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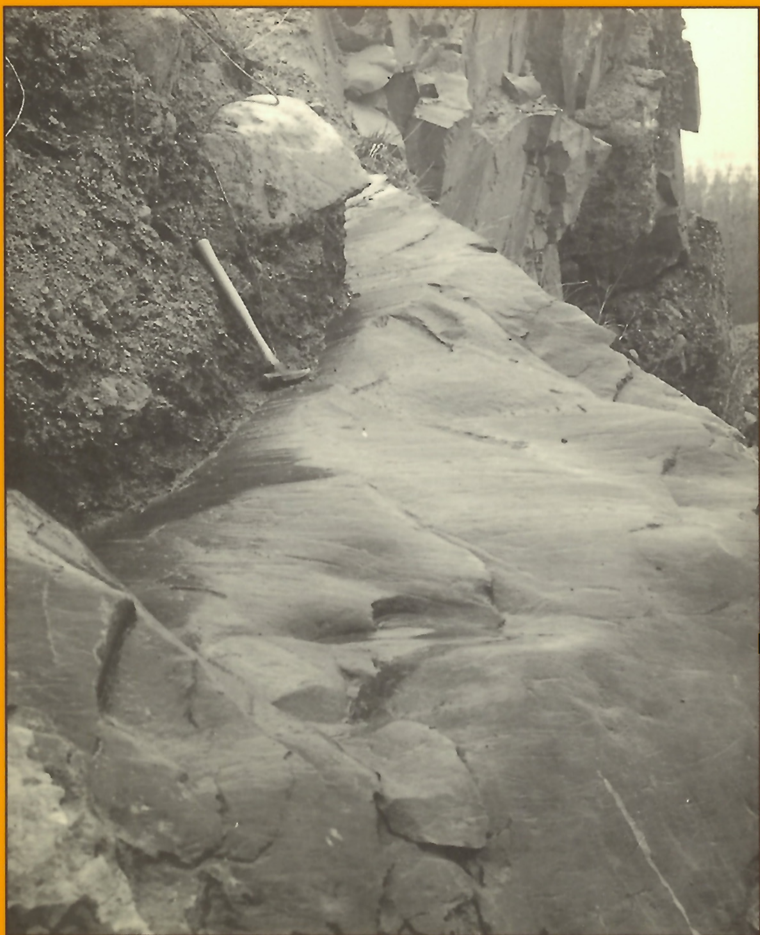
ICE FLOW AND GLACIAL TRANSPORT IN LOWER ST. LAWRENCE, QUEBEC

Martin Rappol



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Cover description

Striated rock surface with till cover in bedrock quarry, 5 km southwest of Rimouski. Till fabric and striations in the foreground indicate ice movement towards the north-northeast. On the rock knob in the back, protruding from the till cover, younger striations indicate ice movement towards the northwest and west.

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ICE FLOW AND GLACIAL TRANSPORT IN LOWER ST. LAWRENCE, QUEBEC

Abstract

The Late Wisconsinan history of ice movements is reconstructed for the region of Lower St. Lawrence and western Gaspésie based on an inventory of glacial striations and an analysis of the glacial dispersal of Appalachian indicator rocks and Precambrian erratics.

The invasion by Laurentide ice from across St. Lawrence Valley appears to have been the first major glacial event. During this phase, ice moved easterly and southeasterly over the study area. Restricted glaciation may have preceded this event in higher areas; local ice caps likely covered Gaspésie and Miramichi Highlands.

The development of a marine ice stream in St. Lawrence Valley radically changed the ice flow pattern. Ice now moved down-valley towards Gulf of St. Lawrence: in a northeastern direction along the valley axis and towards north or north-northeast over the study area.

Decreasing discharge in the ice stream due to drawdown and accelerated calving as a result of late glacial rise of sea level caused the progression of a calving bay up St. Lawrence Valley, passing the study area between 14 and 13 ka BP. During passage of the calving bay, ice movement over the study area shifted from directions towards north-northeast and north to northwest and west.

During these events, an Appalachian ice divide developed, which stretched from the highlands of central Gaspésie, through northwestern New Brunswick and northern Maine, into the Eastern Townships of southern Quebec.

Fossiliferous tills, observed at several places, indicate that Laurentide as well as Appalachian ice readvanced at least once after passage of the calving bay. Laurentide ice covered the coastal zone of the Rivière-du-Loup area around 11.8 ka BP and in the Rimouski area, Appalachian ice readvanced in marine waters after 12.3 ka BP.

Résumé

L'histoire du mouvement des glaces dans la région du Bas-Saint-Laurent et de la Gaspésie occidentale au Wisconsinien supérieur est reconstituée d'après un inventaire des stries glaciaires et une analyse de la dispersion glaciaire des roches indicatrices appalachiennes et des blocs erratiques précambriens.

L'invasion par la glace laurentidienne traversant la vallée du Saint-Laurent semble avoir constitué le premier épisode glaciaire majeur. Pendant cette phase, la glace s'est déplacée vers l'est et le sud-est dans la région levée. Une glaciation restreinte des régions plus élevées peut avoir précédé cet épisode; des calottes glaciaires locales couvraient vraisemblablement les hautes terres de la Gaspésie et de la Miramichi.

La formation d'une langue glaciaire marine dans la vallée du Saint-Laurent a radicalement modifié la configuration de l'écoulement de la glace. La glace s'est alors déplacée vers l'aval dans la vallée en direction du golfe du Saint-Laurent, dans une direction nord-est le long de l'axe de la vallée et en direction du nord ou du nord-nord-ouest dans la région levée.

Le ralentissement du débit de la glace dans la langue glaciaire dû à un abasisement et à un vêlage accéléré attribuable à une élévation glaciaire tardive du niveau de la mer a entraîné la progression vers l'amont dans la vallée du Saint-Laurent d'une baie de vêlage qui aurait dépassé la région levée il y a entre 14 et 13 ka BP. Lors du passage de la baie de vêlage, le déplacement de la glace dans la région levée a varié, sa direction passant du nord-nord-est et du nord au nord-ouest et à l'ouest.

Pendant ce temps, une ligne appalachienne de partage des glaces est apparue et s'est allongée à partir des hautes terres de la Gaspésie centrale jusqu'aux Cantons de l'Est du Québec méridional en passant par le nord-ouest du Nouveau-Brunswick et le Maine septentrional.

Les tills fossilifères observés en plusieurs endroits indiquent au moins une nouvelle avancée de glace laurentidienne et de glace appalachienne après le passage de la baie de vêlage. La glace laurentidienne a recouvert la zone littorale de la région de Rivière-du-Loup il y a environ 11,8 ka BP, et dans la région de Rimouski la glace appalachienne s'est de nouveau avancée dans les eaux marines plus tard que 12,3 ka BP.

INTRODUCTION

Location and objectives

The study area, located on the south shore of the St. Lawrence estuary (Fig. 1), comprises most of the Lower St. Lawrence region (Bas-Saint-Laurent) and part of adjacent Gaspésie, west of Matapédia and lower Matane valleys (Fig. 2). During the study, it became necessary to extend observations also into northwestern New Brunswick.

The Notre-Dame Mountains of the inland region are generally densely forested and scarcely populated, serving mainly as forestry and wildlife reserves. Summits generally do not reach over 600 m a.s.l. Two elongated zones of lower elevation, extending transverse to the mountain chain, provided important transport routes and include the largest lakes of the region, lacs Matapédia and Témiscouata. Most of the population resides in the coastal area, where much of the land has been cleared.

The glacial history of the area has not been studied extensively, despite its critical location in between the better studied regions of Gaspésie and the Eastern Townships. The aim of this study is to reconstruct the Pleistocene history, mainly in terms of the direction of different ice flow events and the relative importance of these events as debris-transporting agents. To accomplish this, an inventory of glacial striations was made and the dispersal of distinctive indicator rocks was analyzed through boulder counts.

Fieldwork was done in the summer months of 1987 and 1988. Because of the size of the area (over 17 000 km^2) and poor access in much of the inland region, results and interpretations can only be regarded as of a reconnaissance and preliminary nature.

History of research

Most previous work relevant to the present study is discussed in more detail in following sections of this paper. Here it suffices to review briefly the main events in the history of Quaternary research of the area. The early history of research

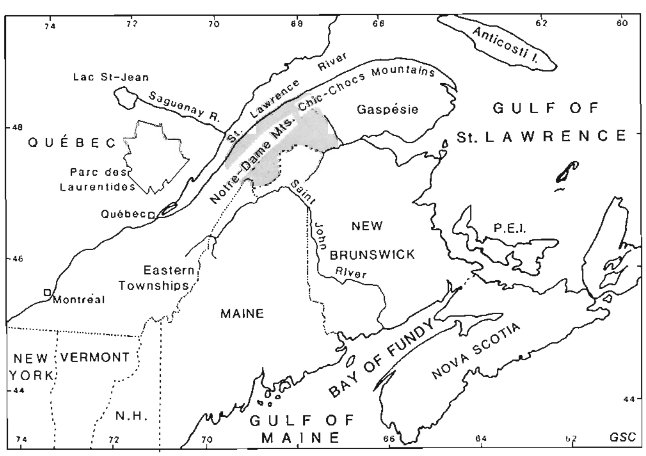


Figure 1. Location of study area.

in Gaspésie was discussed in detail by McGerrigle (1952), and the evolution of grand views on the glacial history of Atlantic Canada was reviewed in detail by Brookes (1982).

Around the turn of the century, the surficial geology of this region and much of eastern Canada was explored by Chalmers (1886, 1887, 1895, 1898, 1906). Chalmers (1906, p. 144) concluded that "the glaciation of South-Eastern Quebec and Northern New Brunswick in the Post-Tertiary age was effected largely by local glaciers, which moved northward and southward from the highest land or watershed adjacent to the Notre Dame Mountains." Chalmers (1887, p. 8) also noted ice movement parallel to St. Lawrence Valley.

Coleman (1922) observed many Precambrian erratics in the area around Lac Matapédia and farther south in Matapédia Valley. He inferred that Laurentide ice crossed St. Lawrence Valley and moved down Matapédia Valley towards Chaleur Bay. However, central Gaspésie was still thought to have escaped a Laurentide ice cover.

McGerrigle (1952) reviewed subsequent work in Gaspésie and concluded that, during an early phase of glaciation, ice crossed the highland areas of southeastern Quebec; later, a local ice cap developed.

Whereas the glacial history of Gaspésie continued to attract interest, surficial geology of the Lower St. Lawrence region seems to have been entirely ignored until the early sixties, with the exception of some oblique references in bedrock geology reports.

In 1962, Lee published the first detailed map of surficial geology for the Rivière-du-Loup : Trois-Pistoles area, and a few years later, Dionne (1968) presented a morphogenetic map for the Trois-Pistoles area. During the 1970s, surficial deposits in the larger part of the present study area were mapped at a scale of 1:100 000 (Lebuis and David, 1972; Lebuis, 1973b; Martineau, 1977, 1979, 1980; Locat, 1978).

The last two decades have seen a gradual increase in research efforts expended in Quaternary geology of the Maritime region. An important topic of research remained the assessment of the relative influence of Laurentide and Appalachian ice masses, but also deglaciation patterns, sea-level change, and compositional work on surficial sediments have attracted much attention. In several recent papers authors reviewed and discussed various aspects of the glacial and postglacial history of the study area and adjacent regions (LaSalle, 1984; Rampton et al., 1984; Chauvin et al., 1985; David and Lebuis, 1985; Parent et al., 1985; Prichonnet and Hétu, 1988; Dionne et al., 1988). Other pertinent data, mostly on glacial dispersal, are contained in recent geochemical exploration survey reports (Maurice, 1986, 1989; Bernier et al., 1987; Bernier and Webber, 1989).

Despite such efforts, discussions on the extent of the Laurentide ice cover and the maximum extent of ice in general during the Late Wisconsinan still continue (Brookes, 1982). The persistence of local ice caps in large parts of the Atlantic Provinces and Gaspésie was advocated by Prest and Grant (1969), Grant (1977), and, more recently, by Rampton et al. (1984). Grant (1977) also represented the

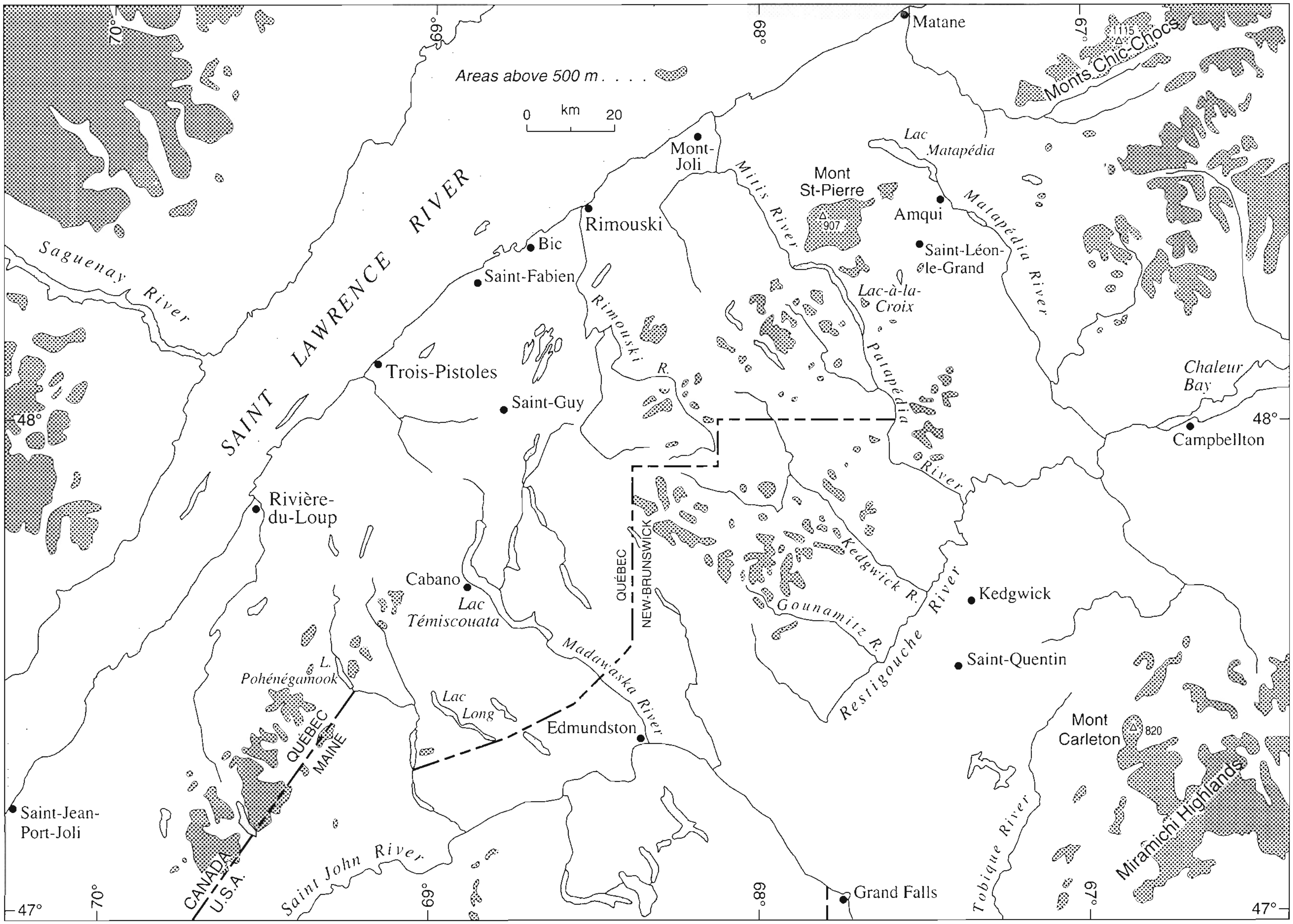


Figure 2. Main topographic features of study area.

view of minimal extent of Late Wisconsinan ice, leaving much of the Gulf of St. Lawrence free of ice. Such views are contrasted by many New England workers, who portray maximal glaciation with strong influence of Laurentide ice throughout the region (e.g., Hughes et al., 1985).

BEDROCK GEOLOGY AND GEOMORPHOLOGY

The St. Lawrence estuary submerges the contact ("Logan Line") between igneous and metamorphic rocks of the Canadian Shield's Grenville Province and the Appalachian fold belt. Appalachian rocks of the study area are predominantly of sedimentary origin and Paleozoic age (Fig. 3).

The coastal zone consists of Cambrian to mid-Ordovician rocks (mainly slate and quartzite), which have been affected by the Taconian orogeny (mid-Ordovician) and constitute the so-called Quebec anticlinorium (Poole and Rodgers, 1972). Between Matane and Rimouski, a number of small volcanic units occur.

The remaining part of the study area is located within the Gaspé — Connecticut Valley synclinorium, where Silurian and Devonian sedimentary rocks unconformably overly the Cambro-Ordovician basement. At La Rédemption, along the northern flank of Mont St-Pierre, this contact is exposed; here the Cambro-Ordovician package is represented by a body of serpentinite and amphibolite with minor diorite (Aubert de la Rue, 1941; Béland, 1960).

During the second part of the Devonian, the whole area was affected by the Acadian orogeny.

Near Lac-du-Pain-de-Sucre, the Silurian Pointe-aux-Tremble Formation, comprising volcanic conglomerates and occasional lava flows (Lespérance and Greiner, 1969; J. David et al., 1985), is intruded by a number of small dioritic bodies. Farther to the northeast, its stratigraphic equivalent, the Lac-Raymond Formation, is intruded by a series of gabbro sills in the area between Lac-des-Echoes and Lac Mistigouèche (Béland, 1960; Lajoie, 1971).

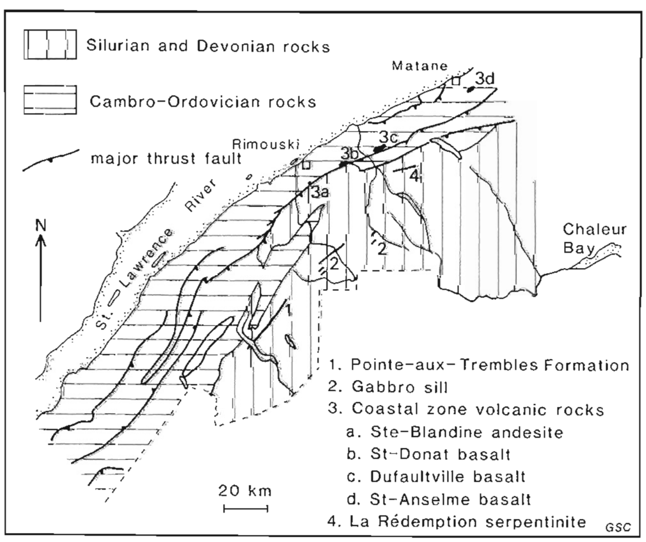


Figure 3. Main features of the bedrock geology (simplified from Ministère de l'Energie et des Ressources, 1987).

In northern New Brunswick also, a number of small igneous intrusions occur, e.g., north of Edmundston and west of Campbellton (Potter et al., 1979). These consist of distinctive quartz-feldspar porphyry or diorite.

The top of Mont St-Pierre (907 m), located southwest of Lac Matapédia, is the highest point in the study area. In a way, this mountain is a remarkable feature, standing isolated and well above the remaining part of the area. The strongly dissected mountainous inland area along the borders with New Brunswick and Maine has closely spaced summits between 500 and 600 m a.s.l.

Towards the coast, the relief becomes gradually more subdued and also more controlled by geological structure. Here, the large-scale morphology is characterized by parallel ridges (330-400 m a.s.l.) of more resistant rock types, separated by valleys, both striking northeast-southwest with the structural trend.

The major valleys, however, are generally transverse to the strike direction. Several large lakes occupy parts of these valleys and owe their existence to a large extend to valley overdeepening by glacial erosion (e.g., Lac Témiscouata).

In general, glacial deposits form only a thin veneer over bedrock. In a few places, however, ice-contact deposits attain impressive dimensions. Among the glacial deposits, numerous eskers form a striking small-scale relief element. For details on these matters, the reader is referred to the regional mapping reports (Martineau, 1977, 1979, 1980; Locat, 1977).

In the near coastal zone, below 150 to 170 m a.s.l., present morphology is strongly determined by postglacial submergence and subsequent emergence, resulting in thick marine deposits and shoreline morphological features.

ICE MOVEMENTS INDICATED BY EROSIONAL MARKINGS

Most currently recognized features of glaciated rock surfaces were discussed thoroughly just over 100 years ago in Chamberlin's (1888) classic monograph "The rock-scorings of the great ice invasions." Recent reviews were given by Prest (1983), Laverdière et al. (1985), and Lortie and Martineau (1987). Many of these erosional forms not only give the orientation of flow lines in the ice, but also indicate the direction in which the ice moved. These features are therefore of great importance for reconstructing glacial history, especially in such areas where ice has moved in different and even opposite directions through time.

In the present study, to derive the direction and relative age of ice movements, I have used the same criteria as those discussed in the references already cited and as tabulated in Lortie and Martineau (1987). Consequently, some aspects of the methodology are discussed only briefly.

Method

Miniature crag-and-tail erosional features (rat-tails) are among the most common and best indicators of ice movement on glaciated rock surfaces. Rat-tails consist of a knob of more resistant rock (a mineral, pebble, or concretion) with a tail of protected surrounding rock in the down-ice direction. Of similar origin and at least as common, are small steps at quartz veins, facing the up-glacier direction.

Rat-tails described as having a clear frontal depression and lateral grooves (Chamberlin, 1888; Prest, 1983; Shaw and Sharpe, 1987) have not been noted during the present survey. Lortie and Martineau (1987) reported that such grooves are present in a few places and assigned these forms to direct glacial abrasion, whereas the other authors have suggested that such forms were originally eroded by meltwater.

With rat-tails, stoss-and-lee relationships were used most frequently as indicators of ice movement. The distribution of stoss and lee sides often was used to derive relative age of striations as well. This applies to the asymmetrical distribution of younger striations on older rat-tails, glacial grooves and larger forms, as well as to the preservation of older striations in protected lee-side positions relative to younger movements.

Nail-head and wedge-shaped striations were used as indicators of ice movement direction where these occur on near-horizontal surfaces and occur in several places or trains (Fig. 4), all indicating the same direction.

On resistent quartzites, striations are rare or absent on the macroscopic scale, but crescentic fractures and scars are common. However, their orientation is often highly variable. Only where these features occur as well-defined trains they were used as indicators of direction of ice movement.

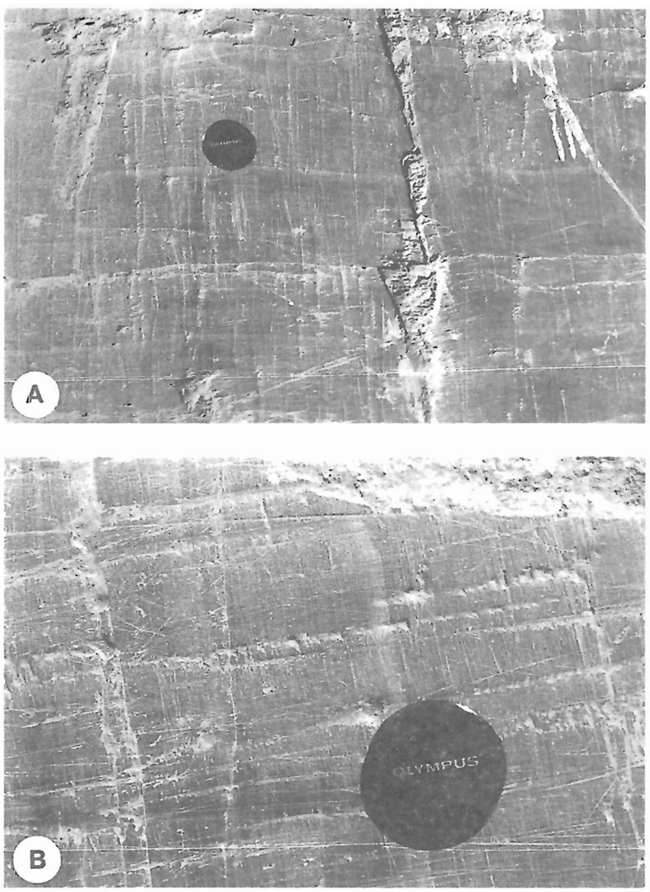


Figure 4. Striated rock surface at St-Jacques, Madawaska Valley (21N/8: 47°26′15″N, 68°24′00″W). **A.** Large wedge shapes along joint trace and trains of nail-head and wedge-shaped striations. Ice movement from bottom to top (to 310°). (GSC 205472-D) **B.** Detail of A, showing trains of wedge-shaped striations and associated chatter marks (ice movement from left to right), cut by younger fine striations towards 35° (from top to bottom). (GSC 205472-E)

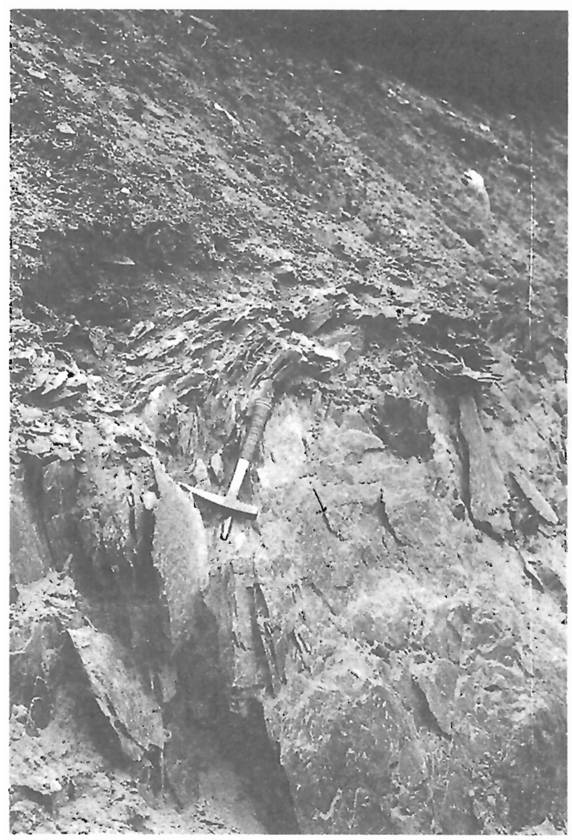


Figure 5. Oxidized till, about 2 m thick, overlying fractured slate at road-crossing, 2 km north of Packington (21N/10: 47°30′03″N, 68°46′20″W). Striations observed at this site indicate ice movement along 155°-335° and overturned slate slabs at base of till indicate that ice movement was towards 335°. (GSC 205472-C)

Besides these main criteria, a number of other phenomena may occasionally provide information on direction and relative age of ice movements.

Slate strata are sometimes bent over in the down-glacier direction (Dredge and Grant, 1987), as illustrated in Figure 5.

Where till overlies striated bedrock, till fabric will align the youngest striation set. Where the till cover is incomplete, rock outcrops protruding from the till surface may record striation sets that are not present on the till covered surface and represent younger ice movements that took place after deposition of the till. An example of this is illustrated in Figure 6.

The till sheet west and northwest of St-Guy (21C/2) was deposited by ice moving in a northerly direction as indicated by its clast fabric and by striations on the rock surface beneath the till. However, bedrock knobs protruding through the till surface record later ice movements towards the northwest and west. Youngest striations on the stoss side of a few large blocks embedded in the till surface also suggest latest ice movement in a northwestern direction and indicate that only the upper 50 to 70 cm of the till were moved and deposited by this flow event.

In areas of thick till cover in general, one has to be aware of such complex relationships. Available striation sites are commonly located at rock knobs protruding from the till surface and may record only late ice movements that affected or deposited only a thin upper layer of the till.

Previous work in the Appalachians

Indications of northerly ice flow directions from local ice divides in the Appalachians have been reported throughout the history of glacial research in the region (see Lortie and Martineau, 1987), but as a result of the strong influence of conceptual models on researchers, their significance was long neglected or denied. Only at the instigation of Lamarche's (1971) publication on northward flow in the Thetford-Mines area, the northward flow event became re-evaluated (Gadd et al., 1972). Subsequent detailed work (Gauthier, 1975; Lortie, 1976; LaSalle et al., 1977; Lebuis and David, 1977) has added to a further development of the modern concept of deglaciation of St. Lawrence Valley and the Appalachians. It is now generally accepted that deglaciation proceeded through the development of a calving bay in St. Lawrence Valley, after drawdown had caused a lowering of the ice surface along the valley axis, giving rise to the development of an Appalachian ice divide (Thomas, 1977; Chauvin et al., 1985; Hughes et al., 1985; Dyke and Prest, 1987).

The effects of the northerly flow event (comprising northeastward and northwestward flow, as well) have now been recorded throughout the St. Lawrence south shore region (LaSalle et al., 1977; Lebuis and David, 1977; Locat, 1978; Martineau, 1979, 1980), including northern Maine (Lowell, 1985; Newman et al., 1985) and northwestern New Brunswick (Gauthier, 1980; Rampton et al., 1984; Rappol, 1986a). In fact, the pendulum has swung: striations indicating southeasterly flow, and unequivocally produced

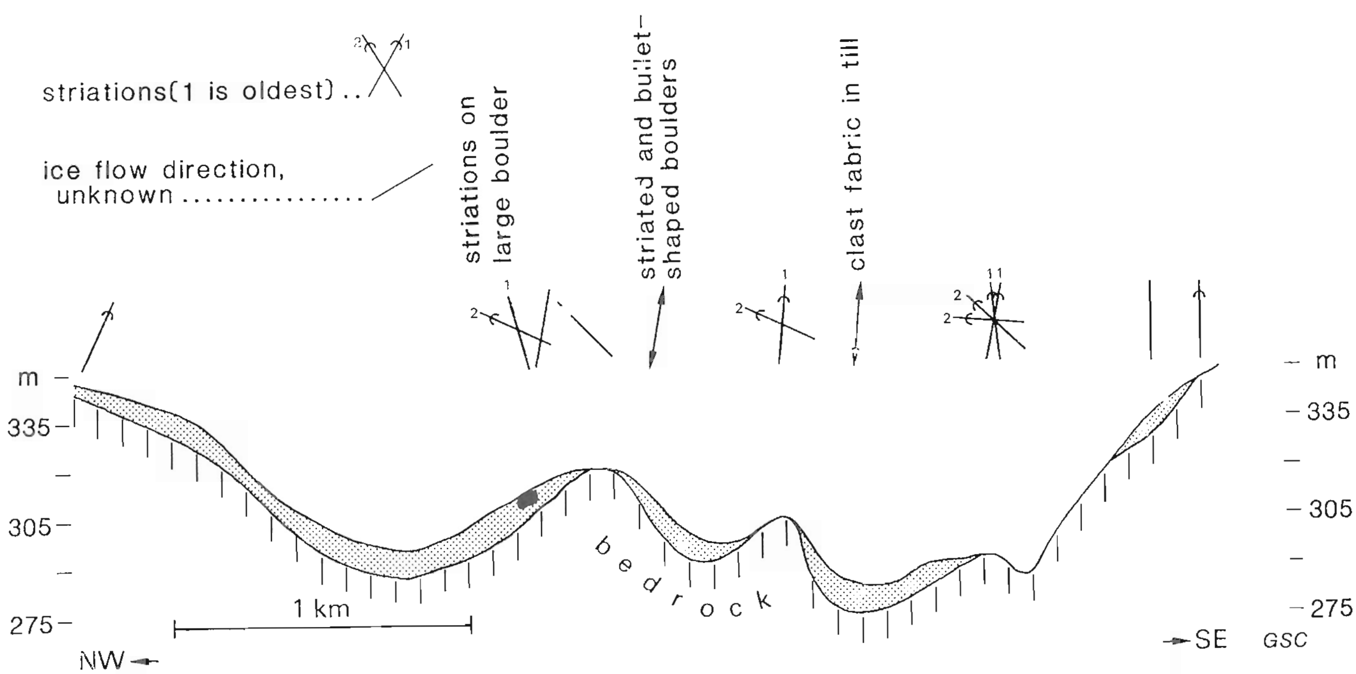


Figure 6. Schematic cross-section along road 296, 2 to 6 km southwest of St-Guy (22C/2), illustrating the relationship between observed bedrock striations and distribution of till cover. The till sheet (shaded) was mainly deposited during ice movement in a northerly direction. The ice mass, which inscribed the younger striations on rock knobs protruding through the till surface, resulted in little reworking or till deposition.

by Laurentide ice, have become hard to find. This has probably led Rampton et al. (1984) to project a Notre-Dame — North Maine ice divide as an Appalachian ice centre throughout the Late Wisconsinan and refer a Laurentide ice invasion to an earlier glaciation. Indeed, no southeasterly striations have been reported from the northwestern flank of the present drainage divide in the Notre-Dame Mountains.

In the present study area, Lortie and Martineau (1987, Fig. 37) suggest that 5 to 10% of striations indicate southeastward flow from the Precambrian Shield. However, their summary map records only one such a direction for striations near St-Léon-le-Grand (22B/5), earlier reported by Lebuis and David (1977). However, this site is south from Mont St-Pierre, the highest mountain in the lowlands of western Gaspésie. Abundant east-southeasterly striations in northern Maine, predating the northward flow event (Lowell, 1985) and those reported from central Gaspésie (e.g., Chauvin et David, 1987) are found in positions that lie southeastward from a possible Appalachian ice divide over the present drainage divide.

Recently, Prichonnet and Desmarais (1985) claim that southeasterly and southerly directions shown by erosional indicators are abundant in northwestern Gaspésie. This deviating result could not be confirmed during the present survey.

The strongest evidence for Laurentide ice invasion during the last glaciation thus does not come from the striation record. It is indicated more clearly by the distribution of Precambrian erratics and their occurrence especially in the upper part of tills, as well as by dispersal patterns of some local Appalachian rock types.

Late glacial flow from Appalachian ice divides

Striations observed during the present survey are summarized in Figure 7 (in pocket). About 10% of measured striations could not be plotted for lack of space on the map. However, the information they contain is already given by the ones that have been plotted.

Striations indicating flow in northerly and westerly directions are by far the most prominent and are omnipresent in the western part of the study area. These striations must represent flow from Appalachian ice divides during the late stages of the last glaciation.

The system is clearly not represented by a regional unidirectional ice flow event. The data suggest an anticlockwise shift in ice movement from north-northeast to northwest or west.

The oldest north-northeastward and northward directions, including northeasterly striations in a narrow coastal zone that parallels the valley axis, represent a major ice flow event down St. Lawrence Valley, which predates the passage of a calving bay. The areal configuration of striations supposedly related to this event suggests that it represents converging flow from the Appalachians and the Precambrian Shield into a fast-moving ice stream along St. Lawrence Valley. This ice stream probably developed as a result of drawdown in the Gulf of St. Lawrence area (Hughes et al., 1985).

With the progression of a calving bay from Matane to Trois-Pistoles, ice movement in the northern part of the study area shifted from northward through northwestward and finally to westward. The late westward event had its strongest erosional power in the Lac Matapédia depression, north of Mont St-Pierre, but related striations are found westward at least as far as Rimouski. It was fed by a strong outflow from the Shick-Shock Mountains and from the area southeast of Mont St-Pierre. The westerly direction of flow suggests that flow during this event was probably no longer controlled by drawdown and calving in St. Lawrence Valley, but that it represents gravitational flow of grounded Appalachian ice caps. From its maximum position, the ice retreated in an easterly direction. Recessional morainic deposits are found near St-Cléophas (David and Lebuis, 1985) and Amqui (Prichonnet and Desmarais, 1985).

Between Rimouski and Trois-Pistoles, many older north-northeastward and northward striations have been preserved, whereas south of Trois-Pistoles they are sparse. A line extending southeastward from Trois-Pistoles separates these two different areas. The pervasive presence of northwestward striations south of Trois-Pistoles indicates an important late glacial flow event, perhaps in the form of a terrestrial ice stream, separated by a sharp boundary from the region north of Trois-Pistoles where ice movement was either much slower or of shorter duration, or both, and had a much less erosive power. The northwestward system appears truncated by the St-Antonin Moraine in the northwest. It extends down the Témiscouata depression into northwestern New Brunswick, where the ice divide was probably located over Grand Falls (Rappol, 1986b).

Eastward and southeastward ice movement

With respect to the occurrence and origin of southeasterly flow indicators, three regions are delineated in Figure 7. Striations within the systems discussed here have directions that vary between east-northeast and south.

The first region is located to the southeast of the eastern limit of the recorded occurrences of northerly and westerly striations. This limit approximately represents the main position of the late-glacial Appalachian ice divide. Striations in the region to the east of this line may have been formed during the time that Laurentide ice invaded the area, but it is probable, however, that most formed during younger flow events after the Appalachian ice divide developed. In the study area itself, few striations were found in this region, but farther east many easterly striations have been mapped across part of Miramichi Highlands by Rampton et al. (1984). Several Late-Wisconsinan easterly flow events (shifting from southeast to northeast) are distinguished in north-central New Brunswick, all of them thought to be related to flow from Appalachian ice divides (Rampton et al., 1984; Pronk, 1987).

In the second region, west of the divide, eastward and southeastward striations are generally sparse, except in some restricted areas. These striations are commonly cut by younger northward or westward trending striations. However, in a restricted part of the upper Kedgwick River basin the latter is not the case. This situation might be explained by a configuration of ice movements and ice divides as proposed by Rampton et al. (1984, Fig. 35a,b). Alternatively, eastward and southeastward striations in this area were formed by Laurentide ice, which appears to be more in concert with observed dispersal of local and Precambrian indicator rocks (Rappol and Russell, 1989).

On many glaciated surfaces to the west of Lac Pohénégamook and at two sites to the north of this lake, east-southeastward striations are found that have undoubtedly been formed by Laurentide ice. An Appalachian ice divide located west of these sites is inconceivable, because several of these sites are well down the northwestern flank of the present drainage divide in Notre-Dame Mountains.

These striations are generally cut by younger striations indicating flow in a northwesterly or northerly direction. Similar relationships have been found in adjacent northwestern Maine (Lowell, 1985) and Eastern Townships (Lortie and Martineau, 1987), where east-southeastward flow is generally assigned to invasion by Late Wisconsinan Laurentide ice.

Till associated with the east-southeastward flow event was found preserved at only one site: along a road, directly on the eastern shore of the northern tip of Lac Long, about 20 km east of Lac Pohénégamook (21N/7, 47°27′35″N/69°00′15″W). This till is more than 3.5 m thick, showing three bands of different colour and slightly different texture. All these units are characterized by a strong east-west fabric, showing slight preference for the long-axes to dip towards the west (Fig. 8). Also striations on large clasts of a stone pavement are consistently oriented east-west. The till appears to consist predominantly of local sedimentary rocks, but its composition was not assessed quantitatively. A correlative till in upper St. John River valley is reported to contain about 1% Precambrian erratics (Lowell et al., 1986, p. 74).

In the rest of this region, striations that are possibly related to Laurentide ice invasion are extremely rare (see also summary map by Lortie and Martineau, 1987). Two sites were found north of Grand Lac Squatec and a few sites are found near Edmundston, N.B., where older southeastward striations parallel the trend of Madawaska and St. John River valleys. A few sites were found on the south-facing slope of Mont St-Pierre, among which the well-known site near St-Léon-le-Grand (Lebuis and David, 1977; David, 1987).

The third region comprises a narrow coastal zone south of Trois-Pistoles and west of the St-Antonin Moraine, which was affected by eastward flow during formation of the St-Antonin Moraine in a re-entrant of the retreating calving bay (LaSalle et al., 1977, fig. 4-7) or during formation of Lee's (1962, 1963) "Younger Till" (see section on "Lateglacial events"). Towards the southwest, this zone becomes broader. Many striations belonging to this system have been mapped in the coastal zone between La Pocatière and Montmagny and southeast of Quebec City (Lortie and Martineau, 1987). They are never cut by younger striations.

In the study area, Martineau and Corbeil (1983) reported a late eastward flow at a site near St-Arsène, about 10 km northeast of Rivière-du-Loup (see Fig. 7). Lee (1962) also reported that his "Younger Till" appears deposited by eastward moving ice on the basis of clast fabric.

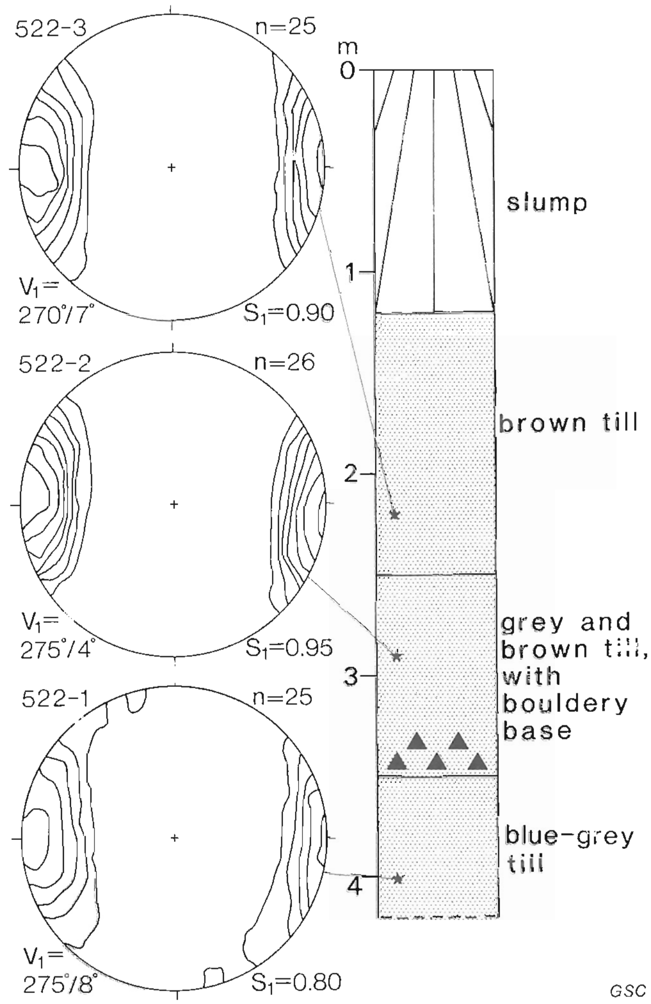


Figure 8. Till section near east shore of northern tip of Lac Long (21N/7: 47°27′35″N, 69°00′15″W). This till is thought to have been deposited during the initial phase of Laurentide ice invasion and to correlate with the lower till in the upper Saint John River basin, described among others by Lowell et al. (1986). This correlation is based exclusively on clast fabric of the tills. The fabric diagrams, and those shown elsewhere in this report, are contoured at 2σ intervals on an equal area projection of the lower hemisphere, n is the number of measurements, and V_1 and S_1 are the principal eigenvector and eigenvalue, giving measures of mean orientation and fabric strength, respectively (Mark, 1973).

An older northeastward flow?

Striations indicating northeastward flow parallel to St. Lawrence Valley are common in a narrow coastal zone and are related to a marine ice stream and the subsequent development of a retreating calving bay in the valley (see above). However, northeasterly striations are also found at a number of scattered sites farther inland (see Fig. 7), which are unlikely to have a similar origin. Because such sites are fairly rare, these striations shown in Fig. 7 may represent an accumulation of accidental striations formed by ice movement deflected by local topography. But there are also some indications that these striations may represent remnants of an older system, perhaps formed during the penultimate glaciation under a regime of regional northeastward flow. At one site, west of Lac Pohénégamook, northeastward striations in the inland zone predate not only the northward or northwestward striations of the late Appalachian systems (Fig. 7), but also east-southeastward striations formed by Laurentide ice invasion.

The only known subsurface till of the study area, the Tamagodi Till of the Matane River basin, was deposited by ice moving towards northeast (Lebuis and David, 1977). Also a lower till at Edmundston contains a northeast-southwest fabric and was probably deposited by ice moving northeastwards (Rappol, 1986b).

In the simplest scenario, both these tills correlate with the Chaudière Till of the Eastern Townships (McDonald and Shilts, 1971; Shilts and Smith, 1987) and a lower till in Saint John River valley, south of Grand Falls (Rappol, 1989). The Chaudière Till probably formed under two different flow regimes: an early Appalachian ice mass moving west-southwestwards and a younger southeastward flowing Laurentide ice mass (McDonald and Shilts, 1971; Bouchard et al., 1987).

If this correlation were correct, then the Appalachian ice mass of the early phase during formation of the Chaudière Till must have been centred on an ice divide located more or less along the Maine — Quebec border, because the lower till in Saint John River valley contains erratics from the Deboullie pluton in northern Maine (Rappol, 1988, 1989).

Elson (1987), based on an analysis of pillow-lava boulder dispersal in Eastern Townships, discussed the possibility of such an ice divide during formation of the Chaudière Till and suggested that it probably extended northward across St. Lawrence Valley over Laurentide Mountains of Laurentide Park, north of Quebec City.

GLACIAL DISPERSAL OF INDICATOR ROCKS

The erosional features so far discussed give valuable and essential information for reconstructions of glacial history. However, for such practical applications as prospecting in glaciated terrains, it is generally still more important to establish dispersal patterns of rocks and minerals. It is not uncommon to find that a youngest ice flow event may have effectively abraded exposed rock surfaces and yet was rather ineffective in eroding and transporting glacial debris. Such a case was described from Eastern Townships in southern Quebec by Shilts and Smith (1987). An illustrative example is also found in the study area near the village of St-Guy (Fig. 6).

Previous work in the Appalachians

Casual observations on glacial dispersal of distinctive rock types have been made since the beginning of geologic exploration in southeastern Canada, but systematic and quantitative analyses are only recently being pursued intensively.

Early work by Shilts (1973a,b) in Eastern Townships of southern Quebec demonstrated southeasterly dispersal of boulders and mineral components from ultramafic outcrops in the Thetford Mines area. Northward dispersal from these outcrops appears to be minimal or absent (Shilts and Smith, 1987; Maurice, 1988; Lortie and Martineau, 1988), even though latest ice movement over the area was towards north (see striation map by Lortie and Martineau, 1987). The possible reason for this ambiguity, as discussed by Shilts and Smith (1987) and Lortie and Martineau (1988), is that the northward flow event probably represented only a brief time interval, prior to which the outcrops had been stripped and smoothed by older ice movements, making material less readily available for glacial erosion during the subsequent northward ice movement.

In northern Maine, Halter (1986) applied dispersal studies of boulders, pebbles, and heavy minerals on two small plutons of granodiorite and syenite. A total of 118 counts were recorded, each sample consisting of 500 boulders with an intermediate axis of 25.6 cm or more. Boulder counts indicate the presence of two dispersal trains: one towards east-southeast and a much weaker one towards north-northwest. These directions correspond with two main striation sets found on bedrock surfaces in the area (Kite and Lowell, 1982; Lowell, 1985): the older direction towards east-southeast (variable between east and southeast), the younger one towards north and northwest, supposed to be associated with Late-Wisconsinan Laurentide and Appalachian ice masses, respectively.

Indicators from the most northern pluton in Maine (Deboullie syenite and granodiorite) have been observed in western New Brunswick (Rappol, 1988). In the northern part of their occurrence in New Brunswick, about 10 to 20 km south of Grand Falls, these indicators appear to be associated primarily with a lower till deposited by eastward moving ice during the penultimate glaciation of the region. These occurrences are 80 to 100 km due east of the Deboullie pluton, and it is therefore unlikely that the area of these occurrences was influenced by the Late-Wisconsinan east-southeastward dispersal from the Deboullie pluton.

Martineau (1979) determined dispersal of erratics around a small quartzdiorite body near Lac-du-Pain-de-Sucre, about 8 km southeast of Squatec. The counting method remains unspecified, but three dispersal directions are suggested on the basis of 34 counts (Martineau, 1979, fig. 3).

Southeastward dispersal is supposed to be connected with movement of Laurentide ice over the area, whereas northwestward dispersal is related to an Appalachian ice mass. According to Martineau (1979, p. 15), an apparent third dispersal direction towards the north might be due to a second outcrop of the same rock type. However, striations indicating ice movement in a northerly direction, that predate those indicating northwestward flow, were observed at several sites in the area during the present survey.

Lebuis (1973a,b), Lebuis and David (1977), and David and Lebuis (1985) reported on dispersal of Appalachian indicator rocks in western Gaspésie. These authors used a somewhat complicated method of frequency calculation, in which the frequency of occurrence of a certain indicator is measured against the frequency of other indicator rock types, only. This method has the advantage of getting data that are independent of variations in the amount of indistinctive and local rock types incorporated but has as a disadvantage that apparent frequencies of a certain indicator are a function of the dispersal patterns of the other indicators used. Another disadvantage of their method is that data figures are sometimes based on as little as 40 boulders. However, their results do not differ basically from those obtained by other methods in the region (Prichonnet and Desmarais, 1985; Rappol and Russell, 1989).

Boulders of the Val Brillant orthoquartzite are found dispersed southeastward and north-northwestward from their sources (Lebuis and David, 1977). The southeastward dispersal train from one of the sources parallels the only reported striations indicating a southeastward ice-flow event, from a site located near St-Léon-le-Grand, about 15 km south of Amqui, where they are cross-cut by younger striations of northward moving ice (David, 1987). The southeastward ice movement is thought to represent flow from a Laurentide source from across the St. Lawrence Valley during the Late Wisconsinan (David and Lebuis, 1985). Indicator rocks from Shick-Shock Mountains were found to be abundant north and south of their sources (David and Lebuis, 1985, p. 90).

Lebuis (1973b) showed, however, that erratics derived from the St-Anselme volcanic occurrence, about 13 km southeast of Matane, are predominantly dispersed in a northerly direction, only.

More recently, Prichonnet and Desmarais (1985) and Prichonnet (1988) reported on boulder counts in an area of western Gaspésie, west of Lac Matapédia. These authors inferred south-southeastward dispersal of several local rock types and denied the presence of a significant component of glacial dispersal in a northerly direction in the area. Rappol and Russell (1989) opposed this latter suggestion, primarily on the basis of dispersal from the La Redemption serpentinite complex, north of Mont St-Pierre. Prichonnet (1988), moreover, referred to a dispersal band of Precambrian amphibolite. It is likely, however, that this concerns dispersal from amphibolite associated with the La Rédemption serpentinite body (Rappol and Russell, 1989).

Several detailed studies were conducted recently in central Gaspésie (Chauvin, 1984; David and Bédard, 1986; Chauvin et David, 1987; David et al., 1988), mainly concerning the McGerrigle Mountain granite train. Two main dispersal directions have been identified: towards south-southeast and towards northeast.

On the basis of dispersal trains and striations throughout central Gaspésie, a detailed chronology of ice movements has been deduced. Unfortunately, the foundations from which these deductions follow are sometimes difficult to grasp, because the matter has been discussed mainly in abstracts (David et al., 1985; David and LaSalle, 1987; LaSalle et al., 1985). As summarized by David et al. (1988), at least five ice flow events have been recognized from late Sangamonian to Late Wisconsinan time. According to these authors, the south-southeastward dispersal from McGerrigle Mountain granite is related to Laurentide ice overflowing the entire peninsula during the Early Wisconsinan.

However, data published so far do not seem incompatible with flow from an ice divide over the highlands of central Gaspésie, responsible for south-southeast dispersal from the McGerrigle Mountain granite. Several authors have reported that Laurentide erratics are extremely rare, if not absent, in central and eastern Gaspésie (David and Lebuis, 1985; Cloutier and Corbeil, 1986; Veillette, 1988; among others), which is in sharp contrast with their abundance in western Gaspésie and Lower St. Lawrence.

Method

Of more than 500 boulder counts carried out during the 1988 fieldwork, more than 60% represent counts of 1000 boulders and only three samples contained less than 500 boulders. The 10 to 30 cm fraction was chosen because it assures that a sufficient amount of boulders could be found easily at most sites.

Sample sites include gravel pits and road cuts, boulder piles in fields, surface boulders in cleared forestry areas, and a few natural exposures. Sample locations and the nature of sampled material or sediment genesis is shown in Figure 9 (in pocket).

At each site, the number of Precambrian erratics from the Canadian Shield and selected Appalachian indicator rocks were recorded. Anorthosite, a characteristic and very distinctive Precambrian erratic, was generally counted separately; some attempt was made to distinguish other common and distinctive Precambrian indicators, such as mangerite.

Except for ice-contact deposits formed at or slightly below marine limit, such as those of the St-Antonin morainic system, no counts were made below marine limit. The great abundance of Precambrian material below marine limit has been well documented (Dionne, 1971, 1987a) and generally attributed to glaciomarine deposition and ice-rafting during and after deglaciation (e.g., Chalmers, 1906; Coleman, 1922; Lee, 1963; Dionne, 1987a).

Preliminary results of this study were presented earlier by Rappol and Russell (1989). The main results and conclusions are reviewed and discussed here briefly, incorporating a few additional data not used previously.

Dispersal of Appalachian indicator rocks

Rock types used in this study (Fig. 3) comprise:

1. andesitic components of the Pointe-aux-Trembles Formation (Lespérance and Greiner, 1969; J. David et al., 1985);
2. gabbro sills in the area between Lac-des-Echoes and Lac Mistigouèche (Béland, 1960; Lajoie, 1971);
3. coastal zone volcanics, with small outcrops at Dufaultville, St-Donat, and Ste-Blandine (Aubert de la Rue, 1941; Liard, 1972; Rappol and Russell, 1989); and
4. serpentinite and amphibolite of the La Rédemption serpentinite complex (Aubert de la Rue, 1941; Béland, 1960).

Dispersal of Val Brillant and Kamouraska quartzites and red slates was not studied. Their dispersal was assessed earlier by Lebuis and David (1977) and Prichonnet and Desmarais (1985). Moreover, these rock types have extensive outcrop areas trending transverse to the main ice flow directions, which presents difficulties in estimating the exact direction of dispersal.

A computer plotted and contoured representation of dispersal from Pointe-aux-Trembles andesite is shown in Figure 10, indicating a somewhat irregular train in a well defined southeasterly direction. This train extends outside the study area down to at least the Grand Falls area.

Dispersal towards north and northwest appears stronger close to the source but falls off more rapidly than the southeastward dispersal train. Northward and northwestward dispersal cannot be clearly identified separately as in Martineau's (1979) analysis of a nearby diorite. Striation evidence, however, indicates two separate events of northward and northwestward flow, of which the latter is the younger one. Both these directions are preceded by ice movement responsible for the southeastward dispersal.

Dispersal from gabbro sills present between Lac-des-Echoes and Lac Mistigouèche is depicted in Figure 11. At least four dispersal trains are apparent: towards east-southeast (Chaleur Bay area), towards south-southeast, towards north and towards northwest. These dispersal directions are supported by striation evidence, although such evidence is rather scanty in the southeastern part of the area.

Gabbro boulders are also regularly found to the northeast of the outcrop area, although always at a very low frequency. Possibly, these occurrences are related to the older northeastward flow event discussed previously.

The two southeasterly trains may be explained in different ways. Earlier, it was suggested that these were formed more or less synchronously and represent flow of Laurentide ice

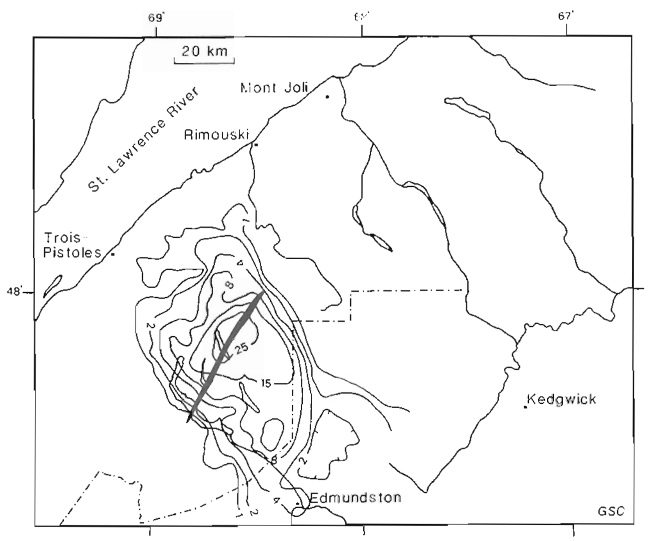


Figure 10. Dispersal from andesite of Pointe-aux-Trembles Formation (black areas). Frequencies in number per 1000 boulders.

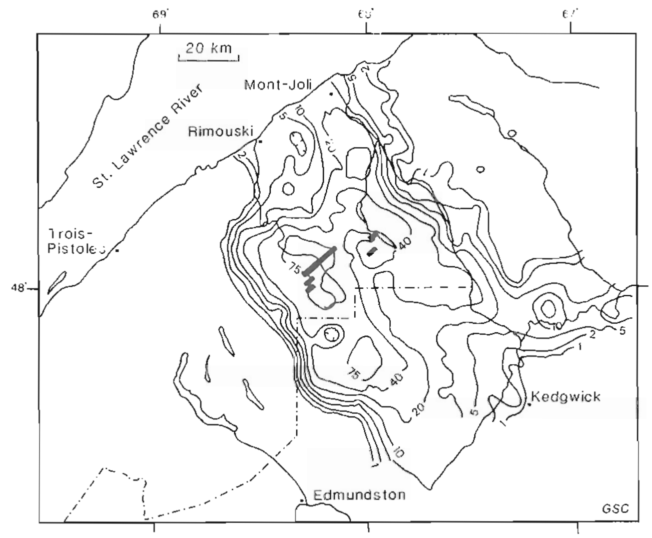


Figure 11. Dispersal from gabbro sills (black areas) of the Lac Raymond Formation. Frequencies in number per 1000 boulders.

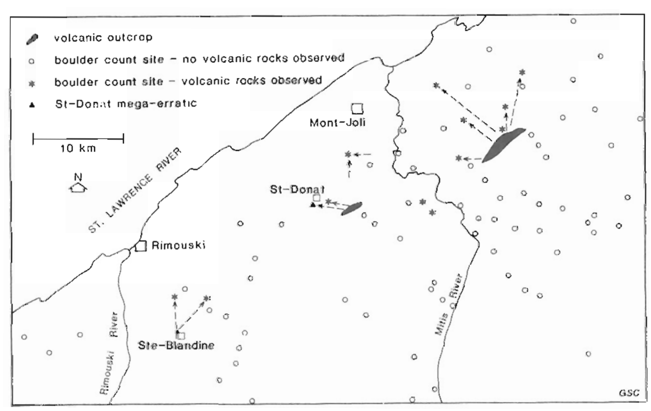
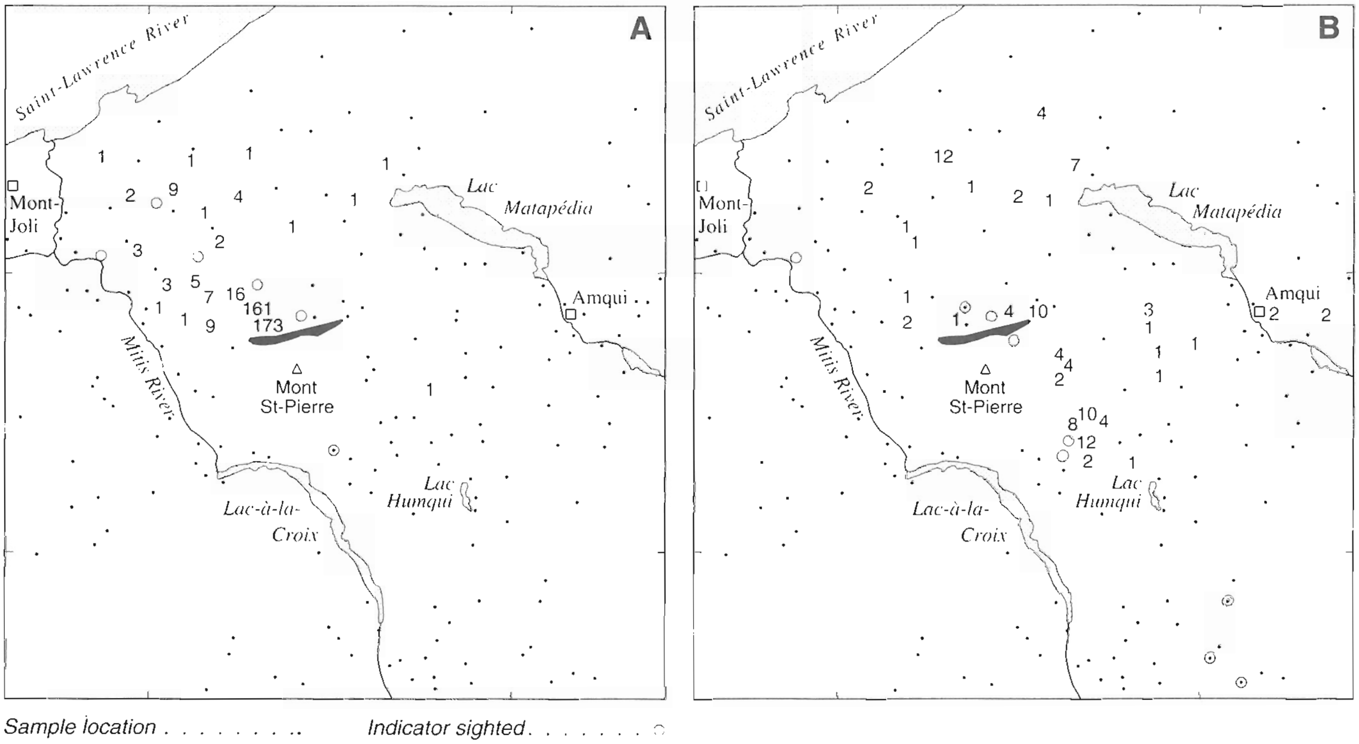


Figure 12. Observed dispersal from occurrences of volcanic rocks in the coastal zone.

that was diverted by local ice over Miramichi Highlands (Rappol and Russell, 1989). Hughes et al. (1985) proposed that Laurentide ice invading the area flowed first towards southeast and later towards east, but on the basis of the strength of the dispersal trains, rather the reverse sequence of flow directions would be expected.

Southeasterly dispersal by local Appalachian ice might seem possible under a configuration of late glacial ice divides as envisaged by Rampton et al. (1984, Fig. 35). However, an ice divide located northwest of the gabbro outcrops is difficult to explain given the topographical situation. Moreover, the striation evidence indicates northwestward flow throughout the outcrop area to be the latest glacial event.

Northward and northwestward dispersal of gabbro correspond with that found for the Pointe-aux-Trembles andesite. The northwestward dispersal falls off rapidly, but the slightly older northward flow event left a well defined dispersal train reaching down to the present coast.



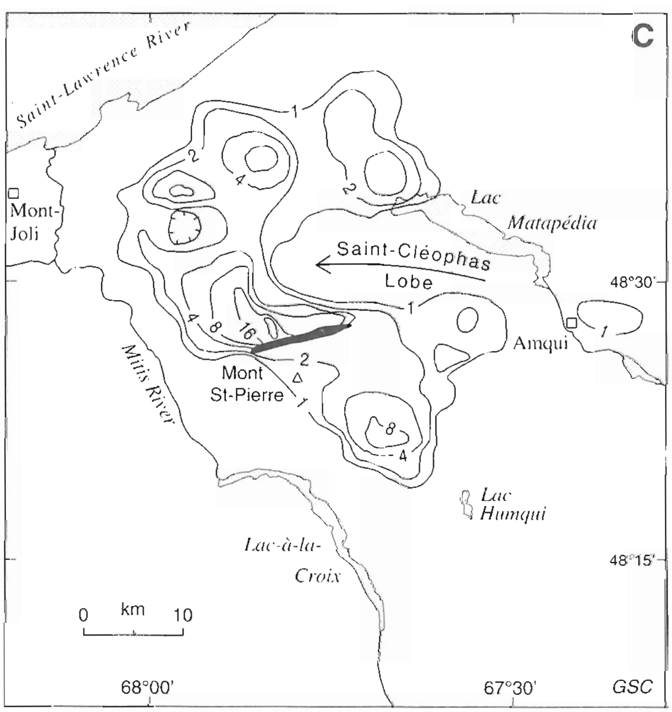


Figure 13. Observed dispersal from La Rédemption serpentinite complex (black area). **A.** Serpentinite and associated diorite, **B.** Amphibolite. Frequencies in number per 1000 boulders. **C.** Composite dispersal pattern of serpentinite and amphibolite.

Observed dispersal from coastal-zone volcanic outcrops is generally in northerly and westerly directions (Fig. 12), as was earlier reported for the St-Adelme volcanic outcrop near Matane (Lebuis, 1973b). Older southeasterly dispersal connected with invading Laurentide ice appears completely removed by younger ice movements from Appalachian ice divides. Two basalt boulders found due east of the St-Donat outcrop are either derived from the St-Donat or Dufaultville basalt. Their present position is probably the result of reworking of an older southeasterly dispersal by late northward or westward flow.

Observed dispersal of serpentinite and amphibolite from the lower north-facing slope of Mont St-Pierre is shown in Figure 13. Dispersal from this rock body is somewhat enigmatic because of the quite different patterns given by its two main components.

Serpentinite displays a clear northwesterly dispersal train and is found only rarely to the northeast, east, or southeast of its outcrop. Dispersal of amphibolite, however, appears strongest towards south-southeast, but amphibolite boulders are also regularly found dispersed in all other directions, except westerly.

The dispersal patterns north of Mont St-Pierre must have been strongly influenced by the late westerly flow from Lac Matapédia basin, that probably caused removal of most of the northerly dispersal of amphibolite and displaced the serpentinite train towards the northwest, when confluencing with north-northwestward moving ice in Mitis Valley. David and Lebuis (1985) considered a system of ice-marginal deposits and associated eskers west of Lac Matapédia to have formed as a result of a readvance (St-Cléophas lobe). Another factor that controlled northward dispersal is possibly the fact that the north facing slope of Mont St-Pierre is fairly steep, thus protecting the outcrop area from strong glacial erosion in a lee-side position.

The absence of a southeasterly dispersal of the serpentinite may be the result of reworking by flow down Mitis Valley. It seems also possible that the larger part of the serpentinite body was unroofed only during the last glaciation.

Recently, Prichonnet (1988) suggested the presence of a Precambrian amphibolite train, more or less coinciding with the occurrence of amphibolite erratics as shown in Figure 12. However, the local origin of these amphibolite boulders is strongly supported by the fact that those dispersed in northerly directions are seldom accompanied by Precambrian indicators. At the sites where 7 and 12 amphibolite boulders were observed in 1000 boulders inspected (Fig. 13), not a single Precambrian erratic was observed.

Distribution of Precambrian erratics

The nature of sampled material and the number of Precambrian erratics per sample of 1000 boulders are shown on Figure 9 (in pocket) and a computer-contoured map of the frequencies is given in Figure 14.

Precambrian erratics from the Canadian Shield occur in surficial deposits throughout the study area and have been found close to the summit of Mont St-Pierre, the highest point in the area. Their frequency of occurrence shows considerable variation, however.

Shield indicators comprise a wide variety of igneous and metamorphic rock types, among which, anorthosite, mangerite, gneiss, and granite-gneiss of the Grenville Province are most characteristic and distinctive.

Few small intrusions of distinctive igneous rocks occur in the study area and can easily be distinguished from shield indicators. No indications were found, either in the field during the present survey or in the geological literature, that igneous rocks from the Miramichi Highlands of central New Brunswick or from central Gaspésie were ever transported into the study area.

Precambrian erratics are most abundant in the southern part of the study area. In the area of Lac Témiscouata, frequencies of 2.5% are common, with a maximum of 5.0%. Precambrian erratics continue to be abundant farther to the southeast along Saint John Valley. A few counts in the area of Grand Falls, New Brunswick, gave frequencies between 1 and 5%, also.

Towards the coastal zone, values generally fall. Ice-contact deposits at and below marine limit (St-Antonin Moraine and related deposits) contain generally less than 1% Precambrian erratics (see also, Dionne, 1971).

To the northeast, the zone of high frequencies for Precambrian erratics seems delimited by a rather sharp boundary along a line trending southeast from Trois-Pistoles. It is remarkable that this line more or less coincides with the northeastern margin of a possible terrestrial ice stream already mentioned (Fig. 7). Whether these features are related

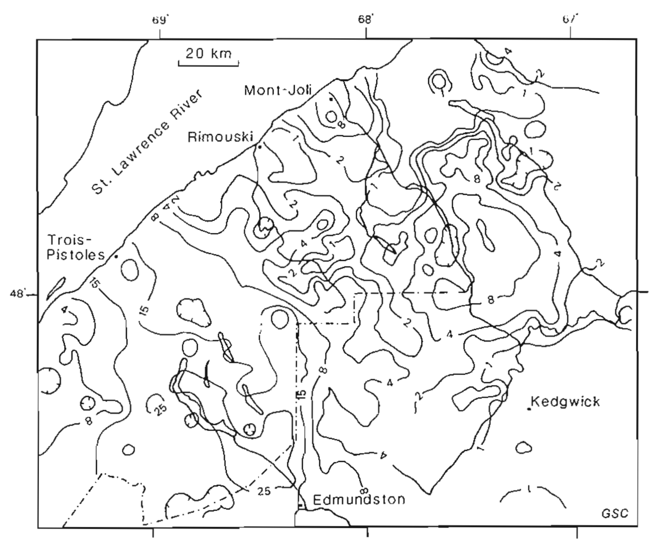


Figure 14. Distribution of Precambrian erratics in surficial deposits of the study area. Contoured frequencies in number per 1000 boulders.

or coincidental is difficult to assess at present. Maurice (1989) found a similarly located boundary from the frequency distribution of Precambrian heavy minerals (garnet and ilmenite) in stream alluvium.

A second area where Precambrian erratics are abundant is located south of Mont St-Pierre in western Gaspésie. In contrast, the area directly north of Mont St-Pierre is among the areas most depleted in these erratics. In fact, in a broad coastal zone north of Trois-Pistoles, Precambrian erratics are rare, with the exception of an area near Mont-Joli. The latter area coincides with the well preserved northerly dispersal train from the gabbro sills.

In the southeastern part of the study area (Kedgwick region), Precambrian erratics are present, but generally rare. The limit of their occurrence could not be mapped. According to Pronk et al. (1990), Precambrian erratics occur in map area 21O/3 (Riley Brook) west, but not east, of Tobique River. Farther north, only local igneous erratics were observed in Mamozekel Valley and in the area of Mt. Carleton Provincial Park. At Plaster Rock (21J/14), however, located south of the Riley Brook map area, igneous rocks of Miramichi Highlands occur in ice-contact deposits together with Precambrian erratics and indicators from the Deboullie pluton in northern Maine.

In practice, it is virtually impossible to demonstrate the complete absence of a certain component. The distribution of Precambrian erratics is probably much wider than generally assumed. Thus, their distribution as recently projected by Pronk et al. (1990, fig. 6) is certainly too limited; Precambrian erratics (including anorthosite) were found in the lower reaches of Restigouche and Matapédia rivers (Fig. 9). Late glacial flow from the Appalachian ice divide must have distributed Precambrian erratics over a large part of northern and southwestern New Brunswick, even when Laurentide ice *senso stricto* may not have reached these areas. Precambrian erratics may be less conspicuous in these regions, because of the abundance of local igneous and occasionally also metamorphic rock types.

Anorthosite boulders have been found throughout the study area, but their frequency of occurrence shows large regional variation. Reliable data are, however, not available for the entire study area, because (1) their frequencies were not determined during the first part of the fieldwork, so few data were obtained for map areas 22C (Rimouski); and (2) for some map areas the number of counts or the total number of observed Precambrian erratics is simply too small for computing significant values.

High anorthosite frequencies were observed south of Mont St-Pierre, in map areas 22B/4 and 22B/3, with 10.5% (28 in 267) and 7.0% (8 in 114) anorthosite boulders among the Precambrian erratics. These values contrast sharply with anorthosite frequencies obtained in the area of Lac Témiscouata: 1.9% (2 in 102) in map area 21N/10 (Cabano) and 1.7% in map area 21N/11 (St-Honoré).

The relative frequencies of mangerite, abundant in the western part of the study area yet virtually absent south from Mont St-Pierre, and anorthosite, abundant in the east, together with the evidence of striations, suggest that ice invading the western part of the study area originated or traversed the highlands of Laurentide Park, north of Quebec City, where a major mangerite occurrence has been mapped (Laurin and Sharma, 1975). The eastern part of the study area, on the other hand, may have received its Precambrian erratics mainly from ice that moved along and north of Saguenay Valley, down from the Lac St-Jean area, where major anorthosite bodies occur. Anorthosite and mangerite, however, have widely distributed occurrences north of St. Lawrence River. The inferences on the main source area for these erratics should be regarded as a preliminary hypothesis, finding some support in observed features.

There appears to be some relationship between the abundance of Precambrian erratics and the nature of the sample material. In the class of undifferentiated gravel (Fig. 9), valley floor gravel usually contains few Precambrian erratics, although they are abundant among surface boulders (of till?) of adjacent higher grounds. In glaciomarine deltas and subaqueous fans of the coastal zone, including deposits of the St-Antonin Moraine, Precambrian erratics are also relatively rare. On the other hand, glaciolacustrine deltaic deposits of the Lac Témiscouata area contain remarkably high amounts of Precambrian material.

Compared to their abundance among surface boulders, Precambrian erratics are scarce in dense and silty subglacial tills (see also Dionne, 1971, and Lebuis and David, 1977). Few counts were done in till during the present survey. No boulders were actually picked from within the till, but in the few cases where till is indicated as the sampled deposit (Fig. 9), boulders rolling from up slope may have contaminated sample material.

A few Precambrian indicators were found embedded in massive and dense till, and they are ever abundant in a thin bouldery surface horizon and in ice-contact deposits formed during deglaciation. This presence suggests that most Precambrian erratics were introduced to the study area during its last ice cover and were deposited during a late phase of till formation, possibly by melt-out during final deglaciation. It indicates also, that Precambrian material was transported at relatively high englacial levels within the ice: a common feature in the case of far-travelled debris (Boulton, 1970; Rappol and Stoltenberg, 1985). Because flow velocities in active glacier ice increase rapidly from the base upwards, the Precambrian debris in high-level transport positions represents the most mobile element of the glacial debris assemblage and was therefore strongly affected and redistributed by late glacial flow from Appalachian ice divides. The present distribution of Precambrian erratics is thus as much a reflection of the late glacial flow from Appalachian ice divides as of the earlier invasion of Laurentide ice.

Transport and erosion by late glacial Appalachian ice flows did not affect all parts of the area equally. Notably in the ice divide zones where their effect will have been minimal, we may expect a high frequency of Precambrian erratics. Away from these ice divides, Precambrian material became progressively more diluted by Appalachian material

Table 1. Radiocarbon dates pertaining to deglaciation and submergence, Lower St. Lawrence region.

Locality	Coordinates N	Coordinates W	^{14}C date (years BP)	Lab. no.	Elevation (m)	Enclosing material	Reference
A. Rimouski — Mont Joli area							
Price	48°36'38"	68°06'20"	11 110 ± 370	QU-261	62	sand and gravel	Locat (1977)
Mont-Joli	48°35'35"	68°12'32"	11 380 ± 470	QU-262	72	sand and gravel	Locat (1977)
St-Anaclet	48°29'00"	68°22'40"	12 220 ± 450	QU-263	82	silty sand	Locat (1977)
St-Donat	48°30'11"	68°15'55"	13 360 ± 470	QU-264	98	clayey silt	(Locat (1977)
Luceville	48°30'21"	68°21'30"	10 400 ± 320	QU-266	70	sand	Locat (1977)
Grand-Métis	48°36'47"	68°06'00"	11 590 ± 430	QU-267	30	silty sand	Locat (1977)
St-Octave	48°36'48"	68°06'22"	11 360 ± 290	QU-268	62	sand and gravel	Locat (1977)
Bic	48°21'14"	68°45'21"	9 830 ± 150	QU-270	19	sand	Locat (1977)
St-Fabien	48°18'25"	68°51'12"	13 390 ± 690	QU-271	138	silty sand	Locat (1977)
St-Fabien	48°18'25"	68°51'12"	12 300 ± 260	QU-272	138	silty sand	Locat (1977)
St-Donat	48°30'30"	68°16'10"	12 000 ± 160	GSC-1104	98	clay	Dionne (1977)
Bic	48°22'35"	68°42'25"	9 450 ± 150	GSC-1216	15	clayey sand	Dionne (1977)
Price	48°37'00"	68°06'30"	10 500 ± 100	UQ-1034	58	sand	Prichonnet and Hétu (1988)
Rivière Mitis	48°33'00"	68°08'00"	13 400 ± 200	UQ-1081	80	clayey silt	Prichonnet and Hétu (1988)
Rimouski	48°23'00"	68°32'30"	13 900 ± 170	GSC-4698	107	till	this report
Bic	48°21'30"	68°41'40"	12 400 ± 100	GSC-4707	137	stony clay	this report
Ste-Blandine	48°23'50"	68°26'00"	12 700 ± 130	GSC-4726	122	marine clay	this report
B. Rivière-du-Loup — Trois-Pistoles area							
Rivière-du-Loup	47°49'12"	69°30'48"	10 340 ± 130	GSC-61	101	clay	Lee (1963)
St-Épiphane	47°56'18"	69°19'12"	11 410 ± 150	GSC-63	95	clay	Lee (1963)
Cacouna	47°57'18"	69°27'24"	9 830 ± 130	GSC-68	16	clay	Lee (1963)
Isle-Verte	47°58'06"	69°19'54"	9 690 ± 150	GSC-69	55	clay	Lee (1963)
Isle-Verte	47°57'42"	69°19'24"	10 600 ± 170	GSC-70	79	clay	Lee (1963)
Trois-Pistoles	48°07'42"	69°08'00"	12 720 ± 170	GSC-102	99	clay	Lee (1963)
Rivière-des-Vases	47°58'00"	69°25'30"	6 970 ± 100	GSC-112	15	peat	Lee (1963)
Rivière-du-Loup	47°48'00"	69°28'00"	9 520 ± 170	GSC-176	107	gyttja	Lee (1963)
Anse-à-Persil	47°52'50"	69°32'05"	10 095 ± 160	GX-1491	12	clay	Dionne (1972b)
St-Patrice	47°48'40"	69°34'45"	9 865 ± 180	GX-1492	16	clay	Dionne (1972b)
Cacouna	47°54'25"	69°29'55"	9 975 ± 210	GX-1493	38	line sand	Dionne (1972b)
Saint-Modeste	47°50'30"	69°24'15"	10 300 ± 150	GSC-1684	130	silty sand	Dionne (1977)
St-Épiphane	47°54'36"	69°22'00"	10 330 ± 140	QU-577	75	diamicton	Martineau *in* Lortie and Guilbault (1984)
Rivière-Verte	47°47'12"	69°27'30"	11 370 ± 150	QU-578	132	diamicton	Martineau *in* Lortie and Guilbault (1984)
St-Épiphane	47°52'30"	69°24'00"	11 720 ± 160	TO-947	110	till	this report
Rivière-du-Loup	47°50'08"	69°°20"	12 450 ± 160	TO-948	114	clay	this report

and was also moved back into and down St. Lawrence Valley. For example, north of Mont St-Pierre, westward and northward flow events removed virtually all evidence of an earlier Laurentide ice cover.

LATE GLACIAL EVENTS

Earliest deglaciation and marine invasion

With the progression of a calving bay up St. Lawrence estuary and the waning of Appalachian ice masses, marine waters submerged the coastal zone of the study area.

The elevation of marine limit (Fig. 9) increases towards the southwest from about 100 m a.s.l. at Matane, to 140 m at Mont-Joli, to 155 m at Bic, and to about 170 m near Rivière-du-Loup.

Radiocarbon dates from the study area that are relevant to the timing of deglaciation, marine submergence and emergence are compiled in Table 1. Some important dates from the St. Lawrence south shore of Gaspésie and Lower St. Lawrence are summarized in Figure 15.

The dates along the north shore of St. Lawrence Valley are much younger than on the south shore; dates older than 13 ka are common in Gaspésie, whereas dates from the north shore are younger than 11 ka (Bigras et Dubois, 1987, Fig. 3).

Anticosti Island was being submerged as early as 14.5 ka BP (Gratton et al., 1984). The oldest dates along the St. Lawrence south shore are close to 14 ka, the oldest being 13 900 ± 170 BP (GSC-4698) on shells from a till at Rimouski. From dates listed in Table 1 and those cited in Figure 15, it follows that the calving bay passed the study area between about 14 and 13 ka. It reached the Quebec City area around 12.5 ka (LaSalle, 1987). With an accelerated deglaciation rate, marine waters may have reached the Ottawa region about 12.2 ka (Fulton and Richard, 1987).

Dates from the area around Chaleur Bay are younger than 13 ka (Lebuis et David, 1977; Rampton et al., 1984), except for a date of 13 890 ± 160 BP (QU-275) from southwestern Gaspésie, which is thought to predate a glacial readvance (Lebuis et David, 1977; Fig. 15). However, site and date of

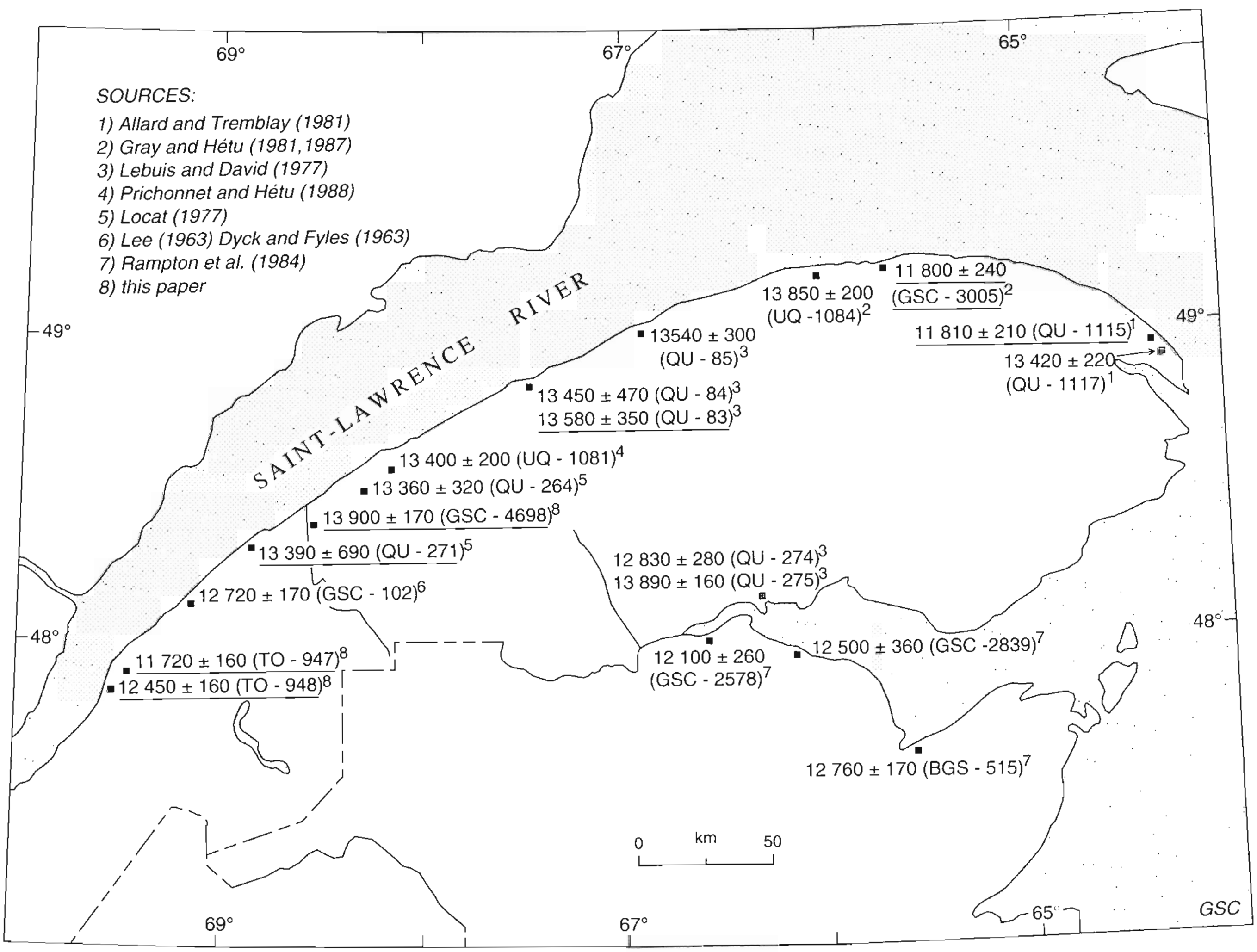


Figure 15. Location of selected dates pertaining to earliest deglaciation and glacial readvances (the latter are underlined) of St. Lawrence south shore and Chaleur Bay.

QU-275 have recently been checked, suggesting that this date may be too old (J.J. Veillette, personal communication, 1990).

In the present study area, virtually all the land area that now lies at elevations below marine limit was actually submerged, indicating that a broad coastal zone was rapidly deglaciated upon arrival of the calving bay. Marine waters penetrated far inland into the major valleys. Some of these valleys may themselves have developed calving bays. A calving bay within Trois-Pistoles valley could explain the anomalous youngest southwesterly striations observed north of St-Cyprien (21N/14). Sedimentation controlled by a nearby marine base level took place in Mitis Valley at least 20 km inland from the present coast, at the junction with Ruis Bernier (22C/8).

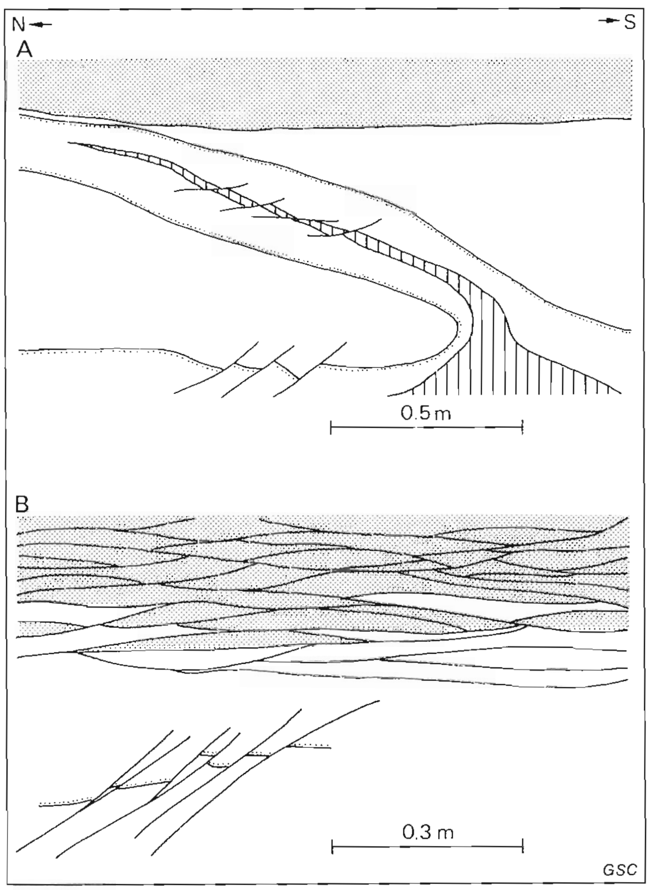


Figure 16. Characteristics of subglacial deformation during a glacial readvance near Rimouski (22C/7: 48°22′55″N, 68°32′30″W). A. Dragfold in marine silt/sand deposit with core of attenuated clay layer (hatched vertically). B. Shear-plane foliation transgressing the contact of till (shaded) and sub-till marine sediments. At greater depth below the till base, down-glacier dipping normal faults replace subhorizontal shears. In both figures, ice movement is from right to left.

Glacial readvances

Rimouski area

In previous publications on the area, only oblique mention is made of possible glacial readvances. Locat (1978) mentioned the occurrence of a fossiliferous till near St-Valérien, south of Bic (22C/7); unfortunately, this material was not dated. Dionne (1977, 1987b) interpreted a diamicton overlying marine deposits at St-Fabien as till and suggested that shells from this site dated by Locat (1977, 1978) were collected from this till (see Table 1).

During the present study, the best evidence for a late-glacial readvance was found in Rimouski Valley, about 7 km south of Rimouski (22C/7). Here, two gravel pits exploit ice-contact gravel, overlain by a thin sheet of marine silt and clay, which is, in turn, overlain by a sandy till. Striations on bedrock exposed below the ice-contact gravel indicate northward flow. At both sites, the till is heavily jointed along subhorizontal shear-planes giving it a foliated appearance (fissility). These shear-planes also penetrate the underlying marine sediments and at depth are associated with down-glacier dipping normal faults (Fig. 16B). In the southernmost of the two pits, marine deposits were folded by the overriding ice (Fig. 16A), in a style considered typical for subglacial shearing. Structural aspects of deformation and the preferred orientation of elongated clasts in the till (Fig. 17)

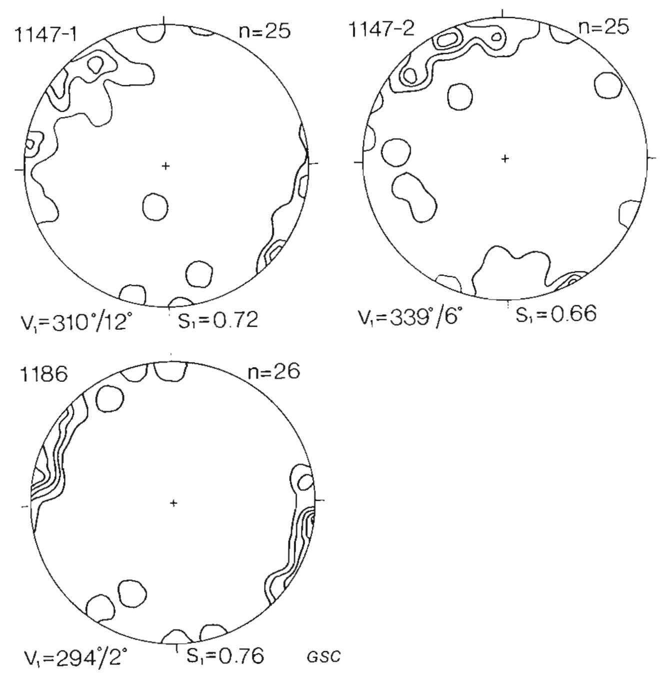


Figure 17. Clast fabrics of till formed during glacial readvances at Rimouski (1147) and St-Fabien (1186). The fabric maxima at the Rimouski site exhibit a pronounced down glacier dip, which is here probably due to a down-glacier slope of the original glacier bed.

indicate that ice moved northwest during formation of the till. Whereas the ice-contact gravel contains little Precambrian material, the till is fairly rich in these erratics, which have presumably been reworked from the marine deposits. At one site in the southern pit, the base of the till contained many marine shells that were dated at 13 900 ± 170 BP (GSC-4698, Table 1).

Reference to the St-Fabien delta was made by Locat (1976, 1977, 1978), Dionne (1977, 1987b), and Dionne et al. (1988). According to Locat, the pits at St-Fabien expose ice-contact deposits overlain by deltaic sediments deposited in Goldthwait Sea. Dionne (1987b) and Dionne et al. (1988), however, suggested deposition of deltaic ice-contact deposits in a nonmarine water body, enclosed between Laurentide and Appalachian ice masses. Two radiocarbon dates (13 390 ± 690 BP, QU-271; 12 300 ± 260 BP, QU-272, Table 1) were reported by Locat (1976, 1977). According to Locat (1976), the oldest date is more reliable, and the shells were collected from material labelled as silty sand. According to Dionne (1977, 1987b), the sampled material is a diamicton or till. During the present survey, no fossiliferous material was observed, but a massive marine clay was seen overlying deltaic ice-contact deposits in the central part of the southern pit.

A sandy till occurs near the northwestern entrance of the St-Fabien pit. Its clast fabric (Fig. 17) and the differential movement of two separated parts of a crushed boulder (Fig. 18) indicate ice movement towards west-northwest during its formation. The age relationship of till and massive clay could not be deduced because the two do not overlap. However, like the readvance till at Rimouski, the till is relatively rich in Precambrian erratics, which suggests reworking of marine deposits. The deltaic and ice-contact deposits contain very few Precambrian erratics. A boulder count gave only 0.2%, which is exactly the same amount of Precambrian material as determined by Dionne et al. (1988).

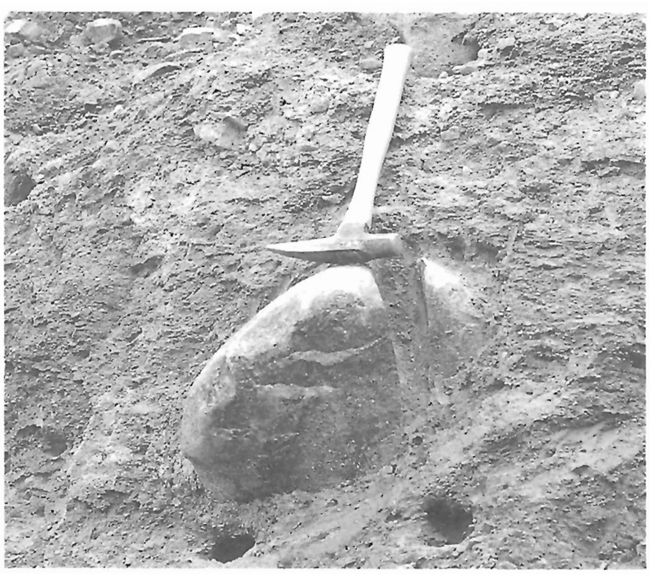


Figure 18. Shear-banded till at St-Fabien with crushed boulder. Ice movement from left to right. (GSC 205472-B)

A similar sedimentological setting is found in pits south of Bic. Exposed ice-contact deltaic deposits, with foresets sloping towards north, in places are overlain by strongly sheared marine silt and clay. Shells sampled from the clay were dated at 12 400 ± 100 BP (GSC-4707; Table 1). A diamicton, possibly till, was observed at one site, underlain by a thin layer of marine silt over deltaic sediments. An up to 2 m thick beach deposit, rich in Precambrian erratics, overlies the mentioned deposits at the surface.

A fossiliferous till from the ice-marginal sediment complex at Bic was reported by Locat (1978). He tentatively correlated this till with the Petite-Matane Till described by Lebuis et David (1977). However, the Petite-Matane Till is supposed to have formed "during the first stages of deglaciation when the ice sheet broke up in the St. Lawrence system" (David, 1987, p. 27), which is thought to have occurred at about 13.5 ka BP (Lebuis et David, 1977; David and Lebuis, 1985).

At present, based on the youngest date from St-Fabien and the date from Bic, I suggest that the readvance in this area has a maximum age of 12.3 ka and occurred well after the earliest marine submergence.

For the sediment complexes at St-Fabien and Bic, the following sequence of events is reconstructed.

The main sediment bodies were deposited as ice-contact deltas or subaqueous fans (or both) at the contact of an Appalachian ice mass and Goldthwait Sea, perhaps as early as about 13 900 ± 170 BP (GSC-4698) and at least before 13 390 ± 690 BP (QU-271). After further retreat of the ice, these deposits were submerged and shallow marine conditions existed till at least 12 300 ± 260 BP (QU-272; and GSC-4707, 12 400 ± 100 BP). This date is also the maximum age of a brief readvance of Appalachian ice, moving northwesterly. The till at Rimouski may represent the same readvance; alternatively, it may correlate with the Petite-Matane Till. In that case, however, the readvance of the Petite-Matane Till postdates passage of the calving bay in the Matane area, which is also implied by the 13 900 ± 170 BP date (GSC-4707) from Rimouski.

Rivière-du-Loup area

In the coastal zone of the Rivière-du-Loup area, Lee (1962) mapped a so-called "Younger Till," which is also found on the western flanks of the St-Antonin Moraine. Lee (1962, 1963) considered this till to be the subglacial stratigraphic equivalent of the moraine. The "till submergé" of Dionne (1971) is probably equivalent to the younger till; it contains a much higher percentage of shield-derived clasts than other till: 5.0 and 0.3%, respectively (Dionne, 1971, tab. I).

Dionne (1972b, p. 55) reported the occurrence of several shell species in a unit mapped as younger till by Lee (1962) near St-Modeste, but neither author appears to have considered the younger till to represent a readvance of Laurentide ice in the marine environment.

The latter became evident, however, through an excavation at a construction site near Rivière-du-Loup, where two tills are found separated by a marine clay unit (Fig. 19).

The lower till is a grey, texturally inhomogeneous till, in which not a single Precambrian clast was found. Clast fabric and striations on the top surface of till-embedded boulders indicate ice movement towards northeast during formation of this till. The till is overlying fractured bedrock or a thin gravel unit.

The lower till is overlain by a marine clay, slightly silty and faintly laminated, containing sparse dropstones. In 100 dropstones, only one crystalline rock fragment was found. The clay contains few small and fragile shells of the species *Portlandia arctica.* An accelerator date from a collection of shell fragments indicates an age of 12 450 ± 160 BP (TO-948; Table 1).

The marine clay shows all characteristics of the Trois-Pistoles clay described by Lee (1963; see also Dionne, 1972b). According to Lee and Dionne, the Trois-Pistoles clay (Goldthwaitian I deposit, in Dionne, 1977) represents the oldest marine unit in the area, containing shells dated at 12.7 ka BP (Table 1). It was originally thought to occur only in the area of Trois-Pistoles, where it is overlain by coarser deposits of the Trois-Pistoles delta. Lee (1963, p. 6, 19) suggested that the Trois-Pistoles clay predates formation of the younger till. This age relationship is now confirmed by direct superposition in the Rivière-du-Loup section.

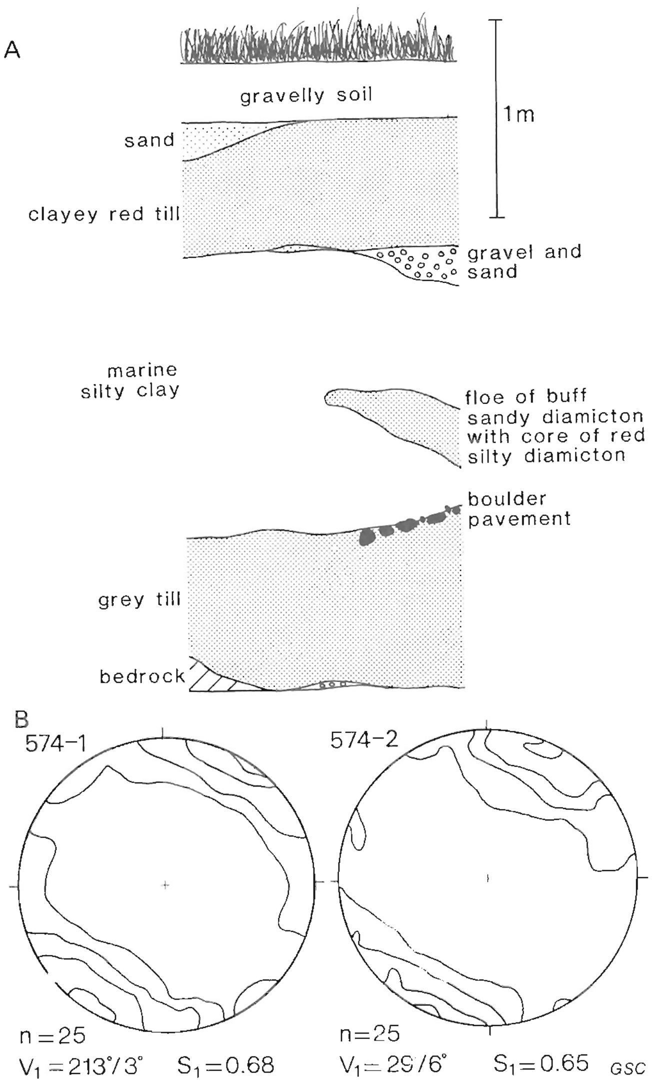


Figure 19. A. Schematic representation of two-till section near Rivière-du-Loup (21N/13: 47°50′15″N, 69°30′20″W). The two tills are separated by a marine deposit, containing shell fragments dated at 12.45 ka. B. Elongated-clast fabrics from lower till indicating ice movement towards north-northeast, parallel to St. Lawrence Valley.

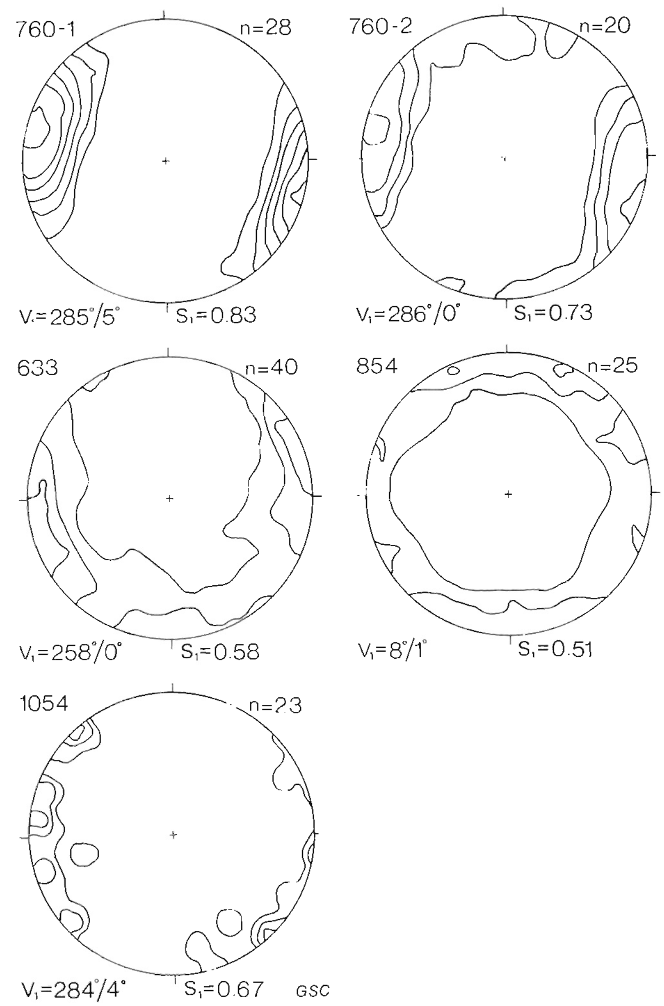


Figure 20. Fabrics from till formed during readvance of Laurentide ice in Rivière-du-Loup area ("Younger Till" of Lee, 1962).
Location of fabric sites:
760 St-Antonin, NTS 21N/14: 47°45′15″N, 69°27′15″N
633 St-Epiphane, NTS 21N/14: 47°52′30″W, 69°24′00″N
854 Cacouna-Est, NTS 21N/14: 47°58′35″N, 69°26′00″N
1054 St-Modeste, NTS 21N/14: 47°49′40″N, 69°24′20″N

The marine unit is overlain by an upper reddish till, in which Precambrian erratics are common. Because the section was soon destroyed, no fabric measurements could be done.

A fossiliferous clayey till was found in a segment of the St-Antonin Moraine, about 5 km north of St-Modeste. The till overlies ice-contact deltaic gravel, showing deformation structures produced by melting of contemporaneous ice as well as by shearing during overriding and till deposition. The till is overlain by an undisturbed marine delta. Boulder counts in both gravel deposits indicate about 1% Precambrian erratics.

The till is dark grey to black, but where oxidized it is red. It has a weak easterly direction to its clast fabric. Shells are abundant but occur almost exclusively as small and fragile fragments of the species *Portlandia arctica*. An accelerator data indicates an age 11 720 ± 160 BP (TO-947; Table 1).

Lee (1962, p. 1) stated that "directions of flow within the [St-Antonin, i.e. "younger-till"] ice lobe were northeasterly along the present coast of the St. Lawrence and more easterly closer to the position of the end moraine, as shown by fabrics in the glacial till [...], and by features including striations on the glaciated surface." Unfortunately, this fabric evidence is not presented, but several clast fabrics measured in the younger till at locations near the St-Antonin Moraine, indeed show preferred easterly orientations, be it that the fabrics have low strength (Fig. 20). At one of these sites, also striations on slickensided shear-planes within the till had an easterly orientation, with shear-planes dipping to the west. Moreover, a site near St-Arsène, as reported by Martineau and Corbeil (1983, p. 20), shows youngest striations indicating ice movement towards east, postdating striations formed by ice movements towards 350° and 45°.

The readvance of the younger till, as interpreted here, partly overrode the earlier formed St-Antonin Moraine as is indicated by the distribution of occurrence of this till as mapped by Lee (1962). Also deltaic deposits at St-Modeste (Dionne, 1972b, p. 61) were partly overridden, where

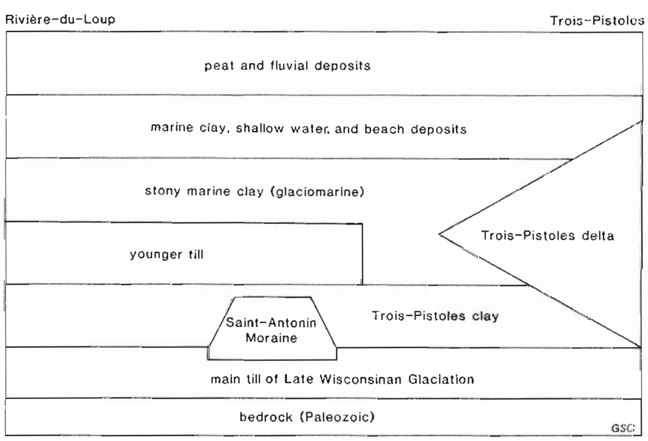


Figure 21. Proposed stratigraphy of the Rivière-du-Loup — Trois-Pistoles area, modified after Lee (1962).

deformation structures in marine prodelta sand and clay deposits suggest eastward flow of ice during deposition of the overlying till.

On the basis of the preceding observations and considerations, the revised stratigraphy of the area is shown in Figure 21.

Because at the time of the readvance (at least after 11.9 ka BP, as suggested by TO-947; 11 720 ± 160 BP; Table 1), the calving bay in St. Lawrence Valley had extended upstream far beyond Quebec City (see e.g., Parent et al., 1985; Dyke and Prest, 1987), the readvance likely came from across St. Lawrence Valley. The average of 5% Precambrian erratics in the younger till (Dionne, 1971) may seem low in this case, but is probably the result of a massive reworking of pre-existing Trois-Pistoles clay; the latter is also indicated by the textural characteristics of the till. Glaciomarine stony clay associated with the readvance contains as much as 30% Precambrian erratics as dropstones and according to Dionne (1972b, p. 28), surface boulders of this clay are predominantly (over 75%) of Precambrian origin.

The readvance built no important ice-marginal deposit; however, meltwater coming out of the Appalachians was diverted in a northeastern direction as evidenced by systems of glaciofluvial channels east of the St-Antonin Moraine, and by the glaciofluvial sediments deposited at St-Épiphane (see also Dionne, 1972b).

The St-Antonin Moraine as named and mapped by Lee (1962, 1963) was originally thought to represent an ice-marginal position of the retreating Laurentide ice front (Lee, 1963) and was supposed to represent the continuation of the Highland Front moraine of southern Quebec (Gadd, 1964; Gadd et al., 1972; Dionne, 1972a). It was later recognized that the St-Antonin Moraine was deposited, at least in part, in an interlobate position, between Appalachian ice on the east and Laurentide ice to the west of the moraine (LaSalle et al., 1977; Martineau, 1977). More recently, these authors interpreted the moraine as having been emplaced by Appalachian ice only, with the ice front facing northwestward (Martineau et Corbeil, 1983; Chauvin et al., 1985).

This latter interpretation is based mainly on the Appalachian source of most material deposited in the moraine (more than 98%) and on paleocurrents measured in waterlain units of the sediment complex.

The fact that the moraine is composed almost entirely of Appalachian source materials is not really relevant to this point, because ice present on the northwestern flank of the moraine formed part of the ice stream moving down St. Lawrence Valley, which was fed by Appalachian ice as well as Laurentide ice. The suture between ice from these sources may have been located well westward from the present position of the moraine. If this was indeed the case, the ice present on the northwest flank of the moraine contained Appalachian rocks and debris from farther up the valley.

Moreover, paleocurrent data presented by Martineau et Corbeil (1983) indicate that flow was parallel to the moraine in the lower units exposed near St-Arsène. Although

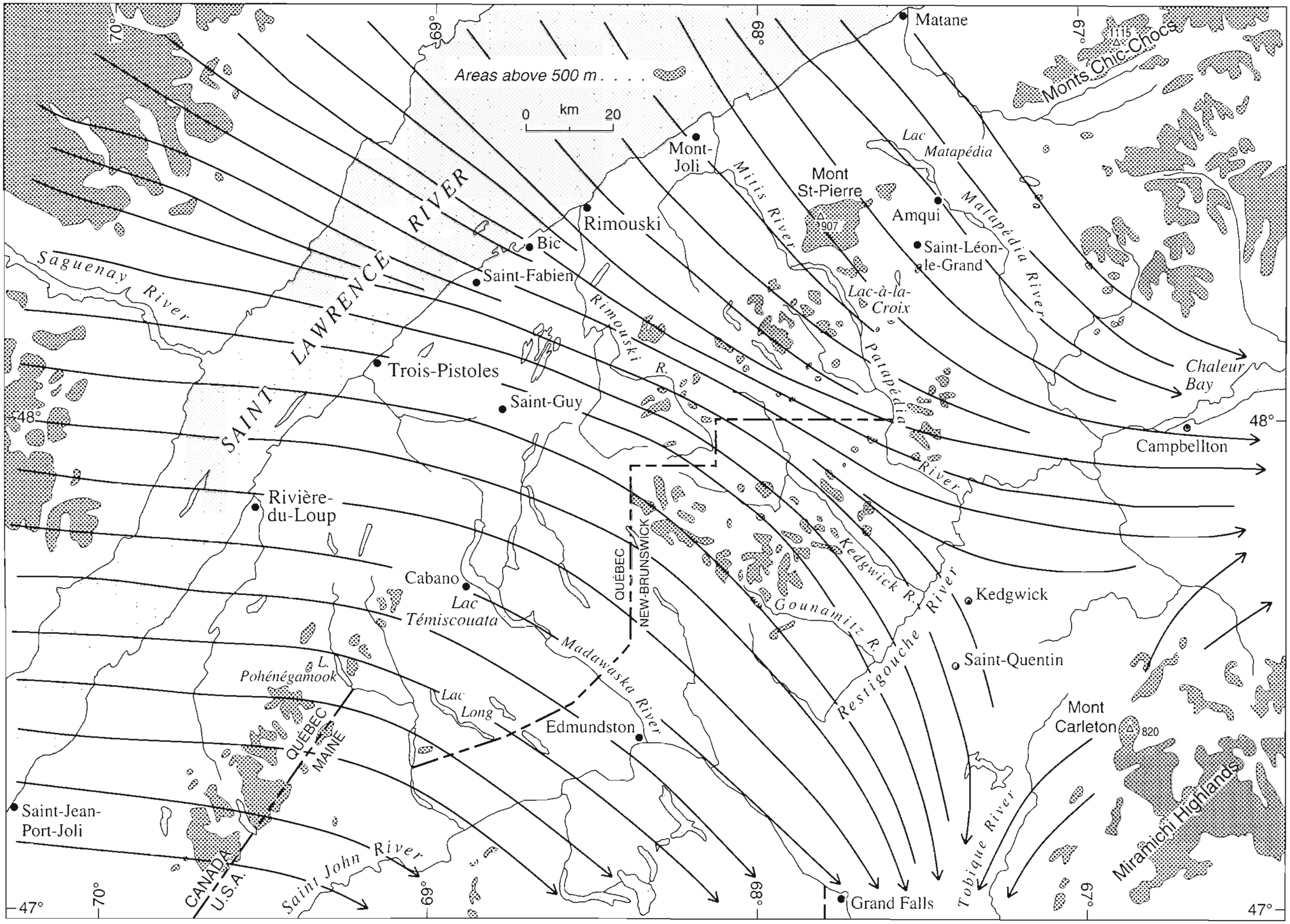


Figure 22. Glacial flow lines during invasion of Laurentide ice in early phase of the Late Wisconsinan.

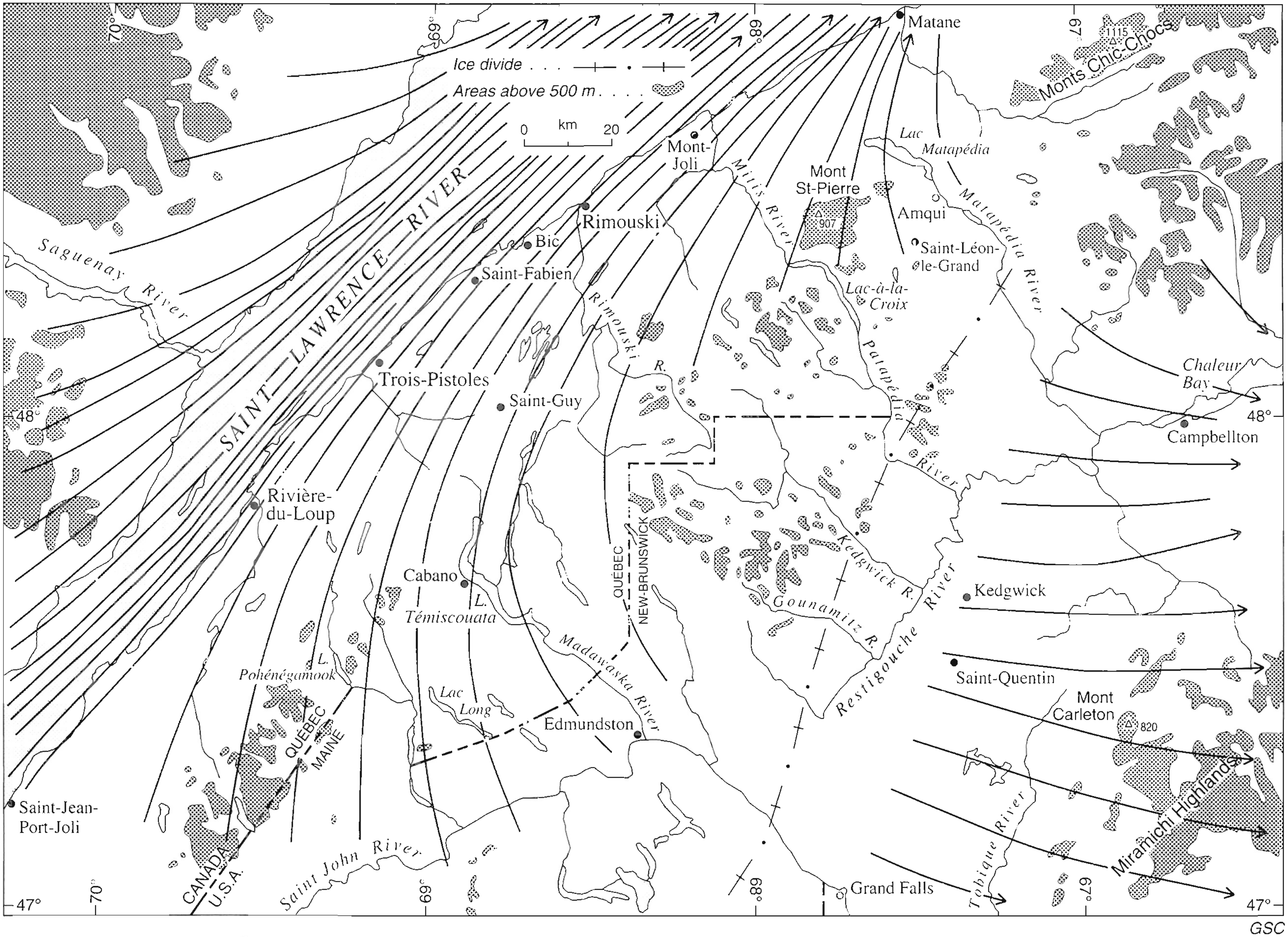


Figure 23. Glacial flow lines over study area during inception of St. Lawrence Valley ice stream.

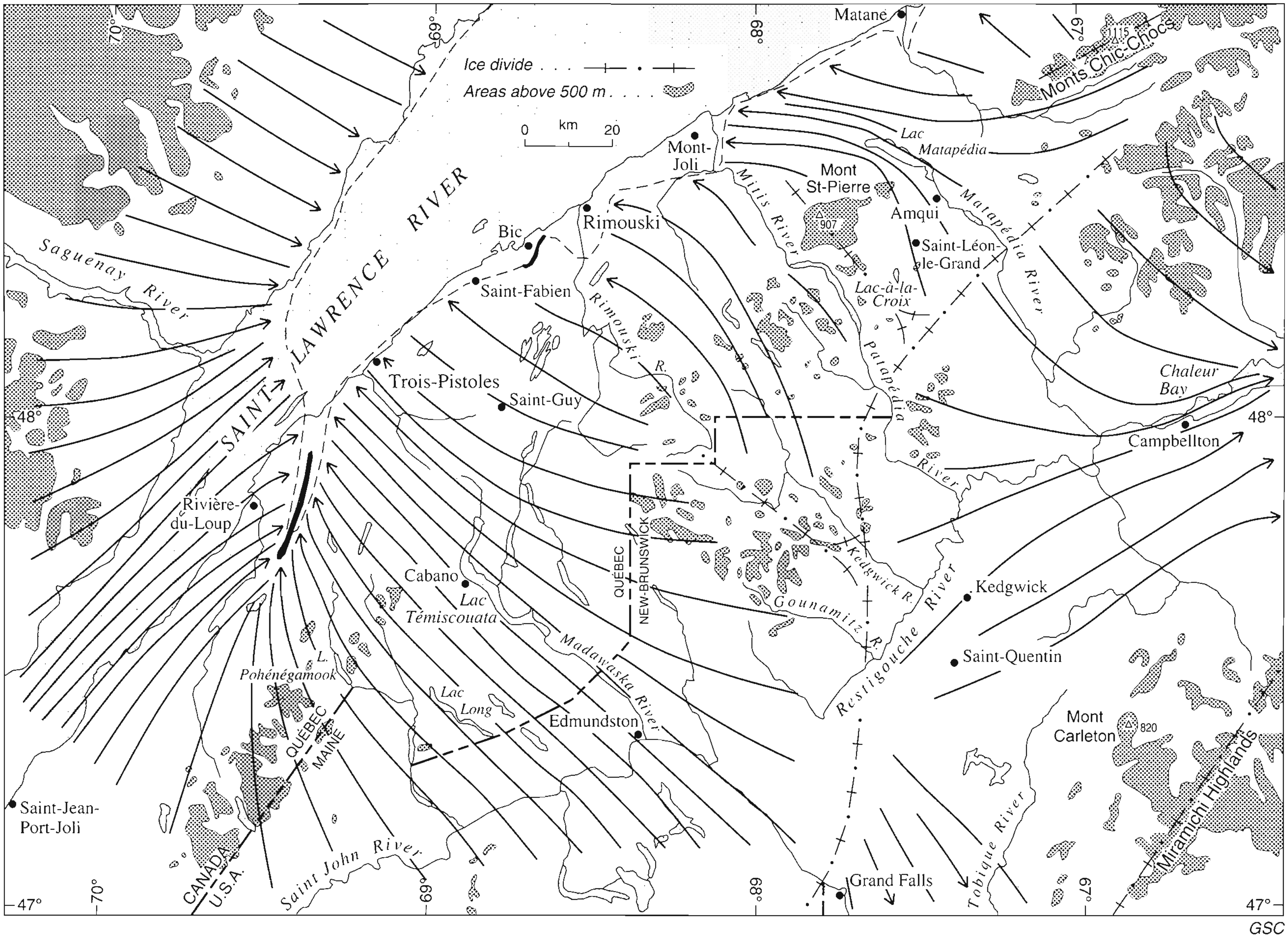


Figure 24. Glacial flow lines after progression of calving bay up to Rivière-du-Loup and during formation of St-Antonin Moraine. It is tentatively assumed here that the ice-marginal deposits at St-Fabien and Bic are formed synchronously with the moraine.

Lee (1963) and Dionne (1972b) reported deformation structures in the northwestern part of the ridge at St-Arsène, Martineau et Corbeil (1983) claimed that these are absent and reinterpreted an anticlinal glaciotectonic structure observed by Lee as a sedimentary structure. However, during the present survey, glaciotectonic deformations were observed exactly as indicated by Lee, consisting of an anticlinal fault block. Moreover, these deformed sediments were overlain by a stratified diamicton, probably representing ice-contact flows of supraglacial debris. The St-Antonin moraine is here regarded as a time-transgressive formation, formed intermittently with retreat of the re-entrant in the ice front, being essentially as originally proposed by LaSalle et al. (1977).

Regional significance of late glacial readvances

The readvance of Laurentide ice in the Rivière-du-Loup area was probably of short duration and may not have affected the prevailing marine conditions upstream in the St. Lawrence Valley system. Perhaps the ice lobe was not even grounded in the central part of the valley. The phenomenon, however, does not stand alone as a possible localized surge of Laurentide ice.

Allard and Tremblay (1981) and Gray and Hétu (1981, 1987) inferred a minor readvance of local Appalachian glaciers in north-central and northeastern Gaspésie. Fossiliferous tills indicate expansion of Appalachian ice around 11.8 ka (Fig. 15).

A glacial readvance indicated by a fossiliferous till is also demonstrated for Anticosti Island (Painchaud et al., 1984). The youngest date on shells from till associated with the Ste-Marie Moraine is 11 680 ± 190 ka BP (QU-1262).

In the Great Lakes region, Huron and Michigan lobes readvanced after the Two-Creekian interstadial that lasted from 12 to 11.8 ka (e.g., Eschman and Mickelson, 1986).

A readvance of Laurentide ice into Champlain Sea in the Quebec City area appears significantly younger: about 11 ka BP (LaSalle, 1987), but farther south, a late glacial readvance of Laurentide ice, postulated by Shilts and Smith (1987, p. 75; see also Blais and Shilts, 1989) to have taken place in Chaudière Valley, may well be correlative with dated readvances already cited.

Youngest dates on the readvance in the Rimouski area are somewhat older, but as these dates can only be regarded as maximum estimates, the readvance in this area may well be more or less synchronous with that at Rivière-du-Loup.

The readvance in the study area, occurring about 11.8 ka BP, thus appears to be more than of local significance. Because Laurentide ice as well as local Appalachian glaciers seem to have expanded at the same time, the event is likely to represent a response to short term climatic deterioration.

SUMMARY OF ICE FLOW HISTORY

Based on the evidence so far presented, the evolution of the ice cover during the last glaciation is summarized briefly in the following.

There is little direct evidence as to how long ice covered the area during the last glaciation. However, if the Tamagodi Till of western Gaspésie (Lebuis et David, 1977) and the lower tills in northwestern New Brunswick (Rappol, 1989) correlate with the Chaudière Till of Eastern Townships (McDonald and Shilts, 1971), then an important nonglacial episode must be assumed for the Middle Wisconsinan. Indications of a Middle Wisconsinan ice-free period for parts of New Brunswick and Nova Scotia were discussed by Grant and King (1984). Tentatively, I therefore assume that the last glaciation of the study area coincides with the Late Wisconsinan (oxygen-isotope stage 2: about 25 to 11 ka) and was preceded by a Middle Wisconsinan ice-free period. This interpretation also agrees with the recently revised stratigraphy of the central St. Lawrence Lowlands (Lamothe, 1987).

The first major event of the Late Wisconsinan glaciation was the invasion of Laurentide ice from across St. Lawrence Valley. In the western part of the study area, the ice moved in from the west, originating in the mountainous area of Laurentide Park, north of Quebec City. In the northern part of the study area, ice probably moved more towards southeast.

At this time, a local glaciation was possibly in effect in some of the higher regions, and local ice caps would have covered the highlands of central Gaspésie and New Brunswick. Flow of Laurentide ice, colliding with ice over Miramichi Highlands of central New Brunswick, was bifurcated: (1) towards south down St. John River valley and (2) eastward towards Chaleur Bay (Fig. 22). A third flow was deflected down St. Lawrence Valley by the highlands of central Gaspésie and the ice cap on top of these. In this model it is thus assumed that Laurentide ice did not cross Gaspésie and Miramichi Highlands during the Late Wisconsinan.

The Gulf of St. Lawrence area may have been largely ice-free throughout the Late Wisconsinan (Grant, 1977; Dyke and Prest, 1987), and, with late glacial sea level rise, the topographic situation presents an ideal setting for the development of a marine ice stream in St.Lawrence Valley. Drawdown effectuated by this ice stream caused the development of an Appalachian ice divide from which ice moved north or north-northeast over the study area (Fig. 23). On the other side of the Appalachian divide, drawdown was effective towards Gulf of Maine and Chaleur Bay. Given the available deglaciation dates, it seems likely that the ice-flow configuration as portrayed in Fig. 23 was initiated somewhat earlier than the generally assumed age around 14 ka BP (Hughes et al., 1985; Dyke and Prest, 1987).

Due to a decrease of discharge by the ice stream as a result of diminishing ice thickness, and to a rise of relative sea level during the late glacial, a calving bay could progress up St.Lawrence Valley. It passed the study area between 14 ka and 13 ka. When the ice margins of the Appalachian ice mass became grounded, a radial flow from the Appalachian ice divide formed, with western and northwestern flow in the study area (Fig. 24). The calving bay showed no symmetrical development across the valley, as indicated by the much older age of marine deposits on the south shore compared to those of the north shore. South of Trois-Pistoles, the axis of the calving bay was in fact located over the present south shore, giving rise to formation of the St-Antonin Moraine (LaSalle et al., 1977).

After passage of the calving bay, Appalachian ice readvanced in a large area around the town of Rimouski. So far, the maximum age of this readvance is 12.3 ka, but it may well be as young as 11.8 ka, when it would be synchronous with readvances in other parts of the region.

Laurentide ice readvanced from the west into the Rivière-du-Loup area, probably around 11.8 ka.

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