basin of Lac Mistassini, associated with Phase 1 of the glacial lake, is probably due to the geometry of the lake basin as well as to the nature of the material at the coastline, as discussed in previous sections (Chapter 3).

Reconstruction of the water level from the outlet to the ice margin shows that the water there could have been at around 412 (-) m altitude. Phase 1 terminated when the ice retreated from the position shown in Figure 48a and uncovered new, lower outlets on the west side of Lac Mistassini.

Phase 2

During Phase 2, a single lake extended into the south part of the basins of Lac Mistassini and Lac Albanel. The basin of Lac Waconichi became isolated during this phase (Fig. 48b). Drainage was westward into the Broadback River system through outlets situated near the ice front.

During the retreat of the ice between Phases 1 and 2, the lake extended gradually westward into the lowlands west of Lac Mistassini. As the Broadback-Rupert divide became progressively uncovered, the lake drained through a series of channels situated below the 396 (-) m altitude across the divide. Of these channels, those located northeast of Lac Frotet and east of Lac Troilus are of notable size.

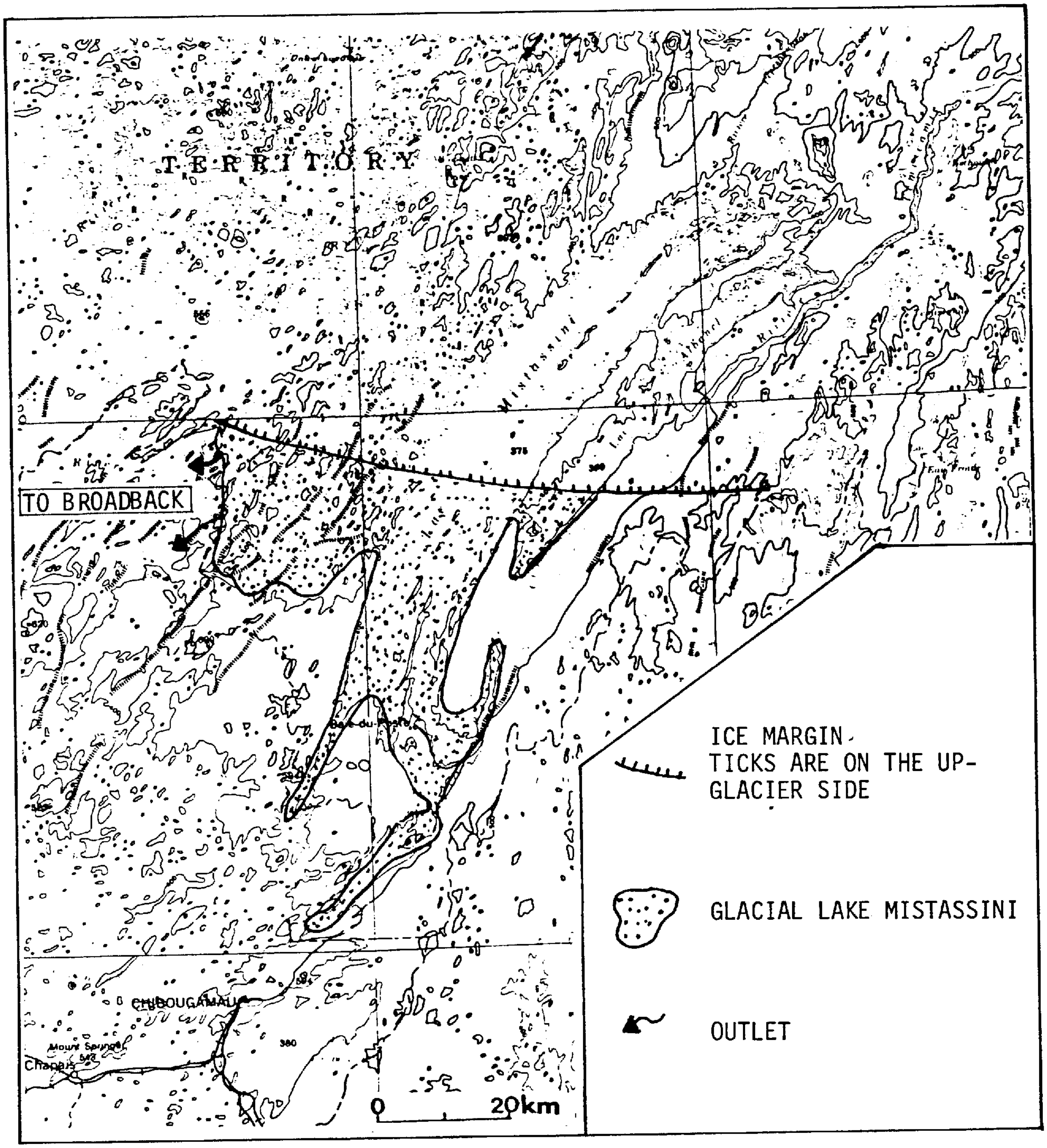



FIGURE 48 b. HYPOTHETICAL RECONSTRUCTION OF GLACIAL LAKE MISTASSINI.

PHASE 2.

During Phase 2, "relict" organisms became dispersed from the basin of Lac Mistassini into the basin of Lac Albanel. The De Geer moraines west of Lac Mistassini were formed at this time.

Reconstruction of the water level from the 396 (-) m altitude of the outlet channels in the north, southwestward to the latitude of Lac Waconichi, indicates that the water level there was probably well below 380 m. Consequently, at this time, the basin of Lac Waconichi must have become isolated from Glacial Lake Mistassini and varve deposition in the Waconichi and La Perche River valleys was interrupted. If the position of the ice front as shown in Figure 48b, coincides in time with the interruption of varve deposition in those valleys, then, the rate of recession of the ice front can be estimated based on varve counts. Ca 160 to 180 varves were deposited in the La Perche River valley while the ice front receded over a distance of 40 km. Based on the same assumptions as those given earlier in the case of the Opataca ice frontal position, further supported here by the continuous upward decrease of thickness of the couplets, the rate of frontal recession is estimated at about 220 to 250 m/year. A similar calculation based on the minimum number of varves (210) in the Waconichi River valley, indicates a maximum rate of frontal recession of about 260 m/year.

No strandlines are found anywhere in the basins of Lac Mistassini and Lac Albanel that would be associated with this phase of Glacial Lake Mistassini. In addition to the physical limitations for the development of strandlines as discussed previously, this might be due to the rapid lowering of the water level during this phase.

Phase 2 terminated when further recession of the ice front uncovered lower drainage routes leading into the Rupert River system.

Phase 3

During Phase 3, the basin of Lac Albanel and Lac Mistassini were occupied by separate, but inter-connected, water bodies, much in the same way as at the present system within the Mistassini area (Fig. 48c). Drainage was westward into the Rupert River system. Although the present course of the Rupert River would not be free of ice until the ice retreated a further 30 km northward from the position shown in Figure 48c, innumerable drainage routes across the lowlands west of Lac Mistassini were available for the evacuation of lake waters. Since that area lies outside the limits of the present reconnaissance work, not all the possible drainage ways were examined. However, a preliminary study by the Société de l'Energie de la Baie James (Min. Terres et Forêts, Québec, pers. comm.) has shown the presence of a number of drainage ways there. In their study they demonstrated that in order to dam the present Rupert River and hold the water level in Lac Mistassini at a maximum of 387 m, that is 13 m above the present level, 13 accessory dams would have to be built across the lowlands south of the Rupert River in order to prevent the drainage of the lake by other routes joining the main Rupert River course further downstream. It is inferred from that that the water level in the basin of Lac Mistassini must have receded to below 387 m as soon as the ice retreated north of the Broadback-Rupert divide and uncovered parts of the lowlands. At the same time, the water level in the south part of Lac Albanel basin, stood above 389 m.

At the time when the full course of the present Rupert River was deglaciated, the water level within the Mistassini basin receded probably to very near the present elevation of 375 m. This had to occur before

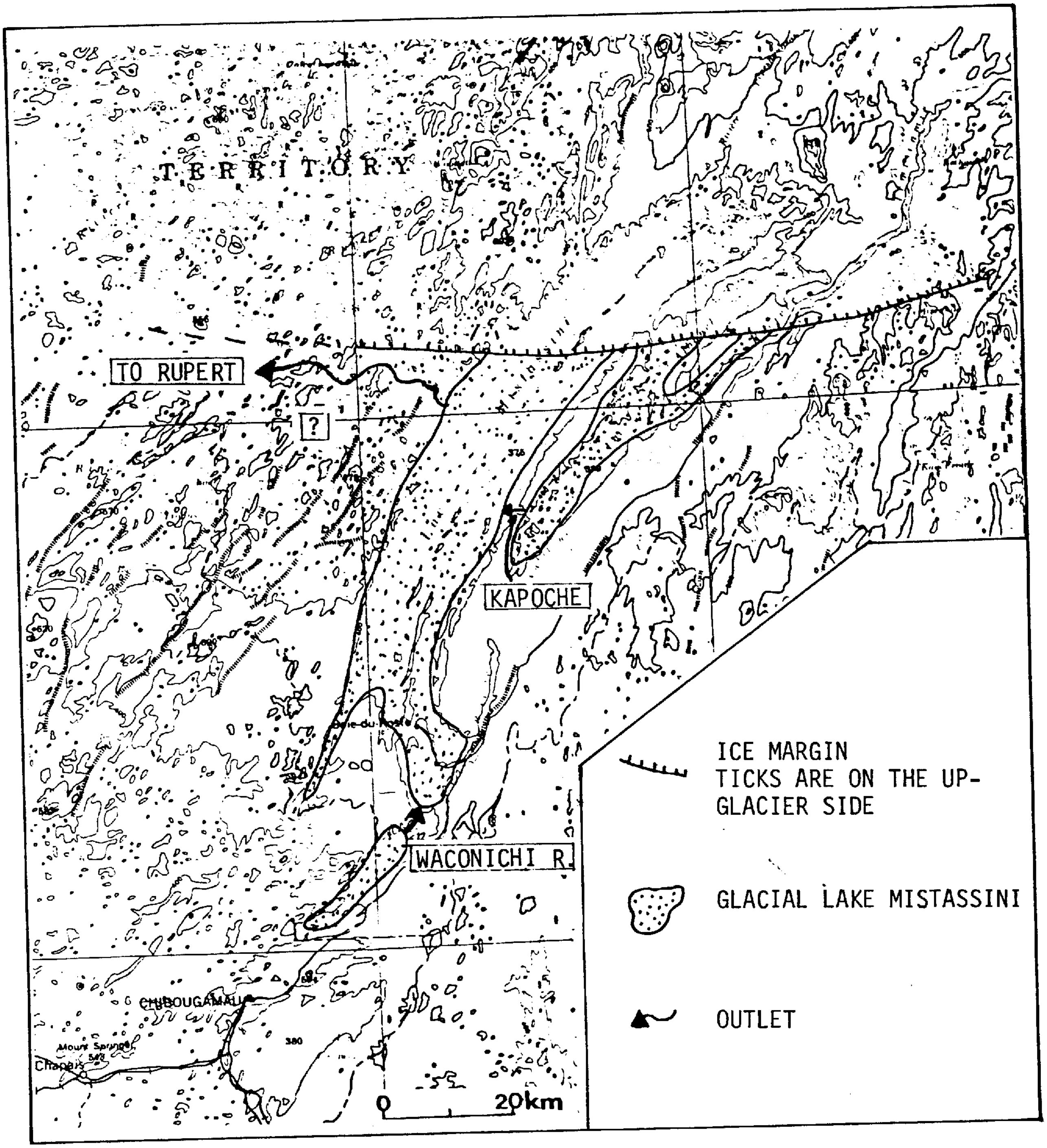



FIGURE 48 c. HYPOTHETICAL RECONSTRUCTION OF GLACIAL LAKE MISTASSINI.

PHASE 3.

the ice retreated into the Témiscamie area. Consequently, the strandlines which are situated at 398 m altitude at the northeast end of Lac Mistassini in the Témiscamie area, indicate an average linear isostatic uplift gradient of ca. 0,55 m/km rising to the northeast in the direction of glacial retreat.

Biogeographic data suggest that upon further ice recession, the glacial lake in the Mistassini basin extended an arm up one of the valleys west of the Tichégamie Mountains and flooded an area which is now part of the Eastmain drainage basin. It is doubtful, however, that the lake ever drained north into the Eastmain River system. On the one hand, full uncovering of a possible outlet over the drainage divide at the head of the valley could not have occurred until the ice retreated another 20 km north, and, on the other hand, there are no channels leading north across the divide.

Within the Albanel lake basin, up until the time when the ice retreated to the present Opitchouan outlet, drainage was into Lac Mistassini basin by way of a conspicuous abandoned channel across the Fort-Dorval Peninsula, near the south end of present Lac Albanel. The channel is more than 200 m wide and approximately 5 m deep. It has a rocky floor which lies between 389 and 396 m elevation. It is known as the Kapochépouchékochitéchinenaneoutch portage by the Crees of Mistassini (Rousseau 1948) and is here referred to as the Kapoche outlet (Fig. 48c). Strandlines at ca. 404 m elevation in the south part of Lac Albanel were probably formed at the time when the Kapoche outlet controled the water level in this basin. When the ice retreated to the present Opitchouan outlet, the strandlines situated at ca. 401 m in the north part of Lac Albanel basin within the Témiscamie area, were formed. When the ice retreated further into the Témiscamie area (Fig. 37b), the two separate water bodies in the basins of Lac Mistassini and Lac Albanel were joined via the Clairy spillway (Fig. 29).

Further evolution of the water levels in the various basins of the Mistassini area was controlled by the postglacial isostatic uplift. In the north part of the Mistassini basin, water level receded at an exponentially decreasing rate as suggested by the beach ridge sequence at the mouth of the Papaskwasati River. Since the present day outlet of the lake is located mid-way along the length of the Mistassini basin, it is likely that as corollary to the receding water level in postglacial time in the north part of the basin, the water level must have been rising in the south part of the Mistassini basin, notably in the Baie-du-Poste area, ever since the present Rupert River outlet was deglaciated.

The present reconstruction of glacial lake phases in the Mistassini area allows a speculative calculation of a minimum age for the deglaciation of the Témiscamie area based on the minimum age inferred for the Opataca ice frontal position. If the ice retreated continuously from the Opataca position into the Témiscamie area at a rate suggested by the varves in the La Perche River valley, a minimum age of 7,200 to 7,400 years B.P. is obtained for the deglaciation of the Témiscamie area at the latitude of Lac Niskuk. That estimate is 600 to 800 years older than the age inferred from the radiocarbon date obtained on the sediments of Lac Niskuk. Notwithstanding the speculative nature of the estimate and the time-gap of unknown magnitude involved in the Lac Niskuk date, the two ages are considered compatible with one another.

# CHAPTER
# 5
# GENESIS AND SIGNIFICANCE OF RIBBED MORAINE

Ribbed moraine has been described under various names in Scandinavia since the early twentieth century and in North America mostly since the mid-1950's. There are already at least a dozen theories of origin which postulate formation in supraglacial, marginal, or subglacial environments, in association with stagnant or active ice. However, very few exposures have been available to reveal the internal structures and substantiate the proposed models. In Europe, only two reports, published since 1977, have recorded the internal composition and structure of these moraines. In North America, the internal composition is known from no more than two dozen excavations, less than a meter deep.

The geomorphic characteristics of the ribbed moraine of the Témiscamie area were described in a preceeding chapter. The purpose of this chapter is to describe sections through successive ridges of a ribbed moraine, here called the Témiscamie ribbed moraine, located just off the southern boundary of the study area, and exposed in road cuts and borrow pits. A complete review of the literature pertaining to ribbed moraine is presented first.

## 5.1. Review of literature

In North America ridged topography having all the morphological characteristics of features presently called ribbed moraines was first reported by Tanner (1944). Douglas and Drummond (1953) and Wilson et al. (1953) mentioned similar features under the heading of "ribble till", in their report on aerial photographic reconnaissance of central Québec-Labrador.

Ives (1956) described an area of "rippled till" around Esker Lake in the vicinity of Schefferville, at approximately Lat. 54°15' N, Long. 66°15' W. He noted the association of the ridges with drumlins but reported that they adjoined a large esker following the axis of the depression occupied by the ridges. Natural cuts showed that the ridges were composed of apparently structureless medium- to coarsed-grained sand with few included clasts. From this, and from the assumption that the esker was formed subglacially he concluded that the ridges were also formed subglacially, contemporaneously with the esker. His observations were later challenged by Cowan (1968) who studied the same area. According to Cowan, sand is only a minor constituent of the ridges which are composed mainly of compact sandy till; ridges adjoining the eskers are of a different nature and are presumed to be short tributary eskers.

Hare (1959) reported "ripple-till" from air photo reconnaissance in Labrador-Ungava. He observed the tendency for this type of topography to occur predominantly in valleys and noted the transitional character of drumlinoid topography with transverse ridges. From this, he stated: "The impression grows that the ridges are as much a glacially moulded form as is a drumlin belt" (cited in Hughes 1964).

Lee (1959) in a reconnaissance study of the surficial geology of the east part of the District of Keewatin, N.W.T. described "ribbed minor moraines". He noted their association with drumlinoid ridges and thought that these partially overlapped the morainic ridges. The surfaces of the ridges as well as the inter-ridge troughs, are commonly littered with predominantly locally derived boulders, some exceeding 2 m in diameter. One shallow excavation showed sandy till, containing an estimated 20% clay, with apparently no structure worth reporting. He refered to the ridges as "shear moraines" and thought, that they were essentially recessionnal marginal features. He reported similar occurrences in the Sakami Lake area (Lee 1960) and later proposed that the ridges were formed "subglacially near the ice margin where the glacier rode up and over an inverted V of heavily loaded basal drift" (Lee 1962, p. 241).

Henderson (1959) described "cyclical moraines" in the vicinity of Dyke Lake, southeast of Schefferville, in Labrador. The tract he studied includes the area previously investigated by Ives (1956). Two shallow excavations, 75 cm deep, showed a hard, compact, gray sandy till, differing from the till underlying adjacent ground moraine only in that it possesses a well developed horizontal fissility. The ridged topography here has boulder fields that locally mantle its surface. Boulders, which may be of huge size, appear to be predominantly locally derived. Henderson discussed the analogies with wash-board moraines described by Mawsdley (1936) and Norman (1938) in the vicinity of Chibougamau and by Sproule (1939) in Saskatchewan which were thought to be essentially recessionnal moraines formed annually. He found that the morainic ridges near Dyke Lake were essentially similar but of larger size. Therefore, he suggested that they were recessionnal moraines formed periodically, possibly annually. An important factor which could have led to their larger size was their occurrence in areas of easily plucked and eroded bedrock which could deliver a voluminous debris load to the ice.

Hughes (1964) described "ribbed moraine" in the Caniapiscau Plateau of central Québec. He discussed fully the problem of terminology and proposed the term ribbed moraine because it described the morphological aspect of the topography, and emphasizes the collective association rather than the individual occurrence of the ridges. Hughes observed the transition from drumlinoid topography in interfluvial areas to ribbed moraine in valleys, swales or basins. In addition, he reported distinct flutings crossing ridges. Four shallow excavations in a ridge in the vicinity of Cow Lake, Lat. $52^{0}32'$ N, Long $70^{0}29'$ W, revealed a compact sandy till with abundant predominantly sub-angular clasts. Orientation of the long axis of 50 clasts was measured at four sites along a curved ridge. This showed that pebbles in the till have a statistical preferred orientation of their long axes in the direction of glacial flow, and that this is true even in parts of the ridges which curve and become oblique in trend relative to the flow direction. He concluded that "the final form of the ridges was moulded under active ice" (Hughes 1964, p. 7).

Because there is no evidence of recurrent retreat and readvance of the ice front in adjacent drumlinized ground moraine, he thought it improbable that the features could have been formed by over-riding of minor ice-marginal moraines. Although Hughes did not propose a mechanism for their origin, he reported a suggestion by J. Fyles that the formation of the ridges is perhaps related to hydrostatic pressure at the ice-margin in ephemeral proglacial lakes impounded in the valleys or depressions in which the ridges occur. However, Drummond (1965) found no evidence of glacial lakes associated with ribbed moraine in the Cambrian Lake area of Labrador.

Cowan (1968) studied the pebble fabric of till in about 20 shallow excavations in tops and sides of ribbed moraine ridges near Schefferville. He found that the ridges were composed predominantly of "very stiff" sandy till and did not note any difference between the till composing the ridges and that underlying adjacent drumlinized ground moraine, nor did he find evidence of variation in composition along individual ridges. The following conclusions were reached: the ridges bear no relationship to eskers and appear to be antecedent to them; they do not appear to be related to any long lasting proglacial lake; their association with drumlinoids and fluted ground moraine suggests that they were formed at a late stage in the glacial recession. Pebble fabric studies showed that the clasts generally have their long axes parallel to the glacial flow direction and that this is most consistent on the proximal sides of straight ridges. In areas of curved ridges, the pattern is less regular and some fabrics have long axes trending normal to the ridges or at some intermediate angle between the ridge and the drumlinoid trend. He suggested that the ridges were probably formed collectively by pushing and over-riding of material by re-activated ice.

Elson (1968) reviewed the general characteristics of "wash-board moraines and other minor moraine types"; he adopted the term ribbed moraine from Hughes (1964), and distinguished this type from De Geer moraines, minor moraines, swell and swale topography, and rectilinear till ridges. He pointed to the similarity between ribbed moraine and the Rögen moraine of Swedish authors. He suggested that the regular spacing of some of the minor moraine types may be the result of some "searching" process "tending to maintain a uniform dissipation of the glacier's energy toward the ice margin" (Elson 1968, p. 1218), analogous to the regular sinuosities, riffles and pools of streams.

Shilts (1977) shows an aerial photograph of a field of ribbed moraine east of Kaminak Lake, in the Keewatin District, which is strongly suggestive of "plates of sediments lying on the back of one another".

Carl (1978) described a "ribbed moraine-drumlin transition belt" in the St. Lawrence Valley, New York. He proposes an hypothesis that considers "ribbed moraine as till megaripples produced by glacial overriding". Underlying his hypothesis is the similarity in the geometry and arrangement of the ribbed moraine features to stream bedforms, namely the "fairly regular spacing ..., some diversity of adjacent forms, a tendency for similar forms to cluster, and the occurrence of forms that can be considered end members of a series" (Carl 1978, p. 564). However, the assignment of the features he describes to ribbed moraine is in some doubt because these were interpreted earlier as remoulded and modified drumlins due to ice advancing from a different direction (MacClintock and Stewart 1965, Terasmae 1965).

Ridges topography currently called Rögen moraine has been known in Sweden since early reports by Hogböm (1894), Fröden (1913) and Tanner (1915). Their name is in reference to the type area of Lake Rogën, in Harjedalen, western Sweden. In 1969, J. Lundqvist published a paper entitled "Problems of the so-called Rögen moraine" and much of the pre-1969 Swedish literature review presented hereafter is taken from that report.

In early reports, the ridges were considered to be essentially end moraines, on account of their orientation transverse to the main ice flow direction. Tanner (1915, 1944) thought that they were crevasse fillings in areas of stagnant ice. G. Lundqvist (1937) agreed with Tanner and considered the ridged topography to be a special type of dead-ice moraine. The ridges appeared to have a profusion of boulders on their surface, and these are partly buried, which led him to suggest that the moraines were associated with melting but still active ice or with a re-activated ice margin. He (G. Lundqvist 1948) found that the orientation of the long axes of the clasts embedded in the till composing the ridges was mostly transverse to the ridges, but that this was not entirely consistent.

Granlund (1943) suggested that the ridges were formed subglacially by squeezing of till into open basal crevasses by the pressure of overlying ice on the material adjacent to the underside of the crevasses. Mannerfelt (1945) postulated a complex origin near the ice margin involving subglacial as well as supraglacial deposits. Hoppe (1952) found that the clasts were oriented normal to the ridges even in places where the trend of the latter is oblique to the glacial flow direction. This led him to accept and emphasize Granlund's hypothesis of subglacial squeezing under active ice. He stated that as well as he could judge, eskers appeared to be younger than the ridges. In the east part of the type area of Lake Rögen, he observed that the material in one ridge was very compact, and that the sandy matrix of the till often contained "sediment veins" giving the material a stratified aspect. This type of till, which is common in Sweden is known as Kalix till (Beskow 1935). According to J. Lundqvist (1969), Kalix till is a type of basal till consisting entirely of water-sorted (?) sediments with very irregular slightly folded bedding, covered with a thin mantle of more ordinary, often boulder-rich till. It is apparently common in Rögen moraine. Fromm (1965) reported Kalix till in ridges similar to Rögen moraine, and J. Lundqvist (1969) observed in a series of hummocks which have a ridge-lake appearance, a thin mantle of "ordinary basal till with abundant large boulders overlying Kalix till, over 8 m thick".

In accord with his hypothesis of subglacial squeezing, Hoppe (1957) considered the Rögen type moraine to be a ridged type of "hummocky moraine landscape associated with active ice". Another type of this category of features is the Veikki type moraine characterized by poorly developed trends and rim-ridged plateaux. According to him, pressure structures and shear planes are common in the interior of these hummocky landscapes.

In the vicinity of Lake Orsjon, Sweden, J. Lundqvist (1958) observed in a large cut through a moraine hummock associated with Rögen moraine, a layer of very coarse bouldery ablation till, 1,5 m thick, overlying 1 to 1,5 m of "glaciofluvial gravel", undisturbed and horizontally bedded, in turn overlying more than 5 m of basal till with low boulder content. The stratigraphy suggested a crevasse filling origin for this particular hummock.

Kuujansu (1967) described in Finnish Lapland a ridged and hummocky topography which he termed "Pulju moraine", a type of terrain essentially analogous to the "hummocky moraine associated with active ice" of Hoppe (1957). Pulju moraine includes ridges, 1 to 5 m high, mostly oriented transverse to the flow direction. They are predominantly sandy till comparable to till underlying adjacent areas; clasts showed a preferred orientation parallel to glacial flow direction. Locally, the surface bears flutings. He favored a mode of origin by subglacial squeezing into cracks or cavities in the basal ice.

J. Lundqvist (1969) commented on the fact that although Rögen moraine is widespread in Sweden, the internal composition and structure is poorly known for a lack of adequate deep cuts. In spite of the reports of complex stratigraphy involving Kalix till (Hoppe 1952, Fromm 1965), he had the general impression that the ridges were composed predominantly of ordinary basal till. He himself however reports on an area in eastern Jamtland, where the material composing the ridges is conspicuously more sandy than that in the surroundings. He suggested that the ridges were formed subglacially as a sort of boudinage structure, or as moulds of embryonic crevasses which resulted from tensional stress in the basal ice as it passed over depressions.

Wastenson (1969) noted that the upper surface of ridges of Rögen moraine bear distinct flutings and, furthermore, that the boulders lying on the surface are preferentially aligned in the direction of glacial flow.

In the area of Koillismaa, in southeast Finnish Lapland, Aario et al. (1974) described the transition from drumlins in interfluvial areas to ridged topography in valleys. In 1977, Aario referred to Rögen moraine as a special type of landform in an assemblage collectively termed "hummocky active ice moraine". He suggested that the transverse elements may represent forms offering the greatest resistance to glacial flow and that "the flow of ice at this point was more strongly characterized by up and down movements

(Aario 1977, p. 96). The material composing the "Rögen hummocks" is stated to be: "mainly basal till, although the upper parts may be of ablation till. The layered horizons with much sorted material are also common" (p. 91).

Minell (1977) described a section through transverse moraine ridges in the Solvbacktjarn area of western Sweden. He found the ridges to be composed of thrusted and folded beds of shattered bedrock, and till, overlain by a hard compressed, fine sandy to silty "foliated till", overlain in turn by weakly "foliated till" with occasionnal conspicuous "segregations of sand", particularly around pebbles. He suggested that the features were formed subglacially, in areas of compressive or retarded flow, with admixture of local materials becoming more apparent the longer the process has continued.

Shaw (1979) described sections in Rögen moraine ridges from three areas in central and western Sweden. The internal structure of the ridges showed folded till bodies, dislocated by thrust planes; he observed a large proportion of angular, predominantly local clasts in the sections. The orientation of the long axes of pebbles in the till showed no preferred two-dimensional orientation, but the dip of the pebbles was found to be conformable to the tectonic structure. He suggested that the ridges formed by "basal melt out of folded and dislocated englacial debris zones in areas of former compressive flow" (Shaw 1979, p. 409).

Observations of the geomorphic characteristics of ribbed moraine in the Témiscamie area are in accord with most of the previous descriptions of ribbed or Rögen moraine elsewhere. Geomorphic features observed in the main of the study area and which are newly reported are the following: (1) the ice flow direction indicated by flutings on the ridges and by transitional drumlins may diverge from that of larger ice flow features in the vicinity, (2) flutings are commonly developed as tails of drift in the lee of boulders resting on ribbed moraine.

The observations in the Témiscamie area do not support the view that ribbed moraines and eskers are co-genetic (Ives 1956), or that their formation might be associated with glacial lakes (J. Fyles in Hughes 1964).

## 5.2. Témiscamie ribbed moraine

The Témiscamie ribbed moraine is just south of the southern edge of the study area. All the observations made are from roadside cuts and borrow pits. Sections are located in reference to mile posts still present along the road; mile 0 is at Chibougamau. Altitudes were read from a pocket altimeter, calibrated to the water level of Lac Albanel (389 m) in Capotagen Bay, and uncorrected for changes in atmospheric pressure.

Methods of descriptions of the material exposed along the road differ slightly from that done for the till as observed through surficial excavations in the main of the area. Descriptions include color, firmness, surface aspects of clasts, grain-size analysis of the minus 4 mm fraction, and structure and lithologic composition. An index of firmness which is used here is the unconfined strength as measured with a pocket penetrometer (Soiltest Cl-700). Testing was done both horizontally and vertically and reported values are averages of a minimum of 10 measurements. Lithologic composition is that of the clast fraction. It is based on a minimum of 50 boulders, cobbles or pebbles counted at the sections. For some samples, an additionnal 100 to 150 grains in the fine gravel fraction were counted under a binocular microscope. Clasts which are considered locally derived are those which are from the underlying Témiscamie Iron Formation although this rock type extends 10 to 12 km in an up-ice direction from the site of the sections. Dolomite clasts may be locally derived or might have experienced a minimum glacial transport of over 12 km. Clasts which are termed erratics are quartz sandstone and conglomerate (Papaskwasati or Indicator Formations) and granite, gneiss, greenstone, and gabbro, commonly referred to as the Aphebian clastics and the Archean rocks.

The orientation of the long axis of clasts in till was not measured because the underlying bedrock is the magnetite rich Témiscamie Formation which deflects the compass needle, and because the till contains a significant porportion of clasts derived from this formation. These local magnetic fields vitiated the use of till fabric as a means of studying the structure of the ribbed moraine. Pebble fabric was measured at one location, outside the ribbed moraine, in an exposure along the road where the till overlies an iron-free member of the formation and is itself devoid of iron-rich clasts. It was assumed that the deflection of the compass needle, being of a source external to the site would not induce distortion in the diagram even though the resulting trend might be incorrect.

From a rolling lowland east of Témiscamie River, Albanel road runs northwest across the river and Kallio Plateau, then turns northeast, and finally northwest again to the shore of Lac Albanel (Fig. 49). At about 1 km southeast of the bridge over the Témiscamie River, between mileages 103 and 104, the road traverses the Témiscamie ribbed moraine.

East of the Témiscamie River, which is presumed to occupy a fault bounded valley (Wahl 1953, Neilson 1953), the underlying bedrock is mainly the upper member of Albanel Formation (Wahl 1953). However, northeast trending faults and folds also have affected the rocks, and as a result prominent bedrock ridges, composed mainly of Témiscamie Formation are present. The bedrock underlying the swale between these ridges is not exposed.

The Témiscamie ribbed moraine (Fig. 49) covers about 16 x $10^4$ $m^2$, at an altitude of 412 to 415 m, about 10-15 m above the water level of Glacial Lake Mistassini, in a basin-lake swale which has a closure to the south between two bedrock ridges. Figure 50 is a large-scale stereogram of the area of ribbed moraine, and Figure 51, the same area after the road was built, shows the location of cuts in relation to the original topography.

Figure 49. Stereo-pair showing the location of the Témiscamie ribbed moraine (square) and of other exposures of till (A, B) along the northernmost 10 km of Albanel road.

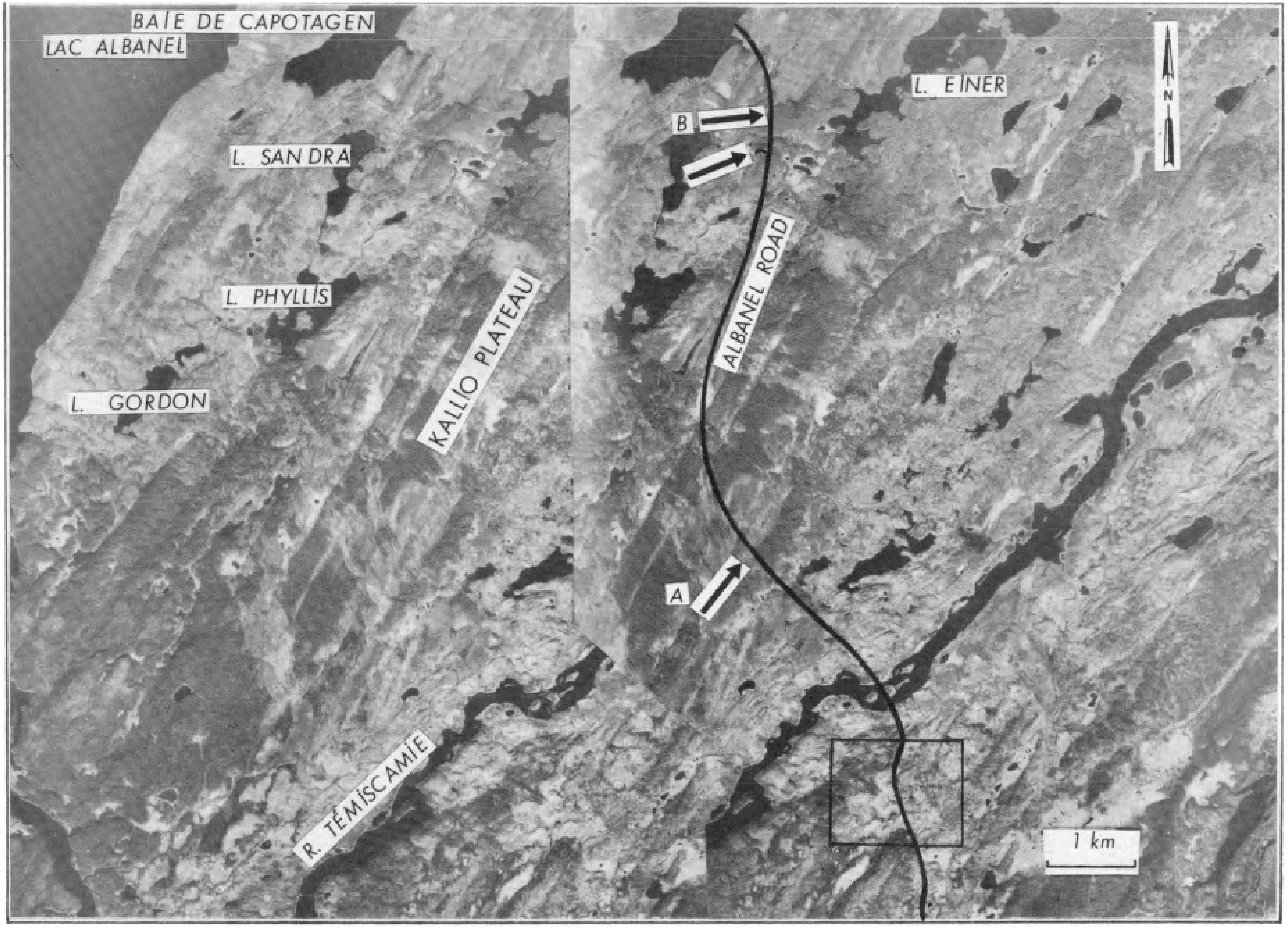

BAIE DE CAPOTAGEN
LAC ALBANEL
L. SANDRA
L. PHYLLIS
L. GORDON
KALLIO PLATEAU
R. TÉMISCAMIE
L. EINER
B
A
ALBANEL ROAD
N
1 km

Figure 50. Stereo-pair showing the ridges of the Témiscamie ribbed moraine (numbers).

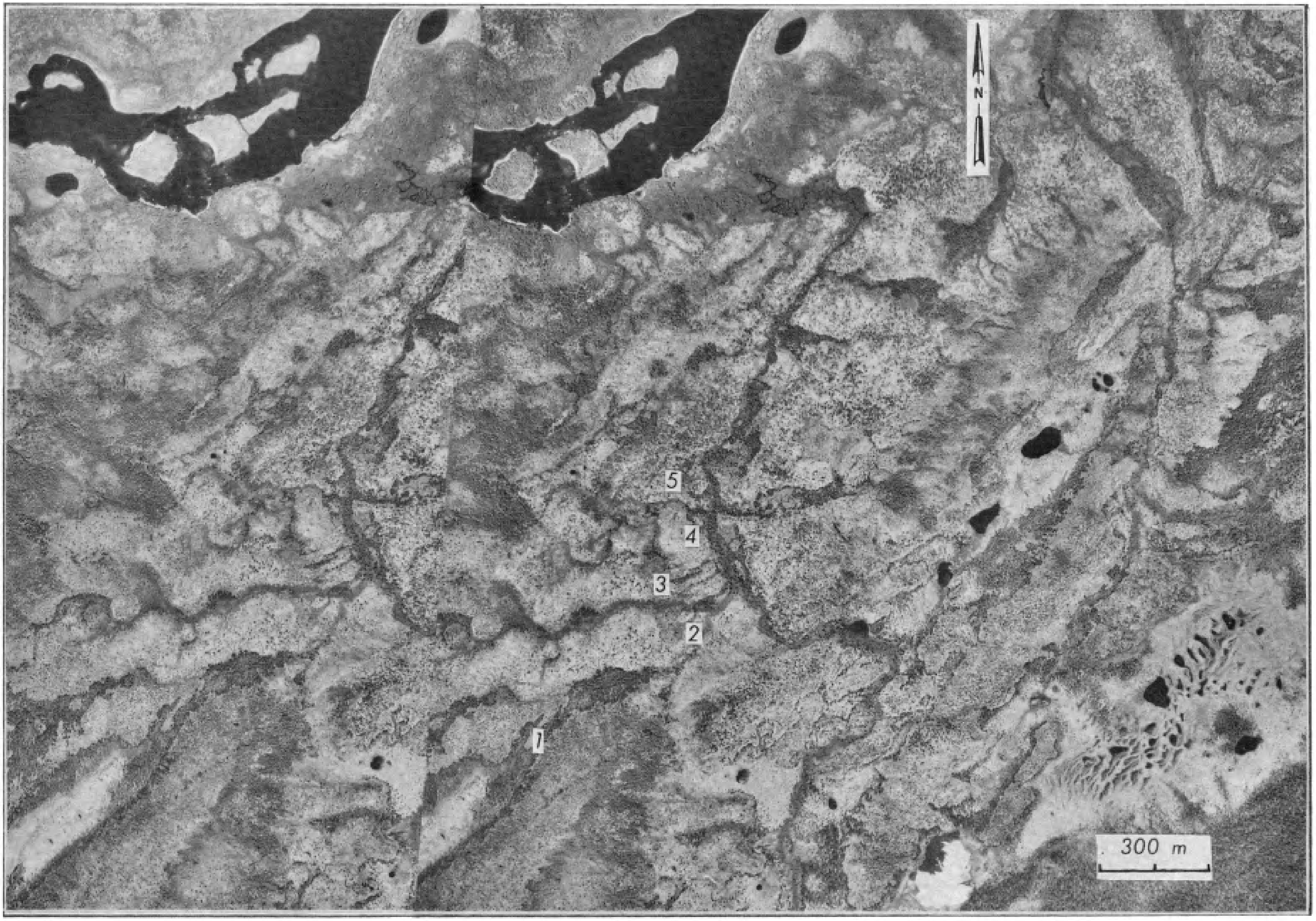
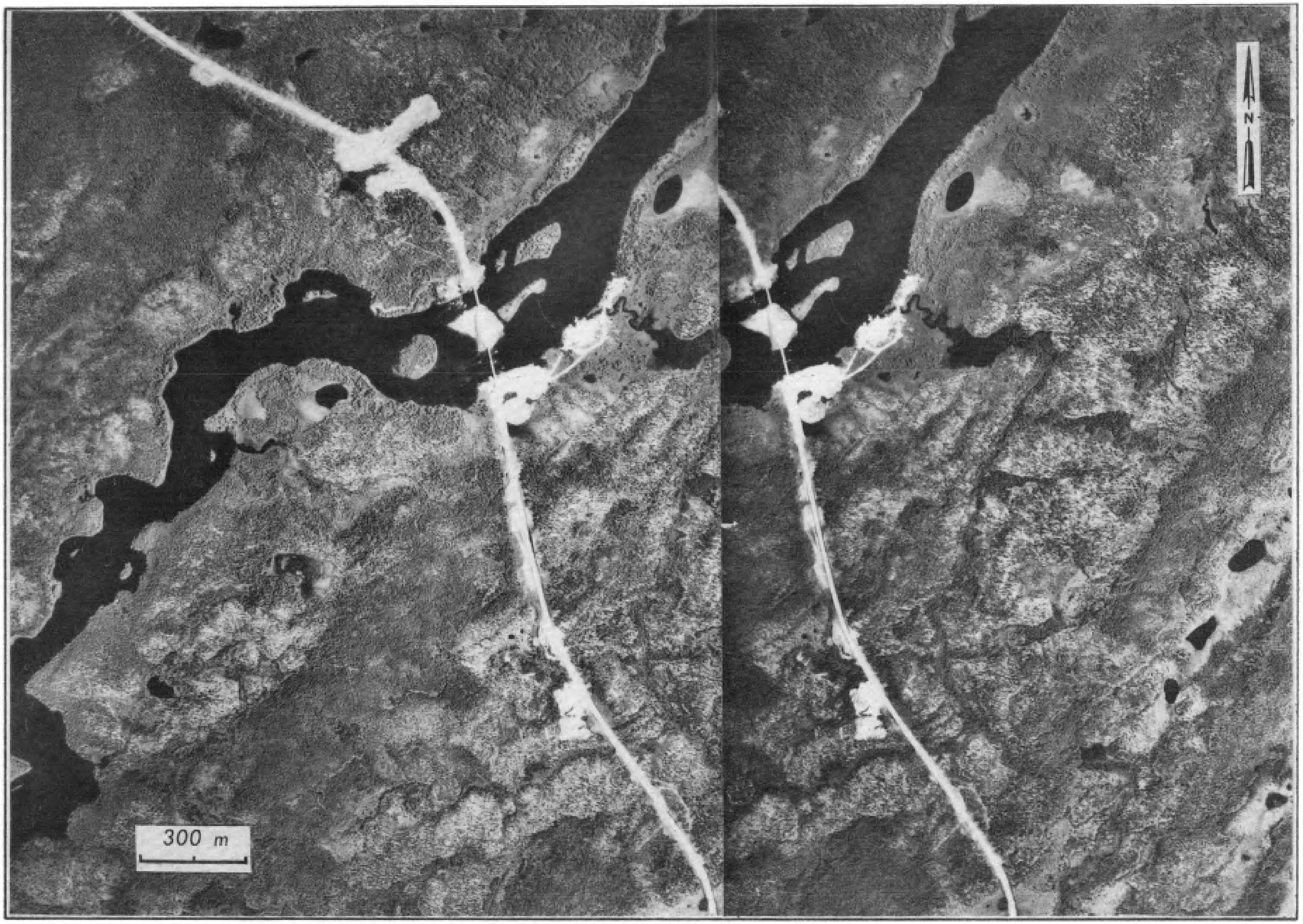

N
5
4
3
2
1
300 m

Figure 51. Stereo-pair showing the Témiscamie ribbed moraine and the location of borrow pits in the moraine.


300 m
N

The Témiscamie ribbed moraine shows all the characteristics of the other ribbed moraines in the main part of the study area (Chap. 3). The ridges trend obliquely to the main glacial flow direction which is S 25° W according to the trend of the drumlinoid ridges on Kallio Plateau and of the drumlinoid topography north-northwest from the ribbed moraine. The moraine ridges trend from S 85° E to due east; this is 20 to 25° more easterly than the orthogonal to the main glacial flow direction. The trend of the ridges is conformable to that of the reconstructed ice margin further south (Fig. 48, Chap. 4) and further north (Fig. 37) from this location.

A form line map drawn from Figure 50 is shown in Figure 52. The field is composed of 5 ridges which are numbered from south to north (Fig. 50).

Ridge 1

Ridge 1 is a small low feature, not higher than 5 m above the floor of the depression, no more than 450 m long, and about 120 m wide. The ridge appears to join two low elliptical hills aligned transverse to the axis of the ridge.

Ridge 2

Ridge 2 is the largest ridge in this field. It is 160 to 175 m (crest to crest) north of ridge 1, and is conspicuously higher, and longer. It extends N 85° E for nearly 1 km. Its maximum width is

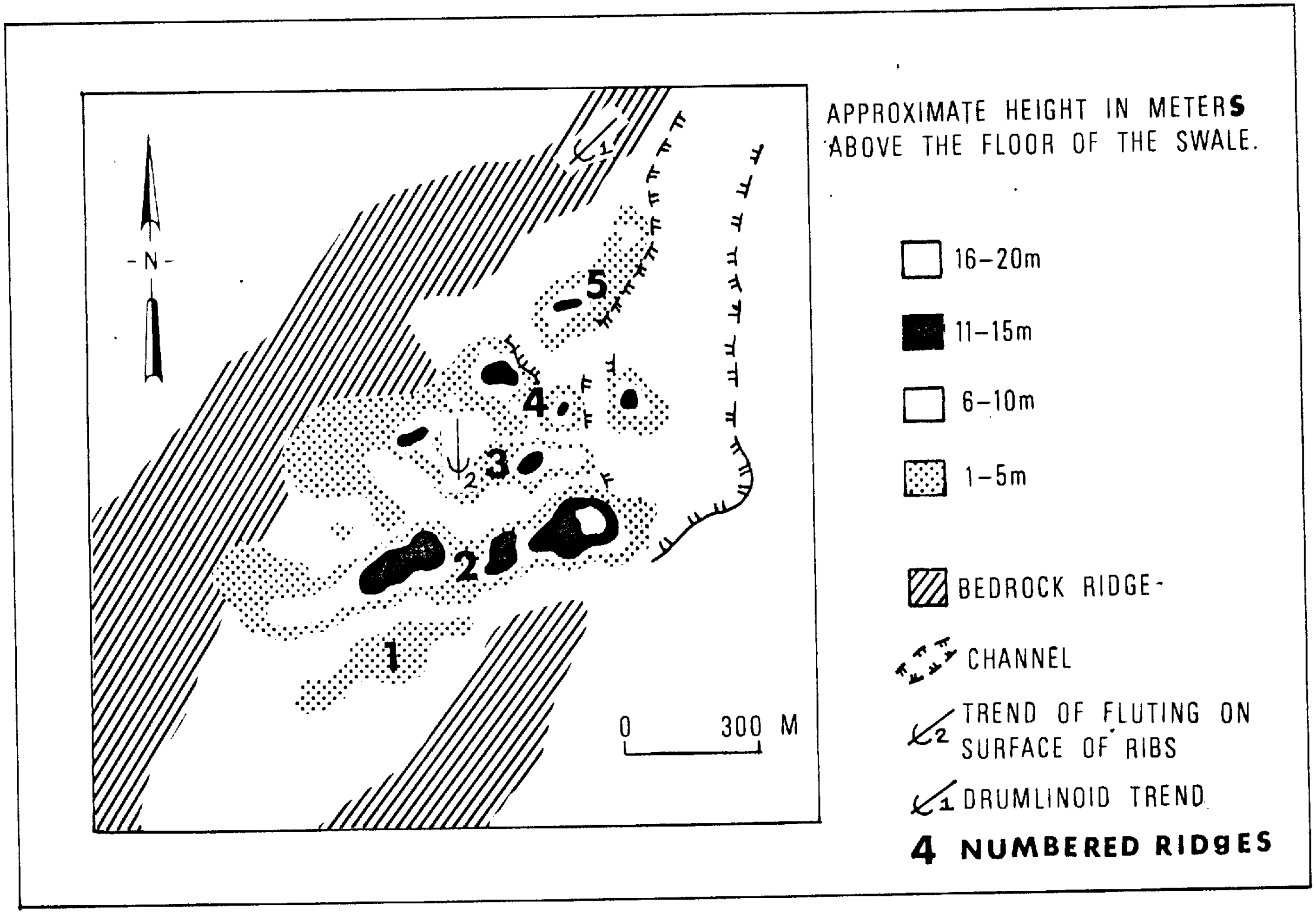



FIGURE 52. FORM-LINE MAP OF TEMISCAMIE RIBBED MORAINE; DRAWN FROM FIG. 43.

160 m, and its height is 15 m. It terminates eastward at a scarp which forms the west side of a large channel, more than 200 m wide, and 15 to 20 m deep, leading northward to the main Témiscamie valley. The significance of this channel is discussed later in this chapter. There is no clear asymmetry in the profile of the ridge. The ridge crest has a variable height, and joins three hillocks separated by saddles. In plan, the ridge is sinuous, with a wavelength of 300 to 400 m. The sinuous pattern is enhanced by the configuration of the line which joins the deepest part of the troughs situated between this ridge and the neighbouring ridges. On the proximal side, high parts of the ridge correspond to segments convex northeast whereas the saddles coincide with segments concave northeast. One saddle separating the two westernmost mounds has quite straight and steep sides, suggestive of a breach. Close examination of the surface of the ridge shows a faint, barely visible, closely-spaced lineation trending nearly at right angles to ridge. This is particularly noticeable low on the proximal side of the middle hillock. No cut exposes the material in ridge 2.

Ridge 3

Ridge 3 is 120 m north of ridge 2. It is much shorter, only 450 m long, but comparable in width and maximum height ot ridge 2. It is also terminated to the eastern end by the channel. Like ridge 2, it has a wavy outline and appears to consist of arcuate segments convex northeast. Examining the distal side of this ridge, it appears that ridge 3 could be imbricated onto the proximal side of ridge 2.

Closely spaced fluting trending slightly east of south is clearly visible low on the proximal side of the ridge, especially at the west end. This lineation disappears under the hillock in the east end of the ridge. Some of the lineations are consistently parallel to each other, and are comparable to the many examples of fluting observed in the main part of the study area, while others diverge. This divergence may be due either to the presence of other types of lineation, such as slump scars, or fault line traces, or to post-fluting slumping that modified the original trends.

A borrow pit was cut in the eastern part of ridge 3. The main face of the pit trends about north-south across the ridge. The proximal slope of the ridge is inclined at 18 degrees. The section exposes conformably dipping layers of finely stratified till (Fig. 53). The lower part of this till is a light yellowish brown (2.5 Y 6/4), compact (2 to 2,5 $kg/cm^2$), moderately sorted, bouldery (20 to 25% clasts larger than 4 mm), fine sandy diamicton. The till appears stratified from numerous closely spaced subhorizontal lenses of medium to fine sand, 1 cm or less thick. The lenses are no more than 1 to 1,5 m long, and have very gradational boundaries. Boulders are angular, locally derived, and some argillite clasts originating from the Témiscamie Formation bear striations. At places thicker lenticular zones, 15 to 20 cm thick, are concentrations of poorly sorted coarser-grained matrix. A sample from one of these is classified as a coarse sand till. Boulder content decreases upward and in the upper part of the till accounts for only 1 or 2% of the grain size distribution. The uppermost 25 cm of the section is a pebbly to bouldery, complexly deformed and contorted, moderately sorted, fine sandy diamicton. This material is also compact (2,5 to 3,0 kg/cm$^2$); contortions appear as deformed sand lenses. At about mid-length of the proximal slope, and restricted to the upper 25 cm of the section, an asymmetric fold is observed (Fig. 54). The axial plane trace of this fold dips north and the upper limb is conformable to the slope. This is suggestive of a drag fold with movement from north to south along and up the proximal slope. Toward the central part of the ridge, still in the upper 25 to 30 cm of the face, near-vertical lenses in this deformed unit are truncated by the surface of the ridge (Fig. 54b). Clasts in the upper part of the section also are mainly locally derived (Fig. 53).

The general attitude of the lenses, which is conformable with the proximal slope, shows that the proximal slope of the ridge is a dipslope. The types of deformation observed in the upper part of the section, suggest that glacier flow occurred over the ridge during or after deposition.

Ridge 4

Ridge 4 is an alignment of three almost isolated hillocks, about 15 m high, and 65 to 70 m in diameter, separated by flat-floored

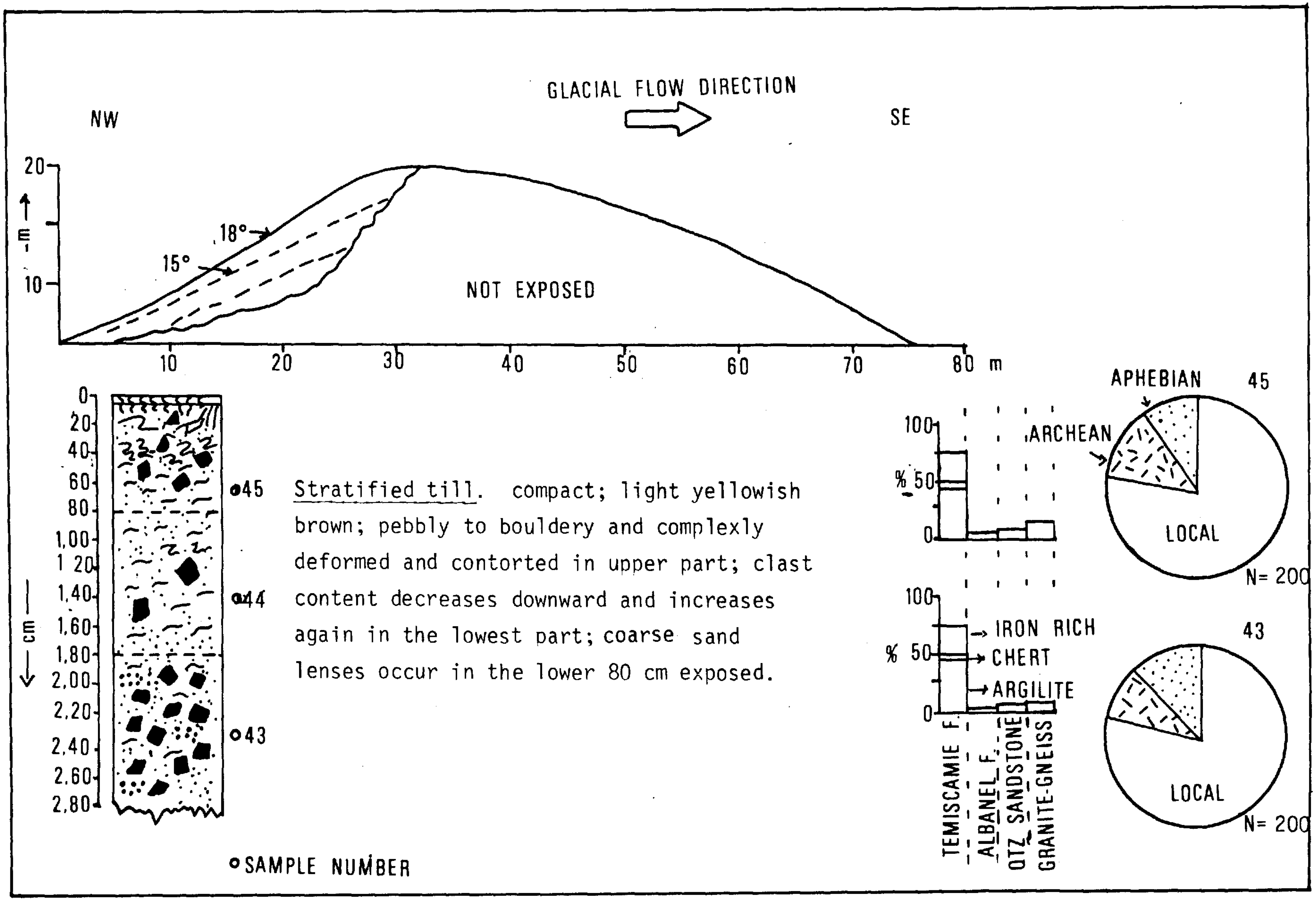



FIGURE 53. SUMMARY OF OBSERVATIONS IN BORROW PIT CUT IN RIDGE 3, TEMISCAMIE RIBBED MORAINE.

Figure 54a. Asymmetric fold and contortions of the sand lenses in the upper part of the stratified till, ridge 3, Témiscamie ribbed moraine.

Figure 54b. Near-vertical lenses of sand in the upper part of the stratified till, ridge 3, Témiscamie ribbed moraine. The lenses are truncated at the surface of the ridge.

gaps. The east gap has steep sides and its east margin coincides with the west boundary of the large channel that also cuts all the other ridges. The proximal side of the western hillock appears to have been eroded by water flowing in a tributary channel extending along the north side of the ridge into the larger main channel. A surface lineation, faintly developed, is seen on close examination of the lower part of west slope of the westernmost hillock. This lineation is comparable in trend, spacing, and aspect to that observed on the surface of ridge 3.

As may be seen on Figure 43, exploitation in a gravel pit has almost completely erased the central hillock. Sections studied are in the remnant distal side of this hillock (Fig. 55). The faces are about at right angles to each other, one trending S 60$^{0}$ E and facing north, the other trending N 20$^{0}$ E and facing east. The section shown in Figure 55 is a compilation from both faces which show essentially two units separated by a sharp contact.

The lower unit is a compact (1 to 1,5 kg/cm$^2$), pale brown (10 YR/6/3) to light yellowish brown (2,5 Y 6/4), bouldery, poorly sorted, fine sand till. The maximum clay content is 1% and occurs in the lower part of the unit. The lower half of the unit is massive with dispersed boulders, while the upper half becomes progressively more bouldery upward and is stratified. Individual lenses are 1,5 to 2 cm thick, subhorizontal and slightly undulating with a wave length of 12 to 14 cm. They show minor normal faulting,

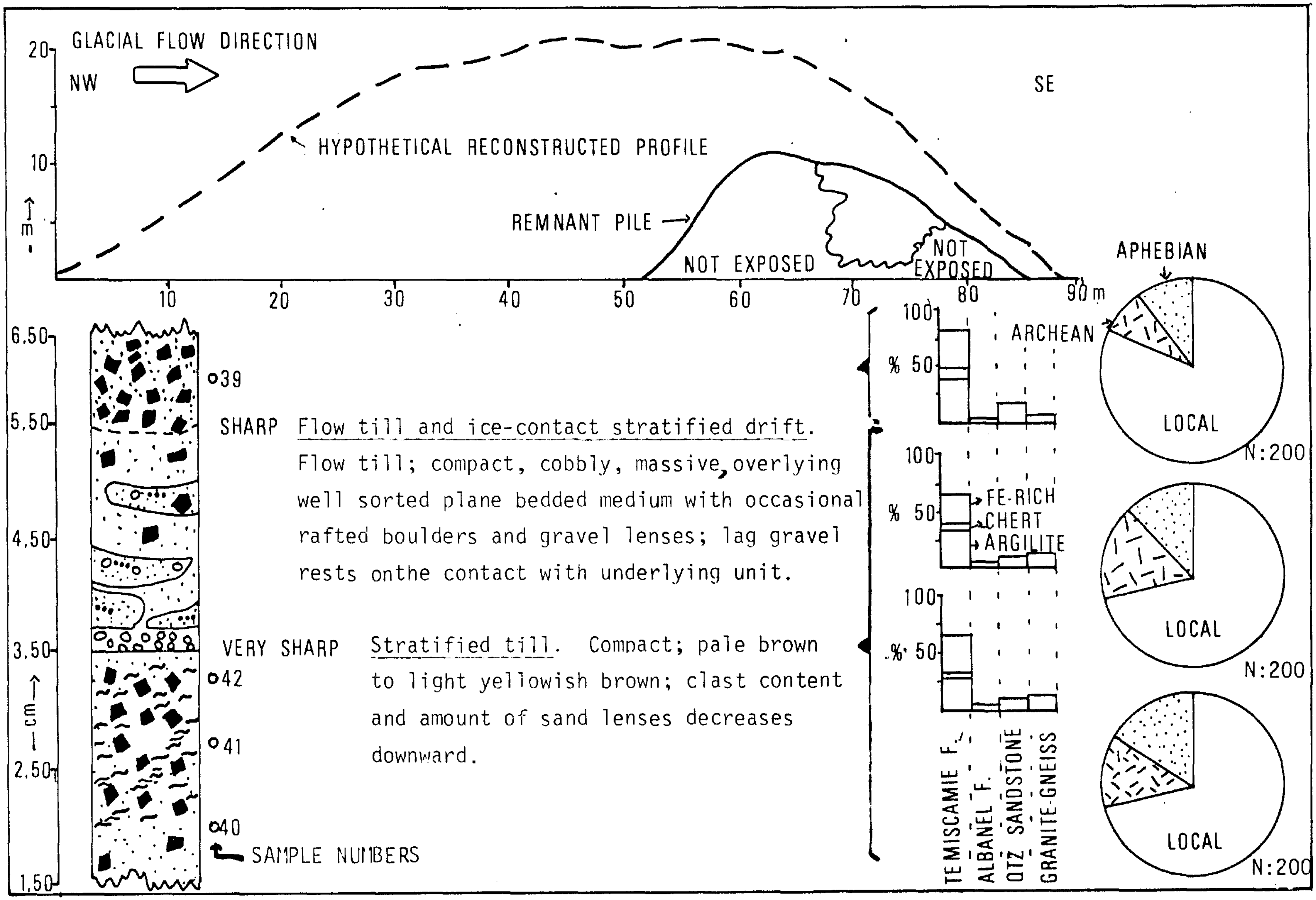



FIGURE 55. SUMMARY OF OBSERVATIONS IN BORROW PIT, CUT IN RIDGE 4, TEMISCAMIE RIBBED MORAINE.

with a few millimeters of displacement. Clasts are angular, predominantly locally derived, and few are striated.

Overlying this unit with a very sharp east dipping erosional contact, there is a well sorted plane bedded medium sand, with occasional rafted boulders, seams or pockets of gravel, and lenses of coarse pebbly loose diamicton. The lower contact is marked by a pebbly and cobbly lag gravel, about 40 cm thick. In the upper part of the exposure, this unit is capped by a cobbly, compact, massive sandy diamicton (Sample 39, Fig. 55) with sparse striated clasts. Clast lithology in all units is similar, and is predominantly of local origin (Fig. 55).

The lower unit is similar to material exposed in ridge 3. The upper unit is however quite different. Stratification is of a different nature as plane bedding and lamination in the medium sand are clearly recognized (Fig. 56), pockets or lenses of pebbly sand and gravel have sharp contacts with the surrounding matrix and are up to 0,5 m thick and this varies within short distances. In the lee of rafted boulders in this upper unit, small foreset bedding is observed in the sand suggesting free water flow (Fig. 56). The upper unit, together with its coarse massive diamicton capping, notwithstanding that the sections are incomplete and that the tops are missing, is interpreted as an interdigitation of flow till (Hartshorn 1958, Boulton 1968) and ice-contact sediments. Because water was freely flowing it is unlikely that a glacial lake was present in the area of these ridges when they emerged from glacial ice. The location of the section in the low distal part of the hillock is compatible with findings of this stratigraphy.

Ridge 5

This is the least typical ridge in the Témiscamie ribbed moraine. When seen from the ground or from a cursory view of an aerial photograph (Fig. 50), it resembles a drumlin-shaped hill parallel to the main glacial flow direction. Closer examination reveals that the surface of this drumlin-like feature is very irregular, that the trend and elongation is in part due to the erosion of its east side by the large channel that trends NE and cuts the other ridges further south. In reality, the feature is a group of closely spaced ridges or hillocks. A detailed plane table map (Fig. 57) of the southern part of this feature clearly shows small ridges trending east, spaced 25 to 40 m apart, with a surface relief of 3 to 5 m, separated by irregular troughs, some of which are closed depressions. At the north end of the whole feature (see Fig. 52), the suggestion is clearly of separated hillocks. It is interpreted as the western end of a large ridge of the ribbed moraine, most of which has been eroded away. The smaller ridges and troughs are details of the surface topography of this moraine ridge.

The road traverses ridge 5 at its southern end (Fig. 57). A large borrow pit was excavated in the ridge on the northeast side

Figure 56a. Plane bedding and lamination in the sand layer exposed in ridge 4, Témiscamie ribbed moraine.

Figure 56b. Small foreset bedding in the lee of a rafted boulder in the sand layer, exposed in ridge 4, Témiscamie ribbed moraine.

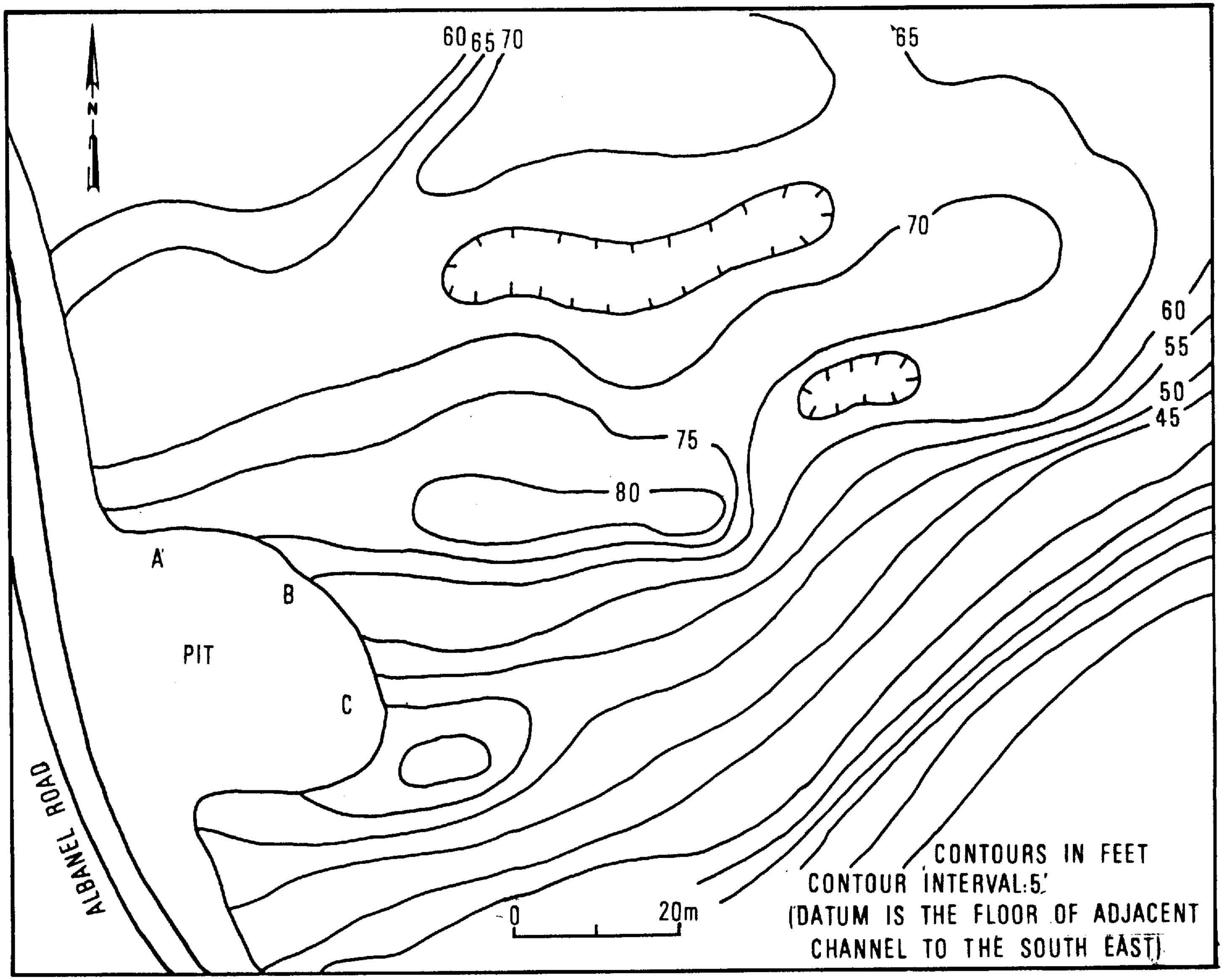



FIGURE 57. PLANE TABLE MAP OF RIDGE 5, TEMISCAMIE RIBBED MORAINE.

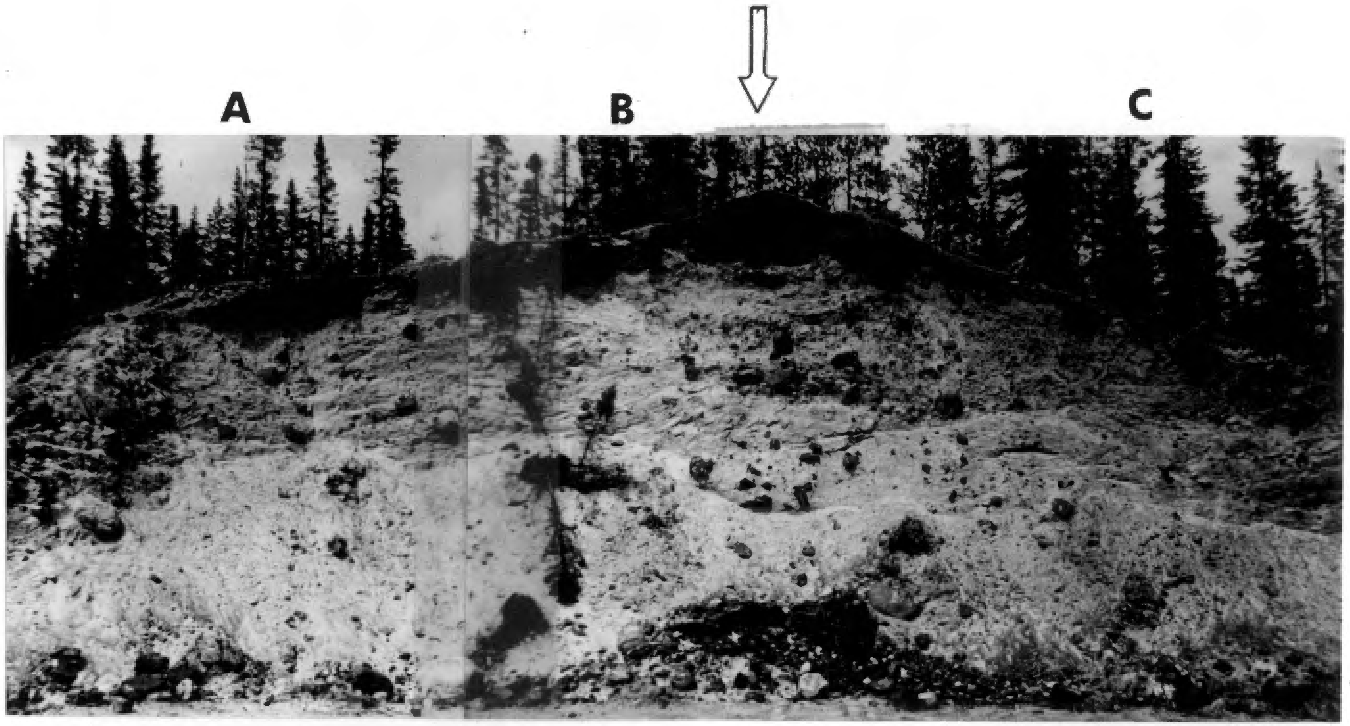



FIGURE 58. PIT FACE EXPOSING THE TILL AND THE STRUCTURE OF RIDGE 5. NOTE THE LARGE BOULDER (ARROW) ON THE SURFACE OF THE RIDGE, THE LARGE RECUMBENT FOLD, AND THE THRUST FAULT. THE LEFT AND EXTREME RIGHT PART OF THE PHOTOGRAPHS ARE FORESHORTENED VIEWS. THE CENTRAL PART OF THE FACE IS PERPENDICULAR TO THE TREND OF THE RIDGE. VIEW LOOKING EAST.

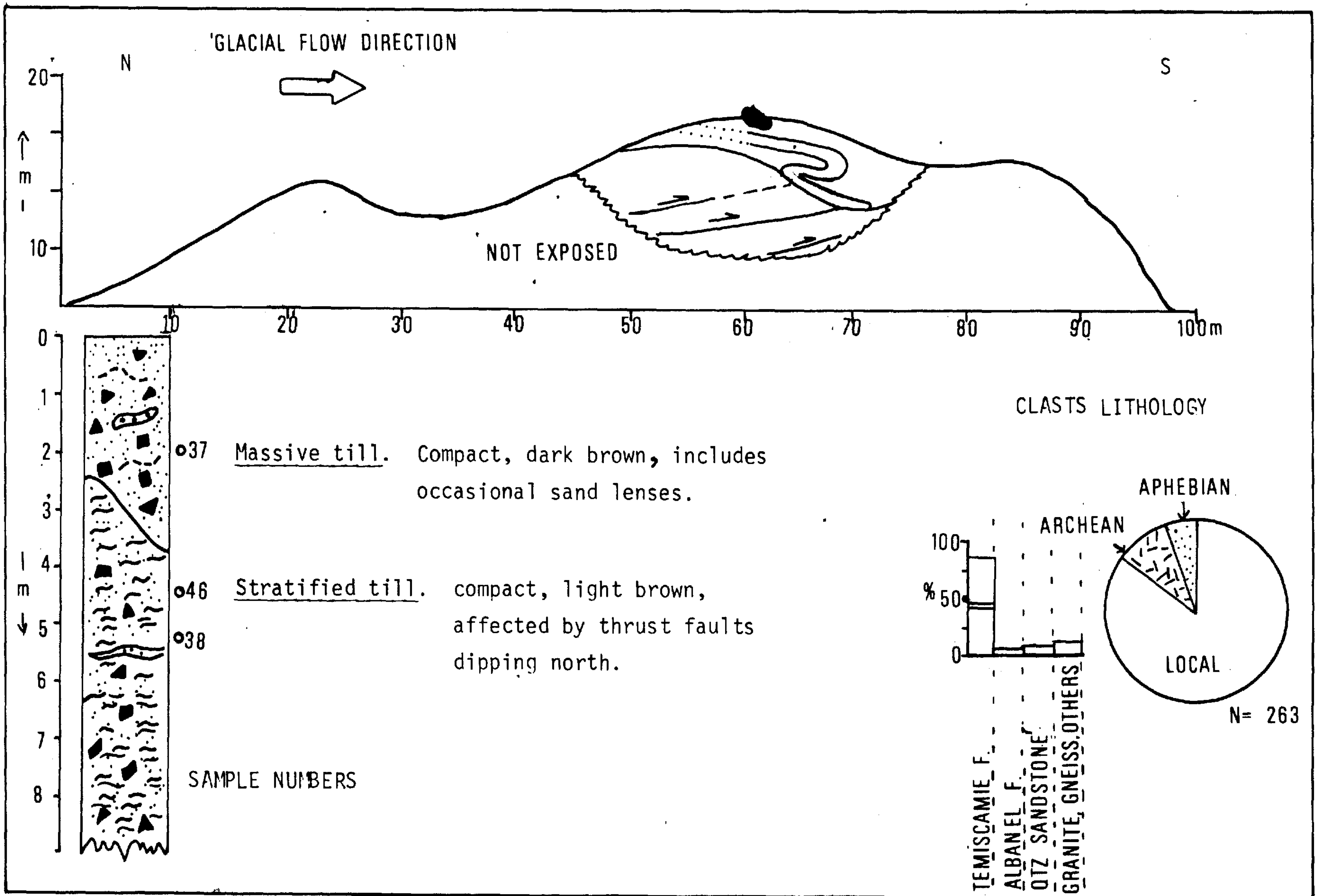



FIGURE 59. SUMMARY OF OBSERVATIONS IN BORROW PIT CUT IN RIDGE 5, TEMISCAMIE RIBBED MORAINE.

of the road. The face is shown in Figure 58. It is divided into 2 parts. AB is a section oblique but close to being parallel with the trend of the ridge. BC is a section almost at a right angle to the main ridge. It exposes two units (Fig. 59): the lower one, which forms the bulk of the ridge, consists of thrusted slabs of sandy till with dispersed boulders: this is overlain unconformably by a more or less massive sandy till of a darker color. A prominent recumbent fold involving a very bouldery part of the upper unit appears below point B in the face (Fig. 58). A huge boulder of the iron-rich Témiscamie Formation rests on top of the section.

The lower unit is separated into two main sheets by a thrust fault inclined northward with an apparent dip of 5 to $7^0$ (Figs. 50 and 59) suggesting pressure from the north. The till is best exposed in the upper slab, in the AB part of the section. It is a light yellowish brown (2,5 Y 6/4), compact (1,5 to 2 $kg/cm^2$), cobbly to bouldery (ca. 20%), poorly sorted, stratified, sand till. Clasts are predominantly derived from the Témiscamie Formation. They are very angular some with knife-sharp edges. A few of the argillite and chert clasts are striated. Granite and dolomite boulders are subrounded.

When seen on a dry face (Fig. 60a), the stratification is conspicuous and appears as sharp lines, spaced 1 or 2 cm part, lying subhorizontally here, but dipping conformably with the thrust fault in the BC part of the face. An attempt to follow one of these lines inevitably leads to "losing" it within 2 to 3 m. Examination of

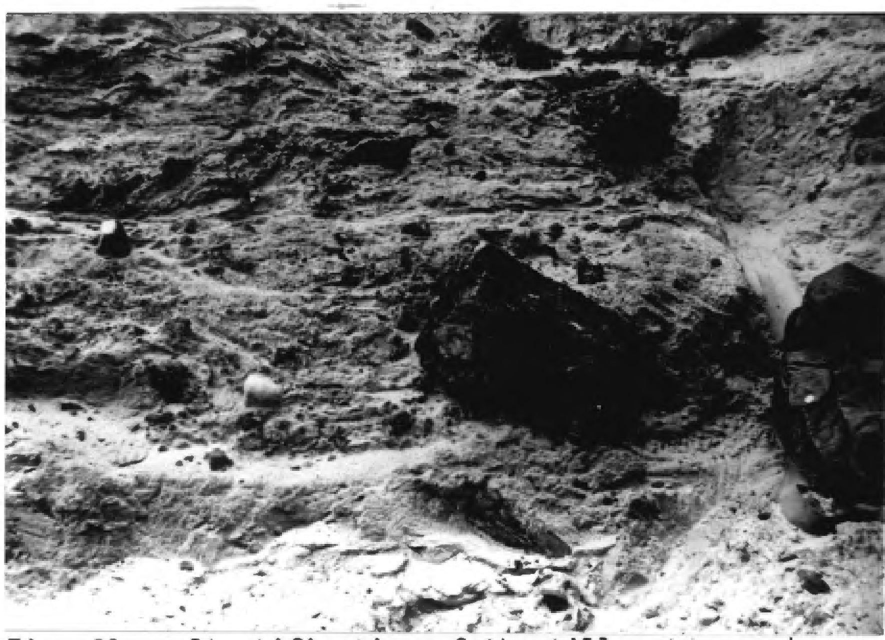


Fig. 60a. Stratification of the till as exposed on a dry face, ridge 5, Témiscamie ribbed moraine.

Fig. 60b. Stratification of the till as exposed on a freshly cleaned surface, ridge 5, Témiscamie ribbed moraine.

a freshly cleaned face (Fig. 60b) shows that stratification is from distinct lenses of massive well sorted medium sand with very gradational boundaries adjacent to the enclosing diamicton. No sedimentary structures such as lamination or cross-lamination were observed in the many small sand lenses examined. Some parts of the till are more sandy and contain fewer clasts; in these parts there is a suggestion of lenses or zones of concentrations of coarser material with indistinct gradational contacts with the enclosing sands.

The relationship between the stratification and the larger clasts is shown in Figure 61a. Below the clasts the layers are undeformed, while above the clasts the lenses are draped over to conform to the shape of the clasts.

In Figure 61a, the prominent cobble, a very angular fragment of the Témiscamie iron formation, is 16 cm high, and lies with a sharp edge upward. The stratification is seen to have conformed to the shape of the clast draping entirely over its upper part and pinching in between this and an adjacent clast, which was removed for the picture, down 7 cm along the side of the cobbles.

Comparable "draping over" structures have been recently described by Shaw (1979) in a till commonly found in central and northern Sweden where it is known as Sveg till from type localities in the Ljusnam and Veman valleys in the Sveg region (Lundqvist 1969a). Sveg till is also stratified. Shaw (1979) suggested that these structures as well as lenticular stratification resulted from "melting out in basal isothermal layer at melting point" of a material presumed to be englacial debris containing interstitial ice and separate ice layers. During melting, cavities are expected to develop in the melting ice layers. Discrete lenses would result from deposition of sorted sediments in these cavities. Differential subsidence around larger clasts due to collapse of cavities would lead to "draping over" structure.

The inference that this type of structure indicates that the material was frozen at some time and contained interstitial or separate ice layers is accepted here for the reasons stated below. Comparable "draping over" structures are generally attributed to differential compaction. A structure larger in size but similar in shape is depicted in Pettijohn and Potter (1964, their Plate 104a). This is in the Pennsylvanian Lusk shale. Shale and sandstone layers bend over a large sandstone ball included in the material. Similarly, the structure observed in the Sveg till or in the stratified till of Témiscamie might be thought of as due to differential compaction. However, in the shale, compaction likely resulted from a slow process of burial under an increasing load of sediments. In the Témiscamie till, there is evidence for over-riding of the material by ice and compaction pressure would have been applied by the overlying ice. The load applied to the sorted layer over the clasts also would have acted upon the clast itself and since it does not rest on an incompressible bed, some deformation of the underlying layers should be expected. Such deformation is not found, and only the layers over the clasts appear to have settled down on them.

Since the draped layers descend down 7 cm below the highest point of a 16 cm diameter clast (Fig. 61a), the loss of bulk for the material involved in this differential settling is slightly over 40%. It is unlikely that this large decrease in the void space of the material can be attributed entirely to a change of packing as a result of compaction because this 40% change covers more than the full range of natural porosity in sands (Blatt et al., 1972). It is more easily explained if the loss of bulk was from the melting of interstitial or included ice layers. If the settling is entirely from melting of ice, this would represent an ice content of approximately 23% as expressed over dry weight of the sediments.

About 3 m down from the top, in the AB part of the section, a lens of sand, 5 to 12 cm thick, and 80 cm long, is found enclosed between a coarse rather massive portion of the till above and a stratified portion of it below. This lens (Fig. 61b) is relatively well sorted medium sand with laminations of alternating light brown medium sand and darker brown fine sand, a few millimeters thick. Where the lens is thin, there are 7 or 8 alternating layers, while, where it is thicker, 13 layers are present. The contacts of the lens with the enclosing till are not as sharp as one would expect of an allochtonous raft of bedded material. In fact, the uppermost layer in the lens is a dark brown fine sand, 15 mm thick, which

Fig. 62a. Deformed sand lenses in the stratified till of the thrust slab, ridge 5, Témiscamie ribbed moraine.

Fig. 62b. Diapir fold formed by the injection upward of a massive sandy part of the till into a coarser diamicton member, ridge 5, Témiscamie ribbed moraine.

lower slab of till was better exposed as excavation had moved the BC face back by about 2 m. The new face exposed a diapir fold (Fig. 62b) formed by the injection upward of a massive sandy part of the till into a coarser diamicton member. It is a complex disharmonic fold with a mainly vertical axial plane trace extending about 1 m upward, and deflected south in the top half. The structure strongly suggests interpenetration of layers of contrasting competencies penecontemporaneously with thrusting.

The upper unit in the pit face is a wedge of till which partly fills the depression in the lee of the upper thrust sheet. In the south part of the face, where it is thickest, it is a dark to very dark grayish brown (2,5 Y 4/2 to 2,5 Y 3/2), bouldery, compact (2 to 2,5 $kg/cm^2$), sandy till. The clasts in it are very angular, and almost exclusively derived from the Témiscamie Formation. It is thought that the color of the till is due to its monolithologic composition. The material is massive with the exception of small, discontinuous, and contorted snake-like veins of lighter sand, 5 to 8 mm thick.

About 0,9 m down from the top, small chip-like fragments derived from iron-rich rocks are aligned as plates. This similarly exhibits complex contortions and cannot be traced for more than half a meter.

A prominent fold occurs in this upper unit in the middle of the section. It is recumbent and extends for nearly 8 m in a north south direction and involves a vertical thickness of 2,5 m. The folded material is mostly a pebbly to cobbly medium sand, with faint deformed lenses, similar to the lower unit, intermixed with pockets of very bouldery material, the matrix of which is similar in color and texture to the upper unit. Almost all the boulders are very angular clasts of the Témiscamie iron formation. The geometry of the fold is clearly visible from a distance but close to the face of the pit, it becomes very indistinct. The upper anticlinal part of this recumbent fold has an axial plane trace roughly horizontal or dipping slightly northward as suggested by the attitude of the upper limb of the fold. The lower limb is lost in the bouldery jumble. There are two possible interpretations of this structure. Accordingly, the bouldery part is either a very tightly folded synform with an axial plane trace dipping south, conformable to the frontal slope of the upper thrust slab, or it represents the distal edge of the bouldery layer, the rear end of which buckled, failed, and was moved south as fold. In the diagram of Figure 59, the first interpretation is depicted. The root zone of the fold is lost in the top part of the face to the north.

The large boulder, 1,5 m in diameter, at the top of the section (Fig. 58) is not standing freely on the surface but is embedded in the upper unit. Its south side is almost buried whereas its north side projects above the surface. A slightly smaller boulder is found on the south side. The larger boulder appears to have been pressed into the surface, with a movement from north to south. Its movement was arrested when sufficient till and a smaller boulder, ploughed up in front, overcame the entraining force.

## Summary

The structural features of the Témiscamie ribbed moraine suggest that it is a series of thrusted sheets of stratified till over-ridden by ice flowing from the north. The trend of the ridges, which is conformable to the trend of the retreating ice margin, suggests that thrusting likely occurred late in the recessional stage of deglaciation.

Truncation of beds and drag folding on the proximal sides of the ridges indicate that over-riding continued after thrusting and that some material was eroded. Diapir folding and load structures in the lower part of the stratified till indicate that at least the lower part of the material being thrust and over-ridden was in a incompetent state during deformation. Draping over structures indicate that part of the till contained interstitial ice which later melted out.

Ice over-ridding the stratified till deposited a till which is lodged preferentially in the available depressions, at the front of the successive thrust slabs. It appears to be composed almost exclusively of locally derived lithologies with angular boulders. There was some mixing with layers of the underlying stratified drift and these were folded as ice flowed into the depressions. Larger locally derived boulders appear to have been entrained at a late stage in the over-ridding ice and are pressed into the surface of the upper till.

## 5.3. Other exposures of till along Albanel road

The stratified till which forms the bulk of the Témiscamie ribbed moraine is not a deposit which is restricted in extent to that particular valley in which that ribbed moraine is found. It is exposed elsewhere along the Albanel road, notably in another ribbed moraine which is situated in a valley-like swale that passes through the Kallio Plateau, 10 km northwest of the Témiscamie ribbed moraine. Still other exposures on the Kallio Plateau show basal till which underlies drumlinized ground moraine, and ablation till which underlies unpatterned ground moraine. The stratified till lies stratigraphically below the ablation till and above, or as a lateral equivalent of the basal till.

Following the description of the observations made along this section of Albanel road, additional conclusisons will be deduced about the formation of ribbed moraines. These are 1) ribbed moraines occurring in adjacent valleys formed probably at about the same time and under similar ice flow conditions, and 2) ribbed moraines formed late during the recessional phase of glaciation, as has already been shown on the basis of geomorphic attribute of the Témiscamie ribbed moraine.

From the stratigraphic observations, an attempt will be made to generalize the stratigraphy from the various till types of the Kallio Plateau to the whole of the Témiscamie area. It will be shown that the basal and ablation tills of the Kallio Plateau are analogous in almost every respect to the basal and ablation tills of the rest of the Témiscamie area, and that on the basis of its sorting and content of fines and its occurrence in ribbed moraine, the stratified till of the Kallio Plateau is analogous to the "ribbed moraine till" of the Témiscamie area. Further on, a case will be made to the effect that stratified till is a deposit of common occurrence on the Canadian Shield, and is possibly as widespread as ribbed moraines are. The reasons for which stratified till has so far been left mostly unrecognized in much of the Shield will also be discussed. Finally it will be argued that this same stratified till of such common occurrence on the Canadian Shield is truly the equivalent of the Kalix and Sveg tills of Swedish authors, equally common on the Fenno-scandinavian Shield.

Till is exposed in road cuts and borrow pits at two other locations which will be referred to as sites A and B (Fig. 49). Both sites are located northwest of the Témiscamie River on the Kallio Plateau.

Going north and then northwest from the Témiscamie ribbed moraine, the road leads into the Témiscamie valley where there is ridged and hummocky topography (Fig. 49). The ridges trend similarly to those of the Témiscamie ribbed moraine, suggesting that the ice movement which led to their formation was not restricted to the small basin like swale. No cuts are available in the valley but in surface clearings the surface is very sandy.

Site A

Site A is at mileage 105,2 about 2,2 km northwest of the bridge over the Témiscamie River, at an altitude of about 469 m. As the road ascends the west side of the Témiscamie valley, onto the elevated plateau surface, it traverses an area of low drumlinoid ridges trending S 25$^{o}$ W.

Cuts on both north and south sides of the road (Fig. 63a) expose a maximum of 4,2 m of massive till resting directly over bedrock which here is the dark argillite of the Témiscamie Formation.

The section is sketched and observations are summarized in Figure 64. The till is gray (5 Y 5/1) to dark gray (5 Y 4/1) but becomes slightly brownish in the upper 1,1 m. Color variation is gradual, does not appear to be related to a textural change, and presumably represents the weathered zone of the till.

The cuts hold steep faces; the till is very compact (3 to 4 $kg/cm^2$). Firmness decreases in the upper weathered part. Clast content, including boulders, is estimated at 7 to 10%. A large number of clasts found in the till are faceted, smooth edged and striated, particularly the dolomite and black argillite fragments. Clay content is 11,6% and the material classifies as a loam till. It is conspicuously finer-grained than the till underlying ribbed moraine.

The till is massive and unstratified. No structure is discernable throughout the section. However, in the lowest 5 cm, directly over bedrock, there are filament-like lenses of lighter gray fine sand. These lenses are several millimeters thick, a few centimeters long, and have irregular outlines but lie subhorizontally and show no intense deformation. They suggest that perhaps some water flowed through or was expelled from the lowest 5 cm of the till when, or soon after, it was deposited.

Fig. 63a. Roadside exposure of basal till at Site A (see Fig. 49 for location).

Fig. 63b. Roadside exposure of ablation till, overlying basal till at Site B (see Fig. 49 for location).

The surface of the bedrock underneath the till was exposed by digging 0,85 m into the face. Striations on bedrock are well developed and trend mainly at S 20° W. The two-dimensional preferred orientation of the long axes of 50 pebbles and small cobbles was measured at four different levels in the section (Fig. 64) to verify possible widespread remobilization of the till in the direction suggested by ribbed moraine trend. These measurements are subject to the magnetic uncertainties explained earlier and the resulting trends may be incorrect. The orientation of striations underneath till is similar within 5° to the trend of the drumlinoid topography on the surface. Significant preferred orientation is shown by clasts in the top and next to bottom samples. The two other fabrics fail to show statistically preferential orientation. The lowest fabric analysis is a clearly bimodal distribution in which a transverse mode is predominant. In the next to highest fabric analysis, randomness appears to be real although a faint vector parallel to flow is present. The two statistically significant fabric analyses show preferred orientations either parallel or transverse to the main ice flow direction indicated by drumlinoid trend. It is concluded that there are no indications that the direction of glacial movement changed significantly while the till was being deposited.

Clasts in the till are dominantly locally derived (Fig. 64). About 1 km west of site A and about 50 m away from the road, the lithology of boulders lying at surface was studied with the results

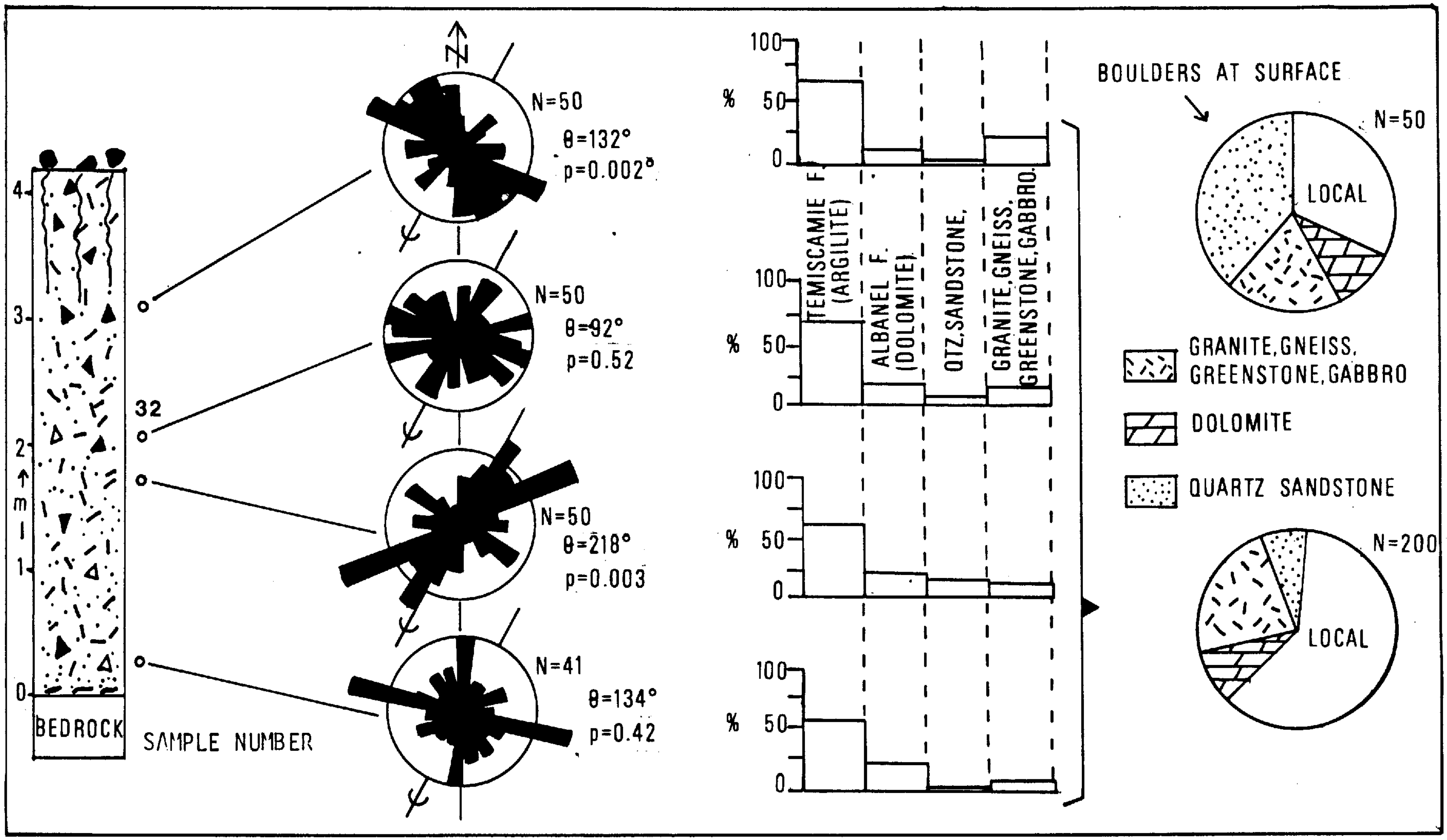



FIGURE 64. SUMMARY OF OBSERVATIONS IN ROADSIDE CUTS AT SITE A, ALBANEL ROAD.

shown in Figure 65. Compositions of these boulders is in great contrast to that of the till sheet in that they are dominantly distantly derived. This suggest that the boulders at surface are perhaps ablation debris. The material exposed at site A is interpreted as a basal till because of its massiveness, compactness, poor sorting, striated clasts, and location over smoothed and striated bedrock.

Site B

Site B is 4,5 km northwest of site A, near mileage 108 on the Albanel road, at an altitude of about 450 m. The bedrock in this area is rarely exposed but according to Wahl (1953) it is mainly the iron-rich member of the Témiscamie Formation. At mileage 107, a roadside outcrop shows the quartzitic member; the surface is smoothed and bears striations and crescentic gouges which indicate a glacial flow direction of S 23$^{o}$ W.

Going north from site A, the road descends from the highest part of the Kallio Plateau and passes across a fault bounded (?) valley, about 1,5 km wide, and goes up again onto a lower flat part of the plateau, where drumlinoid topography and drumlins (Fig. 49) trend S 25$^{o}$ W, similarly to the main glacial flow direction at site A.

The structural trough extending northeast-southwest connects Einer Lake to Phyllis Lake, where it widens and continues southwestward to Gordon Lake, and finally to Lac Albanel. Northwest from Phyllis Lake, an arm extends to Sandra Lake and to the south tip of Capotagen

Bay of Lac Albanel (Fig. 49). The lower parts of this depression including Gordon, Phyllis and Sandra Lakes, is occupied by a ribbed moraine. Southwest of Gordon Lake, the ridges are 160 to 180 m apart, 50 to 80 m wide, 10 to 15 m high, and extend for 400 to 500 m with a trend of S 75$^{o}$ E. The ridges are lunate in plan, convex toward the northeast. Their upper surfaces show closely spaced lineations which trend S 15$^{o}$ W. This orientation bears no relationship to the outline or the trend of the valley in which the ribbed moraine is found. It similarly diverges, being more southerly than the main glacial flow direction as in the case of the Témiscamie ribbed moraine.

Northeast of Phyllis Lake, and particularly in the region traversed by the road, ridged topography is less obvious. It is suggested however by the outline of Einer Lake and by the aerial photographic tone pattern. The level of the floor of the valley is higher than in the southwest part, and the relief of the ridged topography appears to be lower. As the road ascends back onto the area of drumlinoid topography west of the Einer-Phyllis trough, it crosses over a patch of drift overlying both drumlinoid and ridged topography, masking the pattern of both (Fig. 49). About midway into this drift patch, a steep-sided meltwater channel, 40 m wide, is crossed.

Cuts at site B are roadside exposures on both east and west sides of the road over a distance of 300 m, north of the channel, and a garbage dump at the end of a small service road leading west from Albanel road, south of the channel.

The roadside cuts provide a north-south transect from the area of drumlinoid topography to the central part of the unpatterned drift patch (Fig. 64 ). The cuts at the garbage dump extend this transect to the inner part of the valley. Stratigraphic relationships and other observations are summarized in Figure 65.

The lower unit exposed is on the east side of the road, at the north end of the transect, in the area of drumlinoid topography (Section A, Fig. 65). There, an olive gray (5 Y 5/3) till underlies an upper loose sandy till the thickness of which increases southward (Fig. 64b). The lower gray till is compact (1,5 to 2,0 kg/cm$^2$) but obviously less than the till at site A. It does not hold a steep face here. The till classifies as a very poorly sorted fine sand till with a clay content of 5,3%. Upon applying pressure horizontally with the tip of the penetrometer, the material breaks down suddenly into subhorizontal flakes about 1 cm thick. This indicates a poorly developed fissility. The till is otherwise massive.

It contains more dolomitic clasts than the till at site A. It is so, since the south edge of Albanel Formation is only 4 km up-ice from site B. The proportion of Archean and clastic Aphebian rocks, which are distant erratics, is about 25% (Fig. 65), slightly higher though similar to that found at site A. Dolomite and dark argillite clasts in this till are faceted and striated. This till is interpreted as a basal till because of its massiveness, poor sorting, striated clasts, and content of distant erratics similar to that of basal till: within 5 km the clay content decreases from nearly 12% to about 6%.

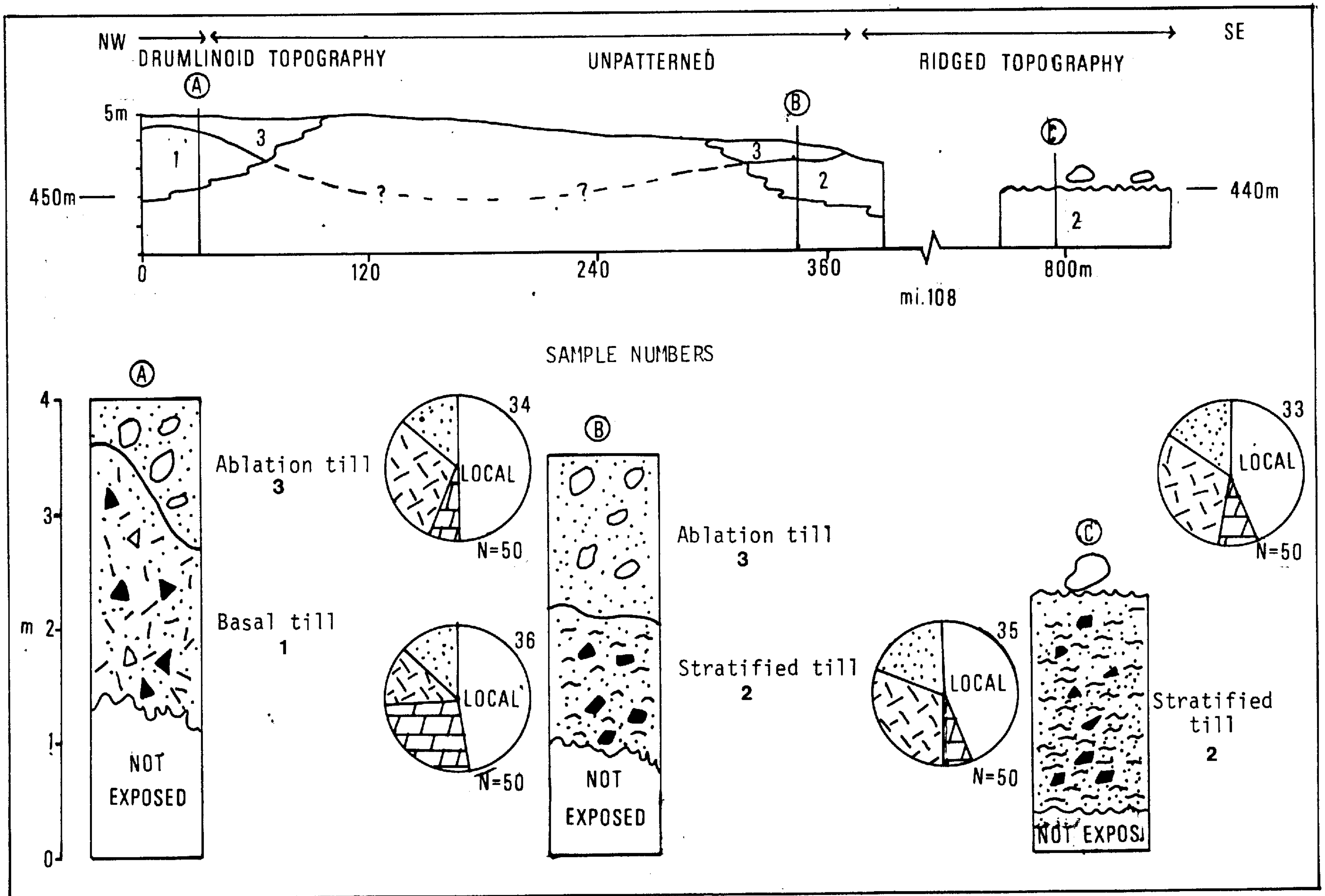



FIGURE65. SUMMARY OF OBSERVATIONS IN ROADSIDE CUTS AND TRENCHES AT THE GARBAGE DUMP,SITE B, ALBANEL ROAD. LITHOLOGICAL SYMBOLS APPEARING IN THE PIE DIAGRAMS ARE THE SAME AS IN FIGURE 64.

This reflects the change of underlying rock type. At both sites A and B basal till underlies drumlinoid topography.

The diamicton which overlies the lower gray till is a massive light yellowish brown (2,5 Y 6/4) cobbly, loose (< 0,5 kg/cm$^2$) till which classified as a poorly sorted fine sand. It is interpreted as an ablation till owing to its stratigraphic position over basal till, its looseness, its higher content of far traveled erratics (Fig. 65), its lesser amount of clay, and on the whole, its better sorting. The boulders lying at the surface at site A are considered a lateral equivalent bouldery facies of this ablation till, or a lag concentrate derived from it.

At the south end of the transect (Section B, Fig. 65), ablation till overlies 1,0 m or more of compact (2,0 kg/cm$^2$), light yellowish brown (2,5 Y 6/4) stratified till with clast content estimated at 5%. A bulk sample of this stratified till is classified as a poorly sorted sandy loam till with a clay content of 0,8%. The till is very similar to the stratified till of the Témiscamie ribbed moraine. Lenticular beds are on the average 1 cm or less in thickness. However, the clast lithology differs markedly from the Témiscamie ribbed moraine in that the till contains a high proportion of distant erratics (Fig. 65), whereas till in the Témiscamie ribbed moraine contains predominantly locally derived clasts.

The top of sections in the cuts at the garbage dump are missing where about one hectare was scraped by bulldozer; numerous very large boulders were left scattered on this cleared surface. A large number of these are dolomite or are derived from the Papaskwasati Formation suggesting much longer distance of glacial transport. Trenches were excavated in the resulting flat surface; the section described is from the wall of one of these trenches, which is about 1,5 m deep.

The sediment exposed is a compact (ca. 2 to 2,5 $kg/cm^2$), pale yellow (2,5 Y 7/4) stratified till with clast content estimated at 5-7%. Sorted lenses are subhorizontal, a few centimeters thick, spaced vertically 1 to 3 cm, and extend for 1,0 m or more laterally. Similarly to the till in the Témiscamie ribbed moraine the lenses drape over clasts of a diameter larger than the interbed thickness. However, the till contains 46% of distant erratics, a percentage corresponding to the ablation till along the road. A bulk sample is classified as a poorly sorted sandy loam till with a clay content of 0,5%.

Discussion

It is evident from the morphological observations that even though the Témiscamie ribbed moraine and that in the Einer-Phyllis trough are 10 km apart, their ridges have similar trends, which are conformable to the trend of the receding regional ice margin. In addition, the surface lineation on the ridges in both valleys diverge from the main glacial flow direction being more southerly. The first observation would suggest that ribbed moraines in the two valleys were formed at about the same time and the second that they developed under identical ice flow conditions. It is obvious then, that while, in general, ribbed moraines are restricted to particular valleys, the ice flow conditions under which they form extend over a larger area along the ice margin. In the case of the two ribbed moraines under discussion their formation involved a sector of the ice margin at least 10 km long.

Confirmation of an earlier conclusion that ribbed moraines are late recessional features comes from both morphological and stratigraphical evidence . It has been shown that, on the one hand, the drumlinoid topography on the interfluve between the two ribbed moraine fields was not modified, and on the other hand, the underlying basal till does not record a changing flow direction similar to that which is observed on the ribbed moraines. It is concluded therefore, that the two ribbed moraines must have formed after the time when deposition of basal till on the interfluves was completed and that subsequent ice flow was inconsequential on the interfluve surfaces. It follows then that the ribbed moraines truly are late-recessional features.

The stratigraphic observations reveal three distinct types of till along the Albanel road on Kallio Plateau, namely, basal till, ablation till, and stratified till, the last of which comes from the area of the ribbed moraine recognizable on airphotos only. The sequence of tills as seen in the exposures is compatible with the three-fold differentiation of till types discussed earlier from the surficial excavations in the Témiscamie area. In the following paragraphs, the general characteristics of the distinct till types observed along the Albanel road will be summarized first and then the tills will be compared with the tills of the Témiscamie area. This comparison will be done based on their grain-size properties using the same type of diagram that was employed for the till of the Témiscamie area (Fig. 66, cf. Fig. 25)

Basal till, exposed along the Albanel road, is fine-grained, massive, compact, and contains predominantly locally derived clasts. The long axis of the pebbles in it show a preferred orientation either parallel or transverse to the main glacial flow direction. The till underlies drumlinized ground moraine. In almost every respect this basal till had the same characteristics as that which forms the ground moraine in the Témiscamie area. On the diagram of Figure 66, the samples of the basal till exposed along the Albanel road plot either within the field of the basal till of the Témiscamie area, or just outside of it in a position which indicates poorer sorting and a higher silt and clay content. This was expected since basal till along the Albanel road is derived from fine-grained sedimentary rocks whereas the basal till in the Témiscamie area is derived mainly from crystalline and coarse-grained sedimentary rocks.

Ablation till, exposed along the Albanel road, is coarser-grained than the basal till which it overlies directly, at places. It is loose, contains predominantly far-travelled erratics, and underlies unpatterned morainic terrain. The characteristics of ablation till are similar to

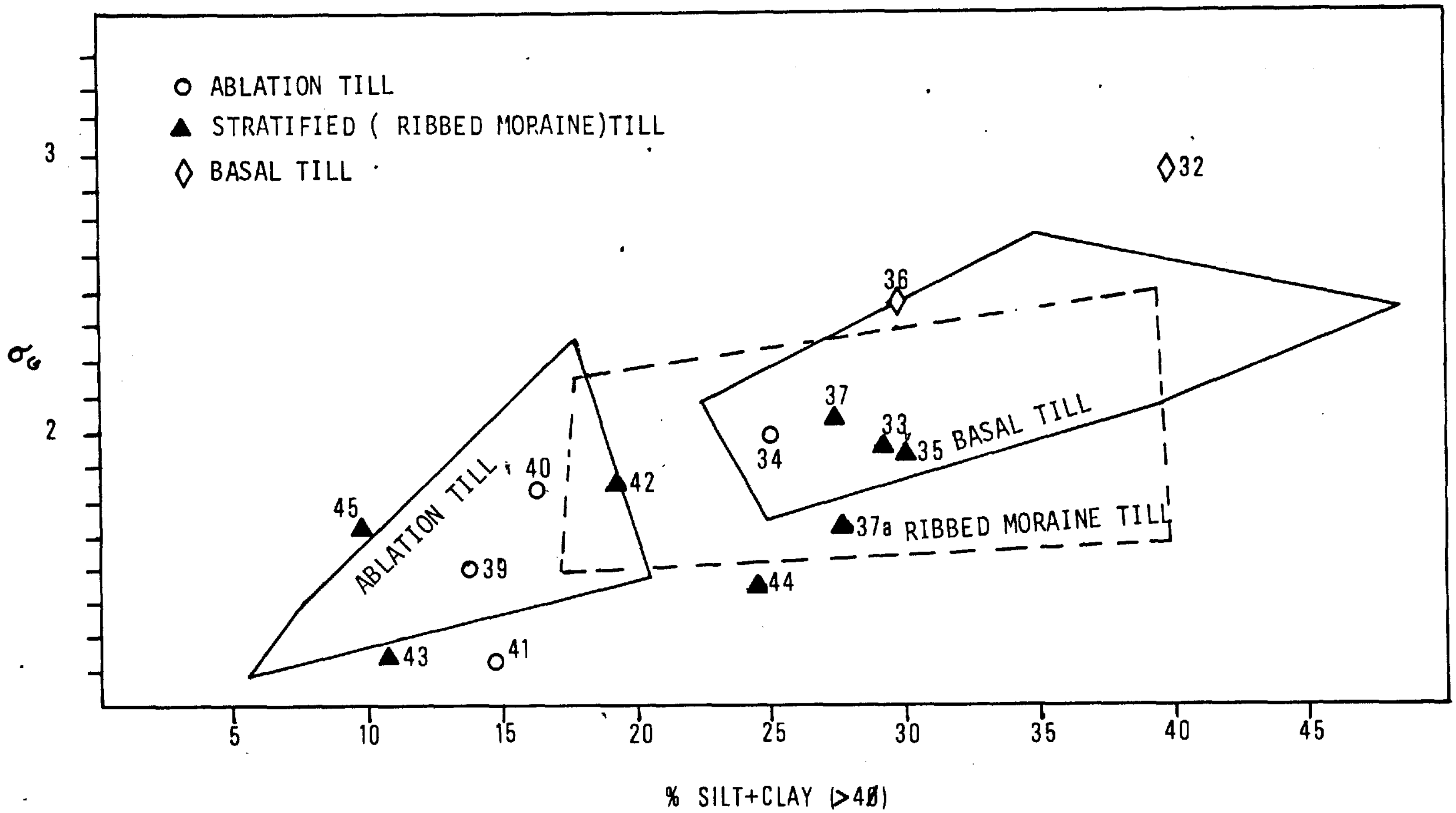



FIGURE 66. DIAGRAM SHOWING THE SORTING ($\sigma_G$) AND THE TOTAL PER CENT CONTENT OF SILT AND CLAY OF THE MATRIX, FOR TILLS SAMPLED ALONG ALBANEL ROAD, AS COMPARED WITH THE SAME PLOT FOR TILLS OF THE TEMISCAMIE AREA.

those of the ablation till found in the hummocky moraine and the unpatterned ground moraine of the Témiscamie area. On the diagram of Figure 66, the samples of the ablation till exposed along the Albanel road plot also either within the field of ablation till of the Témiscamie area, or outside of it in a position which indicates better sorting. One sample plots within the overlapping fields of basal and ribbed moraine till of the Témiscamie area. This sample is not considered to be anomalous, rather, it is believed that if the number of samples used in establishing the original diagram (Fig. 25) had been larger, there would have possibly been an overlapping of fields of the basal and ablation tills in the central part of the diagram. It also illustrates the textural variability of ablation till, a feature which is commonly listed as one of its characteristics (Dreimanis 1976).

Stratified till, exposed along the Albanel road, is distinctly coarser-grained than basal till and more compact than ablation till. It lies stratigraphically below the ablation till and above, or as a lateral equivalent of the basal till which occurs on interfluves. Stratified till occurs mainly in valleys or swales, or put in general terms, in the low parts of the topography; it contains either predominantly far-travelled erratics (Site B) or mostly locally derived clasts (Témiscamie ribbed moraine). It forms the bulk of the local ribbed moraines and in the Témiscamie ribbed moraine it is locally covered by bouldery till. The latter is massive and sandy and is also conspicuously coarser-grained than the basal till on interfluves.

On the diagram of Figure 66, the samples of the stratified till lie mostly within the field of ribbed moraine till as defined for the Témiscamie area, while a few plot outside of it owing to either better sorting or lower content of fines. The similarity of the stratified till to the ribbed moraine till of the Témiscamie area is significant and must indicate that they are, in fact, of the same type and had a similar origin.

Contrary to the easy recognition of the stratified till in the exposures along the Albanel road, in the area of the local ribbed moraine, it was recognized in only two of the fourteen shallow excavations within the Témiscamie area ribbed moraines (cf. Table 3). The explanation lies in the fact that surficial excavations expose a far too small part of the material underlying the ground surface and may not necessarity reach that part of the till which shows well-developed stratification. In fact, there is some chance involved in sampling ribbed moraines through surface excavations. Five possible situations may have affected sampling, as may be shown from the Témiscamie ribbed moraine; namely, it may have been (1) from the upper massive bouldery till overlying the stratified till, or (2) from a massive diamicton member of the stratified till, or, (3) from a modified part of the latter, or, (4) directly from the stratified till where its structure is particularly well developed so as to be very obvious in a small excavation, or, finally, (5) from ablation debris, such as that which occurs on the distal side of ridges.

Since most of the exploration work in the areas of ribbed moraines on the Canadian Shield was from shallow observation pits, it is believed that similar problems may have limited the observations by the various workers and may have led to a general lack of recognition of the widespread occurrence of stratified till in those areas. In fact, an examination of the reports on the nature of the till underlying ribbed moraines in the interior of northern Québec and in the Keewatin District of N.W.T. (Henderson 1959, Lee 1959, 1960, Hughes 1964, Cowan 1968) confirms this contention. These observations may be summarized as follows: the till is sandy, bouldery or not, massive or with a pronounced horizontal fissility (Henderson 1959), compact to very compact (Cowan 1968), and shows no apparent differences with the till underlying adjacent ground moraine. It is believed that Henderson's (1959) "pronounced horizontal fissility" is perhaps the aspect of a thin lenticular stratification of the till as it is visible in small excavations. The apparent lack of dissimilarity of the tills must be due to the fact that in areas where all till types are predominantly sandy, the textural contrast between 'ribbed moraine till' and 'ground moraine till' may not be so great as to be discernible in the field.

Finally, the relatively widespread occurrence of stratified till on the Canadian Shield, even outside the areas of ribbed moraines, is further confirmed by independent observations from Nouveau-Québec. There numberous deep excavations have recently been done in relation to hydro-electric projects. This author had the opportunity of viewing colour slides taken by A. Liard,(then with L.M.N.R. Associates, a consultant engineers firm),in the Caniapiscau River area in some of the larger pits excavated; in many of these, stratified tills strongly similar to that observed along the Albanel road were seen.

The generally widespread occurrence of stratified till on the Canadian Shield is not at all surprising. Similar tills have been reported from the Fennoscandinavian Shield where they are known as Kalix till (Beskow 1935, Hoppe 1952, 1959, Lundqvist 1969b) and Sveg till (Lundqvist 1969a, Shaw 1979) and they occur widespread in northern Sweden and in Finland (Virkkala 1952, 1974 in Dreimanis 1976, Aario 1977). The similarity in nature and occurrence of the stratified till of the study area to the northern European tills is very striking. Indeed, the Kalix or Sveg tills are also characterized by the presence of numerous well-sorted lenses, coarse silty or sandy texture, relatively good sorting, a high degree of compaction, and deformations. Kalix till is also known to occur mainly in valleys, that is, in the low parts of the topography (Lundqvist 1969b) and was commonly observed in the so-called Rögen moraines (Hoppe 1952, Lundqvist 1969a, 1969b, Aario 1977). Furthermore, it is often observed in association with an overlying massive bouldery till (Lundqvist 1969b). A photograph of an exposure of Kalix till, taken near Lake Tisjön, Dalarna, Sweden (Fig. 9 in Lundqvist 1969b), shows a striking similarity to the exposures of stratified till along the Albanel road (Figs. 60 and 61a) including some of the peculiar structures of deformed layers overclasts.

In summary, it is suggested here that the stratified till described from the Témiscamie area is probably more widespread on the Canadian Shield than it has been previously recognized to date, and that it is truly the north American equivalent of the Kalix and Sveg tills reported from northern Europe.

5.4. Origin of the stratified till

Before a model for the genesis of ribbed moraines may be proposed, the origin of the stratified till forming the moraines must be clearly understood. A set of hypotheses is already available with regard to the origin of the till. In effect, in northern Europe, a number of hypotheses has been suggested for the origin of the Kalix and Sveg tills ( Beskow *in* Lundqvist 1977, Hoppe 1959, Lundqvist 1969a, Shaw 1979).Among these hypotheses,only the one proposed by Shaw (1979) appears to account for all the properties of the stratified till of the Témiscamie area. According to Shaw, the Sveg till originated from englacial debris released as basal melt-out till under stagnant ice. The particular properties of the stratified till of the Témiscamie area all of which may be explained by Shaw's hypothesis, are its sedimentary structures, its lithologic composition, its textural attributes, and finally, its stratigraphic relationship with the other tills in the vicinity.

Sedimentary structures

Layering in the debris-laden basal part of modern glaciers is quite commonly observed (Weertman 1961, Goldthwait 1971, Nobles and Weertman 1971); it occurs as closely-spaced bands of englacial debris separated by thin ice layers in a zone which extends a few meters above the base of the glaciers. Boulton (1970a,1970b). described such occurrences of englacial debris bands from near the base of the Svalbard glaciers on Spitzbergen. The thickness of the basal zone in which the layered structure occurs ranges from 3 to 10 m. He observed that the debris bands are lenticular, range in thickness from a few centimeters to a few meters, and show much variation in the debris content, ranging from 15 to as high as 90% in volume. Similar near-base englacial debris layers are also known from such large glaciers as the ice sheets of Antarctica (Gow, Ueda, and Garfield 1968, Gow, Epstein, and Sheehy 1979) and Greenland (Hansen and Langway 1966, Herron and Langway 1979). There, they occur in basal zones which reach thicknesses of 5 and 17 m respectively.

The layered structure observed in glaciers by Boulton (1970a, 1970b) is strikingly similar in appearance to that of the stratified till of the Témiscamie area. Virkkala (1952) also noted the remarkable resemblance that exists between stratified tills in eastern Finland and the layered structures in glaciers. It is suggested here that the lenticular stratification of the till is a feature which was inherited from the layered basal zone of the glacier; the structure was preserved owing to limited disturbance of the debris during the melting of the interstitial ice and of separate ice layers. Disturbance was restricted to the differential settling of layers around larger clasts in the sequence, and the draped structures in the till, as described and discussed earlier, are considered further supporting evidence for the suggested origin of the till. That the disturbance may have been minimal is not surprising as the preservation of englacial structure is a characteristic of melt-out till (Boulton 1971, 1976) which is related to its mode of deposition, that is by the slow melting of the intervening ice under a confining overburden. For example, Lawson (1979) noted only slight changes in the orientation of pebbles upon the melting of the ice in an actual glacier. One would expect as little disturbance in the basal layered structure.

Lithologic composition

According to DiLabio and Shilts (1978), who studied the lithologic composition of debris bands in glaciers on Bylot Island of Arctic Canada, once formed, a debris band may persist for considerable distances down-glacier with little or no addition of local material. The lithologic composition of the ribbed moraine till near Lac Ouellette, characterized by a high content of far-travelled erratics (cf. Table 6), was shown earlier to indicate that the till was derived from the englacial load of the glacier. Equally, the stratified till in the ribbed moraine of the Einer-Phyllis trough on the Kallio Plateau, which similarly contains a high proportion of far-travelled erratics, can also be considered to have been derived from englacial debris.

In contrast to the till at the two previous sites, the till in the Témiscamie ribbed moraine contains a high proportion of clasts which are of the same lithology as that of the underlying Témiscamie Formation. In spite of this, it can be argued that this till was also derived from englacial debris because 1) the Témiscamie bedrock formation extends for a distance of up to 12 km in an up-glacier direction from the moraine, and 2) it underlies, up-glacier from the moraine, prominent bedrock ridges and the Kallio Plateau, all of these features lying at a higher elevation than the moraine. Consequently, it is believed that it was the combined effect of the high relief of these topographical features, and of their location, which was responsible for the emplacement in an englacial position of the rock debris derived from the Témiscamie Formation and found in the till of the moraine (cf. Shilts 1976).

Textural attributes

Along the Albanel road, the contrast in the textural composition of the stratified till and the local basal till, in terms of sorting and of content of fines, is readily apparent. In fact, it was suggested that this criterion is one way by which ribbed moraine till can be distinguished from basal till throughout the Témiscamie area. The reason for such a consistent textural contrast must lie in the difference of origin of the two till types. While subglacial debris is transported in the basal 1-2 m thickness of the ice, which is the zone of maximum comminution during transport (Dreimanis 1976), englacial debris, carried higher up, ca. 5-10 m above the base of the glacier, is not subjected to as much clast-to-clast collision because the grains are separated by interstitial ice. Consequently a till derived from subglacial debris is expected to be generally finer-grained than the till derived from englacial debris. In addition to the lack, or reduced rate, of production of fines in the englacial debris during transport, some fines may also be removed from it during the process of melt-out which leads to the deposition of the till.

Stratigraphic relationship

Stratigraphically, in a sequence of deposits left by a receding glacier, melt-out tills occupy intermediate positions between basal tills below and ablation tills above (Boulton 1970b, 1971, 1976). As it has been shown, the stratified till of the Témiscamie area occupies an identical stratigraphic position, which lends further support to the hypothesis on its origin.

In summary, the sedimentary structures, the lithologic composition, the textural attributes, and the stratigraphic position of the stratified till of the Témiscamie area indicate that it was derived from layered englacial debris transported in the basal zone of the glacier, and that it was deposited as a melt-out till.

5.5. Formation and significance of ribbed moraines.

The model which is proposed here for the formation of ribbed moraines is based on their geomorphic characteristics as well as on their internal composition and structure. It is suggested that ribbed moraines are formed subglacially, back from the margin of the receding ice sheet; their formation involves the debris-laden basal part of the glacier, and they occur in areas where an obstruction to the flow of the glacier causes the development of shear planes and the stacking of slices of stagnant debris-laden ice. The model does not call for a readvance of the ice front or the re-activation of marginal stagnant ice masses for the formation of the moraines. It is presumably applicable to all other ribbed moraines occurring elsewhere on the Canadian and Baltic Shields.

The formation of a ribbed moraine is illustrated in Figure 67 in the form of a sequence of four diagrams which show schematic sections of the base of the ice sheet some distance back from the margin. Neither vertical nor horizontal scales are indicated on the diagrams, and some of the features are exaggerated in size relative to others. This situation is mitigated by statements in the text on the size of the various features depicted. The arrows in the diagrams represent the glacial flow direction. It is emphasized here that this direction is not necessarily the same in the successive diagrams and that the orientation of features formed in a given stage might differ by a few degrees from

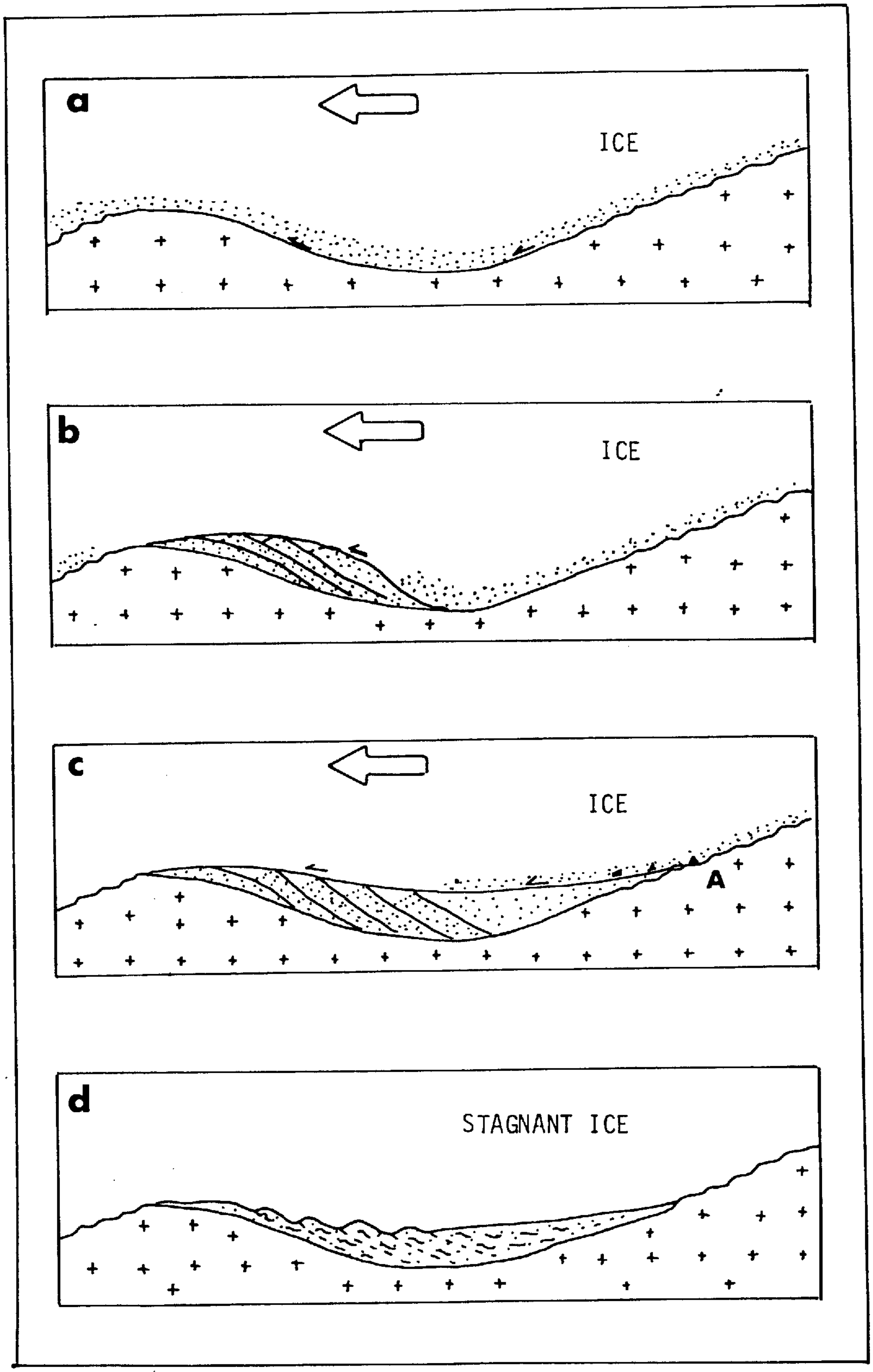



FIGURE 67. SCHEMATIC REPRESENTATION OF THE PROPOSED MODEL FOR THE FORMATION OF RIBBED MORAINE.

that of others formed in earlier or later stages. The debris in the ice is indicated by the dotted pattern in the diagrams. It is shown to be restricted to a near-base zone, in the order of 5 to perhaps 10 m thick; it is visualized to be in the form of englacial debris bands with thin intervening ice layers. The upper limit of the drift-laden basal ice is sharp and probably occurs within an interval of one meter or less as commonly observed in modern glaciers.

Figure 67a shows the basal part of the glacier as the ice passes over a bedrock basin. The basin is conceived as being hundreds of meters to a few kilometers in length and a few to tens of meters in depth. The bedrock is either granite, or gneiss, or some combination of crystalline rocks representative of shield areas. The rock surface is shown purposely by a smooth line on the down-glacier end of the basin in order to reflect the effect of glacial erosion which occurs there mainly by abrasion. At the up-glacier end, the bedrock surface is step-like on a small scale, resulting from the combined effect of plucking and abrasion leading to the development of asymmetric knobs, a few meters high and tens of meters long. The profile of the bedrock floor depicted in the diagram actually corresponds to that underlying most of the ribbed moraines of the Témiscamie area ( cf. Fig.16). It is also the equivalent of the "concave bedrock basin", reckoned to be the most common location for the development of the Rögen moraines ( Lundqvist 1969b) in northern Europe. The basin itself might have a primary structural origin, but was re-shaped by glacial erosion. It is part of the landscape of "areal scouring" which, according to Sugden (1977, 1978), characterizes the Canadian Shield. Consequently, it is thought that the situation illustrated in the diagram ( Fig.67a) is representative of the topography of the bedrock floor of the glacier over large parts of the Canadian Shield and shows presumably the most common situation in which ribbed moraines were formed.

The obstacle to glacier flow created by the bedrock hump at the down-glacier end of the basin causes the development of shear planes in the basal part of the glacier and these, in turn, lead to the stacking of slices of debris-laden ice ( Fig. 67b). In the diagram, four such slices are shown with greatly exaggerated dips in the up-glacier direction. It is believed that each shear plane, separating the slices, developed one after the other progressively in the up-glacier direction, most likely in the manner suggested by Boulton (1970b) for the development of prominent shear planes at the base of Sørbreen and Nordenskiöldbreen glaciers in Spitzbergen. Near the margin of these glaciers, bedrock obstacles over which the rate of glacier flow is increased cause the over-riding of a lower, debris-rich ice mass which deforms less readily, by a higher, relatively debris-free ice mass which is capable of a greater rate of strain. Under the Svalbard glaciers, masses of stagnant debris-rich ice, up to 4 m thick, were left through this process on the up-glacier flank of bedrock obstructions. In a later paper, Boulton (1971) referred to this process of shearing as one of décollement. According to him, the process of décollement is more likely to occur in marginal areas of glaciers because the reduced thickness of the overlying ice leads to the reduction of the "plasticity" of the debris-charged basal ice (Boulton 1970b).

The stacking of successive slices of debris-rich ice, as shown in Figure 67b, would occur if the process of décollement was repeated several times and if sufficient time elapsed before a new shear plane developed. This way, the debris-rich basal ice which was formerly at the floor of the glacier could be brought up over a previously arrested slice. The reason why the process of _décollement_ can occur repeatedly is that the abandonment of masses of stagnant ice at the base of the glacier produces an up-ice expansion of the obstacle to glacier flow.

It is believed that each one of the stacked slices of debris-rich ice as shown in the schematic representation of Figure 67b will eventually form a ridge in the ribbed moraine. Consequently, the spacing of the ridges in a ribbed moraine is a function of a series of parameters, such as the angle of the shear planes, the thickness of the debris-laden basal zone, and the rate of glacier flow at the sole. The width of a ridge is determined by the angle of the shear planes and by the thickness of the debris. In reality, the width and spacing of the ridges may be more variable due to complicating factors. For instances, subsidiary shear planes may develop at the base of the glacier because the whole process of ridge formation occurs in a zone of localized compressive stresses and each slice may be broken up into smaller slabs. Also, if a moving debris-charged layer is brought up farther than the edge of a previously arrested slice, the resulting feature may eventually be a larger ridge involving two or more slabs.

Small-scale structures observed in the Témiscamie ribbed moraine, such as drag folds, truncated layers, and disharmonic folds, are presumably formed at this stage as a result of over-riding. The folds result from the internal deformation of ice and debris layers while the truncated layers are attributed to erosion along an active shear plane.

An additional characteristic feature of ribbed moraines, namely the sinuosity in plan view of its ridges, developed at this stage. The sinuosity is the result of the deformation of the slices along their length as the glacier over-rides a set of them.

The process of shearing and stacking of slices will continue at the base of the ice for as long as there is an obstruction to flow in the rock basin. As soon as much of the basin is filled with stagnant ice, or when the height of the obstacle is reduced, the glacier is able to overcome the resistance to flow through the development of a sub-horizontal plane of décollement (Fig. 67c). With the development of this shear plane, a major irregularity at the floor of the glacier is eliminated and consequently the bed-profile of the glacier becomes smooth. The filling of a relatively deep bedrock depression and the development of a basal shear plane over the stagnant ice mass, such as depicted in Figure 67c, were documented by Colbeck and Gow (1979) from the margin of the Greenland Ice Sheet at Isua.

Following the change in the configuration of the glacier bed, fluting, grooving, and drumlinization of the surface of the stagnant debris and ice mass buried under the glacier is expected. Most of the flow lineaments which are observed on the ridges of ribbed moraines, as well as the small drumlins in the areas adjacent to them, are believed to have formed at this stage.

Some debris is still being transported at the base of the glacier as it over-rides the stagnant ice mass (Fig. 67c). Most of this debris originates from locations upstream from the rock basin and, in addition, may include eroded parts of the underlying stagnant masses. Eventually, this debris will also be deposited locally over the stagnant masses in the form of a massive bouldery till such as the one which was observed at the top of ridge 5 of the Témiscamie ribbed moraine.

Ribbed moraines are commonly found covered with boulders; since the boulders are embedded into the surface and commonly have a drift tail on their down-glacier end, they must have been emplaced before the ice movement ceased. The occurrence of such boulders can easily be accounted for in the present model. Figure 67c illustrates this well. At point A, situated at the upstream end of the rock basin, the changed bed profile causes an increase in flow velocity. Prior to that, before and during the time the slices were emplaced, point A was located in a zone of impeded flow. It is suggested here that the increase in flow velocity results in the renewed plucking of the step-like glacier floor at the up-glacier end of the rock basin (cf. Boulton 1974). Since this process occurs in a late recessional stage, the boulders are carried only a short distance and are deposited on the forming ribbed moraine. The distance to which such blocks have been carried over the ribbed moraines of the Témiscamie area is in the order of 3 to 5 km, which must be therefore a minimum value for the distance at which ribbed moraines are formed behind the ice margin. Boulders are not always abundant on ribbed moraines because their presence requires not only a source area but also that some failure threshold in the rocks of the source area be attained (Morland and Morris 1978).

The final stage in the formation of the ribbed moraine involves the fusion of the interstitial ice in it and the melting of the overlying glacier ice. In the diagram of Figure 67d, the overlying glacier is shown to have become stagnant; this occurs some time, possibly soon after the slices are emplaced. Stagnation of the glacier is brought about by its continued downwasting and by the resulting migration in the up-glacier direction of a marginal stagnant zone; this was shown earlier to have occured during the recession of the ice sheet in the Témiscamie area.

The stagnation of the glacier has three consequences for the final development of the moraine. The first and most important one, is that it insulates the underlying masses and thereby allows the slow basal melting of the interstitial ice from geothermal heat to take place. Fusion probably starts under active ice as soon as the slices are emplaced, but it continues during the whole time the overlying ice is present (Boulton 1970b, Shaw 1979); furthermore, the stagnant glacier confines the underlying sediments, and thereby limits the occurrence of disturbances during the bottom melting (Boulton 1971). This way, the melt-out till of the moraine can be deposited with preservation of much of the original englacial structure. The geometric features of the moraine are also preserved, the disturbances being limited to minor settling, and local modification of the trend and parallelism of the flow lineation imprinted on them. In order that the disturbance during melting remains minimal, the excess water released by the fusion of the interstitial ice must be evacuated instantaneously (Boulton 1970b). Considering the situation of the moraines, this could have occurred easily since the basins and swales in which ribbed moraines are formed are seldom closed on all sides and would allow the meltwater to escape. Some water may have flowed through open cavities in the melting debris, and the sand lens observed in ridge 5 of the Témiscamie ribbed moraine which was interpreted as the filling of a conduit is thought to have formed as a result of this internal drainage. Whether or not the drainage of the water released during the basal melting of the stagnant mass did lead to the formation of well-defined channels in parts of the swales occupied by the moraines is not known as there is no easy way by which such channels could be distinguished from others that would have been developed later from the melting of the overlying stagnant ice, as will be discussed further on.

The second consequence of the stagnation and wasting of the overlying ice is the letting down of ablation deposits onto the forming ribbed moraine. The deposits are derived from the englacial debris situated at higher levels in the ice. These ablation deposits may partly bury the moraine and locally mask the flow lineation on it. Flow-till and ice-contact stratified drift overlying the melt-out till on the distal side of ridge 3 of the Témiscamie ribbed moraine accumulated this way.

Finally, the third consequence of the marginal stagnation of the glacier is that, at some stage of the melting of the glacier ice, the meltwater may be drained through channels which find their way to the base of the ice. These channels may cut the ridges of the moraine, or deepen and alter the original shape of some inter-ridge troughs and concentrate boulders there. The large channel which cuts the ridges of the Témiscamie ribbed moraine, as well as the numerous channels which are found associated with ribbed moraines in general, are believed to have formed as a result of this process.

According to Shaw (1979), the formation of basal melt-out till under stagnant ice requires permafrost-conducive climate or, at least, a severe climate at the surface, because basal melting is a slow process and if the overlying ice melts rapidly, melting of the interstitial ice in the debris from the surface downward would likely lead to remobilization of the whole mass and to the destruction of the englacial structure. However, there are many other factors involved in determining the rates of melting of the overlying ice and of basal melting, and most of them cannot be quantified as yet. Such factors are the thickness of the overlying ice, the amount of debris in that ice which would form an insulating layer by concentration at the surface, the rate of geothermal heat flow at the base and finally the original amount of ice in the debris at the base. Consequently, although it is believed that basal melting beneath stagnant ice leads to the final deposition of ribbed moraine, there is no necessary inference that there was a permafrost-conducive climate at the time of the deglaciation of the Témiscamie area, or of central Québec, in general.

However, the present model, because it suggests that the final development and preservation of ribbed moraine is accomplished under stagnant glacier ice, also suggests that well-developed ribbed moraine characterizes a certain style of recession of the ice sheet, similar to that which occurred in the Témiscamie area, by which a marginal stagnating zone migrates along with the receding glacier.

In summary, ribbed moraines are formed subglacially, as far as 3 to 5 km back from the margin of the receding ice sheet, as a result of obstructions to glacier flow. The final deposition of ribbed moraine is by fusion of the interstitial ice in it under a protective and confining cover of stagnant glacier ice. Ribbed moraine formation does not require re-advances or re-activation of the ice margin. Although the trend of the ridges is more or less parallel with the receding ice margin, the spacing between the successive ridges has no chronological significance for the rate of recession of the ice sheet.

# CHAPTER 6

# SUMMARY AND CONCLUSIONS

The descriptions and the discussions presented in the previous chapters are summarized here in the form of a list giving the main features of the Quaternary geology of the Témiscamie area. The order in this presentation follows the stratigraphy of the surficial deposits of the area.

(1) The surficial deposits of the Témiscamie area include (a) till under ground moraine, ribbed moraines, and hummocky moraine, (b) ice-contact stratified drift, with associated eskers and meltwater channels, and (c) proglacial sediments, which include outwash and glacial-lake deposits, with associated strandlines. Recent deposits include alluvium, peat, and organic mud found in modern lake basins. Most of the surficial deposits are Holocene in age and the glacial deposits record the late-Wisconsin recession of the ice over this part of central Québec.

(2) The till is a bouldery sandy diamicton, derived from crystalline

and coarse-grained sedimentary rocks. Three distinct genetic types of till are recognized which differ in their textural, structural, compositional, and geomorphic attributes. Basal till is compact, massive, poorly sorted, and the clasts in it have their long axis oriented either parallel or transverse to the main glacial flow direction. It contains predominantly locally derived clasts, and underlies ground moraine. Melt-out till is compact, appears stratified at places where it is observed in large cuts, and the clasts in it show a preferred orientation of their long axis similar to that in basal till. It contains predominantly distantly derived clasts, and together with a local massive bouldery till, underlies ribbed moraines. It is considered to be the equivalent of the Kalix and Sveg tills of northern Europe. Ablation till is loose, massive with local lenses or beds of sorted sediments; the clasts in it may show a poorly developed preferred orientation parallel to the glacier flow direction. It contains predominantly distantly derived clasts, and occurs as a cover sediment over other morainic terrains, or underlies hummocky moraine.

(3) Ribbed moraines are formed subglacially, possibly as far as 3 to 5 km back from the margin of the receding ice sheet, as a consequence of an obstruction to glacier flow which results in the shearing and stacking of slices of near-base englacial debris. Interstitial ice in the debris melts under a protective and confining cover of stagnant glacier ice. Although the trend of the ridges in a ribbed moraine closely approximates that of the receding ice margin, the spacing between successive ridges has no chronological significance for the rate of recession of the ice sheet.

(4) The deglaciation of the area occurred between about 7,200 years B.P., based on the history of Glacial Lake Ojibway, and 6,600 years B.P., based on a local radiocarbon date.The recession of the ice sheet was accomplished with the development of a marginal stagnating zone, possibly up to a few kilometers wide, which migrated along with the receding glacier. There was no re-advance of the ice margin during the deglaciation of the Témiscamie area.

(5) Glacial Lake Ojibway extended partly into the Mistassini area and covered part of the Lac Waconichi basin. It drained when the ice margin was at the Opataca ice frontal position, which is marked by locally prominent morainic ridges, and by a correlative short re-advance of the ice margin in the vicinity of the Waconichi River. The Opataca ice frontal position is some 100 km south of the Témiscamie area, and 20 to 35 km south of the Sakamie moraine. It is assigned an age of 7,900 to 7,700 years B.P., based on the history of Glacial Lake Ojibway and of Tyrrell sea in the James Bay Lowlands.

(6) Glacial Lake Mistassini succeeded Glacial Lake Ojibway in the Mistassini area. It extended into the basins of Lac Waconichi, Lac Mistassini, and Lac Albanel, at first as a single body of water and later as a series of disjoined but inter-related water bodies. It drained first southward into the Nottaway River system, later south-westward into the Broadback River system and finally, westward into the Rupert River system. Rates of recession of the ice margin into Glacial Lake Mistassini are estimated at 220 to 260 meters/year based

on varve counts. Strandlines in the Témiscamie area formed while the final outlet, in the Rupert River head area, controlled the water level in the lake; their position suggests an average uplift gradient of 0.55 m/km in the direction of glacial retreat.

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# APPENDIX A

## PARTICLE SIZE ANALYSIS OF TILL SAMPLES

The particle size distribution of all till samples was analyzed. Only the matrix of the tills, defined as the size-fraction smaller than 4 mm, was analyzed.

Samples were pre-sieved with U.S. Standard sieve mesh no. 5 (4 mm opening) afterwards they were split with a Franklin separator and dry-sieved in a rotap for 15 minutes. Sieves were selected at 0,5 Ø interval.

The fraction of grains of a diameter smaller than 0,062 mm (4,0 Ø) of all the silty and loamy samples, and some of the sandy samples, was analyzed by the hydrometer method. The procedure followed is that described by Lambe (1951). The hydrometer data were processed by a computer program designed by Dr. P. P. David, of the Université de Montréal.

Grain-size curves were plotted on probability paper and the graphic sorting index ($\sigma_G$, Folk and Ward 1957) was computed using the relationships:

$$\frac{\emptyset 84 - \emptyset 16}{2} = \sigma_G$$

where Ø 84: particle size in Ø at 84th percentile of the cumulative curve.

Ø 16: ibid. at 16th percentile.

When the 84th percentile was not attained by the particle size distribution curve, it was determined by extrapolation from the last 2 points on the probability curve along a straight line.

The following data are given in Table A.1. for each till sample:

(1) sample number; see maps in the thesis for locations;

(2) per cent gravel (2 to 4 mm), sand (0,06 to 2 mm), and silt (0,04 to 0,06 mm);

(3) graphic sorting ($\sigma_G$);

(4) median grain-size (Md).

TABLE A.I. SUMMARY OF PARTICLE-SIZE DISTRIBUTION OF THE MATRIX OF TILL SAMPLES.

| Sample Number | % Gravel | % Sand | % Silt | % Clay | Graphic Sorting (Ø) | Median Grain Size (Ø) |
|---|---|---|---|---|---|---|
| 1 | 5.70 | 68.60 | 25.65 | < 1 | 2.0 | 2.40 |
| 2 | 4.60 | 72.90 | 20.40 | 2.10 | 2.20 | 2.50 |
| 3 | 3.40 | 64.90 | 30.50 | 1.20 | 2.20 | 2.50 |
| 4 | 5.50 | 80.20 | 16.10 | < 1 | 1.81 | 2.13 |
| 5 | 7.60 | 73.90 | 18.30 | < 1 | 2.08 | 1.95 |
| 6 | 2.80 | 72.30 | 24.50 | < 1 | 1.93 | 2.46 |
| 7 | 2.70 | 64.20 | 32.90 | < 1 | 1.80 | 3.05 |
| 8 | 1.70 | 49.10 | 47.70 | 1.50 | 2.49 | 3.93 |
| 9 | 3.40 | 71.50 | 22.90 | 2.20 | 2.26 | 3.46 |
| 10 | 6.90 | 85.80 | 7.30 | 0.00 | 1.56 | 1.13 |
| 11 | 1.50 | 77.70 | 20.50 | < 1 | 1.66 | 3.47 |
| 12 | 5.50 | 69.50 | 24.90 | < 1 | 2.30 | 2.50 |
| 13 | 8.50 | 73.40 | 17.90 | < 1 | 2.32 | 1.87 |
| 14 | 3.70 | 67.60 | 13.35 | 3.90 | 2.50 | 3.20 |
| 15 | 1.30 | 80.30 | 18.10 | < 1 | 1.70 | 2.12 |
| 16 | 1.20 | 58.60 | 39.10 | 1.10 | 1.97 | 3.55 |
| 17 | 4.90 | 76.10 | 17.40 | 1.60 | 1.38 | 2.60 |
| 18 | 3.75 | 58.60 | 35.30 | 2.30 | 2.73 | 3.13 |
| 19 | 5.20 | 71.95 | 22.45 | < 1 | 2.05 | 2.40 |
| 20 | 4.40 | 69.70 | 25.40 | < 1 | 2.08 | 2.60 |
| 21 | 3.80 | 70.60 | 24.90 | < 1 | 2.13 | 2.60 |
| 22 | 2.60 | 71.40 | 25.70 | < 1 | 1.90 | 2.78 |
| 23 | 5.60 | 69.00 | 24.80 | < 1 | 2.19 | 2.59 |

TABLE A.I. (continued)

| Sample Number | % Gravel | % Sand | % Silt | % Clay | Graphic Sorting (Ø) | Median Grain Size (Ø) |
|---|---|---|---|---|---|---|
| 24 | 7.10 | 69.70 | 23.80 | < 1 | 2.20 | 2.20 |
| 25 | 5.40 | 66.60 | 27.20 | < 1 | 2.20 | 2.60 |
| 26 | 2.70 | 57.00 | 40.15 | < 1 | 1.82 | 2.60 |
| 27 | 4.50 | 55.60 | 39.10 | < 1 | 2.20 | 2.70 |
| 28 | 5.60 | 76.10 | 18.20 | < 1 | 2.00 | 2.10 |
| 29 | 2.10 | 92.30 | 5.60 | < 1 | 1.41 | 1.85 |
| 30 | 10.80 | 71.60 | 16.40 | 1.20 | 2.40 | 2.60 |
| 31 | 3.10 | 59.10 | 36.80 | 1.0 | 2.46 | 3.26 |
| 32 | 2.50 | 58.30 | 27.60 | 11.60 | 2.98 | 3.46 |
| 33 | 2.85 | 68.25 | 28.40 | < 1 | 1.94 | 2.99 |
| 34 | 3.40 | 71.50 | 24.90 | < 1 | 1.98 | 2.64 |
| 35 | 2.90 | 67.30 | 29.00 | < 1 | 1.92 | 2.63 |
| 36 | 3.20 | 67.55 | 23.95 | 5.30 | 2.38 | 3.06 |
| 37 | 3.50 | 69.60 | 26.30 | < 1 | 2.03 | 3.10 |
| 37A | 3.40 | 69.65 | 26.95 | < 1 | 1.70 | 3.20 |
| 38 | < 1 | 82.25 | 17.60 | < 1 | 0.80 | 3.10 |
| 39 | 5.10 | 81.30 | 13.30 | < 1 | 1.60 | 2.52 |
| 40 | 4.00 | 79.70 | 15.20 | 1.10 | 1.82 | 2.25 |
| 41 | 2.55 | 82.65 | 14.40 | < 1 | 1.31 | 2.70 |
| 42 | 4.00 | 76.80 | 18.80 | < 1 | 1.85 | 2.40 |
| 43 | 3.50 | 86.20 | 10.30 | < 1 | 1.35 | 1.90 |
| 44 | < 1 | 75.70 | 23.80 | < 1 | 1.55 | 2.90 |
| 45 | 3.10 | 87.50 | 9.40 | < 1 | 1.70 | 1.20 |

# APPENDIX B

## TILL FABRIC ANALYSES

The two-dimensional orientation of the long axis of 50 pebbles included in the till was measured in shallow excavations at 12 locations, and at 4 different levels in one exposure along Albanel road (Site A).

The analyses of the data follow the vector method of Curray (1956). Orientations were measured with a Brunton compass to a precision estimated at $\pm 2^{0}$. Data were grouped in classes of $10^{0}$ starting at $1^{0}$ azimuth. All orientations were reported in the 0 to $180^{0}$ range. In the computation, the angles were doubled in order to avoid that the resultant vector has only an east component.

The calculations are as follows:

NS component = $\Sigma n \cos 2\theta$

EW component = $\Sigma n \sin 2\theta$

$$\tan 2\theta = \frac{\text{EW comp.}}{\text{NS comp.}}$$

$$R = (\Sigma n \sin 2\theta)^{2} + (\Sigma n \cos 2\theta)^{2\ \frac{1}{2}}$$

$$L = R/\Sigma n * 100$$

$$\overline{\theta} = \tfrac{1}{2} \text{ Arc tan } (\Sigma n \sin 2\theta / \Sigma n \cos 2\theta)$$

where

n: total number of observations;

$\theta$: mid-point of azimuth classes in the 0-$180^{0}$ range;

R: resultant vector magnitude;

L: resultant vector magnitude in per cent;

$\overline{\theta}$: azimuth of the resultant vector.

A test of randomness is provided by the Rayleigh formula

$$p = e^{(-L^2 n)\ (10^{-4})}$$

when

L: resultant vector magnitude in per cent;

n: number of observations

p: probability of obtaining a greater resultant vector magnitude by a pure chance combination of random orientations.

For n = 50, a resultant vector can be considered a statistically preferred orientation if $p > 0{,}05$. The test is however not applicable, although a p value can always be computed, when the vector distribution is clearly bimodal; in that case, a subjective interpretation of the modes is made.

In the table (B.I.), the following data are given for each fabric analysis:

(1) the sample number or the location of the site;

(2) the frequency of observations in $10^o$ classes;

(3) the total number of observations: N;

(4) the azimuth of the resultant vector: $\theta$;

(5) the resultant vector magnitude in per cent: R;

(6) the value of p for the distribution.

## TABLE B.I. DATA FOR TILL FABRIC ANALYSES

| Sample Number or site | 4 | 5 | 6 | 7 | 8 | 9 | 11 | 12 | 14 | Clairy | Sakhask | Huile | Site A: Top | Site A: Next to top | Site A: Next to bottom | Site A: Bottom |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Classes | | | | | | | | | | | | | | | | |
| 1-10 | 2 | 0 | 1 | 4 | 2 | 7 | 6 | 2 | 9 | 1 | 0 | 0 | 2 | 3 | 3 | 5 |
| 11-20 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 3 | 2 | 2 | 4 | 3 | 0 | 2 | 3 | 2 |
| 21-30 | 5 | 4 | 2 | 7 | 3 | 2 | 3 | 4 | 5 | 5 | 12 | 3 | 1 | 4 | 4 | 1 |
| 31-40 | 5 | 5 | 1 | 0 | 4 | 3 | 4 | 5 | 6 | 7 | 9 | 5 | 1 | 4 | 6 | 2 |
| 41-50 | 2 | 8 | 2 | 2 | 6 | 1 | 6 | 3 | 2 | 3 | 11 | 1 | 3 | 2 | 4 | 2 |
| 51-60 | 1 | 9 | 4 | 3 | 3 | 1 | 2 | 3 | 5 | 9 | 4 | 3 | 2 | 2 | 4 | 0 |
| 61-70 | 1 | 6 | 6 | 1 | 5 | 1 | 0 | 5 | 2 | 4 | 5 | 1 | 0 | 2 | 8 | 3 |
| 71-80 | 4 | 1 | 5 | 2 | 4 | 3 | 2 | 1 | 3 | 3 | 0 | 0 | 1 | 5 | 2 | 0 |
| 81-90 | 4 | 0 | 1 | 4 | 1 | 3 | 1 | 3 | 5 | 2 | 1 | 3 | 3 | 1 | 2 | 2 |
| 91-100 | 6 | 2 | 1 | 3 | 2 | 5 | 3 | 1 | 3 | 0 | 4 | 5 | 3 | 4 | 3 | 2 |
| 101-110 | 1 | 1 | 2 | 5 | 2 | 3 | 2 | 2 | 2 | 6 | 4 | 0 | 1 | 5 | 1 | 7 |
| 111-120 | 1 | 2 | 5 | 4 | 0 | 2 | 3 | 3 | 2 | 2 | 2 | 6 | 6 | 2 | 1 | 3 |
| 121-130 | 0 | 0 | 1 | 4 | 4 | 1 | 2 | 6 | 1 | 1 | 2 | 5 | 5 | 4 | 4 | 1 |
| 131-140 | 1 | 3 | 7 | 1 | 0 | 4 | 1 | 5 | 2 | 3 | 2 | 9 | 4 | 3 | 2 | 2 |
| 141-150 | 1 | 0 | 2 | 2 | 2 | 2 | 0 | 2 | 0 | 2 | 3 | 10 | 5 | 3 | 1 | 3 |
| 151-160 | 3 | 0 | 2 | 3 | 1 | 1 | 5 | 0 | 0 | 2 | 1 | 10 | 5 | 3 | 1 | 2 |
| 161-170 | 5 | 3 | 2 | 0 | 4 | 3 | 4 | 2 | 1 | 6 | 1 | 6 | 4 | 0 | 1 | 3 |
| 171-180 | 4 | 1 | 3 | 1 | 4 | 4 | 2 | 0 | 0 | 1 | 0 | 5 | 4 | 1 | 0 | 1 |
| N | 50 | 49 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 59 | 65 | 75 | 50 | 50 | 50 | 41 |
| θ | 27 | 46 | 90 | 91 | 32 | 6 | 12 | 163 | 136 | 137 | 43 | 147 | 132 | 92 | 38 | 134 |
| R | 18.2 | 49.5 | 10.0 | 6.7 | 12.5 | 6.9 | 25 | 8.6 | 32.3 | 21.0 | 40.4 | 39.2 | 35.2 | 63.9 | 33.4 | 14.5 |
| p | 0.12 | <0.05 | 0.61 | 0.79 | 0.45 | 0.14 | 0.10 | 0.70 | < 0.05 | 0.07 | <0.05 | <0.05 | < 0.05 | 0.52 | < 0.05 | 0.42 |

# APPENDIX C

## DESCRIPTION OF SECTIONS EXPOSING PROGLACIAL SEDIMENTS IN THE MAJOR VALLEYS OF THE STUDY AREA.

This appendix includes the description of 24 selected sections exposed in cuts along the Papaskwasati (PA), Takwa (TA and TI), Cheno (CH), Têmiscamie (TE), and Tournemine (TO) Rivers. The location of sections is given in Figures 28 and 35. Each section is described from bottom to top. Heights are in meters above river level.

a) Papaskwasati River

Section PA-1; east bank, 12 m high, 100 long, 1,1 km from mouth.

| | |
|---|---|
| 9,4 to 12,0 | alluvium; light brown, plane-bedded medium-grained sand grading upward into pebble gravel and coarse-grained sand. |
| 3,5 to 9,4 | valley-fill sediment; very light gray, faintly bedded, very fine sand and silt; beds are 8 to 20 cm thick; silty interbeds are thicker and darker; contacts are irregular and suggest interpenetration of layers; dominantly silty and thinly bedded in lower part. |
| 0 to 3,5 | not exposed. |

Section PA-2; east bank, 6 m high, 300 m long, 1,7 km from mouth.

| | |
|---|---|
| 4,0 to 6,0 | alluvium; light brown ,thinly plane bedded to laminated medium- to fine-grained sand; cross-laminations dip 15$^{o}$ downstream in lower part; rest on fine gravel lag at contact with lower unit. |

| | |
|---|---|
| 0 to 4,0 | valley-fill sediment; dark gray, rhythmically bedded silt and silty clay; lighter-toned clay layers, 3 to 20 mm thick, stand out at an average spacing of 13 cm. Silty layers are graded. Upper contact of clayey laminae are sharp; all layers are finely laminated. |

Section PA-3; east bank, 17 m high, 100 m long, 2,2 km from mouth.

| | |
|---|---|
| 16,0 to 17,0 | poorly exposed. |
| 7,0 to 16,0 | valley-fill sediment; very light gray fine- to very fine-grained sand; alternating massive fine sandy layers, 10-12 cm thick, and laminated sandy-silty layers, 15-18 cm thick; cross-laminations observed in some layers; mean grain size decreases downward. |
| 0,0 to 7,0 | not exposed. |

Section PA-5; east bank, 22 m high, 100 m long, 3,2 km from mouth.

| | |
|---|---|
| 15,5 to 22,0 | alluvium; alternating light brown, medium- to coarse-grained sand and fine-grained sand; cross-bedding commonly observed. |
| 9,0 to 15,0 | valley-fill sediment; light to very light gray, fine-grained sand, thinly bedded; cross-bedding common in upper 2 m; between 11,0 and 13,0 m, the unit shows foreset beds; progressively finer-grained downward. |
| 0,0 to 9,0 | not exposed. |

Section PA-6; west bank, 17 m high, 75 m long, 4,0 km from mouth.

| | |
|---|---|
| 14,5 to 17,0 | alluvium; light to dark brown, medium-grained to pebbly sand. |
| 7,0 to 14,5 | valley-fill; very light gray, very fine-grained thinly bedded sand; few medium-grained sand interbeds at places but mostly in lower part of the unit; silty interbeds near top of unit. |
| 0,0 to 7,0 | not exposed. |

Section PA-7; east bank; 13 m high, 30 m long, 7,0 km from mouth.

| | |
|---|---|
| 7,0 to 13,0 | alluvium-outwash; light brown, medium- to coarse-grained sand, plane- and cross-bedded; includes layers of gravel in upper 2 meters. |
| 4,0 to 7,0 | not exposed. |
| 1,5 to 4,0 | outwash; mostly medium- and coarse-grained sand, cross-bedded, with small pockets of gravel; a layer in thick in upper part is very poorly sorted silty gravel with sharp lower contact and gradational upper contact; interpreted as slump debris from nearby melting stagnant ice. |
| 0,0 to 1,5 | not exposed. |

b) Takwa River

Section TA-1; east bank; 12 m high, 50 m long, 6 km from mouth; 390 m.

| | |
|---|---|
| 11,5 to 12,0 | alluvium; light brown, well sorted medium-grained sand. |
| 2,0 to 11,5 | valley fill sediments; light to very light gray, interbedded fine-grained silt and sand; silt is dominant in lower 3 m of section; bedding is 2 to 5 cm in thickness. |
| 0,0 to 2,0 | not exposed |

Section TA-2; east bank; 12 m high, 35 m long, 8 km from mouth; 391 m.

| | |
|---|---|
| 8,9 to 12,0 | alluvium; light brown, medium-grained sand with few coarse-grained sand interbeds. |
| 2.1 to 8,9 | valley fill sediments; light gray, mainly fine-grained thinly bedded sand; the lower 3 m of unit are dominantly silt with fine-grained sand interbeds, 15 to 20 cm thick. |
| 0,0 to 2,1 | not exposed. |

c) Cheno River

Section CH-1; north bank, 10 m high, 200 m long, 4,3 km from confluence with Takwa River; 390 m.

| | |
|---|---|
| 3,0 to 10,0 | valley-fill sediment; light gray, fine-grained sand with few interbeds of well sorted medium-grained sand. Some silt lenses; unit occurs in foreset beds dipping 25° downstream. |
| 0,0 to 4,0 | valley-fill sediment; bottom set beds of light to dard gray silt, rhythmically bedded. |

d) Takwa River (Upper)

Section TI-1; 10 m high, 80 m long, 2 km upstream from Lac de la Tillite.

| | |
|---|---|
| 4,0 to 10,0 | outwash; light brown, interbedded medium- to coarse-grained sand and sandy gravel. All but gravelly beds show cross-bedding downstream. |
| 0,0 to 4,0 | not exposed. |

Section TI-2; 10,0 m high, 80 m long, 1,0 km upstream from Lac de la Tillite.

| | |
|---|---|
| 5,5 to 10,0 | outwash; brown, coarse- to very coarse-grained sand which includes 10% of granules; it overlies with gradational contact a beige to light brown loose, well sorted, fine-grained sand. |
| 0,0 to 5,5 | not exposed. |

e) Témiscamie River

Section TE-1; east bank, 4 m high, 20 m long, 2 km downstream from Tournemine River junction.

| | |
|---|---|
| 2,6 to 4,0 | alluvium; light gray, medium- to fine-grained sand, thinly bedded. |
| 0,0 to 2,5 | not exposed. |

Section TE-2; west bank, 4,3 m high, 50 m long, at the latitude of shortest distance to Lac Albanel.

| | |
|---|---|
| 0,5 to 4,3 | alluvium; light yellowish brown, medium-grained sand showing trough cross-bedding and ripple bedding; includes layers of fine-grained sand, up to 15 cm thick. |
| 0,0 to 0,5 | not exposed. |

Section TE-3; east bank, 3 m high, 50 m long, 1,1 km north of junction of Témiscamie River and outlet of Lac Cawachigamau; Lat. 51°20' N.

| | |
|---|---|
| 0,0 to 3,0 | alluvium; alternating yellowish brown silty sand, light gray medium-and fine-grained sand, and dark gray fine-grained sand. |

Section TE-4; west bank, 12 m high, 75 m long; at confluence of outlet of Lac Sylvio into Témiscamie River.

| | |
|---|---|
| 8,6 to 12,0 | alluvium; very pale brown coarse-grained sand and fine gravel; gravel lag at the contact with lower unit. |
| 4,0 to 8,6 | valley-fill sediment; light brownish gray, rhythmically bedded silt and silty clay; includes 7 zones, 15 to 90 cm thick, of deformed laminations; deformations range from mushroom-like upward protrusions of finer-grained laminae into coarser-grained layers, to detached and contorted lenses of silt or silty clay. Couplets can be seen in undisturbed parts. These are on the average 5 to 9 cm thick. The deformations are suggestive of load structures. |

Section TE-5; west bank, 20 m high, 100 m long, in the segment of the river between Lac Béthoulat and Lac Roxane.

| | |
|---|---|
| 8,2 to 20,0 | not exposed. |
| 5,0 to 8,2 | valley-fill sediment; light gray, fine-grained sand, thinly bedded; includes interbeds of darker gray silty sand, 5 to 6 cm thick. |
| 0,0 to 5,0 | not exposed. |

<u>Section TE-6</u>; west of Témiscamie River, 18 m high, 200 m long, Lat. 51°35' N, along unnamed tributary to Témiscamie River.

| | |
|---|---|
| 13,5 to 18,0 | <u>alluvium</u>; light brown, very coarse-grained sand and sandy gravel; parts of unit are cross-bedded. |
| 3,0 to 13,5 | <u>valley-fill sediment</u>; beige to brown, medium- to fine-grained sand; beds have a general southward dip which ranges from 3 to 11°. Variable dip creates long shallow undulations with 50 to 100 m wave length. The pattern changes vertically in the section. The structures are suggestive of subsidence (from melting of underlying ice blocks?), penecontemporaneous with accumulation. There are kettles at the surface of the valley fill in the vicinity. |
| 0,0 to 3,0 | <u>not exposed</u>. |

<u>Section TE-7</u>; 22 m high, 100 m long, north side of Témiscamie River, along next unnamed tributary, east from that along which TE-6 is located.

| | |
|---|---|
| 18,0 to 22,0 | <u>not exposed</u>. |
| 5,0 to 18,0 | <u>valley-fill sediment</u>; grayish brown, medium- to coarse-grained sand; subsidence structures similar to those exposed in section TE-6. |
| 0,0 to 5,0 | <u>not exposed</u>. |

<u>Section TE-8</u>; west bank, 20 m high, 25 m long, 0,5 km east of confluence of two unnamed tributaries arriving from the north (sections TE-6 and TE-7).

| | |
|---|---|
| 7,0 to 20,0 | <u>valley-fill sediment</u>; light brown, coarse- to very coarse-grained sand, includes gravel layers; one cross-bedded fine-grained sand layer, 2 m thick, midway in the section. |
| 0,0 to 7,0 | <u>not exposed</u>. |

Section TE-9; west bank, 15 m high, 50 m long, 4,2 km upstream from TE-8.

| | |
|---|---|
| 4,5 to 15,0 | valley-fill sediment; beige, very coarse-grained sand to sandy gravel. |
| 0,0 to 4,5 | not exposed. |

Sections TE-10, and 11; east bank, 5 m high, 3,2 and 4,0 km upstream from TE-9.

| | |
|---|---|
| 0,0 to 5,0 | valley-fill sediment; mostly coarse- to very coarse-grained sand gravel; includes finer-grained sand interbeds which are cross-bedded. |

f) Tournemine River

Section TO-1; west shore of Lac Louis-Joliette, 6 m high, 50 m long.

| | |
|---|---|
| 4,9 to 6,0 | valley-fill sediment; light gray, fine-grained sand, thinly bedded; few darker seams from concentration of dark mineral grains; cross-laminations indicate southward flow. |
| 0,0 to 4,9 | not exposed. |