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SURFICIAL GEOLOGY OF THE SEPT-ÎLES AREA, QUEBEC NORTH SHORE

L.A. DREDGE

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Preface

The Quebec North Shore consists of a rugged upland hinterland fringed by a terraced coastal plain. Most settlements, transportation networks, powerlines, and construction activities are confined to the coastal corridor. Expanding regional development has enhanced the need for an understanding of the surficial geology along the Quebec North Shore.

This report describes the distribution, physical character, and geotechnical properties of the surficial materials, as well as the geomorphic processes, on this part of the Quebec North Shore and the potential impact of surficial geology on future land use activities. Also discussed are the glacial and postglacial events and processes that have shaped the landscape.

Through such systematic mapping studies of the Canadian landmass the necessary geological information is provided for making rational land use decisions as well as for developing a framework for understanding the physical evolution of the Canadian landmass.

R.A. Price
Director General
Geological Survey of Canada

OTTAWA, May 1982

Avant-Propos

La côte Nord du Québec est constituée d'un arrière-pays de montagnes de hauteur moyenne et accidentées, bordé par une plaine côtière à paliers. La plupart des agglomérations, des réseaux de transport, des lignes d'électricité et des travaux de construction sont concentrés dans le couloir qui longe la côte. L'expansion de la région a mis en relief le besoin de mieux en comprendre la géologie de surface.

On trouvera donc dans le présent mémoire une description de la façon dont sont répartis les matériaux de surface, leurs propriétés physiques et géotechniques, et une description des processus géomorphiques qui influent sur cette partie de la côte Nord du Québec et des répercussions qu'aurait éventuellement la géologie de surface sur l'utilisation future des terres. Enfin, les phénomènes et processus glaciaires et postglaciaires qui ont façonné le relief y sont aussi traités.

Grâce à ce genre de travaux de cartographie systématique du territoire canadien, nous acquérons les données géologiques dont nous avons besoin pour prendre des décisions judicieuses concernant l'utilisation des terres et pour élaborer un cadre qui nous permette de comprendre l'évolution physique de la masse continentale du Canada.

R.A. Price
Directeur général
Commission géologique du Canada

OTTAWA mai 1982

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SURFICIAL GEOLOGY OF THE SEPT-ÎLES AREA, QUEBEC NORTH SHORE

Abstract

The Sept-Iles map area lies along the Quebec North Shore – a rugged upland hinterland of rounded Precambrian hills and a terraced coastal plain of late Quaternary marine sediments. Surface materials are divided into ten genetic units: bedrock outcrop; sandy till; outwash; a marine offlap sequence consisting of massive and rhythmically bedded silty marine clay, silty deltaic foreset sand, littoral sand and tidal flat clay; alluvium; eolian sand; and peat.

Mamillated bedrock hills and large valleys graded to below sea level were developed prior to the last glaciation, but all surficial deposits relate to the last glacial episode and postglacial events. The main ice flow was to the south-southeast, although striae along the coast in the southern part of the study area indicate early and very late easterly ice flow within the Laurentian channel. The limit of the late Labradorean grounded ice sheet lay about 50 km south of the present coast near Sept-Iles and near the coast in the vicinity of Godbout.

Upon deglaciation, which occurred about 9000 to 10 000 years ago in the Sept-Iles area and somewhat earlier (13 500? years ago) near Godbout, the Goldthwait Sea inundated the region. Marine limit rises from 100 m near Godbout to 130 m at Sept-Iles. Below marine limit a thick marine offlap sequence was deposited as the land emerged. Sediment-laden meltwater poured through pre-existing valleys and debouched into the regressing sea to form coalescing deltas, which were subsequently terraced to present sea level.

Above marine limit sandy, poorly stratified meltout and flow till were deposited as ice retreated northwards. Two major morainic belts trend southwest-northeast: The Baie-Trinité moraines are small, subparallel features; they lie near the edge of the Laurentian channel and may have been emplaced along shear planes in brittle ice near the limit of glaciation. The Laurentian Upland and Daigle moraines are part of a larger morainic system stretching hundreds of kilometres along the North Shore and are associated with a major interruption in the general pattern of ice retreat.

Settlements and transportation corridors are concentrated along the coastal plain, which is underlain by sensitive marine clays subject to flowsliding. The clays are nonplastic and have water contents which slightly exceed the liquid limit. Flowslides or semicircular rotational slips occur where slopes are overstepened or where excessive porewater pressures develop as a result of natural or man-induced disturbance.

Résumé

La région représentée par la carte de Sept-îles se trouve sur la côte Nord du Québec, arrière-pays de montagnes de hauteur moyenne et accidenté groupant des collines du Précambrien, aux formes douces, et une plaine côtière à paliers composée de sédiments marins du Quaternaire supérieur. Les matériaux de surface se classent en dix groupes génétiques: un affleurement du socle rocheux; un dépôt morainique sableux; un épandage fluvio-glaciaire; une série marine en retrait, composée de couches massives et alternées d'argile marine silteuse, du sable silteuse en lits deltaques frontaux, du sable littoral et de l'argile d'estran; des alluvions; du sable dunaire; et de la tourbe.

Des montagnes de roche moutonnée de d'immenses vallées à versants régularisés jusqu'au-dessous de niveau de la mer se sont formées avant la dernière glaciation; tous les dépôts de surface relèvent toutefois du dernier épisode glaciaire et des événements postglaciaires. La principale coulée de glace s'est faite vers le sud-sud-est, bien que des stries jalonnant la côte, dans la partie méridionale de la région à l'étude, signalement une coulée de glace vers l'est très tôt et très tard dans le chenal de la Région laurentienne. La couche de glace ancrée au sol du Labrador supérieur prend fin à environ 50 km au sud de la côte actuelle, près de Sept-îles, et à proximité de la côte, aux environs de Godbout.

A la déglaciation, qui s'est produite il y a environ 9000 à 10 000 ans dans la région de Sept-îles et un peu plus tôt (il y a peut-être 13 500 ans) près de Goudbout, la mer Goldthwait a inondé la région. La limite marine s'élève, de 100 m près de Godbout, à 130 m à Sept-îles. En -deçà de cette limmite, une série marine d'épaisses couches régressives s'est déposée au fur et à mesure que la terre émergeait. L'eau de fonte riche en sédiments s'est déversée dans des vallées préexistantes et a débouché dans la mer en régression de sorte qu'elle a formé des deltas coalescents, qui se sont par la suite transformées en terrasses marquant le niveau actuel de la mer.

Au-delà de la limite marine, des moraines glaciaires de coulée et de fonte, sableuses et peu stratifiées, se sont déposées lors de retrait de la glace vers le nord. Deux importantes ceintures morainiques s'allongent du sud-ouest vers le nord-est: les moraines de Baie-Trinité sont de petites formations subparallèles situées près du bord du channal de la Région laurentienne; elles pourraient avoir été mises en place le long de surfaces cisaillées dans de la glace cassante près de la limite de glaciation. Les moraines des Hautes-Terres laurentiennes et de Daigle font partie d'un système plus important de moraines qui s'étend sur des centaines de kilomètres le long de la côte nord et elles sont associées à une interruption importante de la courbe générale de recul de la glace.

Les agglomérations et les réseaux de transport sont concentrés le long de la plaine côtière, qui est recouverte d'argiles marines sensibles qui ont tendance à glisser par coulées. Ces argiles ne sont pas plastiques et continennent un peu plus d'eau que la limite de liquidité. Les glissements par coulées ou par rotation en demi-cercles se produisent là où les pentes sont surraidies ou lorsque des pressions interstitielles excessives de l'eau se créent sous l'effet de perturbations naturelles ou artificielles.

INTRODUCTION

Scope of the report

This report results from a regional study of the glacial geology of part of the Quebec North Shore of St. Lawrence River. The objectives of the study were to determine the physical character, distribution, and behaviour of unconsolidated materials along this segment of the North Shore and to develop a general model for glaciation and deglaciation. An area of 12 000 km^2 was mapped between 68° and 66°W, roughly between Godbout and Sept-Îles, and inland from the south coast to 50°25'N (Fig. 1). This particular area was chosen in part because its geological attributes are typical of the North Shore as a whole; also, this coastal area is presently under economic development, including clearcut logging, municipal expansion, port development, roadbuilding, and routing of the Labrador power line. These activities require information about the nature, distribution, and behaviour of surficial materials.

The entire area was mapped by airphoto interpretation. Six months of field work was done between 1971 and 1974. Surface materials were intensively mapped within 30 km of the coast by traversing along the coastal road (Route 138) and along lumber tracks, rivers, and railways which provided access inland. Stratigraphic information came from the examination of roadcuts, borehole records, and riverbank exposures. Samples were analyzed for grain size, petrology or mineralogy, density, water content, Atterberg limits, and shear strength.

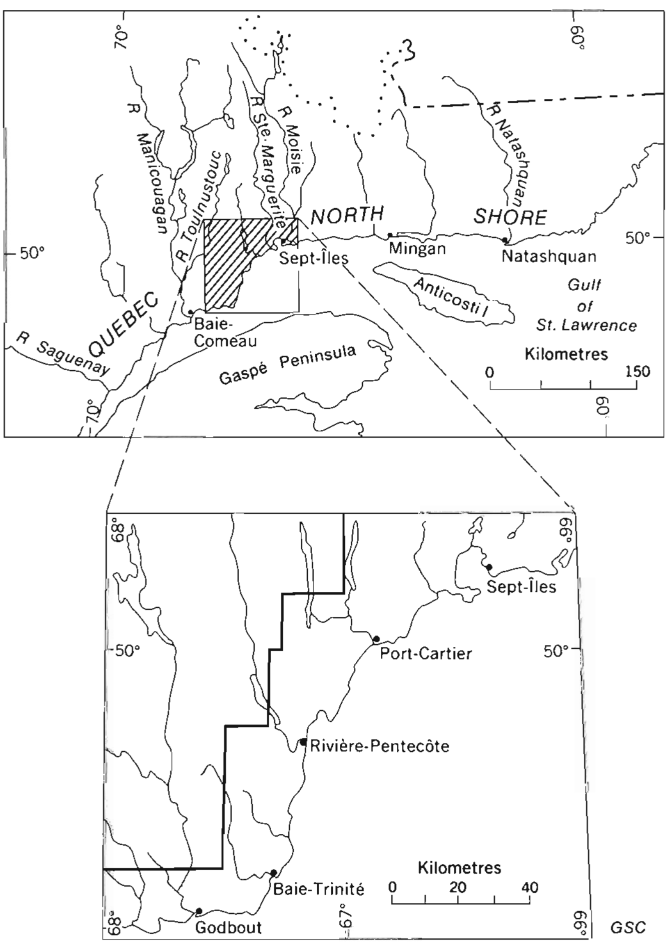


Figure 1. *Location map showing the North Shore region and study area (parts of 22G, J). Field investigations were limited to areas east of the heavy line; the remaining area was mapped by airphoto interpretation.*

Map 1575A portrays the surficial materials for the Sept-Îles map area and forms the basis of this report. Surficial materials are described in terms of their distribution, physical properties and landforms according to, and in order of, their genesis. The glacial history of this region, which serves as a model for the North Shore generally, is summarized in the following chapter. The final sections deal with geotechnical considerations and attempt to show the relationships between the physical attributes, conditions of sedimentation, and engineering properties of materials.

Previous Work

The earliest references to observations of the main elements of the landscape and to the general configuration of the coast date back to accounts of the voyages of Cartier (Pouliot, 1934) in 1535-36 and Champlain (1870) in 1608. For the most part these surveys simply make passing reference to unconsolidated materials in the area, and only recently has systematic geological work been undertaken.

Bayfield (1840) was one of the first visitors who noted Quaternary deposits along the North Shore. As well as mentioning the main rock types along the coast between Rivière Saguenay and Cap Whittle (Fig. 1), he also called attention to stratified valley deposits along the lower reaches of major rivers and the flight of raised beaches at Sept-Îles.

Hind (1864), who made observations along Rivière Moisie, attributed some of the unconsolidated deposits to the work of glaciers. Richardson (1870) described the bedrock along the coast of the North Shore between Rivière Saguenay and Sept-Îles; he identified the principal rock types, including small Paleozoic outliers. De Puyjalon (1882) conducted a similar survey along the North Shore for the Quebec government although his principal aim was to search for deposits of economic minerals. Hunt (1886), Obalski (1901), Dulieux (1912), and Faessler and Schwartz (1941) reported on deposits of iron ore, particularly the titanium- and magnetite-rich gabbro in the Lac des Rapides area and the iron-bearing sands at Moisie. Kindle (1922) noted the elevations of sandy terraces lying in front of the Laurentian plateau from which he assumed that the marine limit was at an elevation of 200 feet. Faessler (1933a, b, 1942a, b, 1945, 1948) mapped the area between Godbout and Moisie by coastal and river traverses; he concentrated on bedrock geology but also mapped sand plains as a major physiographic entity. Franconi et al. (1975) published the most comprehensive bedrock map as part of the Grenville Project. Prior to this, little mapping had been carried out in the inland area except for levelling the profiles of Rivière des Rapides and Rivière Moisie (Québec, Commission des Eaux Courantes, 1948, 1951) and a preliminary map (Moyer, 1959) of the Lac Vermette (Lac Quatre Lieues) area.

Bowman (1931) reported on the palynology of Matamek peat bog, but detailed work involving inorganic surficial deposits was not conducted until the mid 1950s, when Laverdière (1954, 1955) studied the major landforms between Rivière Moisie and Rivière Sainte-Marguerite. Pryer and Woods (1959) and Woods et al. (1959) discussed the characteristics and behaviour of some sediments along the Quebec North Shore and Labrador (QNS&L) Railway north of Sept-Îles. Additional information about the sediments has since become available from borehole logs from various townsites and bridge sites, as well as from a coastal inventory by Dubois (1973).

Two major moraine systems have been identified in this (Dredge, 1976c; Dubois, 1977) and adjacent areas (Dubois, 1976) and the extent and character of postglacial marine sediments have been summarized in Dredge (1976b).

Acknowledgments

The study, funded by the Geological Survey of Canada, constituted a Ph.D thesis (Dredge, 1976a) supervised by P.F. Karrow, University of Waterloo. F.J.E. Wagner and F.E. Cole, Atlantic Geoscience Centre, identified molluscs and forams. Two ponds were cored and analyzed for pollen by R.J. Mott. The Geological Survey of Canada Radiocarbon Dating Laboratory provided radiocarbon dates. Iron Ore Company of Canada loaned company borehole records. Ministère des richesses naturelles provided additional data from three bridge sites. My field assistants were Helen Dumych (1974), Sylvia Ulmanis (1971), and Richard Blais (1972). The manuscript was critically read by J.S. Scott and N.R. Gadd.

PHYSIOGRAPHY

Topography

The study area is part of the Laurentian Highlands of the Canadian Precambrian Shield (Bostock, 1970), which closely corresponds to the Grenville Geological Province of Stockwell (1963). Two distinct units – an upland and a coastal plain – are evident in the map area (Fig. 2). Near the coast, the boundary between these two units is the maximum limit of a high postglacial sea, i.e., the marine limit.

Upland. The southward-sloping Laurentian Highlands constitute the major part of the map area. The landscape is bedrock dominated and is characteristically a succession of rounded rock hills (Fig. 3); both drainage and landforms are structurally controlled. The highest elevation, 720 m, occurs about 8 km northwest of Lac Pentecôte. Local relief is generally 15 to 30 m, although where streams from the interior cross the uplands in major structurally controlled valleys local relief exceeds 300 m (Fig. 4).

Glacial features of Quaternary age contribute only minor topographic detail and few signs of intense glaciation are visible. Large-scale abrasion forms such as U-shaped valleys are widely scattered and are largely inherited from pre-Quaternary events. Two moraine systems lie almost entirely on the uplands. The most extensive is a set of discontinuous, but aligned ridges stretching southwest-northeast from Lac Dionne to Lac Daigle. Near Baie Trinité a second set of minor ridges, also trending southwest-northeast, extends across the southern part of the upland and onto the adjacent coastal plain. The remainder of the upland is bare rock or thinly mantled by till.

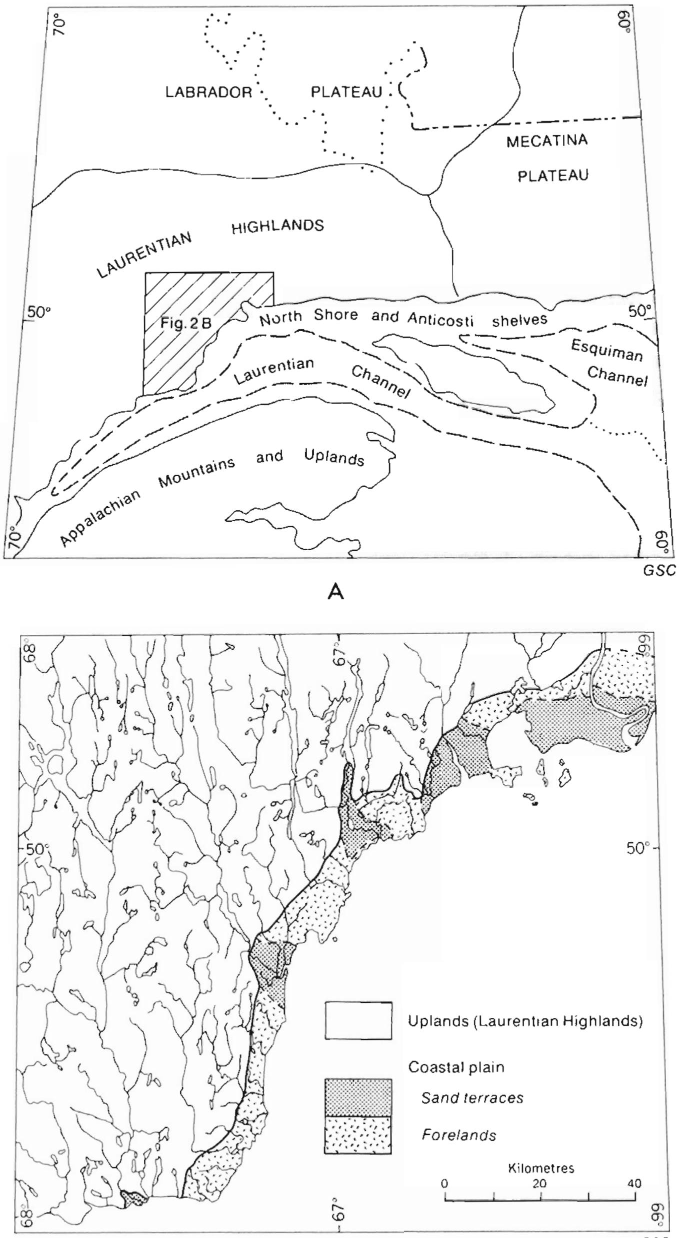


Figure 2. *(A) Regional physiographic setting and (B) physiographic units and drainage pattern of the study area.*

Figure 3

Rolling topography typical of the bedrock-dominated uplands. GSC 188618

Figure 4

A deep, structurally controlled valley within the uplands, occupied by Lac Walker, with sidewalls trimmed by glaciers. GSC 188627

Coastal Plain. The upland is separated from the coastal plain by a fault scarp. Where this scarp is low, bedrock extends from the upland to the coast in a series of en echelon blocks. This configuration has produced a set of low rocky forelands, sculptured by glacial ice and mantled with till and marine sediments.

Sand plains consist of raised deltas which occur at the lower reaches and mouths of large glacial meltwater channels. These deltas coalesce to form sandy lowlands, the largest of which stretches along the coast for 55 km and extends inland for several kilometres up major river valleys. The plains are generally terraced from sea level to about 90 m a.s.l. and are separated from the uplands by an escarpment. At Sept-Îles a flight of prograding beach ridges extends from 75 to 130 m. Except where Pentecôte and Moisie rivers have incised the sediments, local relief is low; the major landforms are beach ridges, river- and wave-cut scarps, dunes, landslide scars, and small bogs. Other landforms include boulder-strewn tidal flats and boulder ramparts which extend along the coast from Rivière-Pentecôte to Baie-Trinté.

Drainage

St. Lawrence River and its tributaries drain the area. Major elements of the drainage pattern have pre-Pleistocene origins related to, and inherited from, structures in Paleozoic rocks which once covered the area (Cooke, 1929). The rock floors of these valleys are graded to a base level about 200 metres b.s.l. but have since been infilled with alluvial, glacial, and estuarine debris. Valleys of the Moisie, Sainte-Marguerite, Pentecôte and aux Rochers rivers thus consist of deep rock-walled gorges up to 2.5 km wide. The modern rivers flow as underfit streams within the valleys and have created a series of terraces as they incise and grade the valley fill to present base level. Rivers flow through the uplands and coastal plain with no marked change in gradient except over reaches where they depart from the pre-existing valley systems. For Rivière Moisie, discharge is about 15 000 cfs for normal summer flow, and 50 000 cfs during snowmelt.

Small rivers, such as Rivière des Rapides, Mistassini, Franquelin, (Québec, Commission des eaux courantes, 1948 and unpublished) and Grande Rivière de la Trinité, postdate glaciation and flow across the upland and coastal plain, cutting shallow channels into underlying bedrock. Water drains southward in a stepped profile over a series of waterfalls and rapids.

Some of the smallest streams on the uplands are adjusted to local structure, but many have no well defined valley. The small scale drainage network is non-integrated; water collects in numerous depressions and spills over from one to another through low areas or poorly defined channels. Streams originating on the coastal plain also have a deranged pattern. In sandy areas water escapes by direct infiltration or is absorbed by organic deposits. Surface drainage over organic terrain is generally restricted to a disconnected lattice of ponds and runnels which allows some of the water to flow outwards from the centres of raised bogs.

Climate

The area lies in a humid subarctic climatic region, south of the zone of discontinuous permafrost. The mean annual air temperature is 0°C; daily means at Sept-Îles airport range between 15°C in July and -15°C in January. Temperatures pass through the freezing point 97 days per year, mostly in April and October, and the frost free period is 108 days (Meteorological Branch, 1969-1974).

Precipitation averages 1080 mm annually, of which 430 mm of water equivalent falls as snow (Meteorological Branch, 1969-1974). Precipitation is spread evenly over the year but snow builds up to 102 cm on the ground and melts rapidly in the spring. Water balance calculations (Dredge, 1976a) show that of the 1080 mm of precipitation, 465 mm is used in evapotranspiration, giving an annual water surplus of 615 mm.

Prevailing winds are from the north and northwest in winter and from the east in summer, at an average velocity of 15 km/h.

Those aspects of the climate that directly affect the geomorphology of the area are as follows:

1. The summers are sufficiently warm and humid to produce large organic accumulations, and the climate is cool enough to prevent rapid decay; peat accumulates in poorly drained areas.
2. Extensive heaving may occur in the spring and fall in frost-susceptible soils.
3. During the snowmelt period, rapid runoff produces turbulent overland flow and high stream discharge. Noncohesive materials, such as sandy till and estuarine valley fill deposits, are subject to accelerated erosion.
4. The prevailing winds are capable of entraining loose dry sands up to 2 mm in diameter. Unprotected or unvegetated parts of the coastal plain are therefore subject to deflation.

Vegetation

The study area lies within the boreal forest (Hare, 1950) and is characterized by stands of closely spaced trees. Black spruce, balsam fir, and white spruce are dominant species, and paper birch is the most common hardwood associate.

Alder and jackpine are secondary species which colonize disturbed sandy areas, whereas tamarack is located near wet sites. The coniferous trees develop interlocking branches which restricted visibility during field work as well as made airphoto interpretation difficult. Peat bogs consist of sphagnum moss, together with some sedges and shrubs. Except for present day tidal flats and newly formed beach ridges which have specific plant communities, similar vegetation associations occur on all types of inorganic terrain; therefore, vegetation cannot be used as an indicator of substrate.

Soils

Soils are low in nutrients. The predominant sub-group is the ortho humo-ferric podzol, which is best developed on well drained, sandy textured substrate. These soils develop in a short period of time, for incipient profiles with bleached horizons were observed on backshore beach ridges along the present shore.

A bleached, siliceous, ashy white Ae horizon, usually less than 15 cm thick, is abruptly underlain by a reddish brown Bf horizon, characteristic of podzols, which extends to a depth of about 2 m. This Bf zone occurs as a hardpan, cemented by iron and aluminum oxides released by the in situ weathering of hornblende, magnetite, and ilmenite grains.

The presence of the indurated layer has affected drainage and vegetation as well as land use:

1. The hardpan has resulted in poor drainage conditions and the subsequent accumulation of peat on the sand terraces at Natashquan (320 km east of the field area; Fig. 1) (Welsted, 1960, p. 93). The same could be true for terraces between Godbout and Moisie, where peat bogs are also prevalent.
2. In areas of wind erosion, deflation is limited once the cemented layer is exposed.
3. The exposed hardpan is locally important as the base for bush roads; it also forms the surface of the airstrip at Baie-Trinité.

SURFACE MATERIALS

Map 1575A shows ten genetic types of surface materials: bedrock (R)*, till (1), glaciofluvial and fluvial deposits (2), a marine offlap sequence (6) consisting of offshore (3), nearshore (4), and littoral (5) deposits, eolian sands (7), modern alluvium (8), and organics (9). Except for bedrock, these materials belong to the last glaciation, the marine episode that accompanied late glacial events, and the postglacial period. Materials are discussed below in order of their approximate stratigraphic sequence. Each unit is described in terms of distribution and composition, texture and structure, topographic expression, and engineering characteristics.

Map 1575A portrays the distribution of surficial materials. Unit boundaries have been defined on the basis of features or tonal changes on airphotos. In many cases, map unit boundaries are gradational: for example, till veneer (1a) thins and becomes indistinguishable from bedrock (R) in places; or glaciofluvial deposits (2) grade into the marine offlap sequence (6).

Bedrock (R)

Distribution and Lithology. Bedrock outcrops over approximately 15% of the map area, mostly within the uplands physiographic unit; another 40% of the map area consists of small bedrock patches within the units mapped as till veneer (1a) and sand veneer (5av). Rocks are Precambrian in age and belong to the Grenville Province (Stockwell, 1963). A well defined multidirectional joint system is developed on all rock types and produces the distinctive rock "grain" seen on airphotos. Rock types are distinguished according to major lithological groups, whose attributes give Quaternary materials their textural and mineralogical character.

The most widespread rock types are grey granite gneisses, with their migmatitic equivalents (R_1). These are medium grained rocks composed of quartz-diorite, and fine grained rocks rich in hornblende and biotite.

Three intrusive bodies occur in the map area, characterized by gabbro (locally with titanomagnetite) and grey-green anorthosite surrounded by aureols of hypersthene monzonite (R_2). These rocks outcrop along the coastline between Rivière-Pentecôte and Moisie, and along an arc from Lac Dionne which intersects the coast near Baie Saint-Nicolas.

Metasediments (R_3), present along the coast between Franquelin and Baie-Trinité, consist of biotite-garnet paragneiss, with minor amounts of amphibolite and crystalline limestone.

When these rocks are abraded or crushed (e.g. by glacier ice), the resulting particles are of sand and granule size.

Paleozoic limestone is reported in two small outliers (Faessler, 1942a, 1945) – one forms low islands offshore from Sept-Îles, the other occurs along the coast 5 km east of Rivière-Pentecôte.

Abrasion and Weathering. Bedrock has an overall fresh appearance and surfaces show signs of abrasion or shaping by glacial erosion. The largest abrasion features are truncated spurs on north-south trending valleysides. Intermediate scale features, such as flutes, whalebacks, and roches moutonnées, as well as small scale chattermarks and gouges, can be seen on all rock types. Small features – striae and polished surfaces – are generally limited to softer, medium to fine grained rock types, chiefly gabbro.

Granitic and metasedimentary rocks are virtually unweathered; arabesque corrosion patterns observed beneath moss mats were only about 1 mm deep. Gabbroic rocks are also generally resistant to weathering or show only slight effects. Some joints, which may have widened by freeze-thaw activity or by postglacial tension stresses, are oxidized, but weathering seldom extends farther than 1 mm in from joint surfaces.

An isolated outcrop of disintegrated anorthositic bedrock (Fig. 5) occurs at Lac Caché, west of Rivière Sainte-Marguerite and over a more extensive area, between Lac Pentecôte and Rivière Vachon. Chemical weathering has progressed inwards from a well developed rectangular joint system, leaving the central cores of the joint blocks relatively sound. The rock appears to be structurally intact but crumbles into sharp pebble-sized fragments of plagioclase and a loose mass of silty red-brown material when it is dislodged. Carbonate analysis of the fines reveals that a very small quantity of the plagioclase has been altered to calcite during the weathering process.

Till (1)

Distribution and Stratigraphic Position. Three till units have been mapped on the basis of thickness, and together they comprise about 60% of the land surface. The most extensive unit is till veneer (1a), comprising till deposits less than 1 m thick interspersed with small patches of outcrop; bedrock

*Map unit on Map 1575A.

Figure 5. *Disintegrated anorthosite; note well defined joint system and grus-covered foreground. Section is 4 m high. GSC 188620*

Figure 6. *Typical sandy till; section of ground moraine at Lac du Pont. GSC 188624*

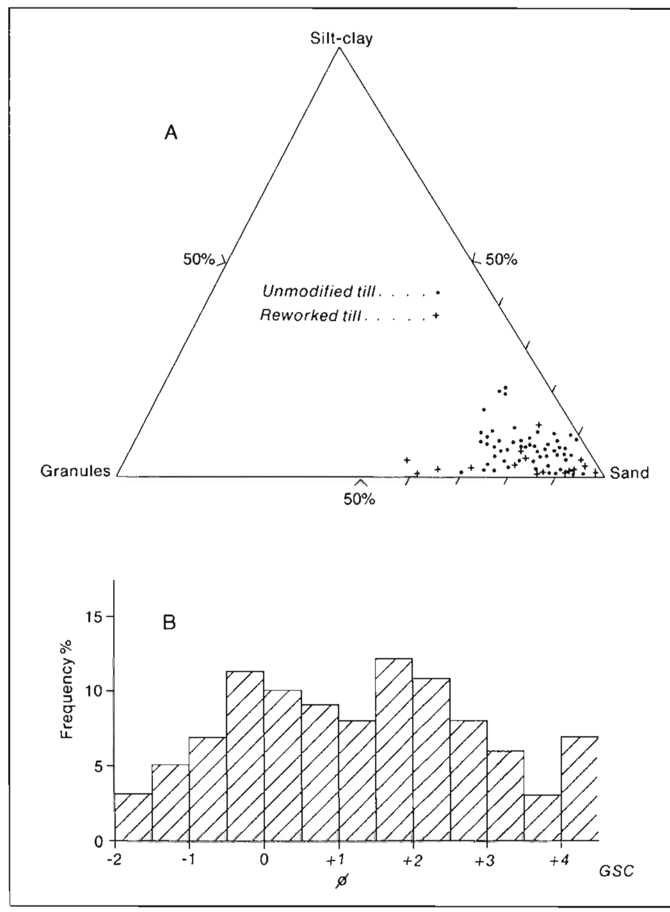


Figure 7. *Texture of matrix (less than 4 mm fraction) of 76 till samples from the Quebec North Shore. (A) Ternary grain size summary of all samples. (B) Typical grain size distribution of the sandy matrix.*

structure shows clearly on airphotos. Blanket deposits (1b) are generally 1-5 m thick and mimic the topography of the underlying bedrock. Thick deposits of till (1c) occur as end moraines, valley fill plugs, and lateral valley terraces, which obscure the topography of the underlying rock unit.

Evidence for more than one till is lacking in the area, and the absence of major textural changes or oxidation layers within the till suggests further that the till sheet represents a single glacial episode.

On the upland, till directly overlies bedrock and forms the surface material. Exposures below marine limit show that the till sheet extends beneath marine deposits. Till has not been positively identified in deep borehole records, although it may be present beneath Sept-Îles where pockets of "gravel" (driller's term for material rich in pebble-sized clasts) were reported in depressions in the bedrock under about 50 m of massive clay and sand; in boreholes that touched bedrock knobs, no trace of the "gravel" was noted. Similarly, in boreholes along the Quebec North Shore and Labrador (QNS&L) Railway "gravel", which could be either till or outwash, underlies marine sands.

In most places till is olive-grey, sandy textured, crumbly structured, and weakly fissile. Colour, texture, and mineralogy, however, are variable according to the character of bedrock sources or to postdepositional alterations.

Texture. Grain-size Characteristics. Till on the North Shore consists of pebbles, cobbles, and boulders in a sandy matrix. Pebbles and larger particles make up from 20% to 25% of the till surface in exposures (Fig. 6). Most of the clasts are subrounded to subangular and many are faceted. Boulders are locally derived joint blocks that are angular to subangular.

Figure 7 illustrates the grain size distribution and the extent of textural variation of the <4 mm fraction (matrix) of 76 till samples, and the accompanying histogram shows typical texture within the sand fraction. Complete curves can be found in Dredge (1976a). Typically the till is 70% sand, 20% granules, and 10% silt-clay (predominantly coarse silt) by weight, except for tills that have been water-sorted, where the fines account for less than 5%.

Granitic tills are poorly sorted, the standard deviation being 1.6 phi (Ø) units. The mean grain size is 1.2 Ø (0.4 mm), and the modal class of the matrix is in the 1 to 2 Ø range (0.5-0.25 mm). The particles in this range are individual mineral grains. Comminution does not appear to have been sufficient to reduce these grains to their "terminal grade" (2 to 5 Ø) as defined by Dreimanis and Vagners (1971). Gabbroic tills display a second mode in the -3 to -4 Ø range (8-16 mm), consisting of small rock fragments that have not been crushed. The frequency distributions of unaltered till are generally unskewed (average skewness +0.04).

Distribution of Particles. Although the till is texturally diamictic, indistinct discontinuous bedding structures are commonly present (Fig. 8). Small crossbeds, wavy laminae, and lenses of sorted sediment are visible in exposures and extend from the surface to the base of the till sheet; this suggests that the till was generally deposited as a slurry.

Fabric analyses show that pebble-sized clasts are preferentially oriented around cobbles and boulders in a streamlined pattern; this streamlining can occur as a response to stresses around fairly small obstacles in the till due to an abundance of interstitial water. Most of the silt-sized particles occur as coatings around pebbles and large clasts.

Textural Alteration by Postdepositional Processes. (Textural variations below marine limit). Reworked till deposits (1br) are recognized in the field by their generally clean appearance due to the removal of silty skins from pebbles, by bedding structures in upper parts of exposures, and by lag concentrations. On the uplands, river currents are responsible for reworking plugs of till in meltwater channels, but at lower elevations wave activity is the dominant agent of reworking. The degree of modification increases from areas near the maximum limit of postglacial submergence down to present sea level. Alteration of the till progressively involves:

1. removal of fines; the percentage of silt-clay decreases and mean grain size increases; the material becomes better sorted (lower standard deviation);
2. development of a cobble and boulder lag at the surface;
3. reorientation of sand and pebbles in the upper 2 m to create subhorizontal sand and pebble beds and imbricated structures; and
4. complete removal of the matrix where reworking is most intense, leaving an open-work remnant of cobbles and boulders up to 4 m thick (e.g., at Baie-Trinité).

Figure 8. *Indistinct bedding structures in till. GSC 188637*

Composition. Pebbles. Pebble lithologies fall into two groups corresponding to the two major rock types present in the study area: 1) an acidic group, composed primarily of pink and grey gneiss and granite, hornblende schist, and monzonite and 2) a mafic group composed of gabbro, anorthosite, green granulite, and diabase. Granites and gneisses are commonly subrounded, gabbroic pebbles are subround to subangular, and schists and anorthosites are subangular to angular. Detailed lithological tables and spatial distributions of clast types are shown in Dredge (1976a).

Pebbles with granitic affinities comprise about 74% of all clasts, whereas about 26% are mafic. These percentages generally reflect the abundance of granitic and mafic rock sources in the area. Both rock types are present in till throughout the study area and reflect the mixed character of till derived from both local and distant sources. Granitic pebbles comprise 78% of pebbles in areas underlain by acidic rock types but are also the major lithologic type in tills over mafic rocks. Mafic pebbles are present in all samples analyzed, but are most abundant (average 46%) in areas underlain by mafic rock types.

Abrupt compositional changes in pebble lithology coincide with corresponding changes in underlying bedrock type. This association indicates that much of the till is derived from local sources. In valleys (e.g. Rivière Riverin), however, the lithological character of the till is less closely related to rock types directly underlying the till, which suggests transport of pebbles from more remote sources in these topographic settings.

Sand Fraction. The till matrix consists of sand-sized fragments derived from glacial crushing of medium grained parent rocks. Figures 9 and 10 portray the mineralogical composition of the fine sand fraction (0.125-0.250 mm) of tills in this portion of the Grenville Province (for other size fractions and spatial distributions, see Dredge, 1976a) and light/heavy mineral (specific gravity >2.95) ratios. The examples shown relate to a till with primarily granitic affinities (e.g. till at Lac Daigle) and one with mafic affinities (e.g. till at Lac du Pont); the two examples show the variation in composition in the till over the area determined from the analysis of 76 samples.

In terms of absolute abundance, quartz is the dominant component of till from both rock types, but it is more abundant in the granitic till than in the till overlying gabbroic rock. Feldspars are also major components of both till types: potassium feldspar predominates the granite-derived till whereas plagioclase predominates the gabbroic till.

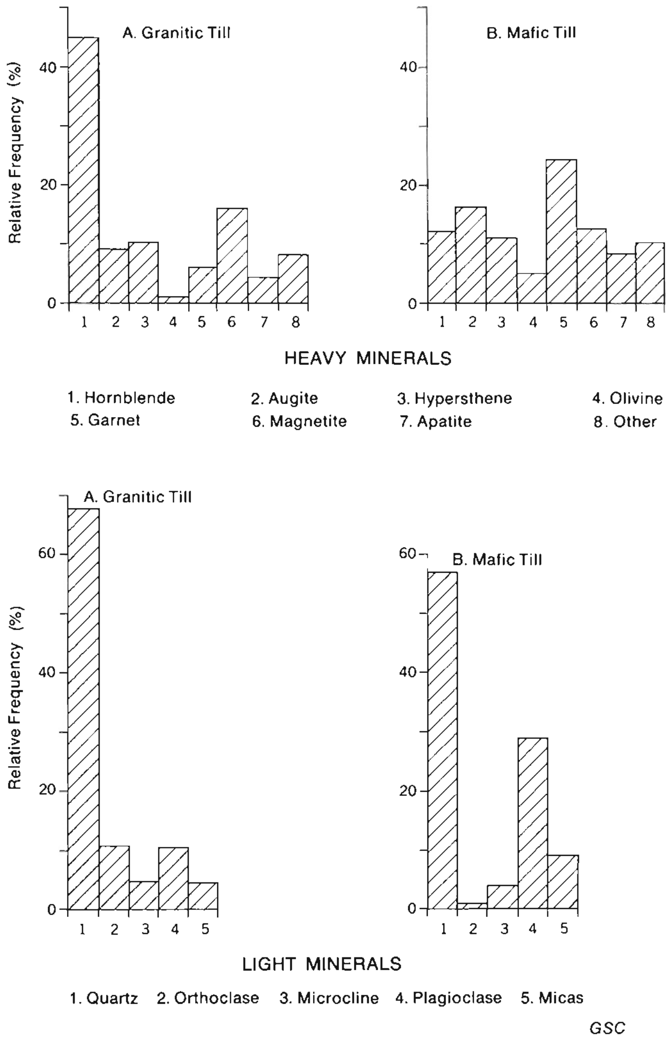


Figure 9. *Heavy and light minerals in the fine sand fraction of representative samples of granitic and mafic tills. Heavy minerals account for 10% of the total minerals in granitic till and 21% in mafic till. (A) Granitic till from Lac Daigle. (B) Mafic till from Lac du Pont.*

In the heavy fraction, amphibole and pyroxene are abundant in both till types and in all sand size fractions. Hornblende is the predominant heavy mineral, forming 45% of the heavy fraction in the granitic till and about 12% in the mafic till. Garnet is also an important component of the mafic till sample but is much less abundant in the granitic till. Apatite and opaque minerals (chiefly ilmenite-magnetite) are also present and together make up as much as 33% of the heavy fraction.

A strong relationship exists between heavy mineral content, grain size, and source rock. Figure 10 indicates that (1) heavy minerals are more abundant in the small grain sizes and that (2) heavy minerals are more abundant in the gabbroic till than in the granitic till.

The data show that both the pebble and sand components possess the characteristics of the underlying and directly surrounding rock type. This indicates that comminution by crushing occurs readily in these rocks. The abundance of local material also suggests a basal transport mechanism.

In the heavy mineral fraction, till associated with granitic rock has a high hornblende content, while that associated with gabbroic rock has a significant pyroxene and olivine content. These differences, together with heavy mineral ratio data permit differentiation of till sources on the North Shore. The reader is referred to Dredge (1976a) for specific criteria for differentiation relevant to mineral exploration.

Silt-Clay Fraction. The silt-clay fraction (mostly silt) accounts for less than 10% of the till matrix.

The principal minerals of the <63 µm fraction are quartz and feldspar, although pyroxene is also important in the representative gabbroic till sample (from Lac du Pont) (Table 1). Micas, garnet, and amphibole are of less importance. As expected because of the predominance of coarse silt, most of the powder is rock flour and few clay minerals are present. Because the fine fraction of a till commonly represents contributions from remote sources (whereas coarser fractions have more local origins), the mineralogy of the fine fraction of these two till types is less distinctive than the corresponding assemblages in the coarser fraction. For example, the granitic sample from Lac Daigle has peaks of plagioclase and pyroxene, whereas the Lac du Pont sample shows the presence of amphibole.

As grain size diminishes, there is a decline in the relative abundance of feldspar and quartz, and a corresponding increase in mica or mica-illite, and also chlorite in the Lac du Pont (gabbroic) samples. Both till samples, but especially that from Lac du Pont, probably contain some noncrystalline materials, since the diffraction peaks of even the major minerals are poorly defined. McKyes et al. (1974) have attributed similar occurrences in their diffractions to the presence of amorphous iron and silica oxide coatings on the mineral particles. Since similar noncrystalline materials are more abundant in till from Lac du Pont, it is suggested that the material could be related to weathering products of ultrabasic rocks.

Morphology/Landforms. Ground Moraine. Till on the upland forms a discontinuous, almost featureless blanket varying from 1 to 5 m thick, but generally the till is less than 3 m thick. Where it thins to a veneer (<1 m), the ground moraine is interspersed with extensive areas of bare rock.

Morainic Ridges. Several sets of small ice-contact ridges are shown in Figure 11 and on Map 1575A by symbols or as unit 1c. The large ridges are end moraines. A series of small ridges in the vicinity of Baie-Trinité do not necessarily mark ice-marginal positions.

Daigle Moraine. The largest moraine in the area, 13 km long and up to 200 m wide, is situated on a rocky foreland at Lac Daigle (10 km northeast of Sept-Îles), directly above marine limit. In plan, the moraine consists of two broadly arcuate subparallel ridges with a hummocky boulder-strewn area between the ridge crests. The distal slope grades into an outwash plain. The highest point is 150 m a.s.l. and maximum relief between ridges and the surrounding area is 20 m. The general trend of the moraine is N70°E (perpendicular to the direction of striae at Rivière des Rapides), but it is slightly lobate to the south. A small limb at the western extremity is oriented northeast-southwest and it is separated from the main ridges by a small re-entrant or water gap. The ridge crests are interrupted by a water gap at Lac Daigle, where outwash from the Daigle channel to the north broke through and spread out to form an outwash plain. As a result, the sides of the ridges around Lac Daigle are indistinctly terraced.

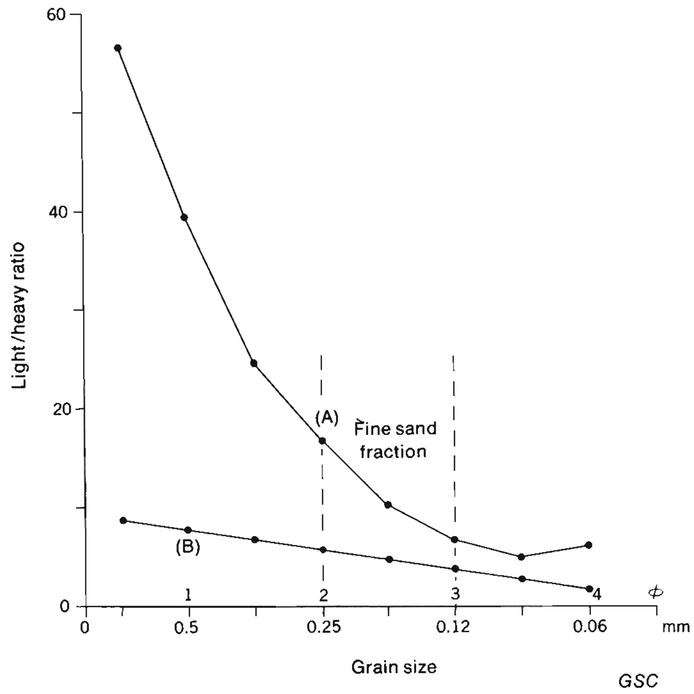


Figure 10. *Light/heavy mineral ratios of various grain sizes of the till matrix for the two representative till samples shown in Figure 9. (A) Granitic till; (B) Till with a mafic component.*

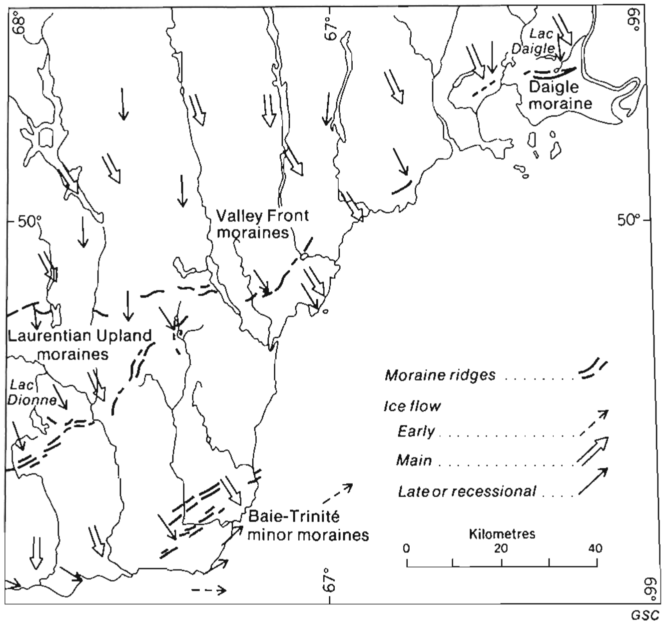


Figure 11. *Principal moraines and ice flow directions of the study area.*

Table 1. Silt-clay mineralogy of till underlain by granitic and mafic rocks

		Principal Minerals	Other Minerals in Order of Decreasing Importance	Remarks
Granitic Till* (Lac Daigle)	powder	quartz, feldspar	amphibole, mica, magnetite, trace calcite	few clay minerals
	<5 μm	mica-illite	quartz, feldspar, mica, pyroxene	sharp decline of quartz, feldspar
	<2 μm	mica-illite, feldspar	mica-illite, possibly kaolinite and montmorillonite	
Mafic Till* (Lac du Pont)	powder	plagioclase, feldspar, quartz, pyroxene	biotite, amphibole, chlorite, garnet	
	<5 μm	mica-illite, chlorite, pyroxene	feldspar, ilmenite, biotite, trace vermiculite	high background; amorphous material significant
	<2 μm	? chlorite/halloysite	minor feldspar	fuzzy peaks; coloration at 575°C suggests chlorite

*The two till samples chosen show the widest range in composition.

Valley Front Moraines. A discontinuous ridge of till is situated 5 to 7 km inland from the coast between Rivière Pentecôte and Rivière aux Rochers. The ridge is low and discontinuous on high ground but widens and rises to about 15 m where it crosses river valleys. The thickest parts lie directly above marine limit.

The string of morainic deposits is oriented perpendicular to the general ice flow direction, and no lateral moraines were found in river valleys. The moraine, therefore, is interpreted as marking the former position of an ice front rather than as a series of moraines formed by late ice tongues in the valleys. The difference in size between the valley parts of the moraine and the contiguous upland ridge could be due to the greater abundance of available debris in valleys, differences in glacial mechanics operating in confined valleys and uplands, and probably, to a lesser extent, to more intensive postglacial subaerial erosion in exposed upland localities.

Laurentian Upland Moraines. A morainic belt can be traced northeasterly from the western edge of the map area to align roughly with the Valley Front moraines farther east. Those moraines southwest of Lac Dionne extend into the end moraine near Manic 2 (to the southwest) reported by Sauvé and LaSalle (1968); they appear as a series of small, sinuous, discontinuous ridges crossing terrain varying in elevation from 260 to 520 m. The ridges are arcuate southwards in some valleys.

Another group of ridges, more discontinuous than those to the south, extends east-west between the western boundary of the map area and Lac Pentecôte to join the Valley Front moraine system near Lac Pentecôte.

Baie-Trinité Moraines. Parts of a set of small sinuous moraines with rim ridges and other ablation features between ridge crests occur west of Baie-Trinité. These ridges are oriented approximately northeast-southwest and have a local relief of about 5 m and a spacing of about 300 m. These disinctive moraines are remarkably similar in form to the Belles Amours moraines along the coast 700 km farther east (D.R. Grant, personal communication, 1982). The ridges occur at an elevation of 100 to 130 m; thus, parts of the ridges were inundated by the sea at one time. Crests and sideslopes are smooth and broadly rounded, and washed boulders lie on the surface. One of the ridges is composed of well sorted sand covering a central rock core, but undisturbed cores of the other ridges are composed of till similar in texture to the nearby ground moraine. Near the surface, reworked parts are less compact and slightly finer than the material below; in other places, wave action has removed some of the fines. At the lower outer edges of the ridges wave activity has produced bedded sand and granule wedges around boulders. Boulder ramparts at sea level (unit 5b) between Baie-Trinité and Islets-Caribou may be highly reworked remnants of the easterly continuation of this morainic system.

Lateral Moraines and Thick Till Features. These are present in the study area, but are of minor extent. Lateral terraces (kame or moraine) occur in valleys for short distances (1 to 5 km) and are associated with small end moraines deposited by lobes of ice flowing in valleys. As these occur low on the valley walls, the features are probably a product of very late glaciation. Hummocky features occur in some valleys and relate to stagnating ice masses cut off from the main ice stream by meltwater channels (e.g. Godbout area); these features are characterized by internal slump structures, abrupt changes in grain size and sorting, and laminated sediment where the blocks finally melted.

Engineering Characteristics. Till is composed of poorly sorted sands and gravels; fines make up less than 10% of the dry weight. Natural water contents are less than 6% of the dry weight on well drained sites but may be greater under conditions of restricted drainage. In situ relative densities, as determined by penetration tests, vary from loose (ablation till) to medium dense (basal till). Both the bulk till and its silt-clay fraction are nonplastic and noncohesive; strength is therefore entirely dependent on frictional properties related to grain angularity and packing arrangement. Laboratory strength tests on similar tills at Manicouagan (20 km west of the study area) resulted in values between 7 and 10 kg/cm^2 (700 and 1000 kPa) over natural water contents (Dussault et al., 1970) and fall within the range of values determined by field tests for the study area.

Glaciofluvial and Fluvial Deposits (2)

Distribution and Stratigraphic Position. Glaciofluvial and fluvial sediments were deposited by streams and rivers associated with the melting of ice sheets and with subsequent river regimes previous to those at present.

Since most of the meltwater flowed southward down the natural slope of the land in pre-existing rock-walled, structurally controlled valleys, the distribution of outwash and related sediment is generally limited to the bottoms of these preglacial features. Relatively minor amounts of sediment are also found on distal sides of end moraines.

Four types of deposits are recognized, each with similar lithological properties but with distinctive sedimentological and morphological characteristics. Where possible, these units have been mapped separately and are described below; however, in many places the units cannot be differentiated at the scale of mapping used, and have been included in unit 2 (undifferentiated).

Stratigraphically these deposits overlie, and to some extent interfinger with, till. The alluvial facies associated with this environment merges into marine deposits near its more southerly extent; furthermore, the alluvial sediments grade to a continuously falling sea level and therefore overlie some of the high level marine deposits.

In places it is difficult to distinguish the boundary between alluvial deposits and delta topsets on the basis of airphoto interpretation.

Engineering Characteristics. Glaciofluvial deposits consist of poorly sorted, rounded cobbly gravel, varying to well sorted sand and gravel. Permeability is moderate to high and variable over short distances. Deposits are well drained and generally are not frost-susceptible.

Eskers

Eskers (symbolized on Map 1575A) appear as discontinuous sinuous ridge segments less than 2 km long and are mainly restricted to the Godbout and aux Rochers valleys and their tributaries. They consist of poorly sorted, commonly massive sand and gravel, including abraded cobbles and boulders; they also include masses of till.

The paucity of eskers and their restricted locations are indicative of an actively retreating glacier where subglacial meltwater was free to drain down the natural slope of the land in pre-existing channels.

Outwash (2a)

Composition. Outwash and related deposits consist primarily of clasts derived from granitic and gneissic (felsic) terranes but some mafic clasts are also present. Except for

Figure 12

Poorly stratified cobbly outwash south of the moraine near Lac Daigle. GSC 188674

micaceous schists, the felsic clasts are solid; gabbroic clasts are commonly highly weathered (crush in the hand), and fine reddish oxides from these mafic rocks coat clasts and act as cement binding the matrix.

Texture. The outwash is coarse grained, composed of rounded cobbly gravel and sand in southward-dipping beds (Fig. 12). High-angle avalanche crossbeds, cut-and-fill structures, involuted sand lenses, and imbricated pebble layers are common large-sized sedimentary structures; they represent rapid deposition in a high energy environment. Abrupt and erratic changes in grain size and sorting are evident, indicative of rapid changes in stream competence either associated with the braiding of shallow channels or from seasonal changes in melt regimes. No systematic vertical change occurs in texture or structure but change does occur along longitudinal profiles downstream, with a tendency towards better sorting and finer texture. Outwash grades to alluvium.

Pockets of fine sand and silty sand, too small to be mapped as discrete units, lie within many meltwater channels where meltwater was temporarily impounded. These deposits are thin, of limited extent, and appear on airphotos as swampy areas with little topographic relief.

Landforms. Vast quantities of sediment were deposited in meltwater channels as terrace or valley fill deposits. Outwash commonly occupies the highest terraces and is differentiated on airphotos from alluvium by the presence of kettle holes and braided channel scars. In large channels, outwash infilled only the lower parts of pre-existing valleys, leaving high rock-walled sides (e.g. Pentecôte and Godbout river valleys). In small channels outwash completely infilled the original channel; the best example is north of Sept-Îles where Ruisseau Daigle has cut through 67 m of outwash which infilled a segment of the proto-Moisie river.

Outwash plains occur in association with moraines near Rivière-Pentecôte, Rivière Riverin, Rivière Vachon, and Lac Daigle. Part of the deposit is derived directly from the moraines, but a substantial component is also derived from more remote sources and transported by meltwater streams which breached the moraines. Deposits are about 6 m thick near the breach points and thin radially towards the sides. The surfaces of the outwash plains are gently convex.

Alluvium (2b)

Although alluvium is the most abundant component of the sediment in meltwater channels, in most places deposits are too small to be mapped as discrete units and have been included in unit 2 (undifferentiated). These fluvial deposits relate to river regimes controlled by melting glaciers in areas to the north; they form a distal facies of outwash. The composition is similar to that of outwash but clasts are clean, rather than coated with reddish powder. Alluvium consists of sand and pebble gravel and is finer textured and better sorted than outwash. Sedimentary structures include medium-scale trough (festoon) beds, current ripple marks, and planar beds of rounded gravels, all of which are identified with relatively uniform flow regimes.

Within rock-walled meltwater channels alluvium occurs as terraces (below outwash terraces) graded to base levels higher than present, and as valley floor deposits presently occupied by grossly underfit streams. Beyond these channels alluvial deposits also form sets of raised gravelly point bars (e.g. lower Rivière Moisie) and meander scrolls (e.g. lower Rivière Sainte-Marguerite) on the coastal plain.

Marine Offlap Sequence (6)

The thickest accumulations of marine deposits occur as offlap sequences where deltas were formed by meltwater emptying into the Goldthwait Sea. Poorly sorted silty clays associated with deepwater environments are overlain by nearshore deposits consisting of fine sands deposited after tractive current transport. These in turn are overlain by littoral sand. Unit 6 designates areas in which the entire sequence is present in the form of delta topsets (unit 5a), foresets (4), and bottomsets (3). On Map 1575A units 3, 4, and 5 depict areas where only that part of the sequence is present.

Marine Offshore Deposits (3)

Distribution and Thickness. Marine clays and silts underlie much of the coastal plain and extend up major river valleys as far inland as 50 km to (elevations of 100 m a.s.l.). They were deposited as the offshore facies of the fluviomarine sequence in the lower parts of preglacial valleys that were drowned in postglacial times, and along the coast as deep water sediments between the main elevated deltas.

Table 2. Mineralogy of offshore clay

Sample Location	Sample No. & Fraction	Sediment Type	Nearby Bedrock	Landslides	General Nature of Diffraction Curve	Dominant Mineral Peaks in Order of Decreasing Magnitude			Other Minerals Present
Sept-Îles	28; $<63\,\mu m$	massive	gabbro-anorthosite	present	distinct	q	fel		am, mi, kl, ca (tr), mag, py
	28; $<5\,\mu m$				distinct	mi	it	fel	am, pn, ch
	28; $<2\,\mu m$				fairly distinct peaks	it	fel	q	ch, am, py, mm (tr)
QNS&L Mile 10	44; $<63\,\mu m$	bedded	gneiss	present	low peaks	pg	q	gt	mi, am
	44; $<5\,\mu m$				low peaks	fel	mi		gt, am
	44; $<2\,\mu m$					it	ch	mx	fel, q, am, mm?
Port-Cartier	56; $<63\,\mu m$	bedded	gabbro	present	-	pg	mi	q	ch-mi, gt, py, ca
	56; $<5\,\mu m$					mi-it	q		pn, fel, am, ha
	56; $<2\,\mu m$					it			q, fel, mx, ca
Rivière-Pentecôte	42; $<63\,\mu m$	bedded	gabbro	absent	very high q peak	q	fel		gt, am, ch, py, ov
	42; $<5\,\mu m$					mi	fel	mx	q, ch, am, ov
	42; $<2\,\mu m$				no strong peaks	it	ch	vm	q, fel, mi, kl
Islets-Caribou	81; $<63\,\mu m$	bedded	gneiss	absent	peaks distinct	fel	q		ch, ov, mi, gt, ca (tr)
	81; $<5\,\mu m$				poor	mi-it	fel		-
	81; $<2\,\mu m$				no peaks	mx			fel (tr), ch, kl
Baie Saint-Nicolas	89; $<63\,\mu m$	massive	gneiss	present	distinct peaks	fel	mi	q	ov, py, pn
	89; $<5\,\mu m$				distinct peaks	mi-it	am	ch	fel, gt
	89; $<2\,\mu m$				low peaks	it	ch	mx	fel, gt, an (tr), ha?

am – amphibole
ca – calcite
ch – chlorite
fel – feldspar
gt – garnet
ha – halloysite
it – illite

kl – kaolinite
mag – magnetite
mi – mica
mm – montmorillonite
mx – mixed-layer
ov – olivine

pg – plagioclase
pn – pyroxene
py – pyrite
q – quartz
vm – vermiculite
tr – trace

In most places these deposits are exposed only in sections: landslides scars below sands in bluffs along Moisie, Hall, Pentecôte, Saint-Nicolas and Mistassini rivers and Petite Rivière de la Trinité; along abandoned recent wave-cut terraces near Sept-Îles, Port-Cartier, Islets-Caribou, and Franquelin; or in railway and road cuttings.

Borehole data indicate that most of the offshore deposits directly overlie bedrock. Beneath part of the Sept-Îles townsite, however, clays are underlain by thin lenses of "gravel" and in the Baie Saint-Nicolas area, the clays are separated from bedrock by a bed of fine sand.

The greatest reported thickness of these sediments is in Moisie valley at QNS&L Milepost 19.3, where 236 m of offshore clay, which extends to a depth of 183 m b.s.l., was logged (R.W. Pryer, personal communication, 1970). At Rivière au Foin (near Sept-Îles) the clays extend from sea level to at least 58 m depth (Ministère des richesses naturelles du Québec, 1973). Elsewhere they are thinner. Along Baie Saint-Nicolas, the bedrock (at -34 m) is overlain by about 42 m of clay.

Generally, the clays are unconformably overlain by thick accumulations of nearshore and littoral sediment.

General Appearance. At old exposures the deep water sediment is a stiff, grey, brittle clayey silt, which breaks with a conchoidal or hackly fracture. The dry surface has numerous fissures ranging from hairline fractures to wide cracks that give the clays a blocky surface structure. The best examples of this structure were observed in outcrop along the north part of Baie des Sept Îles. On wet surfaces, newly exposed faces, and in the subsoil, the clays are soft, blue-grey, and either sticky or slippery.

These clay deposits are sparsely fossiliferous.

Mineralogical Composition. Mineralogical components of six offshore clay samples were determined by X-ray diffraction (Table 2) and are summarized here:

1. The mineralogy of marine sediments is similar to that of the fine fraction (silt-clay) of till, as is expected from material that originated as rock flour. The mineralogical similarity between the offshore clay samples, however, indicates that the sediments at each site are derived from mixed sources and cannot be traced directly to any given rock or till type.

2. Offshore sediments are dominated by nonclay minerals. Quartz and feldspar, particularly plagioclase, are the most abundant minerals; minor amounts of mica and amphibole are also present. The clay minerals are mica-illite, chlorite, and mixed layer minerals. Carbonates are absent or present in trace amounts only.
3. As particle size decreases, clay minerals become more abundant.
4. The X-ray diffraction peaks of the clays are not well defined. The poor definition suggests the presence of amorphous or poorly crystalline material in the finest fractions.
5. No obvious difference is evident in the mineralogy of samples from sites with landslides and those without.

Texture and its Relationship to Depositional Environment. These marine deposits are fine grained, the texture of 17 samples being 10% sand, 56% silt, and 34% clay (Fig. 13). The mean grain size is a fine silt (ϕ = 7.6; 0.005 mm), but small quantities of sand and substantial amounts of clay-sized (< 0.002 mm) material are present. The deposits are almost free of pebbles, which suggests that they represent true marine, rather than glaciomarine, conditions; possible exceptions are at Islets-Caribou where a few pebbles were found within the clays, and at a site west of Lac Pentecôte where fine slivers of rock constituted part of the deposit.

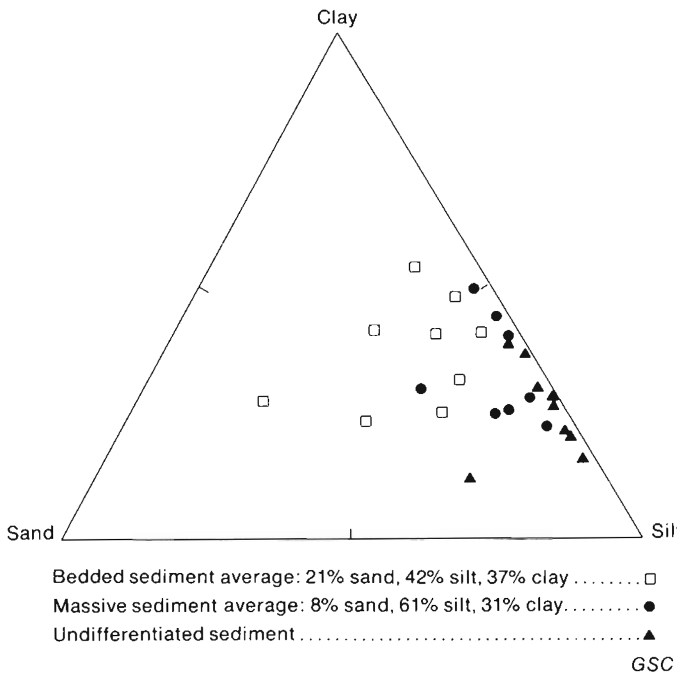


Figure 13. *Textural characteristics of offshore marine deposits.*

The sediment is very poorly sorted (σ = 3.4), probably the result of deposition by flocculation in a marine or brackish environment. The grain size distribution is slightly positively skewed because of a deficiency of coarse material, which cannot be transported into quiet marine environments, rather than by the deposition of an excess amount of fines.

The offshore deposits of this part of the Quebec North Shore can be subdivided into two units – bedded and massive – each characteristic of a different sedimentary environment.

The bedded unit is texturally stratified into cosets of massive clayey silt, 1 to 8 cm thick (average thickness about 2 cm), sharply separated by grey sand partings several millimetres thick (Fig. 14). Beds generally thin upwards. Bedding is commonly nearly horizontal but southerly dips up to 12° were measured along the QNS&L railway. The bedded unit resembles lacustrine varves but can be distinguished texturally from them. Marine varves differ from their lacustrine counterparts as a result of sedimentation into salt water, which is 1) denser than fresh water and 2) causes flocculation; the fine fraction of marine sediments is coarser than its lacustrine counterpart and lacks grading, and both fine and coarse fractions were deposited in "summer" (relatively high energy conditions). Like lacustrine varves, the source sediment was transported by turbidity currents originating as cold freshwater bottom currents. Because of the salinity of the marine environment, the clay particles flocculate, increase their effective size, and are therefore deposited with the silt. The absence of internal stratification and grading is also attributed to flocculation in saline water.

The coarse (sandy) fraction was transported at the head and base of tractive bottom currents and deposited in deep water when the currents lost velocity.

Figure 14. Rhythmically bedded silty marine unit exposed in rills near milepost 9, QNS&L railway. Clay beds are about 3 cm thick, separated by thin sand partings. GSC 188663

The clean break between the coarse sandy band and the finer material reflects a short time lag in the settling of the suspended load. When suspended material from an ice sheet enters salt water, the fine sediment rises to the surface and spreads out because the density of fresh water with suspended load (about 1.007 g/cm^3 according to Kuenen, 1951) is much less than that of salt water ($\approx$ 1.028 g/cm^3). Thus there would be a short delay between the deposition of the coarse sand by tractive bottom currents and the settlement of the flocculated suspended load.

The massive unit is homogeneous clayey silt (Fig. 15) and is texturally similar to the finer part of the bedded unit, although the coarsest material (sand) is absent. This unit was deposited as a flocculated uniform suspension in deep water beyond the zone of influence of riverine tractive currents.

Microstructure. SEM photographs indicate that offshore marine sediments have an open framework (cardhouse or aggregate chain structure) with a high volume of voids. Interparticle contacts are cemented by amorphous gels. The open structure is related to rapid sedimentation and to deposition in a saline environment. Interparticle contacts are a result of the high percentage of nonclay minerals and the presence of amorphous cementing material.

Landforms Associated with Offshore Deposits. Offshore deposits form buried, seaward-thickening wedges, whose topographic expression is not reflected at the surface. The main morphological features associated with offshore deposits are bluffs and landslide scars (see section on Landslides in Clays). Most of the scarps on the coastal plain shown on Map 1575A are wave- or river-cut bluffs consisting of dried marine clay, 5 to 15 m high and steeply sloped ($\approx$ 60°).

Slide scars occur along the bluffs and along road and rail cuttings. The slides are generally clustered and more prevalent at higher elevations than lower. The slides are from 200 to 1600 m across and are separated from one another by steep narrow spurs; within the slides are crescents of slumped blocks. In cross-section the scars have steep backwalls and shallow bowls. Tiers of rotated slump slices are located towards the back of the slide. Beyond these slumped blocks are zones of hummocky ground composed of isolated blocks of intact clay in a sea of amorphous flow debris. Beyond the bowl of active slides are aprons of material that flowed out in a slurry. These aprons are absent on inactive slides, having been removed by waves during times of higher sea level, or by river currents.

Engineering Characteristics. Marine offshore deposits consist of normally consolidated silt and clay with relatively low bulk density and low to intermediate plasticity. Liquid limits average about 32%; the plastic limit is about 19%; water contents slightly exceed the liquid limit. Massive clays have isotropic strength characteristics; bedded clays are anisotropic, with greatest strength in a direction normal to bedding planes. The field vane shear strength on dry surfaces exceeds 5 kg/cm^2 (500 kPa); in the subsoil and active slopes it is 0.2-0.6 kg/cm^2 (20-60 kPa). Remoulded strength is very low. The clays behave as brittle solids: when applied stress exceeds shear strength there is a complete collapse of the soil structure accompanied by extrusion of water.

The sediments have low permeability, except where water is free to flow through sand laminae. Highest water contents are associated with disrupted beds in the banded sediment. The soil is frost susceptible.

Figure 15

Massive marine silt unit with blocky jointed structure. GSC 188684

These characteristics and their relation to geological factors are discussed in greater detail in the section entitled Geotechnical Characteristics of Sensitive Marine Clays.

Marine Nearshore Deposits (4)

Distribution and Stratigraphic Position. The thickest accumulations of marine nearshore deposits are deltaic wedges, situated where sediment-laden waters emptied into fiords and estuaries of a high postglacial sea. Nearshore deposits are widespread below 90 m a.s.l. and have been reported in boreholes to depths of 43 m b.s.l. Deposits are best exposed in bluffs up to 75 m high along lower Moisie, Sainte-Marguerite, Pentecôte, Godbout, and Franquelin rivers.

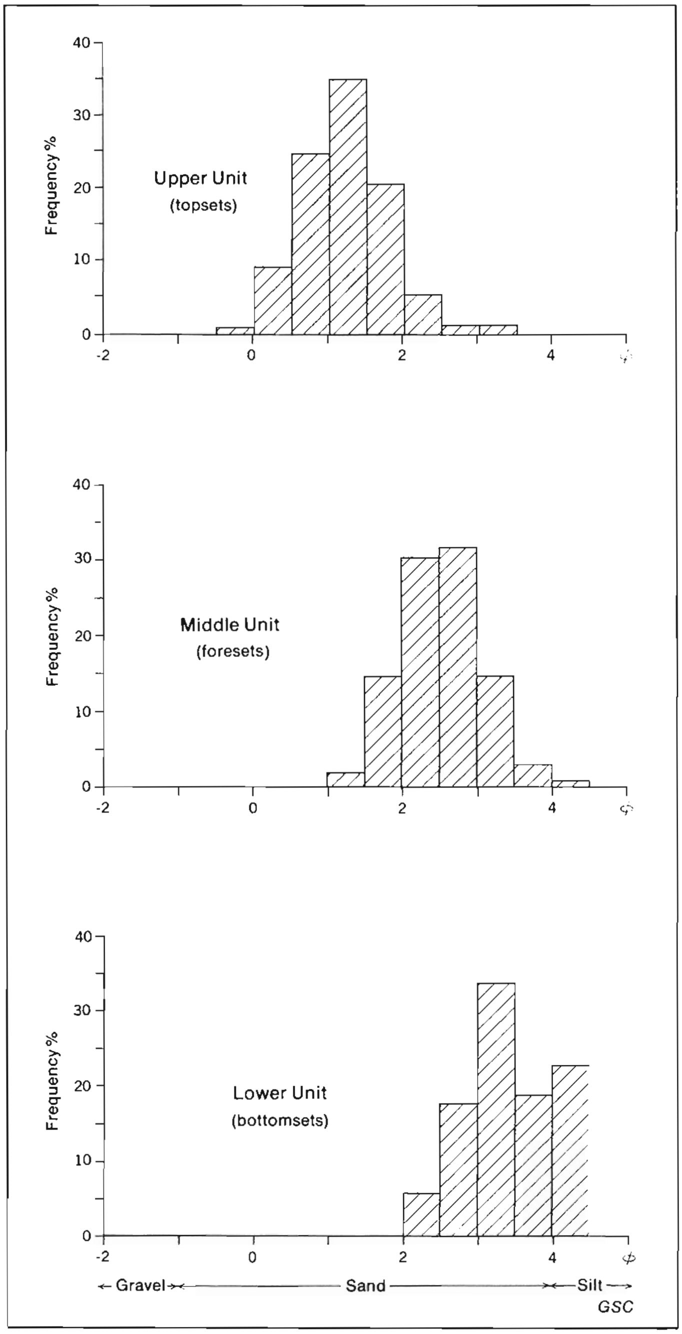


Figure 16. *Grain size characteristics of nearshore deltaic sand.*

A coarsening upward layer of stratified sand overlies the offshore clays. The basal contact is generally undulatory and erosional; upper parts grade into overlying beach sands. These deposits grade laterally northward into glaciofluvial and fluvial deposits (unit 2).

Composition. Nearshore deposits consist of the fine fraction of outwash and have mineralogies characteristic of the regional source rocks. Mica content, primarily biotite and phlogopite, is particularly high. Quartz grains are angular; feldspar and ferromagnesian silicates have subangular to subround edges. The macroscopic surface texture of the grains is irregular, resembling that of the sand component of the tills; modification by water transport and by depositional processes has been minimal.

Texture. Nearshore deposits are part of a coarsening upward sequence of loose, grey stratified sand. The sand is fine grained (average size = 2.97ϕ = 0.13 mm) and moderately well sorted (σ = 0.71) (Fig. 16). In the lower parts of sections, silt content increases and the material becomes slightly cohesive.

Sedimentary Structures. Three types of structural units are associated with the nearshore environment. Forming the contact with offshore clays are bottomset beds – subhorizontal planar strata, 5 to 50 cm thick. They consist of micaceous sand separated by laminae of steel grey clay. In lowermost parts of exposures (e.g. between the first and second falls on Rivière Pentecôte, Fig. 17) the clay strata become thicker than the sand strata and the unit grades downwards into bedded prodelta silts which form part of unit 3.

The intermediate unit, forming the bulk of the nearshore deposits, is the delta foresets (Fig. 18). The beds consist of medium to fine sand in tabular strata 1 to 2 m thick, dipping seawards at angles of up to 15°. Within beds asymmetric ripple-drift forms, thin concentrations of heavy minerals, cross laminae, and planar clay laminae are present (Fig. 19). In some places large scale slump structures and contorted beds can be seen.

The uppermost unit, as characterized by exposures near Sept-Îles airport and lower Rivière Moisie, has festoon and tangential cross strata and contorted silt beds associated with sedimentation or resedimentation under the influence of fluctuating currents of moderately high energy.

Grain size data (Fig. 16) and sedimentary structure provide a basis for interpretation of conditions at the time of deposition.

1. The abundance of ripple-drift structures indicates that sediment was transported mainly by tractive bottom currents and by local turbidity currents.
2. Deposition of fine sands occurs when transporting currents are less than 4.2 cm/s. The weakness of the current at deposition suggests that the water was fairly deep, probably between 30 and 45 m.
3. Given that the sands were deposited in deep water and are present up to elevations of 75 m (Rivière Moisie area) and 90 m (Franquelin), much of the deposition must have occurred within the first thousand years after deglaciation, when sea level was at or near its maximum.

***Figure 17**. Transition zone showing alternating units of bedded offshore clays (dark units) and estuarine sand, Rivière Pentecôte. GSC 188605*

***Figure 18**. Delta foresets, dipping to the south, grading upwards into littoral sand. GSC 188604*

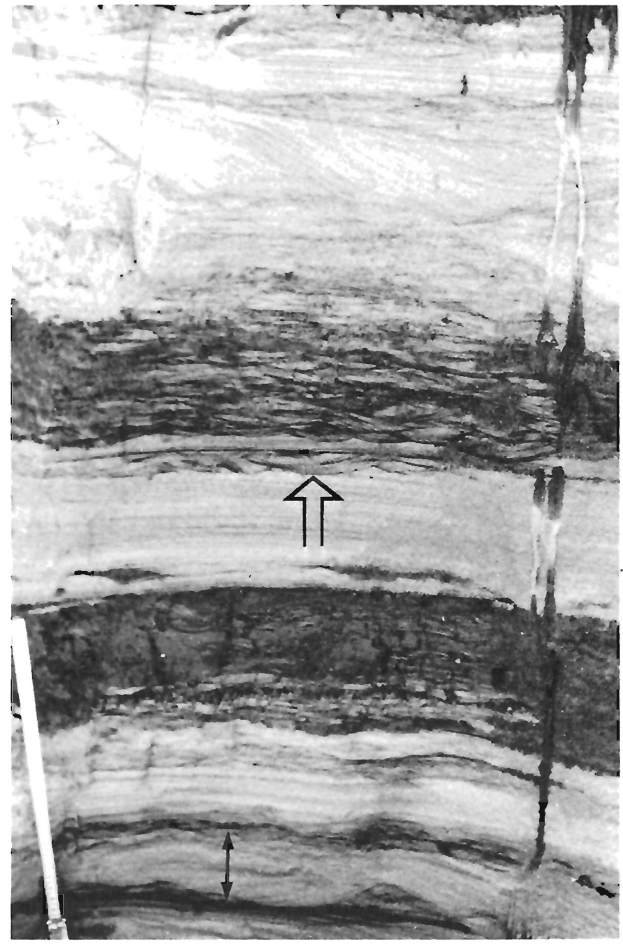


***Figure 19**. Internal structures (ripple drift forms shown by open arrow) and laminae of heavy minerals (black arrow) within foreset beds. Scale is 60 cm long. GSC 188644*

4. Sedimentation was rapid. This is implied firstly by the entrapment of fines and preservation of micas. Secondly, high void ratios, low penetration resistance, signs of internal slumping, and turbidite structures indicate that in places burial was fast enough to prevent sand grains from arriving at stable positions or packing arrangements. In addition, the heads of the main deltas are situated at the edge of an escarpment where streams once spilled out from their confined channels into a postglacial sea. For any given discharge, the sudden lateral expansion into a relatively still body of water would result in a rapid decrease in velocity and therefore rapid deposition.

Landforms. Nearshore deposits have little surface expression, but they do make up the bulk of the coalesced deltas which are extensive on the coastal plain.

Engineering Characteristics. Nearshore deposits are fine, grey, micaceous, sorted noncohesive sand, which becomes silty sand in places. Some deposits are susceptible to frost heaving. The sands are moderately permeable ($k = 4 \times 10^{-3}$ to 12×10^{-3} cm/s based on pumping tests), more so than the underlying offshore deposits but less than the overlying beach sands. Water contents vary from 3% to 24%; the highest moisture values occur where strata are disrupted. Sands have loose to medium relative densities (as determined by penetration tests): dry unit weight averages 1.6 g/cm^3 and bulk densities range between 1.4 and 2.1 g/cm^3.

Marine Littoral Deposits (5)

Marine littoral deposits have been divided into a sand and gravel blanket (5a), boulder ramparts (5b), and tidal flat silt and clay (5c); together they form the surficial material of most of the North Shore coastal plain.

Sand and Gravel (5a) Blanket

Distribution and Thickness. Most of the coastal plain between marine limit and present sea level is covered by a blanket of beach sand, 2 to 5 m thick. The most extensive deposits are associated with raised deltas along Moisie, Sainte-Marguerite, Pentecôte, and aux Rochers rivers. Small sand plains are associated with Godbout, de la Trinité, and Franquelin rivers. Borehole records and open exposures show that in these places the beach material grades downwards into finer, grey, silty nearshore sands. Elsewhere, beach sands lie unconformably over silts and clays or as a veneer over bedrock (5av), as in the Pointe Jambon area or the zone between Rivière-Pentecôte and Baie-Trinité. The limit of sandy marine deposits lies at 100 m at Godbout, 120 m at Rivière-Pentecôte, and 130 m at Sept-Îles.

The beach sands grade laterally into fluvial deposits in the Rivière aux Rochers area and along the right bank of Rivière Moisie.

Composition. The principal components of most of the strata are quartz and feldspar, but some amphibole/pyroxene is present as well as small quantities of biotite. The quartz is fairly angular and only slightly abraded, but the edges of feldspars and most heavy minerals are rounded. Other strata are composed primarily of heavy minerals, chiefly magnetite and garnet, which are interpreted as storm accumulations.

Texture. Near marine limit the sands are coarse, dirty, poorly sorted, and generally similar to their parent material, till. Below this level, where sands have been subjected to coastal processes for longer periods, the average grain size decreases and sorting improves (Fig. 11 in Dredge, 1971). The sands generally are medium to coarse grained; average grain size is 0.47ϕ (0.71 mm) (Fig. 20), but size varies from one stratum to the next. The sands are moderately well sorted (σ = 0.67ϕ units) and very clean. The grain size distribution is slightly positively skewed; this slight excess amount of fines is unusual for wave sorted materials but can be attributed to two factors: (1) with a continuously falling sea level, sufficient time may not have been available for complete washing of the fines by wave activity and (2) the accumulation of fine grained heavy minerals. Heavy minerals, especially magnetite, are abundant in the study area because of the presence of nearby gabbroic source rocks. (Iron minerals – magnetite-ilmenite and hematite – make up to 17% of the sand by weight at Moisie).

Sedimentary Structures. Characteristic beach structures are well preserved. On flat areas bedding consists of planar strata, 5-10 cm thick; the thickness of any one stratum is uniform over its exposed length (Fig. 21). Each stratum is composed only of planar laminae which are readily seen because of their compositional differences; light brown laminae are medium to coarse textured and are composed of a mixture of light and heavy minerals, whereas darker laminae are composed only of smaller, heavier grains. The strata are subhorizontal and dip gently seaward at about five degrees. The low dips and constant dip direction are a characteristic of foreshore deposits, with successive strata being deposited parallel to the beach surface.

In areas where beach ridges are the main topographic feature, more diverse stratification was observed, especially below ridge crests (Fig. 22). Cross-laminations are present in lenses or wedges that truncate or are truncated by the planar laminations. Backbedding is also shown in Figure 22. These landward dipping beds are probably associated with a backshore or high foreshore environment, where erosion and redeposition by wind, storm waves, and runnel scour produce reverse stratification.

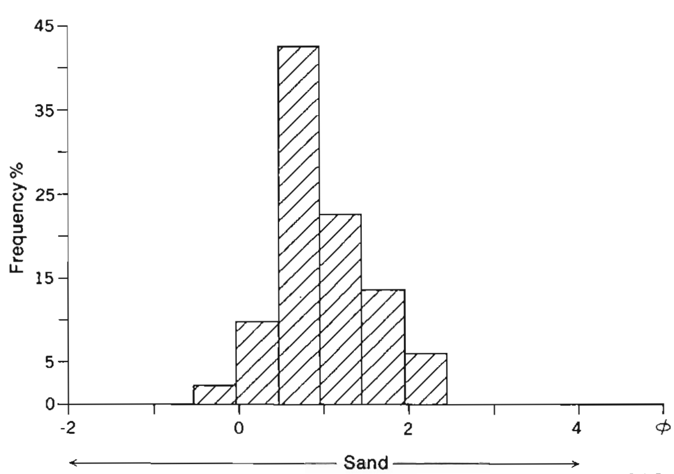


Figure 20. *Typical grain size characteristics of littoral sand.*

Figure 21. *Subhorizontally bedded beach sand at marine limit. Bedding is accentuated by layers of heavy minerals. GSC 188613*

Figure 22. *Cross-stratification and backbedding below a beach ridge crest. Seaward direction is to the right. GSC 188614*

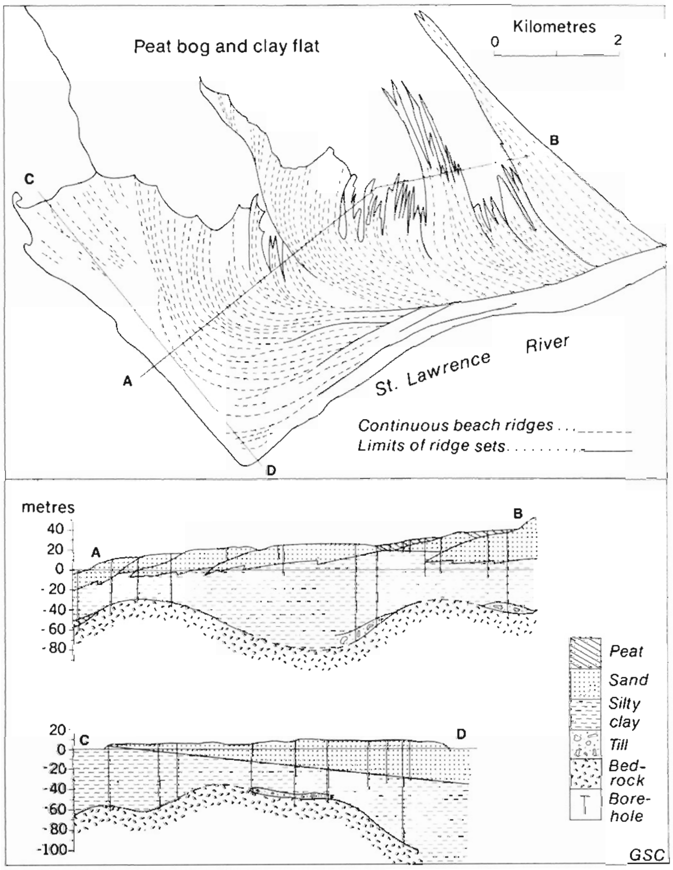


Figure 23. *Plan and cross-sections of sets of raised, recurved spits at Sept-Iles. Much of the townsite is built across the western end of the spit.*

Landforms. Littoral processes have reworked the original delta top topography into almost flat terraces separated by small erosional scarps. Microrelief is produced by sets of rounded beach ridges with intervening shallow lagoonal troughs. The area north of Sept-Îles has two landforms not found in the rest of the area: 1) a flight of prograding beach ridges extending from a major terrace at 60 m to the marine limit at 130 m and situated between the road to Lac Daigle and Rivière Moisie and 2) a complex recurved spit on which the Sept-Îles townsite is located (Fig. 23). Airphotos and borehole records show that it was built in six segments by currents transporting material from east to west.

Engineering Characteristics. Unit 5a consists of uniform or well sorted medium to coarse sand. The soil is well drained and has high permeability. Water contents average about 4% of the dry weight. Sands are moderately dense: dry density is about 1.67 g/cm^3. Penetration resistance below the hardpan is 0.7-2 kg/cm^2 (70-200 kPa).

Boulder Ramparts (5b)

One of the most distinctive features of the present coast is the boulder rampart ("batture"). Boulders are concentrated above the winter low tide line, where ice rafts become grounded. Major accumulations occur around the Baie des Sept Îles, from Pointe-aux-Anglais (Fig. 24) to Islets-Caribou, and at the mouths of Godbout, Franquelin, and de la Trinité rivers. One relict rampart (at about 45 m a.s.l.) was mapped at Islets-Caribou.

The boulders are striated, irregularly shaped to spheroidal, and have rounded edges. The largest one measured was 8 m across. In river mouth sites the boulders have predominantly local lithologies (e.g. those in Baie des Sept Îles are 60% gabbro, the general lithology of the surrounding area). The origin of the boulders in ramparts is not completely clear. In some places the blocks appear to have been torn from rockwalls and rafted into position by both river and sea ice, but other ramparts (e.g. at Islets-Caribou) may represent wave-worked and redistributed remnants of nearby end moraines.

Tidal Flat Deposits (5c)

Clay flats with salt marsh occur in the intertidal zone along the present coast in Baie des Sept Îles (Fig. 25) and Baie des Homards. Relict deposits are found directly north of Baie des Sept Îles up to an elevation of 40 m (Fig. 26). Near Sept-Îles, tidal flat deposits overlie former offshore sediments, but farther west they overlie beach sand.

Deposits consist of soft, very sticky, greasy, nonplastic grey clay (crumbly when dry). This clay differs from offshore deposits (unit 3) in that it contains discontinuous, black, horizontal organic bands and vertical worm burrow casts. Small ridges of contorted sediment lie both landward and seaward of large boulders. These ridges are produced by the bulldozing action of boulders when they are pulled and shoved by ice at ebb tide during the winter and spring. The clay flat is also characterized by cobble pavement; cobbles embedded in the clay are sheared or abraded off at about low tide level, probably by the action of gritty grounded ice.

Eolian Deposits (7)

Eolian deposits are restricted to the sand terrace between 50 and 60 m a.s.l. east of Sept-Îles, and to the beach ridges between 66 and 90 m near Baie-Trinité. Both dune fields are presently stabilized by vegetation.

The dunes consist of yellow-brown quartzose and feldspathic sands, with dull or frosted surfaces and rounded edges. The two dune fields have different sedimentological and morphological characteristics and thus are described separately below.

The Baie-Trinité field consists of about 50 elongate parabolic ridges, open towards the northeast and symmetric about a northeast-southwest axis (Fig. 27). Ridges vary from 120 to 1200 m in length and stand about 15 m above the surrounding plain. Sedimentary structures are poorly defined. The dunes are similar in texture to their parent beach material. Both consist of medium to coarse sand, with average grain size being 0.7 to 1.0 mm (-0.5 to 0ϕ). These dunes are simple blowouts which originated along beach ridges exposed to northeasterly winds prior to their stabilization by vegetation.

The Sept-Îles field consists of about 300 irregularly shaped hills and ridges covering 25 km^2. Crests are rounded, sideslopes stand at angles up to 20°, and relief varies from 2 to 6 m. Internally the dunes consist principally of tabular cross-strata, with avalanche beds inclined up to 34°. Longitudinal sections show that structures are draped, so that the uppermost crest lies to the west of lower crests. The sands are slightly finer than those at Baie-Trinité (mean size is 0.25 to 0.125 mm (2 to 3ϕ).

The dunes appear as a chaotic arrangement of seif and barchan segments, but there is a statistically preferred orientation east-west and a minor secondary north-south one. Internal structure indicates that the direction of the last movement of sand was from east to west. The Sept-Îles field appears to be a relict eolian form resembling true desert dunes rather than coastal blowouts. The field is interpreted

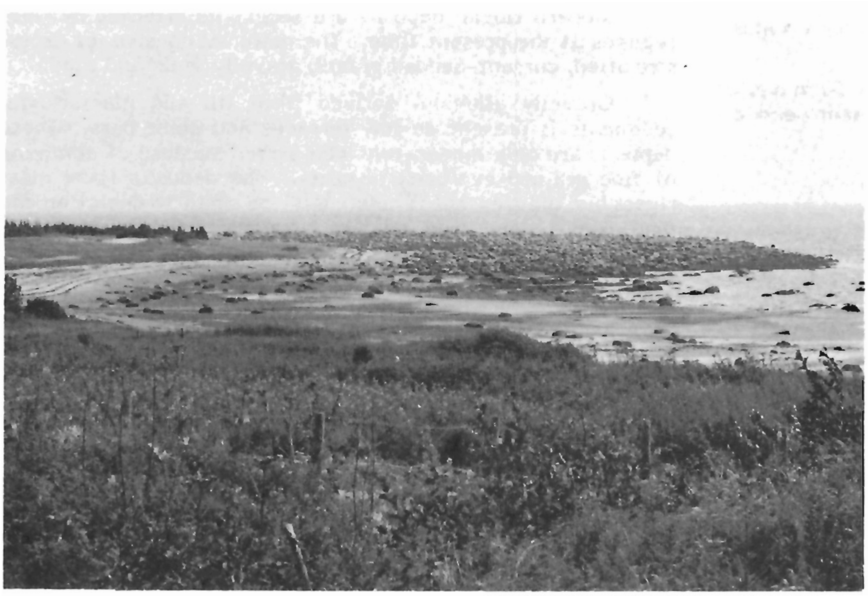


Figure 24

Boulder ramparts along the present shore near Pointe-aux-Anglais. GSC 188693

Figure 25

Tidal flat within Baie des Sept Iles showing typical components of grey clay, ice-rafted boulders, and salt marsh vegetation. GSC 188664

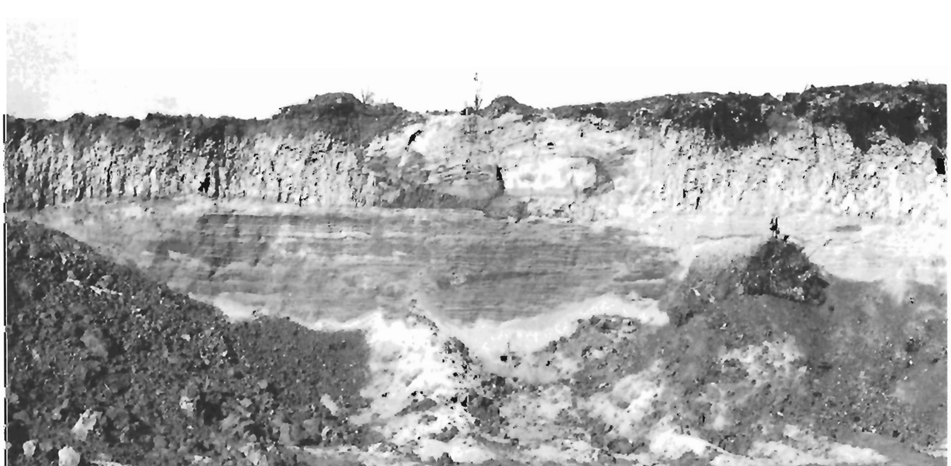


Figure 26

Relict tidal clay and included ice-rafted block, overlying littoral sand. GSC 188669 as being basically a seif field, since degraded. Dunes may have been originally formed by katabatic winds from the north, and later were re-oriented by prevailing easterly winds prior to stabilization.

Dune fields do not appear on terraces below 50 m a.s.l. Emergence data suggests that dune development ended between 6500 and 7500 years ago.

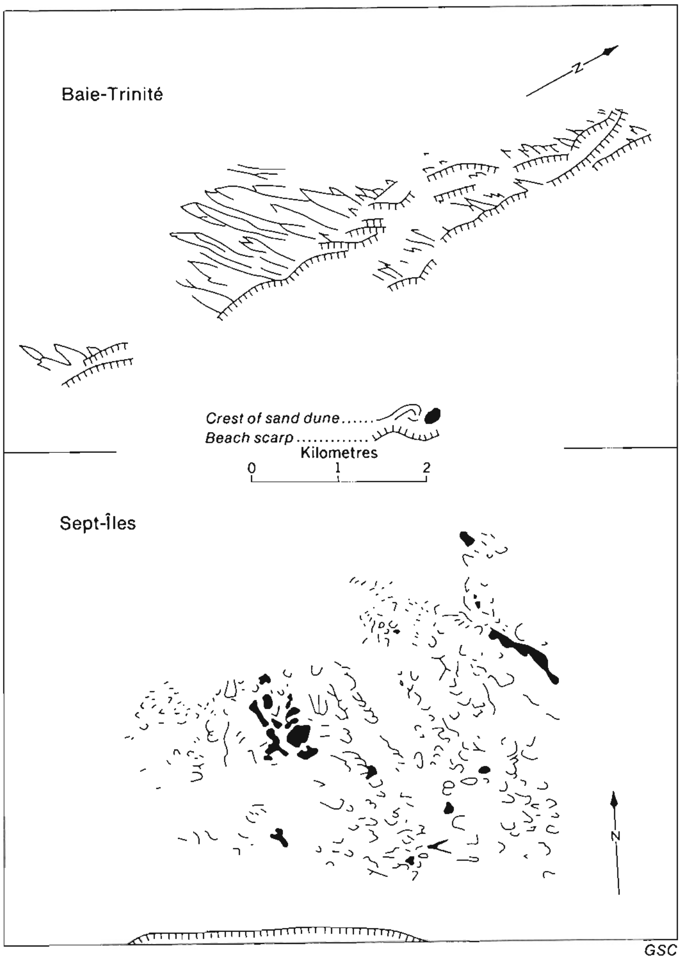


Figure 27. *Crest outlines of dunes, Baie-Trinité and Sept-Iles dune fields.*

Modern Fluvial Deposits (8)

Modern fluvial deposits are sediments affected by river regimes at the present time. The material consists of cross-stratified, current-bedded gravel, gravelly sand, and sand.

Gravelly alluvium derived from till and glaciofluvial sediments is present on low terraces and point bars. These deposits are only moderately well sorted because of admixing of fine grained overbank deposits. The deposits flank most rivers but their extent is commonly too small to depict on the map except along lower Rivière Moisie. Sand and gravel have also been deposited where river gradients decrease abruptly. The most extensive deposits are located at heads of large lakes – Lac Pentecôte, Lac Walker, and Lac Pasteur – but significant deposits are also found within the uplands at places where small streams leave the bedrock and enter flat-bottomed outwash-filled channels. In a similar fashion, the building of dams along Rivière Sainte-Marguerite and Rivière de la Trinité has altered the natural base level of these rivers, the result being increased alluvial accretion at the heads of the artificial lakes and increased erosion below dams.

Large, mobile bars of fine, grey micaceous sand, derived from the erosion of deltaic nearshore deposits, have choked the lower reaches of Rivière Moisie and blocked the harbour at Rivière-Pentecôte (Fig. 28).

Organic Deposits (9)

Organic deposits occupy less than 1% of the land surface. On the uplands, organic deposits are restricted to kettle infillings in till and outwash, and to small bedrock basins; however, most are too small to depict on Map 1575A. On the coastal plain, bogs are more common: Meadow type bogs, generally less than 1 m thick, occupy areas where drainage is restricted by nearby bedrock (e.g. forelands west of Rivière-Sainte-Marguerite). String bogs, by far the most extensive type of organic terrain, have developed on marine terraces near Baie-Trinité, Port-Cartier, Rivière-Sainte-Marguerite, and Sept-Îles. Drainage in these areas is restricted due to lack of relief, the presence of a hardpan in the B soil horizon, and/or the proximity of silty or clayey substrata.

The active growth layer is underlain by 1 to 3 m of peat consisting of brown, spongy, very fibrous, only slightly decayed shrub and moss remains and arboreal pollen. Measured water contents exceed 1000% of the dry weight, and pH of the water is about 5. The basal zone is commonly gelatinous, black gyttja.

Figure 28

Siltation of the harbour at Rivière-Pentecôte. GSC 188691

GLACIAL AND POSTGLACIAL HISTORY

Evidence for only one glaciation has been found in the field area. The following sections reconstruct some aspects of this episode and events that succeeded it.

Bedrock Surface and Topography Prior to the Last (mid to late Wisconsin) Glaciation

The Precambrian bedrock surface may have been essentially unaltered by the last glaciation. The freshness of the till – its textural similarity to bedrock constituents, solidity of clasts and mineral grains, and absence of clay-sized weathering products – argues for a very limited pre-till regolith. The thinness of the till further suggests that easily eroded materials were not available. However, despite this regional pattern, there are areas of deeply weathered anorthosite (see p. 5), and of "gabbroic" till consisting primarily of rotted rock. Although the rock types involved weather rapidly, some of the deep rock weathering may be preglacial, and the "gabbroic" till may be partly composed of gruss.

The lack of Paleozoic clasts in the till indicates that the Paleozoic cover, which once mantled the Shield in this area (Ambrose, 1964), was stripped off prior to the last glaciation.

Hare (1959) has noted that, although the central Labrador Plateau shows signs of intense glaciation, the "clearcut glacial grain" of that landscape disappears at the northern edge of the Laurentian Highlands (Grenville Front). The topography of the Shield, with its mamillated hills and large, broad valleys, has not been substantially altered by glaciation. The large valleys, which are prominent relief features in the landscape, have preglacial, not glacial origins. Cooke (1929) has shown that the major river systems have their origins in Tertiary and pre-Tertiary times. More recent borehole evidence (R.W. Pryer, personal communication, 1970) shows that bedrock base levels of these valley floors lie far below sea level and are integrated with the proto-St. Lawrence drainage and the Laurentian Channel. The valleys have since been subjected to overdeepening by glacial scouring, but their general preglacial form and the integrated drainage pattern have remained intact.

Because the till cover is generally thin, few depositional landforms alter the overall preglacial appearance of the landscape. The small rock basins prevalent on the uplands are glacial features, but they may have been formed during pre-Quaternary glaciations.

Glaciation

Age and Limits

There is no chronology along the North Shore that relates directly to the deposition of the till and the glacial events it represents. Although earlier glaciations must have contributed to landscape development (e.g. in the removal of a weathered mantle and formation of small bedrock basins), the materials and landforms described in this report are considered to be the product of the last (i.e. Wisconsin) glaciation. Because no stratigraphic evidence for more than one till has been found in the study area and there are no indications for multiple advances, the deposition of the till could well span the entire Wisconsin. The withdrawal of Labradorean ice from the St. Lawrence and James Bay Lowlands, which resulted in the deposition of the St. Pierre (Gadd, 1976) and Missinaibi (Terasmae and Hughes, 1960) beds, does not appear to have reached the area of the North Shore. The North Shore may therefore have been covered by Labradorean ice during the entire Wisconsin glaciation.

Note, however, it is uncertain when the weathering of anorthosite outcrops found in areas near the coast occurred. It is possible that anorthositic weathering did occur during an early nonglacial interval, in which case ice may have receded slightly inland from the (present) coastline during the early Wisconsin.

During the last glaciation, eastern Canada was at some time covered by ice whose main centre of outflow lay over central Labrador-Ungava (Labrador Plateau). Controversy has recently arisen over whether Labradorean ice, especially that of late Wisconsin age, reached into Gaspé (supported by Lebuis and David, 1977), flowed down the Laurentian Channel (Loring and Nota, 1969) and extended as far as the continental shelf (King, 1969); or whether ice cover was more limited so that independent ice domains prevailed in maritime areas (e.g., Grant and Prest, 1975; Grant, 1977). Evidence presented in Dredge (1976a) and in this report suggests that for the middle and late Wisconsin at least, the outer limit of Labradorean ice lay just beyond the Quebec North Shore. The limited amount of total isostatic depression suggests that the study area, and North Shore in general, was near the margin of the ice sheet. Furthermore, the pattern of regional differential rebound indicates a thinning ice profile over the study area, with the ice cover in the southwest (Godbout) part being substantially thinner than that over the northeast (Sept-Îles) area. From the emergence data, ice profile calculations (Dredge, 1976a), and extrapolations of the Baie-Trinité minor moraines to a "peak" in the offshore seismic profiles of Nota and Loring (1964; profile S-62-5), it is postulated that grounded Labradorean ice from the Laurentian Highlands extended beyond the North Shore only to about the 300 m bathymetric contour. A tongue of grounded ice also existed in the western part of the Laurentian Channel. An ice shelf extended beyond the limits of grounded ice.

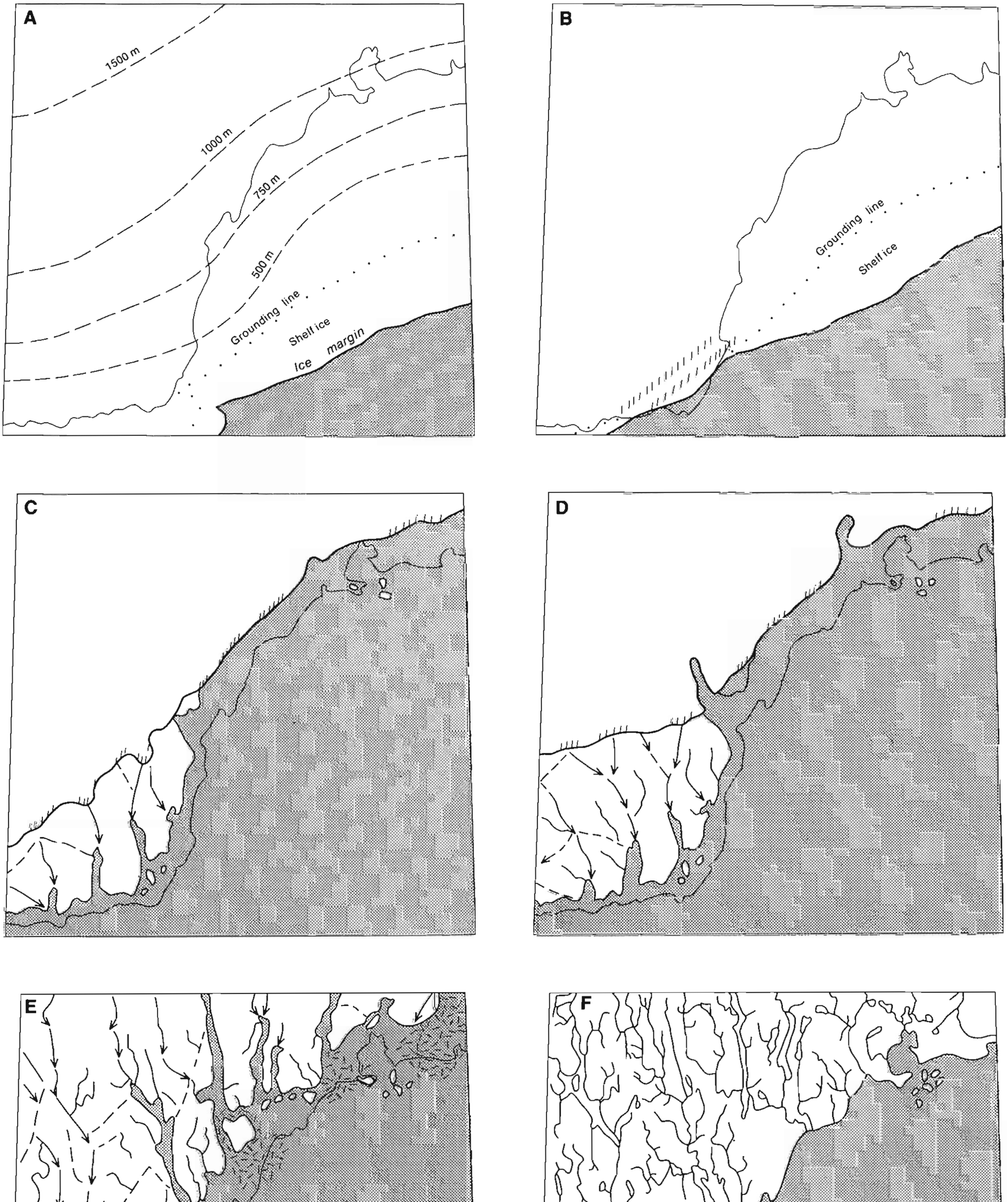
Character of the Ice and its Effects on the Landscape

Indirect field evidence suggests that for much of its duration the ice sheet may have been frozen to its base (cold-based ice) and did not have much power to erode. There are virtually no large-size classical erosional forms, and the till sheet – the depositional product of glacial erosion – is commonly less than 2 m thick. In addition, small pegmatite dykes in weathered gabbro have not been displaced by overriding glaciers. This evidence suggests that the ice sheet here, although it may have covered the area for at least 100 000 years, was generally incapable of erosion. Towards the end of the glacial episode, however, the ice sheet became more erosive and wet based, and a basal meltout till, which clearly shows the influence of abundant water in its fabric, texture, and structure, was deposited . Normal plastic ice flow was prevalent on the upland areas, but extended streamlined flow, indicated by far-travelled pebbles in till, occurred where ice was funnelled in valleys.

The ice was continually in an 'active' state (i.e., plastic and flowing) even during its retreat. There are no remains of stagnant ice features, except for a few kames. This situation is markedly different from the widespread stagnation that occurred on the Labrador Plateau.

Although glaciation did not alter the major aspects of the landscape, which are pre-Quaternary in origin, it did affect the microtopography and caused substantial erosion in limited areas:

1. Where bedrock is fine grained or relatively soft, it is highly polished and striated; coarser hard surfaces have been roughened and chipped.
2. Small grooves, streamlined and roche moutonnée forms are present over the upland and beneath sediments of the coastal plain. Streamlining is most obvious near the coast at Pointe des Monts, Port-Cartier, and Rivière-Pentecôte.


A
1500 m
1000 m
750 m
500 m
Grounding line
Shelf ice
Ice margin
B
Grounding line
Shelf ice
C
D
E
Ice margin
Moraine
Outwash channel
Overflow channel
Goldthwait Sea
Principal delta
F
Kilometres
0
40
GSC

3. A till blanket mantles much of the area, smoothing out the underlying topography, and sets of moraines add topographic ornamentation to the regional Precambrian landscape.

4. On a larger scale, glaciation has altered the landscape by trimming parts of the large preglacial valleys, creating faceted spurs and hanging valleys, particularly along valley segments oriented north-northwest – south-southeast.

Ice Flow Directions

Striae, chattermarks, streamlined forms, faceted valley walls, and in some cases till fabrics were used to interpret ice flow directions. The orientation of moraines was used in addition to derive flow directions during ice recessions.

Labradorean ice flowed radially from a centre on the Labrador Plateau. Consequently, flow was predominantly from the north over the Quebec North Shore during most of the last glaciation.

At Pointe des Monts and Baie-Trinité evidence exists for early easterly ice flow down the Laurentian Channel, but the major direction of ice advance over the map area was towards the south-southeast, with some local deflections into large preglacial valley systems and around topographic prominences (Fig. 11). Late ice flow due east occurred in the south part of the map area. The eastward ice flow directions are limited to areas adjacent to the Laurentian Channel, suggesting drawdown effects. Ice flow over most of the map area was from the northwest during the late stages of glaciation. The presence of multiple modes in some till fabrics may indicate that overriding and very local lobing occurred during retreat.

Low (1896) postulated that the centre of the Labradorean ice mass was near 51°N, 70°W (about 100 km due west of Lac Manicouagan) – much farther south than the centre of the Labrador Plateau, an area of heavy snow accumulation in present times; but field evidence indicates that the prevailing direction of ice flow over the study area was from the north-northwest, in keeping with the theory that the main dispersal area was the central Labrador Plateau. No evidence exists in the field area or in the adjacent map area to the north (Hogan, 1971) to suggest that ice from the various local centres that existed at the end of the late glaciation (Kirby, 1961; Hughes, 1964; Laverdière, 1967) reached the field area.

Figure 29. *Pattern of deglaciation for the study area.*

A. Configuration of the ice sheet at break-up, about 13 500 years ago. Shelf ice, maximum extent of grounded ice, and ice surface contours are shown.

B. Configuration of the ice sheet at the formation of the Baie-Trinité moraines.

C. Ice margin, meltwater channels, and the Goldthwait Sea about 9000 to 10 000 years ago. Retreat phase A, with initial development of the Laurentian Uplands-Daigle moraine system.

D. Retreat phase B, with continued development of the end moraines.

E. Maximum extent of the Goldthwait Sea, major outwash and overflow channels, and principal deltas.

F. Present extent and configuration of the Goldthwait Sea, and major inflowing rivers.

Deglaciation

Mechanism and Timing

At the close of glaciation the Labradorean ice mass stretched southwest into the St. Lawrence Lowlands and beyond, but along the Quebec North Shore the limit of grounded ice lay only slightly beyond the present coastline. A tongue of ice occupied the western part of the Laurentian Channel and may have reached as far east as Anticosti Island. Beyond the grounding lines of the continental ice mass and the ice tongue, ice shelves probably extended into the Gulf of St. Lawrence.

Deglaciation of the study area probably began with the uncoupling and breakup of an ice lobe in the Laurentian Channel south of Godbout (cf. Fig. 29A). This event may be associated with widespread ablation of ice sheets and ice shelves and with coincident sea level rise. At the time of flotation (uncoupling) the equilibrium thickness of ice in the channel must have been about 450 m. Once shelving conditions began off Pointe des Monts, ice from adjacent grounded areas to the north would be drawn down to feed the unstable ice shelf, which would thin and spread out under its own weight. Because of this effect, the grounded ice between Baie-Trinité and the western margin of the map area was probably fairly thin and possibly brittle.

Radiocarbon evidence from other areas surrounding the Gulf of St. Lawrence suggests that breakup in the south part of the field area near the Laurentian Channel occurred about 13 500 years ago (Fig. 30, Table 3).

The northeast part of the landmass (Sept-Îles area), however, is separated from the Laurentian Channel by an offshore platform between 30 and 40 km wide (Fig. 2). The thickness of the ice near Sept-Îles must have been about 830 m (Nye, 1952; Hollin, 1962). It is therefore suggested that the ice remained plastic and grounded offshore south of Sept-Îles for some time after the southwest part of the area was deglaciated, and the style of deglaciation in its initial stages was somewhat different from that postulated above for the southern (Godbout) region (Fig. 29). South of Sept-Îles, the sea presumably abutted against a wall of grounded ice, with a continual lowering of sea level relative to the ice wall. As the glacier retreated up the slope of the Laurentian Highlands, at some point the sea and ice mass must have become separated. This event is reflected at Lac Daigle, where interfingerings of till, outwash, and beach material show the relationship between a terrestrial ice front and subaerial coastal activity. A minimum date for deglaciation is 9140 ± 200 years B.P. (GSC-1337; Dredge 1976b); this date is based on a shell sample at 77 m in deepwater marine deposits at Rivière Moisie.

When the ice and sea separated, evolution of the landscape proceeded along two independent lines: recession of the ice from the landmass and emergence of the coastal area.

Recession of Ice from the Landmass

Formation of Moraines. Two sets of moraines were formed in the early stages of deglaciation as ice retreated northwestwards from the Laurentian Channel: the Baie-Trinité minor moraines and the Laurentian Uplands-Valley Front-Daigle system.

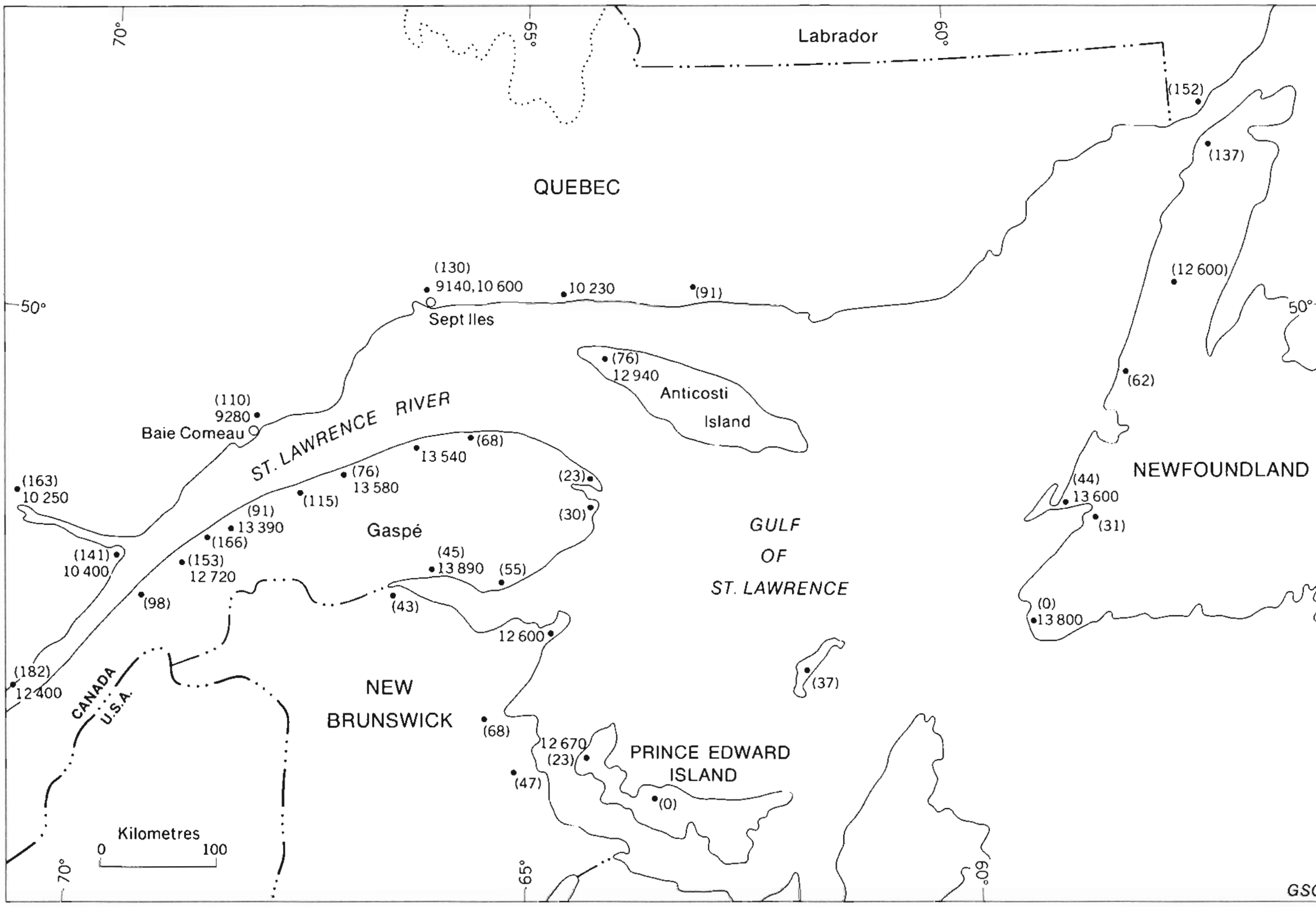


Figure 30. *Limits of marine submergence (in metres) (modified from Prest et al., 1968) and radiocarbon dates (cf. Table 3) pertaining to early deglaciation in the St. Lawrence estuary and gulf.*

Table 3. Dates pertaining to early deglaciation in eastern Canada

Location	Date	Lab Number	Reference
Quebec and North Shore			
Québec	12 400 ± 160	GSC-1533	Lowdon and Blake, 1973
Lac Saint-Jean	10 250 ± 350	Gif-424	La Salle 1972
Tadoussac	10 400 ± 150	I-5922	Dionne, 1977
Baie-Comeau	9280 ± 140	GSC-1565	Dionne, 1977
Sept-Îles	9140 ± 200	GSC-1337	Dredge, 1976b
Sheldrake	10 230 ± 180	Gif-3770	Dubois, 1977
Anticosti Island	12 940 ± 180	GSC-89	Bolton and Lee, 1960
Gaspé			
Rivière-du-Loup	12 720 ± 170	GSC-102	Lee, 1962
Saint-Fabien	13 390 ± 190	QU-271	Lebuis and David, 1977
Saint-Félicité	13 580 ± 350	QU-83	Lebuis and David, 1977
Capucins	13 540 ± 300	QU-85	Lebuis and David, 1977
Baie des Chaleurs	13 890 ± 160	QU-275	Lebuis
New Brunswick	12 600 ± 400	GSC-1383	Thomas et al., 1973
P.E.I.	12 670 ± 340	GSC-160	Dyck and Fyles, 1964
Newfoundland			
Wreckhouse Brook	13 800 ± 260	GSC-2113	Brookes, 1977
Abraham Cove	13 600 ± 180	GSC-968	Brookes, 1969
Flat Pond	12 600 ± 160	GSC-1600	Lowdon et al., 1977

The small, discontinuous till-cored moraines west of Baie-Trinité (Fig. 11, 29B) and the morainic remnants which form boulder ramparts at Islets-Caribou were formed between 13 500(?) and 9000-10 000 years ago (when the Goldthwait Sea extended to the position of Daigle moraine). The ice mass then was thin over the southwestern part of the map area and was grounded along a southwest-northeast line at least between Godbout and Islets-Caribou (Fig. 29). Ice shelf conditions may have existed south of these two points: glaciomarine deposits were found at both sites; at Godbout they mark the position of an ice front terminating in the sea. The moraines were probably the product of basal meltout of material moved along shear planes either at the ice front or behind an area of thin brittle (nonflowing) ice, and are the outermost moraines associated with the late glacial Labradorean ice mass.

As the ice front receded farther inland to the northwest and then north, the Daigle, Valley Front, and Laurentian Upland moraines were formed (Fig. 11, 29C, D). These are end moraines which may relate to minor fluctuations associated with a regional readjustment of the ice sheet. As parts of the morainic system lie directly above marine limit, its genesis may be associated with a quasi-stationary ice front created when the sea and ice mass separated and calving ceased.

General Retreat to the Labrador Plateau. Following deposition of the major moraines, the ice retreated actively to the rim of the Labrador Plateau (where it split up into local centres and finally stagnated). As the ice continued to retreat, valley glaciers or valley lobes of the main ice sheet may have been present for a short time as is recorded by small, lobate end moraines with lateral kame terraces at relatively low elevations within the major valleys.

As the ice sheet retreated northward, vast quantities of subglacial and proglacial sediment-laden meltwater were channelled and carried down the slope of the Laurentian Highlands in preglacial valleys and in a series of overflow channels. As much of the meltwater flowed in previously existing channels, most of the outwash and valley train deposits are found in association with river valleys. The coarsest material was deposited in the upper parts of valleys. Sand and fines partly infilled the inundated lower parts of valleys and built large deltas at the front of the main escarpment. Sedimentation was very rapid, as indicated by sedimentary structures and by the vast quantities of material forming the valley fill and estuarine deltas at a time when sea level was still high.

Goldthwait Sea

Configuration and extent

Goldthwait Sea, a term introduced by Elson (1969), refers to the body of water in the Gulf of St. Lawrence and estuary east of Rivière Saguenay that came into existence from the time of deglaciation and reached levels higher and lower than that at present owing to glacioisostatic deformation. It differs from the Champlain Sea and Mer de LaFlamme in that it still exists today, and in that its levels are found above and below present sea level.

The configuration of the Goldthwait Sea at its maximum extent in the study area is shown in Figure 29E, and the limit of its deposits is shown on Map 1575A. Along much of the area the sea extended inland less than 8 km from the present coast except where drowned preglacial river valleys formed arms of the sea, which extended up to 50 km inland.

Marine Limit

Along parts of the coastal plain raised deltas and beach ridges extend up to marine limit, and the transition from well sorted sediment to unwashed till is abrupt. The elevation of the marine limit increases from south to north: 100 m near Godbout, 103 m at Baie-Trinité, 120 m at Rivière-Pentecôte, 123 m at Port-Cartier, 125 m at Rivière-Sainte-Marguerite, and 130 m north of Sept-Îles. The marine limit is unmarked along much of the coastal plain because beach deposits are separated from unwashed till by a steep bedrock scarp.

In valleys, marine limit is difficult to establish on the basis of airphoto interpretation because the upper part of the marine sequence has been overlain by fluvial and glaciofluvial deposits. Where possible, the limit was defined as the point where high-level kettles and irregular terrace topography were replaced by smooth surfaces or beach ridges. The marine limit either remains the same (based on a contour interval of 50 feet on topographic maps) or slightly increases in elevation from south to north in valleys.

The marine limit is time-transgressive: the pattern of ice retreat and radiocarbon data indicate that the Goldthwait Sea may have existed as early as 13 500 years ago in the Godbout area but probably did not reach Sept-Îles until roughly 9140 years ago.

Marine Fossils

Fossil fauna are present in Goldthwait Sea sediments, although few fossil localities were discovered. Many of the shells are thin-walled and fragile; their fragility may result from the absence of natural carbonates in the marine environment of the North Shore.

A short list of mollusc species from the Rivière Moisie area was published by Laverdière (1952). Tables 4 and 5 list species collected from various localities during field work for the present study. Elevations were determined from topographic maps with the additional aid of a Paulin altimeter.

The highest site (locality 1, Tables 4, 5) at which shells were found is at 100 m a.s.l., about 10 m below marine limit in the Franquelin area. Very little information was derived from this locality since only a few widely scattered shell fragments were found.

The next highest locality (2) is situated above the south portal of the QNS&L tunnel near Rivière Moisie at 77 m a.s.l. Articulated valves suggest that the shells are in place, and the species present indicate cold conditions. As the shells lie within deep water bedded clays, they do not represent a sea level stand at 77 m. The shells were dated at 9140 ± 200 years (GSC-1337; Lowdon et al., 1971; Dredge, 1976b), which can be regarded as a minimum date for the marine limit, which is at 130 m in the Sept-Îles area.

Shells in littoral sands at Rivière des Rapides (locality 3) are articulated and in place. These yielded a date of 7580 ± 70 years (GSC-1809; Lowdon and Blake, 1975; Dredge, 1967b) and represent a sea level stand at about 75 m. A colony of **Mesodesma,** dated at 8280 ± 80 years (GSC-1856), was found in nearshore sands at 45 m at Rivière-Pentecôte (locality 4).

In addition to the mollusc and foraminifera species listed in Table 5, three other faunal fossils were found. A crab claw was collected from Saint-Nicolas (site 11) and the premaxillary (jawbone) from the genus **Gadus** (cod) from west of Rivière-Pentecôte. Part of a whale skeleton, found in a foundation excavation within a raised terrace (18 m a.s.l.) at Sept-Îles, was dated at 1520 ± 70 years (GSC-1911; Lowdon and Blake, 1975); but this date does not represent the age of a sea level stand at the 18 m level.

Table 4. Fossil Reference Data

Field Reference	Locality Number and Name	Latitude, Longitude	Elevation (m)	Substrata	Radiocarbon Date (years B.P.)	Lab. No.	Reference
74-92	1 Franquelin/Lac la Ligne	49°18'N, 67°51'W	100	grey sandy silt			
69-1	2 Rivière Moisie, Mile 12	50°18'N, 66°12'W	77	grey silty clay	9140 ± 200	GSC-1337	Dredge, 1976b
72-50	3 Rivière des Rapides	50°17'N, 66°26'W	75	fine sand	7580 ± 70	GSC-1809	Dredge, 1976b
72-26	4 Rivière-Pentecôte	49°45'N, 67°10'W	45	fine sand	8280 ± 80	GSC-1856	Dredge, 1976b
72-27	5 Rivière-Pentecôte at ramp	49°45'N, 67°10'W	40	grey silt			
72-56	6 Rivière des Rapides, power line	50°17'N, 66°26'W	40	grey silt			
72-41	7 Petite Rivière de la Trinité	49°31'N, 67°14'W	30	grey clay			
72-9	8 Saint-Nicolas, dragline	49°17'N, 67°57'W	30	grey clay			
74-98	9 Saint-Nicolas (upper sample)	49°17'N, 67°57'W	30	grey silt			
BGT	10 Rivière Moisie (gully)	50°16'N, 66°02'W	27	fine sand	6380 ± 150	GSC-1482	Dredge, 1976b
74-88	11 Saint-Nicolas (lower sample)	49°19'N, 67°48'W	15	grey silty clay			
72-12	12 Rivière Mistassini	49°17'N, 67°57'W	12	grey silt			
72-49	13 Sept-Îles	50°14'N, 66°24'W	9	sand	7840 ± 110	GSC-2456	Lowdon and Blake, 1978
BGT/74-7	14 Rivière Moisie (gully)	50°16'N, 66°02'W	7	blue-grey clay	7060 ± 190	GSC-1522	Dredge, 1976b
70-X	15 Sept-Îles	50°14'N, 66°24'W	7	silty clay			
72-11	16 Rivière Saint-Nicolas	49°19'N, 67°48'W	7	sandy silt			
72-28	17 Sept-Îles, Pointe du Post	50°14'N, 66°24'W	0-6	silty clay			
74-45	18 Sept-Îles, Pointe du Post	50°14'N, 66°24'W	3	silty clay			

Shells found along present-day beaches at Islets-Caribou and Pointe-des-Monts; salinity 30°/ₒₒ

Spisula solidissima, Echinarachnias sp., **Lunatia heros, Ensis directus, Thais Lapillus, Skenea planorbis, Littorina littorea, Siliqua costata, Thracia septentrionalis, Chlamys islandicus, Mya truncata, Mytilus edulis, Buccinum undatum, Mesodesma arctatum, Aporrhais occidentalis, Marguerites helicinus, Acmaea testudinalis, Mya arenaria, Spisula polynyma, Lunatia groenlandica.** Collected by L.A. Dredge.

Table 5. Marine fossil assemblages

Species	Locality (see Table 3)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Thracia septentrionalis Jeffreys				O		O												
Nucula tenuis (Montagu)			O			O												O
Yoldia myalis (Couthouy)																		
Nuculana buccata (Steenstrup)									O									
Nuculana minuta (Fabricius)									O									
Nuculana pernula (Müller)						O												
Mytilus edulis Linné		O	A					O	O		O	A						
Clinocardium ciliatum (Fabricius)		A				O		O		O	O			O		O	O	O
Serripes groenlandicus (Bruguière)		O	A				O	O	O	O	O			O	O			O
Chlamys islandica (Müller)		O						O										
Cyclocardi borealis (Conrad)											O							
Astarte undata Gould								O										
Astarte montagui striata (Leach)											O							
Arctica islandica (Linné)								F					A					
Mesodesma arctatum Conrad					O													
Mesodesma deaurata Turton				A	O													
Spisula sp.					O					O								
?Mysella planulata (Stimpson)				O														
Macoma balthica (Linné)			O		O	O		O				O		O				
Macoma calcarea (Gmelin)	F	O	O		F	O	A	O	O	O	A	O		O			A	O
Ensis directus (Conrad)													O					
Hiatella arctica (Linné)		O	O					O			O	A						
Cyrtodaria siliqua Spengler		O																
Panomya arctica (Lamarck)													O					
Zirphaea crispata (Linné)								O										
Mercenaria mercenaria (Linné)												O						
Mya arenaria Linné						O		O		F								
Mya pseudoarenaria Schlesch				O			O	O	O		O	F	O	O		O	A	
Mya truncata Linné		O	O		O			O		O		O	O		O			
Mya truncata uddevallensis Forbes												O						
Mya sp.											O							
?Margarites sp.				O														
Littorina saxatilus (Olivi)												O						
Natica clausa Broderip & Sowerby						O		O										
Lunatia pallida (Broderip & Sowerby)			O						O									
Boreotrophon clathratus Linné?									O									
Boreotrophon truncatus (Strøm)?												O						
?Amauropsis sp.			O															
Buccinum hydrophanum Hancock								O										
Buccinum undatum Linné									O	O								O
Buccinum tenue Gray												O					O	
Buccinum polare Gray																	O	
Buccinum sp.			O			O												
Colus stimpsoni (Mörch)						O												
Neptunea despecta tornata (Gould)																	O	
Balanus balanus (Linné)		O					O				O	A						
Balanus crenatus Bruguière												O						
Balanus homeri (Ascanius)									O									
Hemithiris psittacea (Gmelin)								O										
Strongylocentrotus droebachiensis (Müller)											F							
Islandiella teretis (Tappan)								O										
Globobulimina auriculata gullmarensis Höglund								O										
Buccela frigida (Cushman)				O														
Elphidium bartletti Cushman				O				O										
Elphidium excavatum clavatum Cushman				O														
Elphidiella sp.								O										
Protelphidium orbiculare (Brady)				O				O										
Nonion sp.								O										
Nonionellina laboradorica (Dawson)								O										

A abundant

O present

F fragments

Shells at Site 2 were identified by V. Condé, McGill University. Forams identified by F.E. Cole, Atlantic Geoscience Centre. All others identified by F.J.E. Wagner, Atlantic Geoscience Centre.

Style of Sedimentation

Sedimentation into the Goldthwait Sea was rapid in the first 2000 years after deglaciation. Large quantities of sediment-laden meltwater were funnelled down valleys, accompanied by continual downcutting and reworking of sediments associated with uplift and a dropping base level. An abundance of fine sand and rock flour was carried beyond the meltwater channels into the marine environment so that substantial volumes of sand were deposited as delta foresets at the mouths of valleys, where transporting river currents were slowed by the inert mass of the sea. In some areas sedimentation was fast enough to prevent sand grains from arriving at stable positions or packing arrangements. Turbidity currents also operated in these estuarine environments as indicated by lobate structures within the foreset beds. In deeper water, but where river currents or seasonal changes in regime were still operating, bedded clays were deposited. In open water beyond the estuaries the fine sediment, deposited continuously, has massive structure.

Although at least for much of the area sea water circulated freely, fossil marine molluscs apparently are not abundant. This could indicate that the influx of fresh water was sufficient in estuaries to limit the spread of saltwater species. It is also possible, however, that the scarcity of fossil molluscs is related to the absence of carbonate in the water, i.e. either they never existed or they were not preserved in this environment.

Emergence

From examination of exposures and on the basis of most borehole records it appears that isostatic rebound has exceeded sea level rise, so that the land was progressively emerging. Despite this, some borehole data show reversals in the general fining downwards sequence, particularly at levels between 4 m b.s.l. and 15 m a.s.l. Clay/sand/clay sequences occur in boreholes directly north of Baie des Sept Îles and likely represent tidal clay/littoral sand/offshore clay or spit interfingerings within one episode of marine clay deposition. It is possible, however, that the reversals mark a late postglacial transgressive phase.

Isostatic rebound and therefore emergence may have been intermittent, particularly in its early phases when the rate of uplift was greatest. Discontinuous rebound or emergence is suggested by abrupt vertical texture changes above 75 m in borehole records, abundance of buried slump structures in deltaic foresets, development of well defined terraces (interrupted downcutting episodes) on the deltas, lack of correlation of terrace levels from one delta to another, and abundance of landslides on terraces near marine limit.

As emergence proceeded, wave activity reworked the former deltaic deposits. Well defined terraces and beach ridges were cut into or built upon the exposed delta surfaces and valley fill deposits in estuaries. Longshore currents transported and redeposited sediment until the major terraces coalesced to form the coastal plain; a blanket of sand covered almost all of the fine marine deposits along the coast, producing an almost flat, but terraced sandy coastal plain. One of the major features resulting from longshore transport is the complex recurved spit that underlies Sept-Îles townsite (Fig. 23). During its formation, currents transported material west from the Moisie delta, marking a current reversal from a higher, older ridge sequence to the north which indicates earlier longshore drift towards the east.

Local topography, the configuration of the embayment, and variation in wind and wave energy appear to have greatly influenced both the elevation and the formation of terraces that were cut into the delta surfaces. It is therefore difficult to relate these terraces to sea level stands or to correlate terrace levels from one delta to another.

As emergence continued, the sea also retreated from estuaries that extended well inland so that freshwater streams incised and terraced valley fill marine deposits. In the Moisie area the river eroded laterally eastwards creating an extensive prograded meander scroll belt and a corresponding sequence of river terraces near its present mouth. At Rivière-Sainte-Marguerite and Rivière-Pentecôte streams left meander scars on the raised delta surfaces.

Upon emergence, wave-worked deltas were locally modified by strong winds from the north and then from the east, but eolian features are restricted to terraces above 50 m. Interpolation of ^{14}C dates (Table 4; Dredge, 1976a) indicates that dune development ended between 6500 to 7500 years ago. This period also corresponds to the beginning of organic accumulation in the kettle ponds at Lac Walker.

The principal remaining factors in landscape development have been continued alluvial and coastal accretion, the accumulation of peat on flat terrace surfaces, and the incidence of landslides.

Pollen Records

The earliest absolute dates on organic materials, from basal gyttja in two outwash ponds near marine limit at Lac Walker and Sept-Îles, are 6960 ± 300 years (GSC-1811) and 5460 ± 100 years (GSC-1821), respectively.

Pollen frequency diagrams for cores taken in a kettle pond at Lac Walker (Mott, 1976) and for a bog on the 30-m terrace at Matamec (Bowman, 1931) indicate the presence of boreal forests, dominated by conifers, birch, and alder, throughout the 7000 years represented by the cores. The oldest forest type recorded on Mott's diagram suggests that alder was more abundant than at present, possibly because the sandy outwash delta may have been a low wet area at that time. About 7000 years ago there was a dramatic increase in abundance of balsam fir which lasted until 6400 years ago. Coincident with the decline of basalm fir was an increase in birch followed by an increase in spruce. About 5000 years ago spruce and birch abundance increased further, in a response to more favourable growing conditions. The forest composition remained much the same up to the present day but the declining absolute pollen influx values after 3400 years ago may indicate deteriorating growing conditions.

Correlation of Late Quaternary Events and Features with Other Areas

Although other parts of eastern Canada have stratigraphic records representing a succession of glacial and nonglacial events, the North Shore record consists of a single till sheet relating to the last glaciation and stratified sediments relating to postglacial events.

Areas Covered by Labradorean Ice

Because no interstadial deposits have been found, deposition of the till sheet in the study area may have spanned at least middle and late Wisconsin time, and possibly the entire Wisconsin Glaciation. The North Shore till may therefore correlate with the Gentilly till (Gadd, 1971, 1976) north of the St. Lawrence Lowlands and with the Desbiens till (LaSalle, 1966, 1972) in the Saguenay area, both of which were left by Labradorean ice and span at least the middle and late Wisconsin.

The till on the North Shore has similar textural and geotechnical properties to the lower (basal) component of the till over Labrador-Ungava described by Henderson (1959), Hughes (1964), Kirby (1961), and Eden (1976). The North Shore till is a continuation of the Labrador till, which appears on the surface in the northern part of the field area and underlies marine deposits in the southern part. Presumably this same till extends out into the St. Lawrence estuary to the edge of the North Shore and Anticosti shelves (Fig. 2) because grey sandy till of similar mineralogy covers the northern part of the Gulf and western part of the Laurentian Channel (Loring and Nota, 1969, 1973). Nota and Loring (1964) and Loring and Nota (1969) further claim that Labradorean till was carried eastwards down the Laurentian Channel by an ice tongue that remained grounded in the channel at least as far east as Anticosti Island; those till deposits probably represent at least an early phase of the same major glacial event that is recorded on the North Shore.

The moraine at Lac Daigle and the disconnected morainic ridges that extend westward and southwestward to Lac Dionne appear to be a continuation of the moraine system mapped by Sauvé and LaSalle (1968) northeast of Manic 2 dam on Rivière Manicouagan west of the field area. The minimum radiocarbon date of 9140 ± 200 years (GSC-1337; Dredge 1976b) for the formation of the Daigle moraine correlates fairly well with an age of about 9150 ± 200 years (I-3868; Sauvé and LaSalle, 1968) for moraines at Manic 2 (a minimum date). Daigle moraine is contiguous on the east with the Matamek-Manitou moraines (Dubois, 1976); together these constitute a major system of moraines stretching along the North Shore from Manicouagan to Mingan, a distance of more than 400 km.

The moraines near Baie-Trinité and the boulder rampart at Islets-Caribou may represent a late-glacial limit of grounded ice. No other surface deposits have been found to correlate with these moraines, but a peak on the seismic profile S-62+5 in the offshore area south of Sept-Îles (Nota and Loring, 1964) could possibly be an underwater extension of these moraines

Figure 30 indicates that despite the proximity of the North Shore to the Labrador centre of outflow, the elevation of the marine limit (and the amount of rebound) for the North Shore (100-130m within the field area) is less than that in the St. Lawrence Lowlands where marine strandlines are found up to almost 200 m a.s.l. (Prest et al., 1968). The simplest explanation for this is that the highest marine levels above 130 m on the North Shore lay against the ice front and therefore were not recorded. A second and more probable explanation, however, is that the relatively low amount of isostatic rebound is due to the fact that the ice was relatively thin over the study area, which was near the eastern edge of the Labradorean ice mass. A corollary of this theory is that the ice sheet or ice tongue that reached the continental shelf is either not Labradorean ice or else is neither middle nor late Wisconsinan in age.

Areas Covered by Independent Ice Regimes around the Gulf

Gaspé and the Atlantic Provinces had ice regimes independent from that of the Quebec North Shore during the late Wisconsin (Prest, 1970; Grant and Prest, 1975). Although the style of glaciation may have been different in each area, events marking the end of glaciation may well have been synchronous and dependent on common factors. Radiocarbon data (Table 3) show that areas surrounding the Gulf of St. Lawrence were deglaciated between about 13 500 and 12 500 years ago, which is probably also the time of initial breakup of ice in the Laurentian Channel south of Godbout. Deglaciation of areas surrounding the Gulf, however, was characterized by short readvances of land-based ice: for example, Lebuis (1972) and Lebuis and David (1972, 1977) reported a readvance and rapid calving in the Cap Chat and Tourelle areas of the Gaspé Peninsula about 9800 years ago; and Grant (1975) described a number of readvances as late as 10 500 years ago on Cape Breton Island and Newfoundland. Thus the end of all glacial activity around the Gulf occurred substantially later than 13 500 years ago.

The end moraine system that crosses the study area may be the North Shore correlative of the final glacial activity experienced in other places on the perimeter of the Gulf, particularly if the event relates to a widespread glaciodynamic adjustment associated with the removal of a major ice shelf or to a regional climatic change.

ENGINEERING GEOLOGY OF QUATERNARY DEPOSITS

Introduction

Behavioural characteristics and engineering index values of surficial materials are directly related to basic physical attributes of the materials, their geological stress history, environment of deposition, and present processes acting on these materials. Most surface materials described in this report derive from medium grained unweathered igneous and metamorphic rocks and subsequently have textural and chemical properties associated with granitic mineralogies. Sediment was deposited beneath or at the front of glaciers, from turbid meltwaters, or in postglacial seas higher than present sea level. The environment of deposition (glacial, fluvial, marine), rapidity of sedimentation, degree of sorting, and resulting bedding structures affect grain size, angularity, bulk density, void ratios, permeability, and type of interparticle bonds; bond types in turn affect shear strength and plasticity characteristics. Materials were in equilibrium within their environments when they were initially deposited but are not now because of isostatic uplift, climatic changes, and postdepositonal processes (e.g. weathering). Some materials are presently stable or are stable under some conditions. Others are metastable or highly sensitive; a stress applied to the latter materials generally causes structural readjustment of the material until particles reach a new equilibrium.

Basic physical characteristics and engineering properties of the major terrain units are described in the section dealing with surface materials and in more detail in Dredge (1976a); the distribution of surface materials (each having distinctive engineering properties) is shown on Map 1575A. Table 6 summarizes some engineering properties and ranks the suitability of each map unit to various land use considerations.

Sources of Aggregate

The best sources of coarse gravelly aggregate are fluvial and glaciofluvial deposits (units 2 and 8). The aggregate consists of Precambrian igneous and metamorphic rocks; there are small amounts of schist but no carbonates or chert. The material is generally free of fines. In major river valleys sorting is highly variable, but generally, coarser gravels are on the higher terraces.

Thick deposits of well sorted medium to coarse sand (units 5a and 6) are widespread surface deposits on the coastal plain.

Till (unit 1) can be used as a secondary source of sand and gravel, but deposits are commonly shallow and large boulders make extraction and treatment (crushing and screening) difficult.

On the coastal plain the overburden is generally thick. Low road grades can be attained by cut-and-fill techniques. On the uplands, however, depth to bedrock is commonly less than 2 m, and low grades must therefore be maintained by blasting through bedrock.

Groundwater Sources

The availability of water in aquifers is an important consideration for regional and urban planning. St. Lawrence River in this area is saline and therefore cannot be used as a fresh water supply. In the uplands, bedrock fissures do not provide a significant amount of water. The sandy till is capable of storing small quantities of water, but the thinness and lack of continuity of deposits greatly restrict their usefulness. Buried valleys and partially filled outwash channels are probably reasonably good reservoirs, but most are too far inland to be of use in the near future. For present levels of consumption, therefore, the extensive coastal sand plain provides the most efficient reservoir of groundwater. The aquifer sands are medium to fine grained, well sorted, and 3 to 60 m thick. They are underlain by less permeable silts and clays or by bedrock. Care should be taken to avoid excessive pumping at low elevations because of the possibility of salt water encroachment.

Slope Instability

Effects of Vegetation Removal on Runoff and Accelerated Erosion. Because the surficial Quaternary deposits (till, outwash, and marine sand) are noncohesive, they are prone to rapid subaerial erosion if the protective vegetation cover is removed. Calculations (Dredge, 1976a) show that vegetation removal, particularly by clear-cutting, (1) increases the total annual runoff by 60 to 100% by reducing loss due to evapotranspiration and (2) concentrates the period of snowmelt.

Where the overburden is not thick enough or permeable enough to let excess water infiltrate, the increased turbulent overland flow during snowmelt is sufficient to entrain unprotected sand-sized particles and carry them into streams as suspended load. The effects of accelerated erosion can be seen in the places where vegetation has been burnt off; for example, the burnt-over area northwest of Clarke-City is completely bare of overburden, although nearby vegetated areas are covered with till. Similar landscapes are produced by clear-cutting.

Accelerated erosion due to channelled flow occurs along lumber roads. On the uplands, virtually all the "secondary roads" shown on the topographic map are completely washed out as a result of micro-gullying caused by the channelling of water into ruts. Channellized flow may also have been partly responsible for the catastrophic gullying that occurred in the coastal deltaic sands (discussed below).

Increased peak river discharges associated with vegetation removal cause undercutting and river bank erosion, particularly on the coastal plain where large rivers cut through estuarine sands. Erosion by undercutting is significant in terms of the amount of sediment involved since bluffs are up to 60 m high; mass movement produces large, mobile channel bars and is responsible for siltation of the river channel and harbour at Rivière-Pentecôte (Fig. 28).

Foundering of Construction Equipment in Loose Till (Unit 1). Till that is moderately dense to dense is stable and has relatively high bearing strength and shear strength; however, where tills are loose (having high void ratios) bearing problems may develop if the material is disturbed (especially vibrated) by construction machinery when soils are saturated.

On well drained sites moisture contents are usually about 6% of the dry weight, which is 2 to 4% lower than moisture contents at optimum density as determined by Proctor tests, and the material is stable. On less well drained sites (e.g., broad topographic depressions) or during periods when soil moisture contents are high (e.g., during snowmelt or heavy rain) water contents of loose tills exceed optimum values; pore pressures build up, reducing the frictional strength of the till. Movement of machinery over ground in this condition leads to liquefaction of the soil and to miring of equipment.

These behavioural characteristics are related to the basic composition of the till and its mode of deposition. The sandy texture, lack of fines, and lack of cohesion are determined by the mineralogic character of the parent bedrock and by the relatively short distance of glacial transport. Till masses with high void ratios are associated with flow till or ablation till, dumped by the glacier as a soil-water slurry that was not overridden and compacted by the ice mass.

Flowslides in Deltaic Sands. Raised fine grained deltaic sands (unit 4), which form high river banks on the coastal plain where major rivers emptied into a postglacial sea, are subject to a peculiar type of flowslide gullying. On occasion high pore water forces develop in these sediments due to a combination of high volumes of voids (a result of rapid initial burial), the occurrence of disrupted beds of variable permeability, and the presence of underlying clay deposits which inhibit drainage. In at least one case, on lower Rivière Moisie (see Fig. 31), failure in these sands occurred by liquefaction.

On June 16, 1959, an unidentified observer reported a "hydrant" of muddy water spouting from the side of the sand bank in a small gully 12 km from the mouth of Rivière Moisie. This event was followed by bank failure and flowage, accompanied by movement of trees. The flow lasted about five hours during which time 200 000 m^3 of sediment was moved into the river. The gully expanded headward and branched into tributaries. No major additional flowage occurred until November 4, 1966 when the same gully system was enlarged and a second gully was initiated upstream.

Figure 31. *The gully flow in deltaic sands along Rivière Moisie one week after the flowslide of November 4, 1966. The oldest gully (centre) expanded headwards during this event and another gully (left) was formed. Gully banks are 30 m high. Remnants of the debris fan, which had caused flooding of Rivière Moisie, are shown in the foreground. GSC 188661*

Table 6. Selected engineering characteristics of surficial materials

Unit (see Map 1575A)	Unified Soil Classification	Moisture Content (% dry weight)	Drainage	Density	Frost Susceptibility	Suitability as Aquifer	Suitability as Aggregate	Suitability as Subgrade	Slope Stability
9 Muskeg	Pt	1200	poor	low	high	poor	poor	poor	high compressibility
8 Alluvium	GU/GF SF	low moderate	good poor	- -	low high	good poor	good poor	good poor	
7 Eolian sand	SU	4	excellent	medium	nil	good	good	good	
5a Littoral sand	SP-SU	4	excellent	medium	nil	excellent	good	good	dense, protective hardpan near surface
5b Tidal clay	OL-CL	>33	poor	soft	high	poor	poor	poor	
4 Nearshore sand	SM (SF)	3-24	medium	low-med.	moderate	good	poor	fair	subject to flowslides
3 Marine clay	CL-CI	38	poor	soft	high	poor	poor	poor	subject to flowslides
2a Outwash	GW	<6	excellent	medium	low	good	good	good	
2b Alluvium	SU-GW	4-6	good	medium	low	good	good	good	
1 Till	GW-SW	<6	good-excellent		low	moderate-poor	fair	good	subject to accelerated erosion where unvegetated

On this occasion, 3.5 million m^3 of sediment flowed out and fanned into Rivière Moisie (Fig. 31), temporarily damming the river and subsequently causing flooding of cottages downstream. On both occasions, failure was preceded by excessive rainfall: in 1959, 10.0 cm fell in the two days prior to flow and in 1966, 11.4 cm fell on November 3. The permeable sands overlying less permeable beds became saturated; excessive porewater pressures developed, which were partly released as the observed hydrant in the side of the gully and partly dissipated during liquefaction and subsequent flow of the soil mass.

The unique morphological appearance of the gully flow and the processes by which it formed have been documented by Dredge and Thom (1976). Its importance here lies in the fact that the recurrence of this event in the recent past and the presence of a fossil flow nearby indicate that failures will probably occur again when local soil conditions are abnormally stressed. These flows are located at the site of the easterly extension of Route 138 (formerly Route 15). Because land use changes, combined with natural stresses, can create unstable conditions, utmost care should be taken to minimize disturbance of these loosely compacted deltaic sands.

Flowslides in Clays. Flowslides in clays are of particular importance because economic development has been occurring in slide-prone areas. Major townsites, highways, and power corridors follow the coastal plain, which is extensively underlain by sensitive marine clays. Thus, the occurrence and engineering characteristics of flowslides in clays are treated separately.

Landslides in Clays

The occurrence of landslides in marine clays are of primary concern on the Quebec North Shore because of their wide distribution in areas of economic development. Sensitive clays which are prone to failure by liquefaction underlie much of the coastal plain. Semi-circular rotational slips and flowslides occur where slopes are oversteepened or where excess porewater pressures develop.

Landslide Inventory

An inventory of the occurrence and geometry of both active and inactive slides is shown in Table 7 and Figure 32. Landslide scars are located along the outer edges of flat terraces which range in elevation from sea level to 130 m. The absence of debris at the bases of bluffs indicates that the landslide debris was carried away by wave and current activity when the bases of the scarps were at sea level or local base level. Landslide scars are more common on higher terraces than those near sea level. Several factors may have influenced such a distribution. Firstly, in the first few thousand years after deglaciation the rate of emergence was greater than that during later periods. The greater frequency of landslides at higher elevations might therefore be a result of greater tectonic instability. Secondly, if marine deposits having water contents that are stable in a marine environment drain to equilibrium porewater contents that are stable in subaerial environments over hundreds or possibly thousands of years, the upper terraces may not have had sufficient time for drainage of excessive pore water (following emergence) prior to uplift and oversteepening of bluffs by wave erosion. Because the land is emerging from the sea more slowly at present, lower terraces have had more time to drain.

Inactive Slides. Most flowslides are inactive and are concentrated along the major crenulated scarp north of Sept-Îles (sites 3-9, Fig. 32) and in the raised clayey terraces between Rivière des Rapides and Rivière Moisie.

Table 7. Landslide Inventory

No. (cf. Fig. 32)	Shape	Dimensions (m)	Elevation (m a.s.l.) Base	Top	Maximum Backslope (°)	Active Inactive	Material	Minimum Thickness of Deposit (m)**	Surface Cover
1	gully	*1980x25	0	31	55	A	sand	30	bare
2	flow	*1440x72	15	31	40	I	sand	16	trees
3	semi-circular	720x360*	31	61	43	I	silt	30	trees
4	elongated pear	*3800x1600	55	95	34	I	silt-clay	40	trees, partly devegetated
5	semi-circular	irregular	55	--	53	A	silt-clay	27	bare
6	circular pear	*720x648	43	61	40	I	silt-clay	18	trees
7	converging gullies	*540x25	31	43	55	I	silt-clay	12	bare
8	irregular	720x540*	31	67	50	I	silt-clay	36	bare
9	scarp (3) crenulations	*144x432	98	137	43	I	sand and silt	39	trees
10	bowls (4)	*5x7	0	8	55	A	silt-clay	100	bare
11	irregular (3) slump blocks	*3x7	0	5	55	A	silt-clay	5	bare
12	amphitheatre slump	*180x480	45	76	35	I	sand or silt	31	devegetated
13	amphitheatre slump	*250x790	45	76	45	I	sand or silt	31	trees
14	amphitheatre slump	*144x900	45	76	45	I	sand or silt	31	trees
15	bowls	1x2*	~30	~45	50	A	silt-clay	15	bare
16	amphitheatre bowls	*250x180	61	75	27	I	sand or silt	14	trees
17	amphitheatre bowls	*215x140	61	82	27	I	sand or silt	21	trees
18	open cones (4)	144x360* max.	15	61	53	A	sand	60	bare
19	bowl	*4x5	45	55	65	A	sand	55	bare
20	amphitheatre	*216x288	76	137	53	I	sand and silt	61	devegetated
21	irregular	420x180*	45	85	42	I	sand	40	trees
22	cones (multiple)	*43x43	0	61	38	A	sand	60	bare
23	bowl	*3x4	7	12	50	A	silt-clay	6	bare
24	amphitheatre	*300x300	15	45	40	I	silt-clay	30	trees

* axis orthogonal to river or bluff
** determined from heights of backwall and sidewall

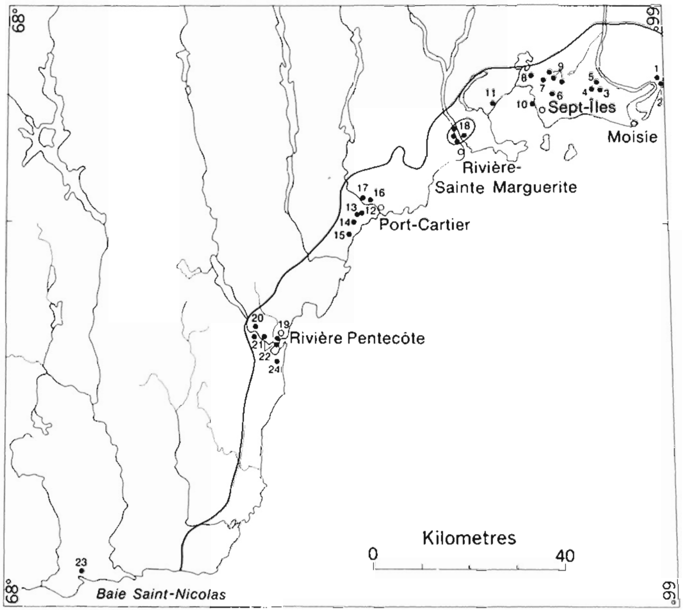


Figure 32. *Distribution of landslides. Numbers refer to slides described in Table 7. The heavy line delimits the coastal plain.*

The QNS&L railway runs along an old pear-shaped flowslide (site 4, Table 7) from milepost 8.5 to 11.4 northeast of Sept-Îles. Within this fossil flow – the largest slide studied (3.8 by 1.6 km) – subsequent failures have occurred during the construction of the railway – (Pryer and Woods, 1959, p. 65):

> "During the excavation of the tunnel in 1951, a short section of the roof near the south portal collapsed and allowed the overlying sediments to subside. Some 60,000 cubic yards of banded sediments entered the tunnel in fluid condition."

In September 1953 and spring 1954 rotational slips occurred in a cutslope near the tunnel. The first failure followed a heavy rain and was attributed to the development of hydrostatic pressure in the discontinuous, permeable sand strata within bedded silty clay. In the second case, a combination of rain and snowmelt raised the water table, which gave rise to local upward artesian conditions in sandy lenses within the clay.

Old slumps near Port-Cartier occur along a 30 m-high bluff which runs parallel to the present coast, about 2 km inland (sites 12-14). Most of the bluff is covered with spruce-fir forest. Failure occurred by rotational slumping along 2000 m of the bluff (Fig. 33). During construction of the Quebec-Labrador power line, vegetation was removed from the slide scar, and pylons were built on the outer edges of the clay terrace. Where vegetation has been removed, heavy precipitation may produce conditions leading to new instability problems along the powerline right-of-way.

Active Slides. The slides that occurred between 1972 and 1974 were small; their significance lies in the fact that they occurred where drainage was restricted (naturally or by human alteration) or where natural slopes had been oversteepened. The occurrence of these slides shows that small incremental stresses are capable of inducing rapid changes in the landscape.

Multiple slide scars in stiff fissured grey silty clays occur in the bluffs along Rivière Saint-Nicolas (site 23) and along a 750 m-long bluff at the housing development around Baie des Sept Îles (site 11). Along the head of the bay the bluff is 10 to 15 m high and consists of about 2 m of stratified beach sand which truncates massive grey silty clay. The clay face is very wet at the top where water accumulates at the boundary of the overlying strata of permeable sand and the underlying relatively impermeable clay but is dry a short distance below; the lower part of the slope is segmented by an integrated network of vertical and horizontal fissures, which are from 20 to 100 cm in length, about 5 cm in open width, and 10 cm in depth. The dry surface of the face of the bluff stands at 50 to 55° and the dry clay has unconfined compressive strengths of 4.5 kg/cm^2 (450 kPa).

Rotational slides and flowslides have developed along this bluff where drains were laid in the overlying sands. Failures were probably caused in part by excessive pore pressures which developed when water leaking from the ill-fitting sections of corrugated pipes seeped through the sand into the fissured clays.

Where the highway cuts through silty clay between Port-Cartier and Rivière Vachon (site 15), small shallow bowls can be seen in the cutbank. The scars are related to downslope movement of clumps of vegetation and soil which break off either at the top of the bank or along the slope, probably during storms. The weight of the sodden root and clay mass, wetting of the slope, and vibrations from large vehicles contribute to the downslope movement of the vegetation clumps which pull away the soil over which they move, leaving a small bowl where the vegetation was originally rooted and a shallow trough downslope.

Figure 33

The Port-Cartier landslide scar, showing backwall and slump blocks. GSC 188676

Table 8. Geotechnical properties of sensitive marine clays, eastern Canada

Sample Reference	Depth (m)	Texture (%) Sand	Silt	Clay	Index properties W%	W_L	Wp	Ip	I_L	Act.	Density (g/cm³) bulk	dry	Soil Class	Shear Strength (kg/cm²) Undisturbed	Remoulded	Sensitivity
A. Study area																
74-27	1	3	47	50	65	-	-	-	-	-	1.76	1.24	ML	0.22	-	-
74-5	0-5	5	73	22	27	23	20	3	2.3	0.14	1.98	1.56	ML	0.43	-	-
74-44	0-5	15	46	39	39	39	18	21	1.0	0.54	1.92	1.37	CI-CL	0.53	0.15	3.5
74-46	0-5	2	54	44	46	35	21	14	1.8	0.32	1.92	1.31	CI-CL	0.15	-	-
74-26	0-5	7	46	47	55	51	17	34	1.1	0.72	-	-	CH	0.37	-	-
74-56	0-5	2	58	40	32	31	19	12	1.1	0.30	2.00	1.52	CL	0.48	0.08	6
Pelletizer	0-5	-	-	-	-	27	17	10	-	-	-	-	CL-ML	-	-	-
74-42	0-5	11	35	54	37.4	50	23	27	0.5	0.50	1.72	1.25	CI-CH	0.79	-	-
74-58	0-5	52	22	26	30	25	16	9	1.5	0.35	-	-	CL	-	-	-
74-81	0-5	25	34	41	32	28	17	11	1.4	0.27	1.99	1.60	CL	1.16	0.19	6
74-30	0-5	24	48	28	30	22	18	4	3.0	0.14	1.37	1.05	ML	-	-	-
74-89	0-5	10	65	25	31	24	18	6	2.2	0.24	1.95	1.50	CL	0.25	0.01	25
74-94	0-5	16	53	31	22	28	18	10	0.4	0.32	2.13	1.63	CL	0.61	0.08	7.5
74-ZV	0-8	1	74	25	33	33	20	11	1.0	0.5	1.76	1.18	CL	-	-	-
Baie St-Nicolas	5	-	-	-	24	15	10	5	-	-	-	-	-	1.0	0.05	20
Moisie	18	2	17	26	47	24	-	-	-	-	1.76	-	-	0.86	0.03	34
Moisie	21	2	59	39	49	27	22	5	-	0.18	1.73	-	-	0.90	0.06	15
Moisie	27	2	77	21	46	24	18	6	-	0.28	1.74	-	-	0.55	0.02	28
Moisie	34	2	68	30	44	23	18	5	-	0.17	1.73	-	-	1.17	0.025	47
B. North Shore and St. Lawrence Lowlands																
Location														References		
Sept-Îles area average				25	33	33	20	11	1.0	0.5	1.76			this report		
Moisie valley				-	37	34	19	15	1.3	-	-			Pryer and Woods, 1959		
Rivière Toulnustouc				30	36	25	20	4.6	3.6	0.15	-			Conlon, 1966		
Nicolet (1)				70	40	56	21	3.5	0.5	0.5	-			Chagnon, 1968		
(2)				50-70	65	55	23	-	1.3	-	-			Crawford and Eden, 1967		
Ottawa Valley (lower sample)				42	-	20-45	-	5-20	1.4	0.2	1.84			Soderman and Quigley, 1965		
Ottawa Valley (upper sample)				80	-	60-85	-	60-35	0.5-1.2	0.5	1.64					

Geotechnical Characteristics of Sensitive Marine Clays

Marine clay deposits consist of clayey silt, the average texture being about 10% sand, 56% silt, and 34% clay (<2 μm fraction). Sediment was deposited as flocs in a high postglacial sea and consequently has an open structure characterized by high void ratios and low dry densities. The deposits consist of non-clay minerals – chiefly quartz, feldspar, amphibole, illite, chlorite, and mixed layer minerals. In general, interparticle electrical bonds are weak and short-ranged. Contacts between particles are cemented by amorphous iron and aluminum precipitates derived from weathered rock flour.

Pore Water. Natural water contents from borehole and field samples average 38% of the dry soil weight (Table 8); field values range between 16% and 64%, the highest being derived from landslide sites at Sept-Îles. Old exposed surfaces of marine sediments commonly have a desiccated outer crust. Along bluff exposures this desiccated layer is limited to the outside 20 cm, but borehole records indicate that the crust is at least 3m thick in some places. Aside from this upper zone there is no systematic change in water content with depth in borehole samples. Water contents are especially variable in banded clays. The high water contents of cores from these sediments may relate to confined sand lenses and disrupted bedding planes, where excessive pore water pressures could develop.

The pore water in these sediments is probably "free" water in the sense that it is not "bound" to soil particles by a diffuse ion layer because most of the particles are uncharged nonclay minerals.

The salinity of the pore water as determined by the conductivity method ranges between 0.8 and 4.6 g/L, and average 1.5 g/L. If the salinity of the pore water at one time approached that of sea water, then it would appear that the North Shore clays have been leached.

Index Properties. Natural water contents generally exceed liquid limit values. For the near-surface field samples, which may be from a partially desiccated zone, water contents are only slightly higher than the liquid limits. Borehole records show that water contents are substantially higher in the subsurface.

The field samples have a wide range of liquid limits. A plot of liquid limit vs. clay content (Fig. 34) shows that the limit is directly related to the amount of clay. Where the clay content is low the total surface area of the mineral particles is low, and the liquid limit is also low because there are few particles that can adsorb ionized water. Where the clay content is greater, however, the total surface area of the mineral particles is greater, more water can be adsorbed and consequently the liquid limit is higher. This assumes that as the percentage of clay-sized material increases, the percentage of phyllosilicate minerals also increases. Mineralogical data (Table 2) bear out this assumption for North Shore clays.

The plastic limit and plasticity index are fairly low, and samples plot as "clay with low to intermediate plasticity" within the CI-CL zone just above the "A" line on the plasticity chart (Fig. 35).

The low plasticity, generally rare for materials with abundant clay-sized particles, is a manifestation of the brittle, short-range (Van der Waals) interparticle bonds.

Shear Strength. Stress-Strain Relationships. Triaxial strain tests of clays from Moisie and Baie Saint-Nicolas show that undisturbed clay behaves as a brittle solid. The clay structure is capable of withstanding initial stresses, with only minor rearrangement of weaker bonds, but once sufficient pressure is applied the framework completely collapses. This

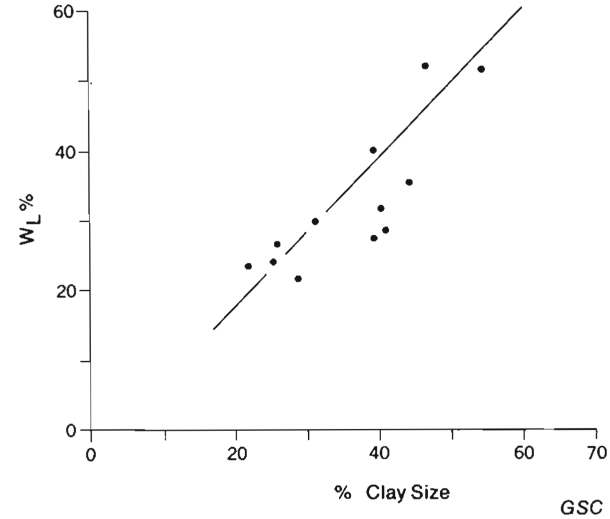


Figure 34. *Relationship of clay content and liquid limit for North Shore clay samples (see Table 8).*

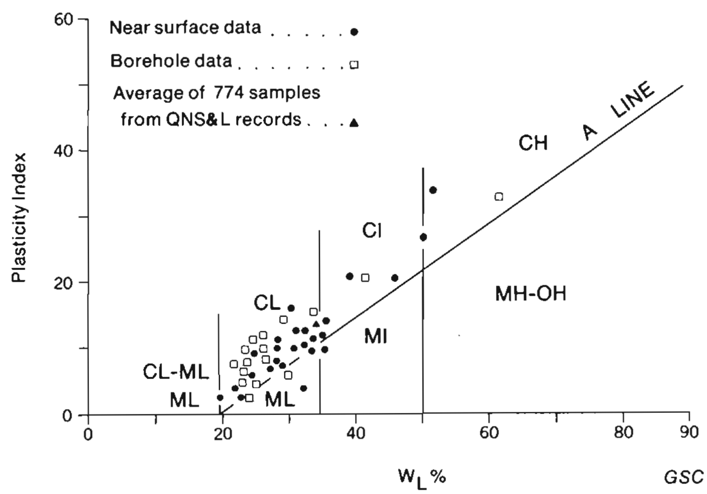


Figure 35. *Plasticity chart showing engineering classification of soils for offshore clay samples given in Table 8. (QNS&L data from Quebec North Shore and Labrador Railway, Sept-Iles, Quebec, unpublished data. Borehole data from Township Office at Sept-Iles, unpublished data.)*

brittle type of behaviour is characteristic of clays having cemented bonds and of materials in which the main interparticle bonds are of the Van der Waals type.

Shear Strength Values. Shear strengths were determined in the field using Geonor shear vanes and a proving ring penetrometer (which theoretically measures unconfined compressive strength). Where tests were performed on desiccated fissured surfaces, shear strengths and penetration values exceeded 5 kg/cm^2 (500 kPa) – the limit of the instruments. Below the weathered crust, shear strength values were low – always less than 1.0 kg/cm^2 (100 kPa) and generally less than 0.5 kg/cm^2 (50 kPa).

Values obtained at depth from borehole records were of the same order. In a few places (e.g., below Sept-Îles townsite), shear strength increases with depth, a trend that can be expected from normal compaction. Generally, however, no relationship is evident between strength and depth below the hardened carapace.

Directional Differences. Shearing resistance in massive clays appears to be isotropic. This is not the case, however, with bedded sediments. In field tests near Lac des Rapides, dry bedded sediments have vertical penetration resistance of 1-3 kg/cm^2 (100-300 kPa), but horizontal resistance is near 1.2 kg/cm^2 (120 kPa). Shear resistances from subsurface samples along the QNS&L railway ranged from 0.05 to 1.17 kg/cm^2 (5 to 117 kPa). Pryer and Woods (1959) noted that the lowest values were derived from sites having the highest silt content and lowest plasticity. It is suggested here that the low values are associated with bedded clays in which the sand partings acted as horizontal planes of weakness.

Where borehole vane tests are performed in bedded sediments, the shear strength values obtained similarly may exceed the horizontal shear resistance at failure.

Sensitivity. Remoulded strengths are about 0.02 kg/cm^2 (2 kPa). Sensitivity values, defined as the ratio of undisturbed to remoulded strengths, ranges from 1 to 52. These clays are considered to range from "medium sensitive" to "very quick" based on the scale devised by Bjerrum (1954).

Strength loss upon disturbance has been discussed in the preceding subsections. In summary, a number of factors, in combination, could be responsible for the high sensitivity ratings in this area.

1. The soils have an open, flocculated structure which contributes to structural strength but at the same time allows the soil to hold large amounts of pore water.
2. Due to leaching, the hydrogen ions in the pore water are not bound to charged soil particles. When disturbance occurs, water is released and flows with soil particles as a slurry.
3. Certain pore water chemical constituents encourage weathering of chlorite and amphibole and subsequently cause release and precipitation of iron, potassium, and aluminum cement at interparticle contacts.
4. Upon disturbance, a complete loss of strength may occur because large proportions of the clay-sized particles are rock flour, which have brittle, short-range bonds.

Comparison of Marine Clays: North Shore and St. Lawrence Lowlands. Clays in Toulnustouc valley, at the western edge of the study area, have mineral assemblages (Quigley, 1968), index properties (Conlon, 1966), and behavioural characteristics similar to those reported above (Table 8).

The marine sediments of the Goldthwait Sea on the North Shore are similar in some respects to Champlain Sea clays in the St. Lawrence Lowlands. Both were deposited in postglacial seas under similar conditions and both have abundant plagioclase, quartz, and amphibole in the silt range, and feldspar, illite, hydrous mica and chlorite in the clay sizes. In the St. Lawrence Lowlands, however, the amount of illite and amorphous silicates (McKyes et al., 1974) appears to be greater than that in the samples from the North Shore; minor amounts of vermiculite and montmorillonite are also present in the Lowlands samples (e.g., Allen and Johns, 1960) and not in North Shore samples. Another difference is that the Paleozoic bedrock of the Lowlands contributes carbonate minerals to the clays, and where black shale is a common rock type, organic gels are present in the clays. The presence of more swelling clay and of organic gels in the Lowlands explains some of the differences in index properties, particularly the higher liquid limit.

Pore water contents are generally lower in clays of the North Shore than in Leda clays in the St. Lawrence Lowlands. In the latter case more water is bound to soil particles because of the higher clay content. The amount of "free" water involved in liquefaction may be the same.

North Shore sample values fall along the same line on the plasticity chart (Fig. 35) as the glacially derived clays in the St. Lawrence Lowland, but the latter are in the CH position of the chart and as such are tougher, exhibit higher dry strength, and have lower compression index than North Shore clays.

Observations on Flowsides at Sept-Îles

Bank failures and flowslides were observed by the author along a shore bluff at Sept-Îles between June 26 and September 23, 1972. Three slides occurred on June 26, following 6.5 cm rain on the June 23 and 25. A fourth slide occurred on September 4 after 10 cm of rain fell in 12 hours. The following description summarizes conditions prior to failure and the sequence of events involved in the development of a flowslide in sensitive marine clay.

The bluff consists of 2 m of very coarse permeable sand which sharply truncates 6 m of massive grey, clayey silt (25% clay). The sands are part of a wedge of beach deposits (shown in Fig. 23) whose lower boundary steadily slopes downwards to the southeast (i.e., inland). Water draining through the sands is not free to drain down the natural slope of the land until considerable head builds up. The base of the bluff is a clayey platform which slopes gently into the adjacent tidal flats. Crescentic fractures, visible behind the face of the bluff, were water-filled, extended about 1 m into the clays, and appeared to have existed for some time.

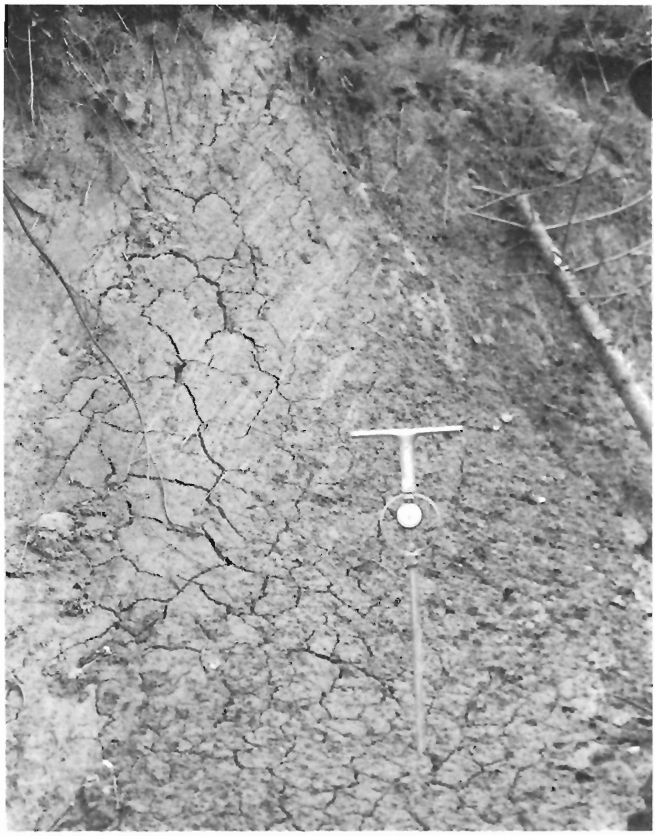


Figure 36. *Fissured backwall of a flowslide at Sept-Îles. Photo was taken in 1974, two years after the slide occurred. Note desiccation cracks and remnants of slickensides (diagonal lines). Penetrometer is 1 m long. GSC 188653*

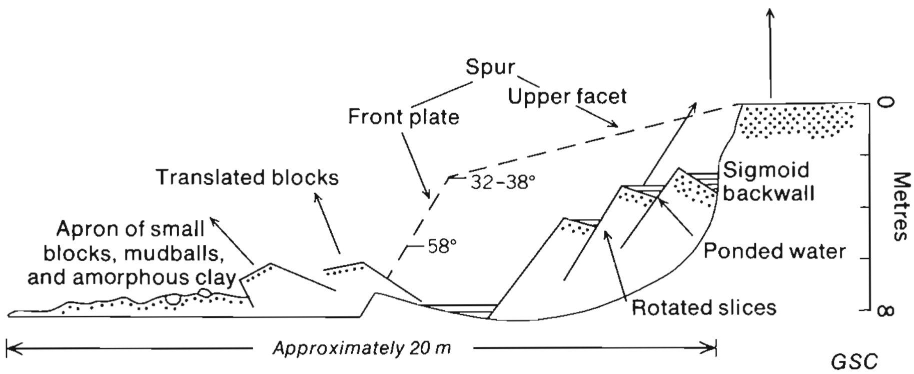


Figure 37. *Schematic cross-section of the flowslides at Sept Iles.*

Three days prior to the slope failures, strength values varied from 0.2 to 0.6 kg/cm^2 (20 to 60 kPa), but commonly were near 0.35 kg/cm^2 (35 kPa). No systematic change in strength values was evident over the bluff: values were similar for areas which later became the failure surfaces, translated material, and stable spurs. The remoulded strength, taken one minute after shearing, was virtually zero.

A description of the slope failures follows:

1. At the beginning of failure the exposed part of the bluff and bare surface directly behind the edge fractured into small hackly fragments 2 to 5 cm across; the edges of fragments liquefied, and the fragments became detached from the face and disintegrated into a slurry. At the same time, shallow arcuate (crescentic) fractures, spaced 0.5 to 1 m apart, appeared behind the bluff.
2. Massive failure began within a few minutes with systematic slumping of slices from the outside of the bluff inwards. The slump slices translated downslope, producing a steep, sigmoidal slickensided backwall and a shallow bowl (Fig. 36, 37). Some liquefaction occurred, particularly along abraded edges of slumped blocks, but most slices remained more or less intact.
3. Liquefaction increased as disturbance continued and blocks began to rotate and translate (Fig. 37) to the front of the bowl. Small fragments were formed into clay balls which moved in the muddy slurry which formed an apron of sediment extending about 25 m from the bluff.
4. Movement ceased after about 15 minutes but pinhole hydrants continued to issue from the backwall. The quick conditions persisted for several days after the slide, and the clay backwall remoulded on contact with the shear vane apparatus.

Increased pore pressure associated with heavy rainfall probably triggered the flowslides. The areal extent of the failure depended on the length of time or distance involved in dissipating the excess stress by extrusion of water and adjustment of the soil-particle structure.

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