retreat of the Marquette ice. With the opening of outlets northwest of Lake Superior from the Agassiz basin, surges of water spilled into the Superior basin and caused spasmodic downcutting of the Gros Cap moraine sill to bedrock, and the lowest level — Lake Houghton — was reached (Farrand and Drexler, 1985).

Deglaciation of the North Bay area marks the end of the glacial history of southern Ontario. The effect of residual isostatic upwarp continued to play a role, however, and as the North Bay outlet rose, waters again transgressed southward until they once more spilled through the Port Huron and Chicago outlets, creating the Nipissing phase by about 5.5 ka (Lewis, 1969). Rich fossil assemblages of molluscs and plants are often found in or under Nipissing deposits. In the north these distinguish them from barren Algonquin deposits, and in the south they contrast with species assemblages found in Algonquin deposits (Miller et al., 1985). With downcutting of the Port Huron outlet, the Chicago outlet was abandoned and the water level gradually lowered in the Huron and Georgian Bay basins to the present 177 m. In the Superior basin, Lake Houghton was succeeded by the Nipissing phase; as the Nipissing phase gave way to lower levels and the rock sill at Sault Ste. Marie rose isostatically, a separate Lake Superior was created at 183 m (Farrand and Drexler, 1985). While the postglacial sedimentation record in the Great Lakes has been studied in several deep bottom cores, that of the land area has been studied in bogs and small lakes. This record has been largely the focus of palynological studies, which are described elsewhere in this volume.

QUATERNARY GEOLOGY OF ST. LAWRENCE VALLEY AND ADJACENT APPALACHIAN SUBREGION[1]

S. Occhietti

St. Lawrence Valley and adjacent Appalachian subregion is bounded on the north by the St. Narcisse Moraine, on the south by the Canada — United States Boundary, on the west by the limit of the Champlain Sea in the Ottawa Valley and the Frontenac Arch, and on the east by Saguenay Valley. It includes the Appalachians of southern Quebec, the lowlands of Ottawa and St. Lawrence valleys and of Lake Champlain in Ontario and Quebec, and the southern margin of the Laurentian Highlands (Fig. 4.1). These lowlands, referred to here collectively as St. Lawrence Valley, occupy the central part of the St. Lawrence sedimentary platform, and overlap the eroded margins of the Appalachians and the Canadian Shield.

BEDROCK GEOLOGY

The greatest part of this subregion is situated on the St. Lawrence sedimentary platform. The St. Lawrence sedimentary platform occupies an ancient rift system, bounded on the north by a system of en echelon faults (Wilson, 1964) or by an unconformity, and on the south terminates where the Appalachian Orogen has been thrust over the platform along Logan's Line (Fig. 4.21). The sedimentary cover which underlies this platform is composed of Cambrian and Ordovician sandstones, dolomites, limestones, and shales (Houde and Clark, 1961, Fig. 4.21), with a total thickness of 2300 m in the central Quebec basin. The northwest-southeast Oka-Beauharnois arch southwest of Montréal isolates a thinner sedimentary sequence in the Ottawa Embayment. The lower units, Upper Cambrian sandstones and Lower Ordovician (Beekmantown) dolomitic limestones are exposed on the flanks of the Frontenac Arch, the north edge of the Adirondack Mountains, which lie in the United States to the south and on the Beauharnois arch. In the central part of the Quebec basin, only Middle Ordovician formations are exposed. Due to the thickness of Quaternary cover, Paleozoic outcrops are confined to the beds and banks of streams and to a few structural rises. Downstream from Québec, the extent of Paleozoic rocks is limited largely to a narrow band of rock terraces which extend into the Charlevoix Astrobleme.

The Monteregian Hills are a distinct geological unit, consisting of Lower Cretaceous basic intrusive rocks. These ten plutonic plugs extend in a general east-west line between Mont Mégantic, in the Appalachians, and the Oka complex at the edge of the Precambrian Shield. These hills are composed mainly of gabbros and syenites that were resistant to the erosion that removed the sedimentary rock cover.

The low margins of the Canadian Shield are composed of intrusives, metasedimentary rocks, and gneisses of the Precambrian Grenville Province. In addition to the main Canadian Shield area to the north and west, they include the Frontenac Arch and Rigaud Mountain, and the Oka hills which lie west of Montréal. In the Ottawa Valley reentrant, slices of Precambrian rock are uplifted along a series of WNW-ESE faults which delimit anticlinal folds in Paleozoic sedimentary rocks. North of Ottawa River the structural limit of the Canadian Shield is marked by fault-line scarps. From north of Montréal to Québec, vertical southwest-northeast faults delimit four bedrock terraces inclined towards the southwest (Occhietti, 1980). These terraces are remnants of the ancient, pre-Ordovician, erosion surface. Downstream from Québec, the uplifted Precambrian rocks are separated from the Paleozoic cover

Occhietti, S.
1989: Quaternary geology of St. Lawrence Valley and adjacent Appalachian subregion; in Chapter 4 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.); Geological Survey of Canada, Geology of Canada, no. 1 (also Geological Society of America, The Geology of North America, v. K-1).

1 Translation of a French text.

of the middle estuary of the St. Lawrence as far east as the Saguenay, by a fault-line scarp. This structural configuration is disrupted at the Charlevoix Astrobleme, where a circular depression was produced by the impact of a meteorite during the Devonian (Rondot, 1968).

The Appalachians of southern Quebec are characterized by regional northeast-southwest oriented structures that separate a variety of terranes (Fig. 4.21; Lamarche in Dubois, 1973). The foreland at the southern margin of the St. Lawrence Valley Lowlands is composed of a sediment complex, consisting of flysch, carbonate, and shale that lies between the Quebec basin and Logan's Line. The extensions of the Green Mountain anticlinorium structures of Vermont in Quebec are the Sutton Mountains, composed of Cambrian phyllites and quartzites, and the Serpentine Belt. The latter includes a Lower Ordovician ophiolite complex which contains asbestos deposits. The rock to the southeast consists of a variety of slates, greywackes, limestones, and volcano-sedimentary lithologies.

Upper Saint-François Valley and middle and lower Chaudière Valley provide gaps transverse to the regional structure. In the Chaudière drainage basin, the Beauce, one of the natural subdivision of the southern Appalachians of Quebec, separates the Bois-Francs and the Eastern Townships, in the southwest, from the Notre-Dame Mountains and Lower St. Lawrence in the northeast.

In the eastern part of St. Lawrence Valley, Logan's Line runs close to the Canadian Shield. Because of this structural constriction, the lower part of the upper estuary and the middle estuary (Dionne, 1963a) cross segments of Appalachian basement. The middle estuary valley is narrow, of the order of 25 km wide.

MORPHOLOGY AND DRAINAGE EVOLUTION

To date, no general medium-scale synthesis has been prepared on the geomorphology of St. Lawrence Valley. MacPherson (1967) described the development of the St. Lawrence terraces in the Montréal region, Gadd (1971) described the morphology of a major sector of central St. Lawrence Valley, and Le Menestral (1969) published a geomorphic map of the Blackburn Hamlet area near Ottawa. Dumont prepared a series of maps of the area north of Ottawa River, only one of which has been published (Dumont et al., 1980).

Bedrock morphology

Looking at the overall geomorphology, the gross morphological features of St. Lawrence Valley are due to bedrock topography with low areas filled with Quaternary deposits. The underlying bedrock topography was reconstructed using data from borings made for oil, water, or engineering purposes (Prévôt, 1972; J. Schroeder, unpublished). This topography is characterized by the main St. Lawrence paleovalley, with tributary valleys either buried or reoccupied by present streams. The orientation of buried valleys indicates a preglacial flow towards the northeast, as at present. Upstream from Québec, the river passes through a rocky gorge 55 km long and 2 to 3 km wide. This constriction is possibly due to recent regional upwarping (Gale, 1970). In the Quebec basin, rock escarpments face the drainage axes, suggesting an origin by fluvial erosion. This contrasts with the morphology of the Great Lakes basin where escarpments face up the regional dip, suggesting that they originated as cuestas and more completely mirror bedrock structure.

At the margins of the Canadian Shield, the Laurentian Highlands are cut by fracture lines and faults. These structural discontinuities have been exploited by glacial erosion so that a knob and depression topography has been developed.

The substratum morphology of the southern Appalachians has been dealt with in general descriptions (Bird, 1972), summaries (Dubois, 1973), and detailed regional studies (Shilts, 1981). The area appears to have undergone several phases of peneplanation (Blanchard, 1947), which were responsible for surfaces ranging in elevation from 550 to 240 m (Stalker, 1948). Second-order relief features are controlled by the bedrock lithology and structure. Consequently the area is characterized by ridges and trenches which have been modified by glacial action. In the middle of the St. Lawrence estuary, this "Appalachian" relief emerges in the form of long, parallel, and asymmetrical islands.

Karst landforms have locally developed in carbonate rocks (Schroeder et al., 1980). North of Ottawa River, small caves are present in Grenville marble, notably La Flèche, Lusk, Bear, and Pointe Confort caverns. Postglacial karstic phenomena, including lapiés, sinkholes, caverns, seeps, resurgences, and canyons, have developed in the Chazy, Black River, and Trenton limestones. Many caverns are located near major rivers or escarpments, for example, the 900 m-long Saint-Casimir cavern, and the karstic cavities cut into the Trenton limestone during the deepening of the Sainte-Anne gorges, northeast of Trois-Rivières. At Boischatel, in the Québec City suburbs, karst features have developed in these same flat-lying limestones. At one point Laval River is captured by a system of caverns at least 2500 m long.

The substratum is locally affected by glacial tectonics. When excavations were being carried out in Montréal for the Metro system and the Olympic site, Durand and Ballivy (1974) and M. Durand (Université du Québec à Montréal, personal communication, 1984) discovered Trenton limestone thrust sheets more than 900 m long. At Saint-Léonard, in the northern part of Montréal, a system of cavities developed in this limestone by glaciotectonic thrusting (Schroeder and Beaupré, 1985; Schroeder et al., 1986).

Pockets of saprolites and rock weathered during pre-Wisconsinan time have survived the passage of the last ice sheet. On the margin of the Canadian Shield, Bouchard and Godard (1984) reported grus at a number of sites. At Château-Richer, near Québec, anorthosite is kaolinized to a depth of 20 m (Cimon, 1969; Dejou et al., 1982), indicating long-term weathering. Also in the Québec City area at Charlesbourg a saprolite containing kaolinite, smectite, vermiculite, and gibbsite has developed from biotite hornblende gneiss and mylonite (LaSalle et al., 1983). The saprolites of Mount Mégantic (Clément and De Kimpe, 1977; Dejou et al., 1982) and Mount Orford (LaSalle et al., 1985) represent the base of ancient deep regoliths considerably truncated by glacial erosion (see Fig. 4.22 for location map). It is highly probable that all these alteration products reflect pre-Quaternary weathering reactivated during interglaciations and perhaps the Holocene.

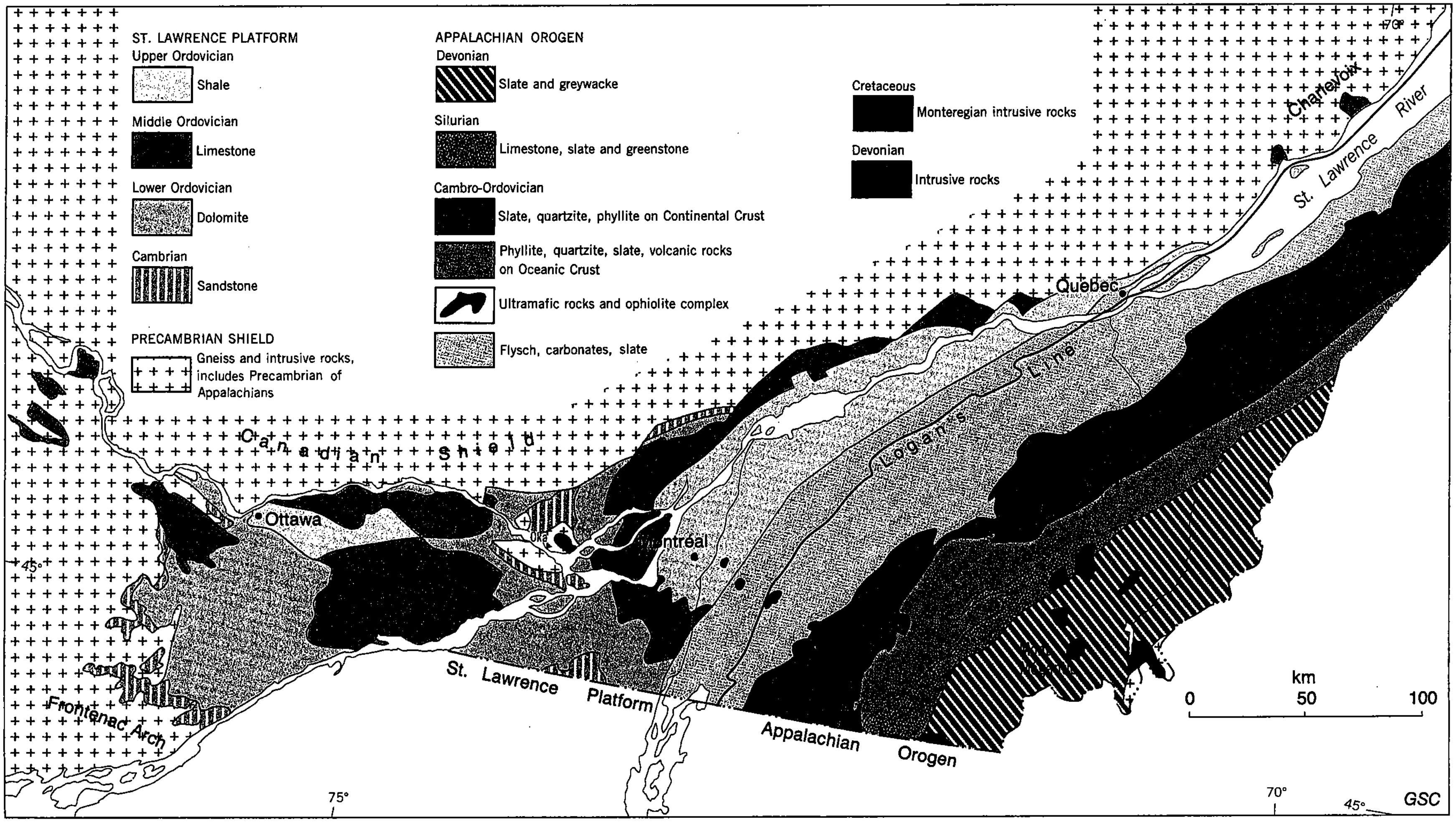

Figure 4.21. Bedrock geology of St. Lawrence Valley and adjacent areas (modified from Houde and Clark, 1961, and Lamarche in Dubois, 1973).

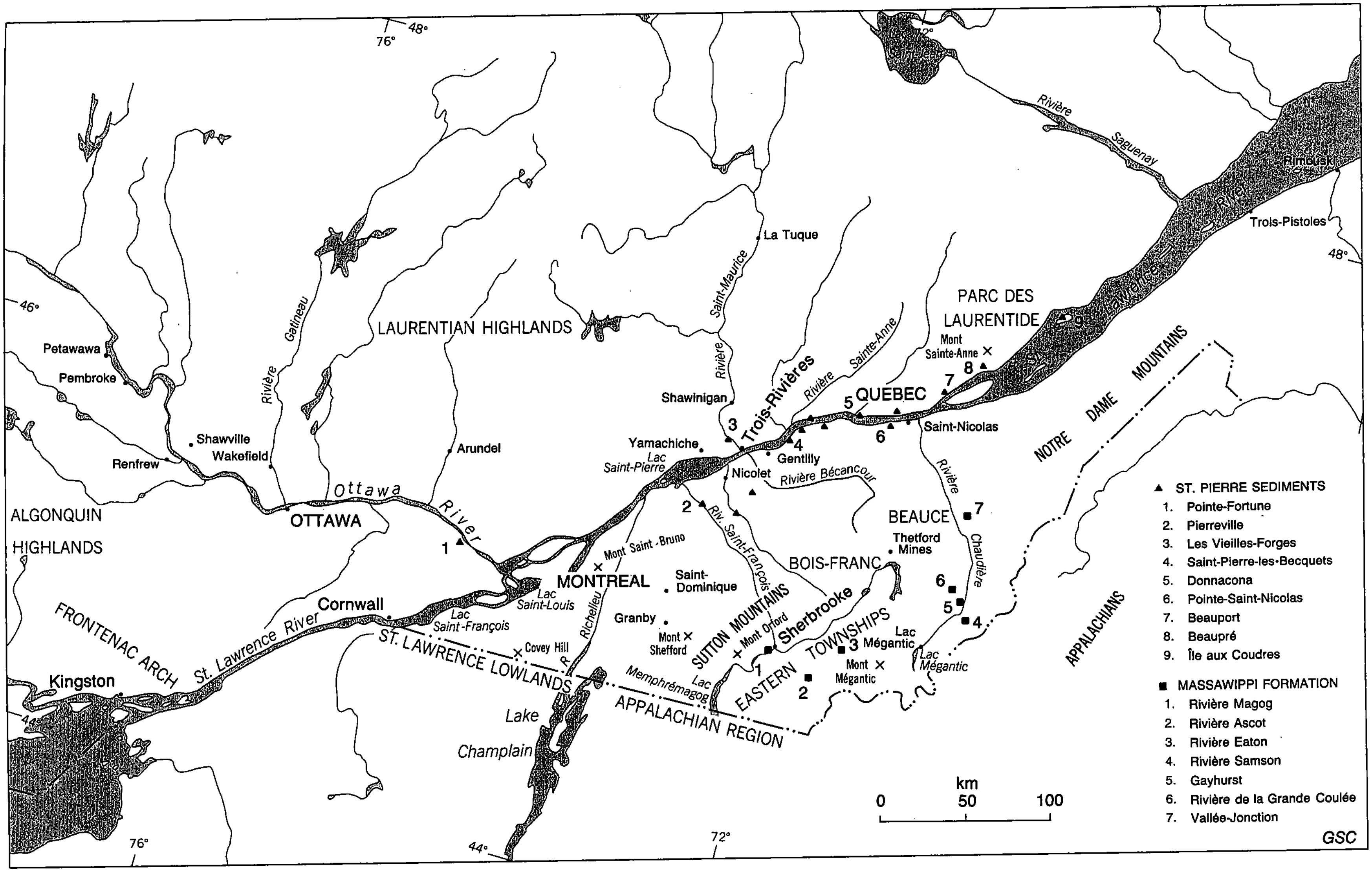

Figure 4.22. Place names used in text and locations of sites containing St. Pierre Sediments, Massawippi Formation, and equivalent deposits.

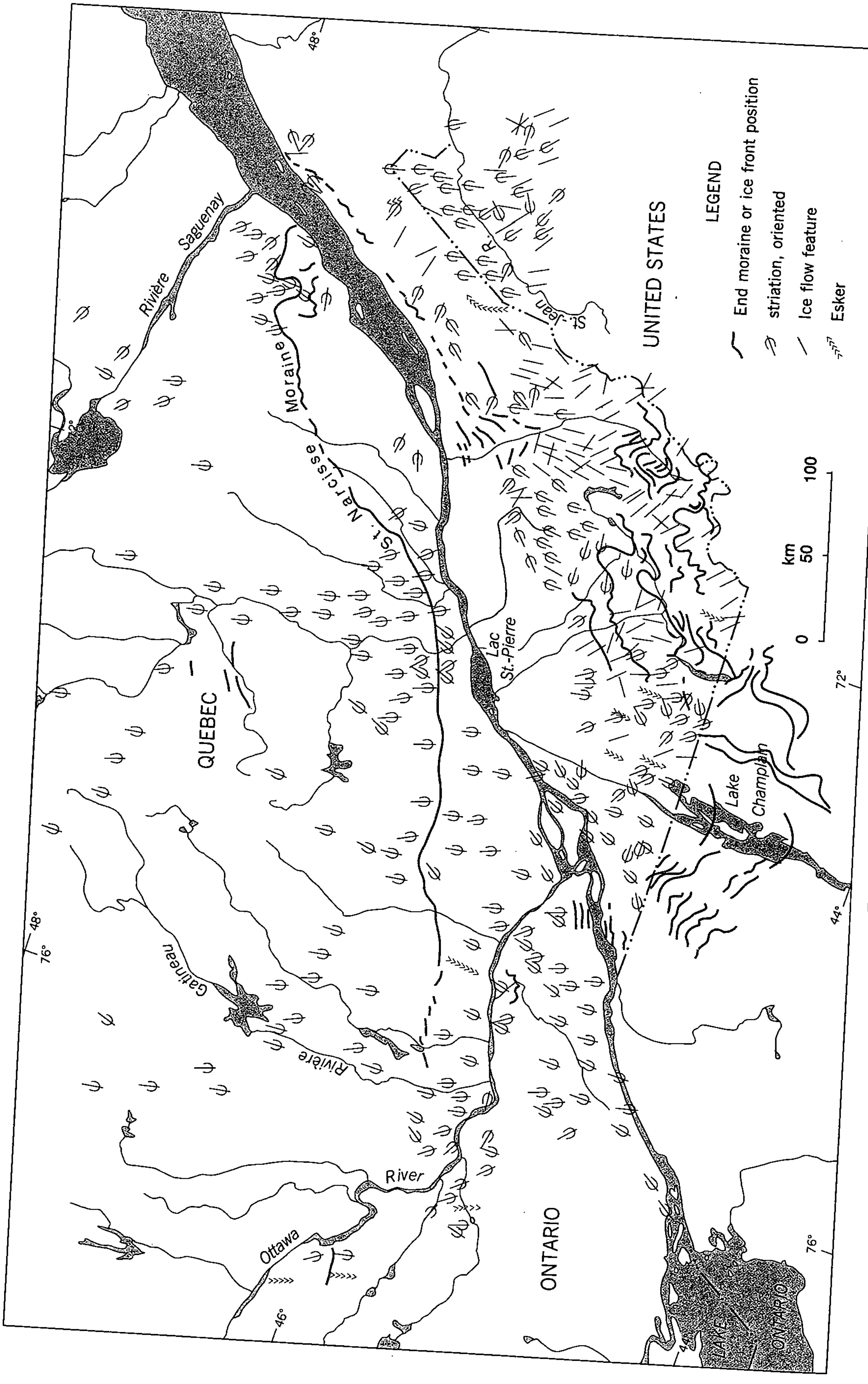

Figure 4.23. Ice flow features and main moraines.

Morphology of Quaternary deposits

Quaternary deposits cover the greater part of St. Lawrence Valley and the main low areas in the Appalachians but are discontinuous on the high ground of the Appalachians and of the Canadian Shield margin. The deposits are more than 100 m thick in the central part of St. Lawrence Valley, in Ottawa Valley, as well as in several buried valleys; however, in most areas these deposits are no more than a few metres thick and are somewhat thinner on valley slopes and hilltops.

The floor of St. Lawrence Valley consists of a series of terraces and stepped plains formed by littoral and fluvial processes during regression of the Champlain Sea at the end of the Wisconsinan. The channels of St. Lawrence and Ottawa rivers are incised in these plains. A few constructional glacial forms interrupt this generally level terrain. Constructed earlier than the terraces, moraines and other recessional features were partly or totally submerged and reworked by waves. On the Appalachians and the Canadian Shield margin, glacial landforms are relatively unmodified by postglacial processes.

Moraines in this area (Fig. 4.23, 4.24) commonly are composed of till ridges and discontinuous masses of ice contact sediments. They are generally tens of metres in height and width, and several hundreds of metres to several tens of kilometres in length. They parallel contours in the Appalachians, and are more or less straight in St. Lawrence Valley. Glaciofluvial constructional features such as kames, perched deltas, and outwash fans are associated with them. Because till sheets are generally thin, till plains and other till surfaces reflect the form of the substrate. Till-cored forms, measuring tens of metres long, have been noted in the Montréal region by Prichonnet (1977) and isolated drumlins occur between Ottawa and Cornwall, but the drumlin fields of the Great Lakes subregion to the west, end at the western limit of St. Lawrence Valley. Eskers of the order of 1 to 10 km long are relatively common (Fig. 4.23). Kame terraces, valley fills, deltas, and raised glacial lake beaches are abundant in the Appalachians.

Marine clay plains and terraces; sand terraces of marine, lacustrine, and fluvial origin; and incised deltas are the most extensive landforms in St. Lawrence Valley. They carry the imprint of ancient tidal channels and abandoned channels of the St. Lawrence and its tributaries, many of which are now occupied by swamps and bogs. Eolian activity remodelled the surfaces of sandy terraces and raised deltas. Locally parabolic dunes attain 20 m height and 300 m length and form "crêtes-de-coq" networks (Gadd, 1971).

Drainage evolution

The main valleys of the present drainage system (St. Lawrence and Ottawa rivers and Lake Champlain) are a reflection of major structural features. Conversely, tributary stream courses developed in valleys almost entirely filled by glacial, marine, lacustrine, and deltaic deposits under the influence of postglacial isostatic uplift. Despite this, many streams have managed to reoccupy their preglacial valleys. In the Appalachians, the orthogonal drainage system, governed by bedrock structure, converges towards three major drainage systems — the Saint-François in the Eastern Townships, the Chaudière in the Beauce, and the Saint John on the Atlantic slope of the Notre-Dame Mountains. Glacial filling and overdeepening are responsible for changes to the pre-Quaternary system. This is well displayed in the basins of lakes such as Memphrémagog and Saint-François (Bird, 1972; Dubois, 1973). The abundant gorges, rapids, and falls in the Appalachians and St. Lawrence Valley indicate, according to local circumstance, either superposition or renewal of erosion in the paleohydrological system, during the Holocene.

Figure 4.24. Morainic ridge associated with the St. Narcisse Moraine, southeast of Lac Simon, Quebec; the more gently sloping left side of the ridge is the distal side of the moraines. 200300-Y

CLIMATE

St. Lawrence Valley and adjacent Appalachian subregion has a temperate continental climate. Winters are long and rigorous, with heavy precipitation. Trois-Rivières appears to be the western limit of the main oceanic influence with a markedly greater precipitation at Québec than at Montréal. During the summer, Montréal has the same monthly average temperatures as Toronto, where temperature extremes are somewhat dampened by the influence of Lake Ontario. At Québec, however, summers are cooler and winters colder. In the Appalachians, temperatures are lower and precipitation higher than in the lowland to the west.

One of the more noteworthy phenomena resulting from influence of climate on fluvial activity is the "glaciel" process (Dionne, 1977). Streams are frozen during the winter; flooding, stream and tidal flow, during spring breakup results in transport of debris frozen in ice and shore erosion by seasonal ice. Other important climate related phenomena are thawing and heavy precipitation, which may be responsible for triggering landslides in marine clays and mass movements in Appalachian tills.

NATURE AND DISTRIBUTION OF QUATERNARY DEPOSITS

Quaternary deposits of much of St. Lawrence Valley and the adjacent Appalachians have been mapped by geologists of the Geological Survey of Canada, Ministère de l'Énergie et des Ressources du Québec, Ontario Geological Survey, and universities in Quebec and Ontario. Early surficial deposits maps were published by Gadd and Karrow (1959) and McDonald (1966). Gadd (1971) prepared a map and report on the east-central part of St. Lawrence Valley. Reports and maps prepared by the various government agencies constitute the main body of descriptive information on

Quaternary deposits, but considerable additional information is available in journal articles, unpublished theses, and field trip guidebooks.

During Quaternary glaciations, ice entered St. Lawrence Valley from the major Laurentide distribution centres to the north and first blocked the valley at the constriction between the highlands of Parc des Laurentides and the Appalachians. This damming resulted in a large lake which extended into the Great Lakes basin to the southwest and Lake Champlain Valley to the south. Once the ice reached St. Lawrence Valley it flowed southwestward towards the Lake Ontario basin, southward into the Lake Champlain basin, and northeastward into the Gulf of St. Lawrence. Loading by the ice during glaciation, isostatically depressed the area; during the last glaciation this glacial isostatic subsidence was great enough to allow the area to be submerged by marine water at the time of deglaciation. Because of the relief, greater elevation, and marginal position in relation to Laurentide ice, the glacial pattern of the Appalachians is more complex than that of St. Lawrence Valley. In addition to the southward push of Laurentide ice, there was at times an input of Appalachian ice and consequently a vying for dominance between Laurentide ice and northward-moving Appalachian ice. Due to the moderate relief of the area, ice retreat was characterized by the development of local stagnant ice tongues in many valleys and by numerous glacial lakes.

Several episodes of fluvial deposition and erosion have affected St. Lawrence Valley during the Quaternary; glacial sediments have been interleaved with the fluvial sediments and glacial erosion has further complicated the stratigraphic picture. Early workers apparently oversimplified the stratigraphic succession and recent workers have suggested revisions (Lamothe, 1985, 1987; Occhietti et al., 1987).

Nonglacial terrestrial deposits

In St. Lawrence Valley and the adjacent Appalachians, terrestrial nonglacial deposits can be divided into three categories: deposits of the Sangamonian optimum, deposits predating the Late Wisconsinan glacial maximum, and postglacial deposits dating from the end of the Late Wisconsinan and the beginning of the Holocene. The older deposits are of fluviolacustrine, fluvial, and organic origin, and locally outcrop in lower parts of sections. The postglacial deposits are extensive and are of lacustrine, fluvial, eolian, and organic origin.

Deposits of the Sangamon optimum

Subtill deposits at Pointe-Fortune, on the Quebec-Ontario border, consist of unfossiliferous sand overlying organic-bearing sand and silty sand, massive clay, sand-clay, and till (Veillette and Nixon, 1984). Pollen and macrofossils from the organic-bearing sediments are characterized by high pine content and by deciduous taxa such as elm, oak, beech, and hickory. This suggests a climate slightly warmer than that of today (T.W. Anderson, J.V. Matthews Jr., and R.J. Mott, Geological Survey of Canada, personal communication, 1987). The samples which contained the warm climate, organic remains came from below the floor of a gravel pit, so stratigraphic relationships are not clear. However, because this is the first horizon below the surface till that contains evidence of warm (interglacial) climate, it is assumed to date from the optimum of the Sangamon Interglaciation.

Deposits predating last glacial maximum

All other nonglacial deposits recorded in St. Lawrence Valley that contain organic matter and predate the last glacial maximum have been included in a formation called the St. Pierre Sediments (Gadd, 1960, 1971). These sediments outcrop sporadically over an area extending from Ottawa Valley (Gadd et al., 1981; Veillette and Nixon, 1984) to the middle estuary of the St. Lawrence (Brodeur and Allard, 1985; Fig. 4.22). They include gravels, sands, silts, silty clays, and accumulations of organic matter (Table 4.5) and vary in thickness from less than 1 m to more than 8 m. The type section is located west of Saint-Pierre-les-Becquets, in the ravine of an intermittent stream (Site 4 of Fig. 4.22; Gadd, 1960, 1971); at this site, the St. Pierre Sediments consist of three beds of compacted peat containing pieces of flattened wood, interbedded with stratified sediments comprising sand, silty sand, and silt with disseminated organic matter. The overall thickness is about 4 m. At other sections nearby the units are underlain by a till, the lower of two tills in the area. Exposures of clean gravels and gravelly sands, underlying the upper till, have been mentioned by Gadd (1971) in the Bécancour and Saint-François valleys. These fluvial sediments, of local lithological composition, possibly are coarse stream facies that were deposited along the margin of the basin during the main St. Pierre Interval.

Later research has questioned this relatively simple succession. Lamothe (1987) suggested that a second organic-rich sand (St. Pierre I event), overlain by varves and till, underlies the unit described by Gadd (1971).

The St. Pierre Sediments is a heterogeneous group of fluvial, lacustrine, and paludal sediments (Fig. 4.25). The extent of the complex basins in which the sediments were deposited is as yet unknown but the sedimentation framework during the St. Pierre Interval apparently was closely analogous to the present situation. The St. Lawrence flows through several large shallow lakes (such as Saint-François and Saint-Pierre). They are generally less than 3 m deep; their shores are either sandy or muddy and are enclosed by impenetrable alder thickets; spring flooding produces ephemeral channels and associated deposits; marshes and bogs are common. During deposition of the St. Pierre Sediments the river channel meandered over a valley floor that was at least 50 km wide opposite Rivière Saint-François; the elevation of St. Pierre Sediments varies from 5 m at Les Vieilles-Forges, 25 m on Île aux Coudres, and 42 m at Pointe-Fortune.

In the southern Appalachians of Quebec, two nonglacial units predate the Wisconsinan glacial deposits — the pre-Johnville sediments and the Massawippi Formation. The pre-Johnville lacustrine and fluvial succession which outcrops on the banks of Rivière de la Grande Coulée underlies a till correlated with Johnville Till (McDonald and Shilts, 1971). At its base are clayey sands containing fragments of organic matter, overlain by 150 laminations of clayey silt. This is overlain by sands and gravels encrusted with iron oxide and containing clasts from the Canadian Shield (Shilts, 1981). McDonald and Shilts (1971) attributed this oxidation to an interglacial pedogenesis and hence propose a pre-Wisconsinan age for the sediments.

The Massawippi Formation predates Chaudière Till and appears to lie on Johnville Till. In the type section on Rivière Ascot (Site 2 of Fig. 4.22) noncalcareous laminated silts, 5.8 m thick, contain fragments of organic matter and vivianite (Fig. 4.25). Lacustrine and fluvial sediments in the same stratigraphic position outcrop on the banks of the Magog, Eaton, Samson, and Grande Coulée (McDonald and Shilts, 1971) and at Vallée-Jonction (LaSalle et al., 1979). Pollen in the lacustrine silts indicates a climate cooler than that of today. The organic has provided nonfinite ^{14}C ages (Table 4.5). Because of these considerations and its lithostratigraphic position, the unit has been correlated with the St. Pierre Sediments (McDonald and Shilts, 1971).

Postglacial deposits

Following the retreat of the last ice sheet and of marine waters, lacustrine, fluvial, paludal, eolian, estuarine, and littoral sediments were deposited.

In St. Lawrence Valley, marine clays (described in a later section) grade upwards into stratified silt and silty sand of a former lake characterized by *Lampsilis siliquoidea* (Elson and Elson, 1959). Such sediments presently fill the basins of lakes Saint-François, Saint-Louis, and Saint-Pierre and make up much of the shore deposits of the middle estuary. Sand and silty sand of the lacustrofluvial system of the proto-St. Lawrence and the modern St. Lawrence overlie the lake sediments. Marine, lacustrine, and fluvial sandy and silty facies in the area are virtually identical. This is in part because older marine silt and sand have been continually remobilized and redeposited in fresh water during isostatic uplift of the area. As a consequence, these facies can be differentiated with a degree of certainty only where they contain autochthonous fossils.

Table 4.5. Main occurrences of fossiliferous St. Pierre, Massawippi and possibly correlative sediments

	Locality	Nature of sediment	Plant macrofossils	References	Selected dates and references
ST. PIERRE SEDIMENTS	Pierreville	peat	*Larix laricina, Picea*	R.J. Mott, unpublished GSC Pollen Identification Report 83-27	enriched ^{14}C: 74 700 +2700/-2000 BP, QL-198, Stuiver et al., 1978; 67 000 ± 2000 BP GrN-1711, Gadd, 1971
	Les Vieilles-Forges	peat	*Picea* stumps; branches, trunks, roots of *Larix laricina* and probably *Picea*	R.J. Mott, unpublished GSC Pollen Identification Report 83-21; A. Larouche, Université de Montréal, unpublished report 23-2-1983	>30 840 BP, Y-255, Gadd, 1971; 32 200 ± 2800 BP, UQ-588, unpublished
	Pointe Saint-Nicolas	sands and silts, (Anse aux Hirondelles Sediments)	*Larix laricina* and possibly *Picea*	A. Larouche, Université de Montréal, unpublished report 23-2-1983	38 600 ± 2000 BP, UQ-388, Occhietti, 1982; >42 000 BP, GSC-3420, LaSalle, 1984
	Beaupré	varves with interbedded sands	mosses: *Sphagnum, Drepanocladus revolvens, Aulacomnium palustre, Ditrichum flexicaule, Polytrichum juniperinum*	M. Kuc in LaSalle et al., 1977b	>39 000 BP, GSC-1539, LaSalle et al., 1977b
	Saint-Pierre-les-Becquets	peat	*Picea*, possibly *Larix*, fruits of *Menyanthes*	R.J. Mott, unpublished GSC Pollen Identification Report 83-20	65 300 ± 1400 BP, GrN-1799, Gadd, 1971
	Beauport	sandy beds of upper varves	*Picea* sp. or *Larix* sp.	LaSalle et al., 1977b	>37 000 BP, GSC-1473, LaSalle et al., 1977b
	Donnacona	silt and silty sands			>44 470 BP, Y-463, Karrow, 1957; >35 000 BP, UQ-678, Clet et al., 1986
	Pointe-Fortune	sand and silty sand			>42 000 BP, GSC-2932, Gadd et al., 1981; Veillette and Nixon, 1984
MASSAWIPPI FORMATION	Rivière Ascot	laminated silts			>54 000 BP, Y-1683, McDonald and Shilts, 1971
	Rivière Magog	lacustrine sediments			>41 500 BP, GSC-507, McDonald and Shilts, 1971
	Rivière de la Grande Coulée	medium to coarse sand			>40 000 BP, GSC-1084, McDonald and Shilts, 1971
	Vallée-Jonction	laminated sandy sediments	Bryophytae: *Aulacomnium turgidum, A. palustre, Racomitrium canescens* var. *ericoides*	W.C. Steere in LaSalle et al., 1977b	>39 000 BP, QU-327, LaSalle et al., 1977b
	Île aux Coudres	peat and wood in sand			34 430 ± 1770 BP, UL-11; 28 170 ± 800 BP, I-13549; Brodeur and Allard, 1985; >39 000 BP, GSC-4252, >35 000 BP, UL-11-2, M. Allard, personal communication, 1986

Sandy deltaic and channel deposits between 5 and 30 m thick, with horizontal and crossbedded sedimentary structures, have been deposited at the base of the escarpment at the edge of the Laurentian Highlands (Gadd, 1971; Occhietti, 1980). Similar deposits, with associated silts, also underlie low terraces and islands in Ottawa Valley and occur at the head of Lac Saint-Pierre. In addition to fluvial deposits, abandoned channels of the Ottawa-St. Lawrence River system have been progressively filled by peat bogs or swamps. These organic deposits are up to several metres thick (Terasmae, 1965).

Eolian and niveo-eolian sands — sand-snow mixtures resulting from eolian and periglacial activities — are scattered over the high and middle terraces. These deposits are up to 30 m thick and form series of fixed dunes, associated with deflation areas that are commonly occupied by peat bogs (e.g., on the high terraces east of Shawinigan and south of Québec; Gadd, 1971; Dubé, 1971; Occhietti, 1980). Silty eolian sands, and sandy silts, 0.3 to 1 m thick, locally form a discontinuous blanket on till and glaciofluvial deposits (e.g., near Shawville, R.J. Fulton, Geological Survey of Canada, personal communication, 1984; and in the vicinity of Shawinigan, Occhietti, 1980).

The upper and middle estuary are subject to a tidal range of 0.3 to 5 m (Fig. 4.26). At low tide, in the middle estuary the strand in places is several hundred metres wide. The tidal zone deposits commonly consist of alluvial mud and coarser sediments, from 0.1 m to several metres in

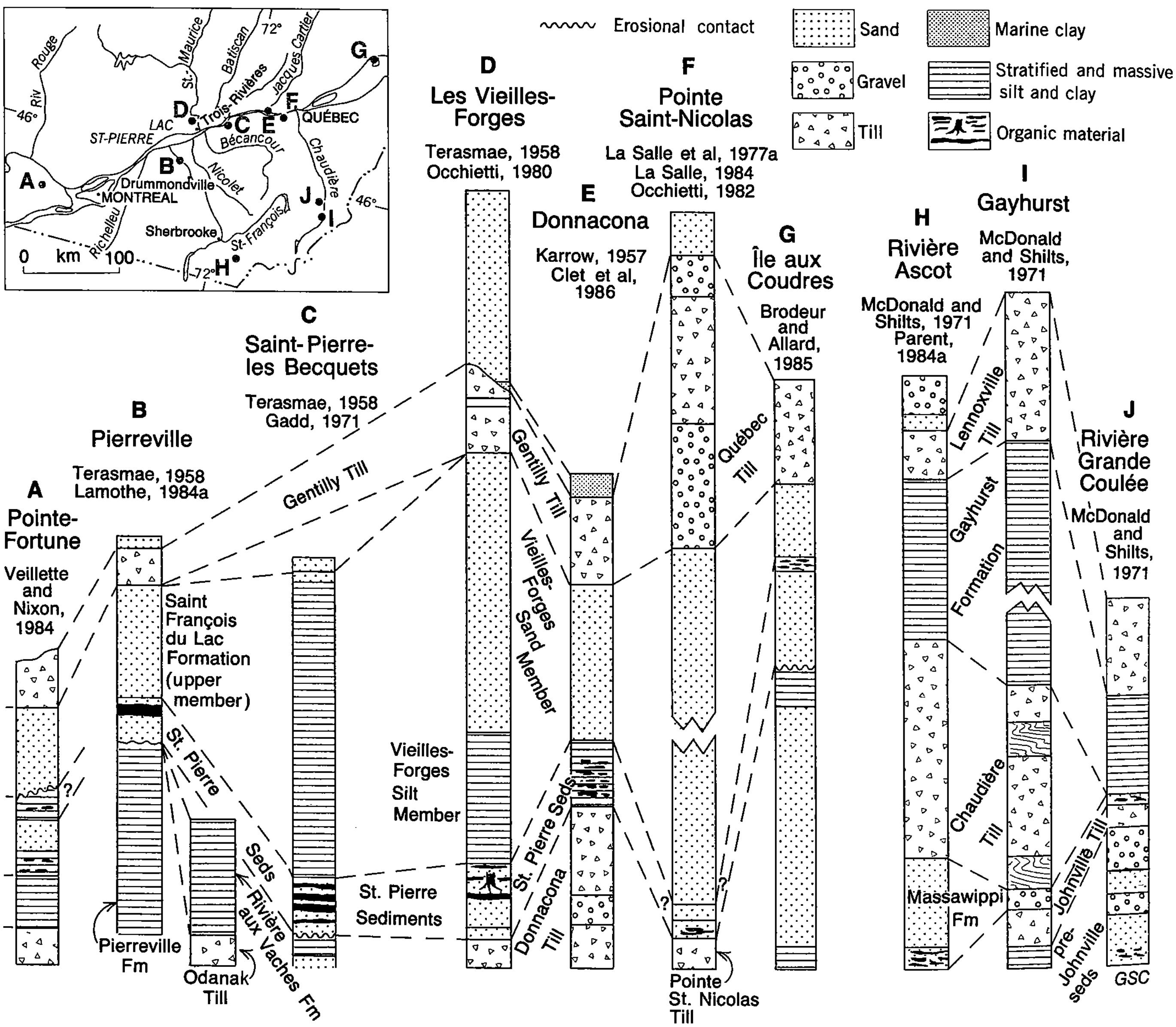

Figure 4.25. Stratigraphy of St. Pierre, Massawippi, and correlative deposits.

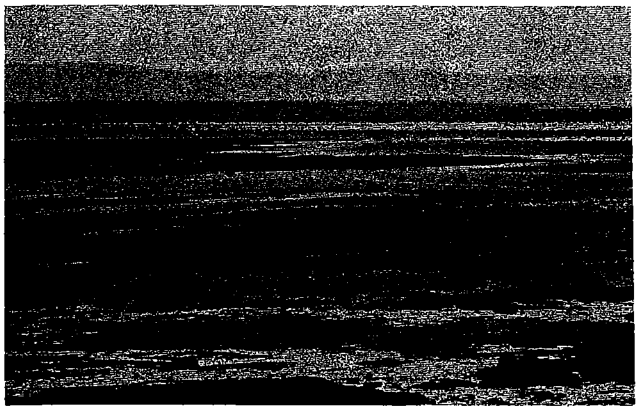

Figure 4.26. Tidal flats of the middle estuary of the St. Lawrence at mid tide; view from south shore of Île aux Coudres towards the Appalachians. 200300-U

thickness. Seasonal ice rafted or "glaciel' boulders are common. They indicate longshore movement and transport of clasts from the north shore to the south shore (Dionne, 1968, 1969, 1972b, 1977).

Glacial deposits

Glacial deposits include tills, ice contact deposits, proximal and distal glaciofluvial deposits, glaciolacustrine, and glacial lake deposits. Glaciomarine deposits are discussed in the next section along with marine deposits.

Tills

Three general types of regional tills and of till successions are present in this subregion. On the Canadian Shield, the till is usually loose with a grey, noncalcareous, sandy matrix. Thickness is variable, between a few decimetres in ground moraine, to several metres in morainic ridges and locally in the lee of rock knobs. The composition of these consists solely of Precambrian materials reflecting the regional geology. The till cover is discontinuous and preferentially occurs around the flanks and on the lee side of hills. Locally this till is deposited as small moraine ridges and also occurs within the St. Narcisse Moraine (Fig. 4.27). Occhietti (1982) includes the shield till in his Matawin Formation (Table 4.6A).

On the St. Lawrence sedimentary platform till occurs in places as several superimposed sheets. The thickness of individual sheets varies between 0.5 and 6.6 m; texture is generally clayey, and the matrix calcareous (Tables 4.6B, C); and the degree of compaction of older tills is more pronounced than that of the younger till. Clast composition is divided between Precambrian lithologies and local sedimentary rocks, but the matrix consists largely of materials abraded from the local sedimentary rocks and is the main determinant of colour. The sheets, of different ages, are relatively continuous and are more extensive and thicker south of Ottawa and St. Lawrence rivers than to the north. Downstream from the Ottawa-St. Lawrence confluence, and in lower Ottawa Valley, the tills are commonly buried by marine deposits; they do, however, outcrop on the northern edge of the Quebec Appalachians. West of the confluence, the upper till protrudes through younger overlying material in several areas. It has been reworked during marine regression but in many areas displays a rolling surface that is locally drumlinized.

Three till sheets have been described in the Appalachians but have not been described from a single section. The evidence for the lowest till is limited to information from bore holes and in two sections. The intermediate till sheet is common in depressions but seldom occurs at the surface. The upper till is relatively extensive and continuous in the Appalachian valleys and discontinuous on the ridges and monadnocks. All Appalachian tills are grey, have silty to silty sand matrixes, are relatively compact, distinctly Appalachian in lithology, but contain some shield debris. A facies, transitional between tills of the St. Lawrence Lowlands and those of the Appalachians, occurs at the northern margin of the Appalachians.

According to their lithostratigraphy, the tills of St. Lawrence Valley and southern Appalachians can be divided into two groups according to stratigraphic position: tills younger than St. Pierre Sediments (Table 4.6A, C) and older tills (Table 4.6B). Stratigraphic position is commonly the main criterion used in identifying the old tills, and is the only criterion in the Appalachians, where the Johnville Till has the same visual characteristics as the surface tills (Tables 4.6B, C). In places the lithological composition of the old tills reflects that of the local bedrock, suggesting active glacial erosion of the bedrock and only moderate transportation. The old tills are commonly oxidized but the clays do not show significant alteration (Gadd, 1971; Shilts, 1981). The red colour as well as degree of compaction have been used as identifying criteria but are not a means of recognizing old tills.

Differences between the young tills largely reflect the regional variation of glacial transport patterns after the St. Pierre Interstade. Three regional lithostratigraphic successions have been identified: a succession with two glacial units in upper St. Lawrence Valley and Montréal region (Table 4.6C); an Appalachian succession with two glacial units (Table 4.6C); and apparently a single glacial unit younger than the St. Pierre Interstade in the remainder of

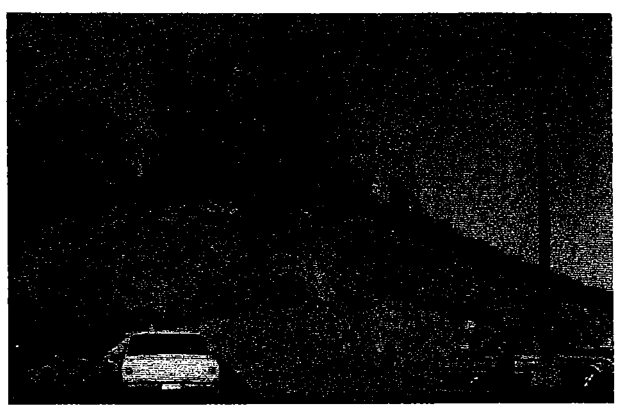

Figure 4.27. Cut in the St. Narcisse Moraine north of Portneuf, Quebec. 200300-X

Table 4.6. Description of named till units

Name	Locality and extent	Description	Direction of glacial flow	Stratigraphic position	References
A. Single tills younger than St. Pierre Sediments (central St. Lawrence and southern edge of Laurentian Highlands)					
Gentilly Till	Gentilly, central St. Lawrence Valley and Appalachian Lowlands	grey sandy till, calcareous, slightly compacted; mixed lithology, Precambrian and sedimentary; thickness 3 m	towards the SE	equivalent of Early, Middle, and Late Wisconsinan if St. Pierre Sediments are late Sangamonian or early Early Wisconsinan	Gadd, 1971 Occhietti, 1980
Québec Till	Québec area	calcareous till, very compact, sandy to clayey; mixed lithology: sedimentary, Precambrian and Appalachian		equivalent to Gentilly Till	LaSalle 1984
Matawin Formation (member: till)	Saint-Joseph-de-Mékinac, Laurentians, shield lowlands, and Saint-Narcisse Moraine	sandy diamicton, grey, variable compactness, fissile, Precambrian lithology, noncalcareous discontinuous; dominantly ablation facies, thickness generally less than 1 m	towards the SE but locally towards the S and the SSW (Prichonnet, 1977)	Late Wisconsinan	Occhietti 1980 1982 Scott 1976
Rochette glacial deposits	southern area of Charlevoix between Baie Saint-Paul and la Malbaie	diamicton and ice marginal deposits; Precambrian lithology, charateristic anorthosite and ilmenite blocks	towards the ESE	glacial flow interpolated between Late Wisconsinan glacial maximum, with flow towards the SE, and the St. Narcisse readvance, with flow towards the S	Rondot 1974
B. Tills older than St. Pierre Sediments					
Bécancour Till	Rivière Bécancour; south shore, central St. Lawrence Valley	sandy clayey diamicton, usually calcareous and red, with medium compaction; consisting of sedimentary and Precambrian rocks fragments; thickness 3 m	S to W (?)	older than St. Pierre Sediments	Gadd, 1960, 1971
Pointe Saint-Nicolas Till	Pointe Saint-Nicolas; Québec area; on the south shore of St. Lawrence River	greenish diamicton, with silty matrix, moderate compaction; consisting of shield, sedimentary platform, and Appalachians debris; thickness 2.5 m	unknown	older than Anse aux Hirondelles Sediments (equivalent to St. Pierre Sediments)	LaSalle et al. 1977b LaSalle 1984
Odanak Till	Pierreville; Rivière Saint-François	brick red, sandy clayey diamicton, calcareous, very compact, with two units divided by a gravel pavement or a sand bed; consisting of sedimentary and Precambrian lithologies; thickness 4 m	NNW-SSE	older than Pierreville Varves and St. Pierre Sediments	Lamothe 1984a
Pointe-Fortune till	Pointe-Fortune	sandy silty diamicton, dark greyish brown, calcareous; consisting of shield Paleozoic sedimentary lithologies; thickness 2.25 m	towards the SW likely	older than clays and silts containing organic matter that might be of Sangamonian age	Veillette and Nixon, 1984
Donnacona Till	Donnacona; north shore of the St. Lawrence between Rivière Yamachiche and Québec	grey sa[illegible] silty diamicton, calcareous, medium to very compact, divided locally into three units by fine grained sediments; consisting of Precambrian and sedimentary debris; thickness 2-12 m	towards the SSW	older than St. Pierre Sediments	Coleman, 1941 Karrow, 1957 Occhietti 1980
Johnville Till	Grande Coulée River; in southern Appalachians	grey diamicton, very compact, noncalcareous; Appalachian lithology, oxidized; thickness up to 1.6 m	towards the SE	questionable evidence of a till older than Massawippi Formation (correlated with St. Pierre Sediments)	McDonald and Shilts 1971; Shilts, 1981 Parent, 1984a

Table 4.6. (cont.)

Name	Locality and extent	Description	Direction of glacial flow	Stratigraphic position	References
C. Two tills younger than St. Pierre Sediments (upper St. Lawrence, Montréal area, Appalachian region)					
Till B (ex-Fort-Covington Till)	St. Lawrence Seaway; upper St. Lawrence Valley and margins of the valley	sandy diamicton, grey, moderately compacted; shield and Paleozoic debris; thickness to 9 m	towards the SSE	younger than stratified sterile sediments; either Late Wisconsinan (usual interpretation) or Middle and Late Wisconsinan	MacClintock, 1958; Fullerton, 1980; Clark and Karrow, 1984; Dreimanis, 1985
Till A (ex-Malone Till)		clayey diamicton, very compact, dark blue grey, dominantly Paleozoic debris, 10% shield debris; locally two units divided by stratified silts; thickness to 15 m	towards the SW (240°)	older than stratified sterile sediments; younger than the St. Pierre Interstade; equivalent to Chaudière Till (usual interpretation), so Early Wisconsinan	
Upper till	Montréal Island	grey diamicton with variable texture, fissile		same position as Till B (above)	Prest and Hode-Keyser, 1962, 1977
		complex of till and stratified drift			
Lower till		basal till, silty to sandy, with large Paleozoic and Precambrian blocks, compact		same position as Till A; with the lower complex apparently equivalent to the upper unit of Till A	
Saint-Jacques Till	Saint-Jacques-le-Mineur: area to the S and E of Montréal	clayey till, grey or reddish, Paleozoic and Precambrian debris		same position as Till B (above)	LaSalle, 1981
Upper till	Granby area; southern Piedmont of the Appalachians	sandy diamicton, grey; largely noncalcareous with Appalachian lithologies; thickness 1-3 m, and 10-15 m	towards the SE-SEE during the pleniglacial, late flows towards the S and the SSW	same as Till B; could be equivalent to Lennoxville Till	Prichonnet et al., 1982a; Prichonnet, 1982a, 1984a
Ange-Gardien Till		grey diamicton, pebbly, slightly calcareous; thickness 1.5 m	towards the SW (220°)	same position as Till A; could be equivalent to Chaudière Till	
Lennoxville Till and Thetford Mines Till	Rivière Ascot, southern Appalachians	sandy and clayey silty diamicton, dark olive to dark grey, moderately compact; slightly calcareous, dominantly appalachian lithologies with some shield debris; units of lacustrine sediments locally intercalated, generally leached; thickness 3.5 m	towards the SE (110°, 130°, 140°)	surface till, Late Wisconsinan, Laurentide Ice Sheet deposit	McDonald and Shilts, 1971; Shilts, 1970, 1978, 1981; Chauvin, 1979a; Parent, 1984a
Chaudière Till and Norbestos Till		olive grey to olive black diamicton, calcareous, variable texture, highly compacted, exclusively Appalachian lithologies; thickness 1 m and more	fabric towards the W, WSW, and N	middle till; younger than Massawippi Formation, Appalachian ice cap deposit	

St. Lawrence Valley (Table 4.6A). Differentiating between these tills in the field, where no clear stratigraphic relationships are available, often requires detailed analysis. Distinguishing parameters that have been used are fabric, lithological composition, heavy minerals, alteration and percentage of clay-silt and of carbonates in the matrix (Shilts, 1981; Prichonnet, 1984a; Parent, 1984a; Lamothe, 1985). In association with the last till sheet, ablation tills and covers of coarse angular clasts occur throughout the Appalachians and the Laurentians.

Ice contact deposits

Ice contact and ice marginal deposits constitute considerable parts of frontal ridges, interlobate moraines, and other recessional deposits. These deposits are characterized by collapse structures, slumps, faults, and sedimentary discordances. The texture is extremely varied and units may contain diamictons and flowtills, boulder beds, massive and stratified gravels, sands and silts, and silts and sands interbedded with the coarser sediments (Denis and Prichonnet, 1973; Rondot, 1974; Lamothe, 1977; Pagé, 1977; LaSalle et al., 1977a; Occhietti, 1980; Prichonnet 1982a, b). They occur in a variety of geomorphic forms. An outwash plain was described north of Saint-Raymond-de-Portneuf on Rivière Sainte-Anne by Faessler (1948) and deltaic fans associated with the St. Narcisse Moraine system are well developed at Arundel (Laverdière and Courtemanche, 1961) and other locations (Gadd, 1971; Denis, 1976; Occhietti, 1980). Ice contact deltas are abundant in the Appalachians and are invaluable in helping to outline positions of the retreating ice front (McDonald, 1968; Prichonnet et al., 1982a; Boissonnault and Gwynn, 1983; Larocque et al., 1983b). At least one segment of the Saint-Antonin Moraine is formed of fluvioglacial deposits of exclusively Appalachian origin (Martineau and Corbeil, 1983). The great majority of deglaciation ridges in the Granby region (Prichonnet, 1984a) are formed of ice contact and outwash deposits. In areas below marine limit most of these types of deposits have been reworked (Hillaire-Marcel, 1974; Harrison, 1977; Richard, 1982). Subaqueous outwash deposits and features are common in areas inundated by the Champlain Sea (Rust, 1977; Chell, 1982) although there is some dispute over the exact nature and origin of some of these sediments (Gadd, 1978b; Rust, 1978).

Glacial lake and glaciolacustrine deposits

Glaciers periodically blocked St. Lawrence Valley and adjacent Appalachian valleys during ice advance and retreat, creating ice-dammed lakes. Exposure of deposits associated with these pondings are, however, of limited extent but may be 10 to 30 m thick. These glacial lake sediments include several distinct facies, true varves, rhythmites, interstratified or massive silts and sands, and turbidites, and are found in association with several distinct lithostratigraphic units of different ages (Table 4.7).

Sediments interpreted as glaciolacustrine (deposited in contact with or adjacent to the ice margin) locally contain materials that are interpreted as indicative of glacial activity. These materials include dropstones, diamictons, stratified silts, sands, and gravels, and turbidites. Sands with a suggested proglacial significance lie between the Les Vieilles-Forges silts above St. Pierre Sediments and Gentilly Till of the central St. Lawrence Valley (Fig. 4.25). In the Montréal and upper St. Lawrence Valley areas,

Table 4.7. Glaciolacustrine, glacial lake and lacustrine sediments (St. Lawrence Valley and southern Appalachians)

	Ottawa Valley	Upper St. Lawrence Valley	Montréal area	Central St. Lawrence Valley	St. Lawrence Estuary	Appalachians
Lacustrine units younger than Champlain Sea	*Lampsilis* Lake silts and sands (Elson and Elson, 1959)					
lacustrine units immediately predating marine invasion	varved silts of Ottawa-upper St. Lawrence area (Anderson et al., 1985; Fransham and Gadd, 1976)	laminated sediments (Rodrigues, 1987)	Côte-Saint-Luc rhythmites (Prest and Hode-Keyser, 1977) Lake Chambly sediments (LaSalle, 1981)	Nicolet and Saint-François varves (Gadd, 1971)	Saint-Féréol clays (LaSalle, 1978), Saint-Maxime varved silts (Gadd, 1978a) in lower Chaudière Valley	lacustrine sediments of glacial lakes Vermont and Memphrémagog (MacClintock, 1954; McDonald, 1968; Parent, 1984a)
lacustrine units immediately predating final glacial advance		lower and upper rhythmites of the intermediate complex (MacClintock and Stewart, 1965)	Châteauguay sediments (LaSalle, 1981), lower and upper rhythmites of the intermediate complex (Prest and Hode-Keyser, 1962)			Gayhurst Formation (McDonald and Shilts, 1971), Ruisseau Perry Formation (LaSalle, 1984; Chauvin, 1979a)
glaciolacustrine units associated with post-St. Pierre ice advance	? silts lower than till (Johnston, 1917)	rhythmites under lower till (MacClintock and Stewart, 1965)		laminated (turbidites) silt and clay underlying Gentilly Till (Occhietti, unpublished data)	Beauport and Beaupré varves (LaSalle et al., 1977a)	
lacustrine and glaciolacustrine units associated with St. Pierre Interval	Pointe-Fortune sediments associated with St. Pierre Sediments (Veillette and Nixon, 1984)			Saint-François-du-Lac Formation (Lamothe, 1985); silt and sand at top of St. Pierre Sediments at Les Vieilles-Forges (Occhietti et al., 1987)	Donnacona sediments (Karrow, 1957), Pointe Saint-Nicolas sediments (Occhietti, 1982; LaSalle et al., 1977a), Île aux Coudres sediments (Brodeur and Allard, 1985)	Massawippi Formation (McDonald and Shilts, 1971)
glaciolacustrine units intercalated between older tills and St. Pierre Sediments				Rivière aux Vaches Formation and Pierreville Formation (Lamothe, 1985); Deschaillons Varves (Lamothe, 1987)	Intermediate rhythmites at Île aux Coudres (Brodeur and Allard, 1985)	
glaciolacustrine and lacustrine units older than one of the older tills				varves mixed with Bécancour Till (Karrow, 1957)		pre-Johnville sediments (McDonald and Shilts, 1971)

rhythmically bedded glaciolacustrine silt and sand interstratified with gravel and till is inferred to indicate ice marginal fluctuations in a glacial lake (Middle Till Complex of Prest and Hode-Keyser, 1962, 1977).

In the Quebec Appalachians, a variety of deposits have been related to lakes formed during deglaciation. These include rhythmically bedded silts, nearshore sands and gravels, bouldery shore zone lags, and deltas perched above the limit of Champlain Sea. These have aided in the reconstruction of various phases of glacial Lake Vermont, which was blocked by the front of the Laurentide Ice Sheet and also of various lakes formed by the complicated pattern of ice retreat in the Appalachians (MacClintock and Terasmae, 1960; McDonald, 1968; Prichonnet, 1982b). In addition, the Gayhurst Formation, rhythmically bedded silt and sand which underlies the surface till, occurs in this area (McDonald and Shilts, 1971; Shilts, 1978; Parent, 1984a). Locally it contains small amounts of fine grained organic materials but this is thought to have been reworked from older deposits and the unit is interpreted as glacial lake sediment deposited when the Appalachians were partly deglaciated during the Middle Wisconsinan.

Marine sediments

At the end of the last glacial stage, a sea occupied St. Lawrence Valley. The valley, isostatically depressed by the ice sheet, gradually opened to the waters of the Atlantic as the ice sheet retreated. The marine basin has been subdivided into the Goldthwait Sea, which occupied the valley downstream from Québec City, and the Champlain Sea, which occupied St. Lawrence Valley upstream from Québec and lower Ottawa Valley (Elson, 1969a). The basin acted as an immense estuary with large quantities of meltwater depositing a cover of fine debris which in places exceeds 100 m thickness. At the same time as deposition was taking place, isostatic recovery was causing the sea to regress from the basin.

These Champlain Sea sediments, the most extensive Quaternary deposits in St. Lawrence Valley, extend from Pembroke in Ottawa Valley to the St. Lawrence estuary, and from the south end of Lake Champlain to La Tuque, in the valley of Rivière Saint-Maurice 130 km north of St. Lawrence River. The lithological and mineralogical composition of the marine deposits is related directly to the glacial deposits. The gravels and sands have the same composition as the regional till; and the clays and silts consist mainly of rock flour that includes quartz, feldspar, amphibole, illite, chlorite, and some interstratified clays. Gadd (1986) described these sediments as they occur in the Ottawa area and treated them as a series of lithofacies. This report groups the marine sediment into facies related to incursion, inundation, and regression. Locally the incursion facies is underlain by "true" glaciomarine or possibly glaciolacustrine deposits and in many areas the regression facies is overlain by deposits of the lacustrofluvial systems of the St. Lawrence basin.

Glaciomarine deposits

The glaciomarine deposits in this report include only materials deposited by processes directly linked to glacial ice. These materials are of limited extent. They include gravels and sands deposited in the sea as ice contact deposits and submarine fans (Rust, 1977; Hillaire-Marcel, 1979). These deposits in general resemble normal subaqueous outwash but locally contain marine fossils. Glaciomarine diamictons, or materials interpreted as deposited directly from debris melting out of floating ice, are rare. They have been described in the Trois-Rivières region at the position of the St. Narcisse Moraine and downstream at Saint-Alban on Rivière Sainte-Anne (Occhietti, 1977b, 1980); at the base of the Saint-Nicolas section south of Québec City (Gadd et al., 1972a; Occhietti and Hillaire-Marcel, 1982); and near Wakefield in Gatineau Valley (Fulton et al., 1986). They are as much as 15 m thick and massive, resemble till, but contain shells or shell fragments. Other deposits referred to as glaciomarine are marine clays similar to those described below but containing clasts and masses of diamicton dropped from icebergs.

Incursion facies

Deposits formed during marine incursion are found at the base of sections but are of limited extent. They are thin (a few decimetres) and mark the arrival of the sea water. They include pseudo-varved facies, rhythmites, and facies with parallel stratification comprising gravel, sand, and silt under the clay of definite marine origin (Gadd, 1971; Occhietti, 1980). Similar appearing deposits which contain the freshwater ostracode assemblage with *Candona subtriangulata* have been referred to as glaciolacustrine (Anderson et al., 1985; Parent, 1987). Rodrigues (1987) confirmed the presence of freshwater fauna in laminated sediments below the marine sequence.

Inundation facies

The marine inundation facies forms a cover from several to 100 m thick over much of the lowland. The sediments were deposited in quiet marine waters from a few tens to 250 m deep. These sediments are commonly called deep water marine deposits but they are not comparable to deposits of deep marine environments. They consist of clay, silt, and locally even fine sand, and vary from massive to finely stratified; fossils are rare. Sedimentation rates were high in ice proximal areas, reaching 200 mm per year in the para-marine basin of Rivière Saint-Maurice (Occhietti, 1980). Occhietti (1980) subdivided these sediments, as they occur at the Laurentian margin of the Champlain Sea, into finely laminated or massive 'decantation facies', nonfossiliferous stratified sediment 'para-marine facies', and 'prodeltaic dispersion facies', represented by sparsely fossiliferous silts with parallel stratification or with contorted structure.

Regression facies

Marine offlap deposits are locally extensive. They generally consist of stratified sands and silts, from some decimetres to some metres thick and are not everywhere fossiliferous. Their mineralogical composition is uniformly quartzitic, and hence they are easily distinguished from glaciofluvial sediments (de Boutray, 1975). Stratification is horizontal or crossbedded. The finest example of this facies is illustrated in the extremely fossiliferous gravel pit at Saint-Nicolas (Gadd et al., 1972a; Occhietti and Hillaire-Marcel, 1982; Fig. 4.28). At the same site, another facies, 4 to 5 m thick, with alternating sand and silt beds, marks the final emergent phase with deposition influenced by tidal fluctuations in a small bay (Hillaire-Marcel, 1974, 1979).

Figure 4.28. Fossiliferous sand of the regression facies of the Champlain Sea at Saint-Nicolas, southwest of Québec City. 200300-W

The littoral facies varies according to paleogeography, duration of shoreline stability, sources of detrital material, and mode of transport of material (Hillaire-Marcel, 1979). Raised shorelines are represented by horizontal bands of washed boulders and pebbles on the rocky slopes, particularly at the base of the Laurentian Highlands. Extensive sandy beach ridges were built on deltas and outwash terraces, and extend from glaciofluvial ridges. Spits were built in sheltered locations, for example, the fossil-bearing spits constructed in the shelter of the Monteregian Hills (Prichonnet, 1977). The most common littoral deposit is a bouldery or gravelly lag produced by marine reworking of the underlying materials. These either occur as coarse unconformable surface layers or as a fossiliferous coarse surface unit in gradational contact with the underlying deposits (Gadd et al., 1972b; Hillaire-Marcel, 1979, 1981a; Occhietti and Hillaire-Marcel, 1982).

Deltaic deposits are abundant at the margin of and within the Champlain Sea basin. These consist largely of sand with characteristic foreset and topset beds, and lie most commonly on well bedded silty prodelta facies. The locus of delta sedimentation migrated towards the centre of the basin as the sea regressed, producing strip deltas that parallel the modern water courses.

Marine fossils

The marine deposits contain a wide variety of marine and terrestrial fossils (Table 4.8). Marine macrofossils have been catalogued by Wagner (1970) and Elson (1969b). Cronin (1977a) used microfossil assemblages in his studies of paleoecology of the Champlain Sea and recognized three environmentally distinct marine phases. Hillaire-Marcel (1977, 1980, 1981a) described the various types of communities found in all the postglacial seas of Quebec and using available ecological data and ^{18}O and ^{13}C isotope analysis, distinguished seven communities and six subcommunities, characteristic of different marine environments (Fig. 4.29, Table 4.8). Rodrigues and Richard (1983, 1986) identified seven macrofaunal assemblages in their studies in the western basin of the Champlain Sea. Some of these correspond to the communities described by Hillaire-Marcel.

QUATERNARY HISTORY

St. Lawrence Valley and adjacent Appalachians occupy a position intermediate between the heart of the Laurentide ice in central Quebec and the terminal zone on Long Island, New York. In addition, the morphological variability of the area resulted in different styles of glaciation in different areas: the main St. Lawrence Valley was generally a conduit carrying ice flowing off the Canadian Shield, into the Gulf of St. Lawrence to the east, into the Great Lakes to the west, and into the Champlain-Hudson trough to the south; the Appalachians were probably a centre of accumulation during glacial inception, were overridden by ice overflowing southward from St. Lawrence Valley at glacial maxima, and may have again been the site of local accumulations during retreat of Laurentide ice. These various factors produced a variety of different and yet synchronous units which are difficult to fit into a consistent Quaternary history.

Several regional and interregional Quaternary history syntheses are available for St. Lawrence Valley and adjacent Appalachian area (Prest, 1970, 1977; McDonald and Shilts, 1971; McDonald, 1971; Gadd et al., 1972a, b; Dreimanis and Karrow, 1972; Dreimanis and Goldthwait, 1973; Dreimanis, 1977; Occhietti, 1982; Karrow, 1984; LaSalle, 1984). The main unit used in making these regional and interregional correlations is the St. Pierre Sediments; it was the only nonglacial unit that could be recognized with some degree of certainty in most parts of the subregion. Because of this, the age of the St. Pierre Sediments is critical to the Quaternary history of the subregion. Samples of plant material, calcareous concretions, and the sediments themselves have been subjected to conventional and enriched ^{14}C dating, thermoluminescence dating, uranium/thorium dating, and relative dating by the amino acid technique. The results have not provided a single chronological framework acceptable to all workers (Gadd et al., 1972b; Lamothe et al., 1983; LaSalle, 1984).

Pre-last glacial maximum

Nonglacial events predating the St. Pierre Interval

The Mic-Mac terrace, identified by Goldthwait (in Gadd, 1971), has been described on the southern shore of the middle estuary by Dionne (1963b) and Locat (1977), and its existence on the north shore has been noted by Brodeur and Allard (1985). This terrace has been correlated with a littoral abrasion platform observed in the Atlantic Provinces and attributed to the Sangamon Interglaciation (Grant, 1977). This feature implies a period of littoral erosion associated with a marine water plane about 6 m above modern sea level but there is no direct measure of its age. In the Québec City area, however, it is overlain by the rhythmites that underlie sediments of the St. Pierre Interval (LaSalle, 1984).

Table 4.8. Marine fossils from the Champlain Sea and western Goldthwait Sea

Marine shell communities Pelecypods, Gastropods Cirripeds, Brachiopods (Hillaire-Marcel, 1977, 1981a)	Other invertebrates (Wagner, 1970; Fulton, 1987)	Fish (Harington, 1978; Fulton, 1987)	Mammals (Harington, 1971, 1972, 1977, 1978; Harington and Occhietti, 1988) Birds (Harington and Occhietti, 1980)	Plants Marine algae (Mott, 1968; Illman et al., 1970) Plants (Fulton, 1987)	
Intertidal or shallow zones: 7 *Hemithyris psittacea* 6 *Mya arenaria* 5 *Macoma balthica* 4 *Mytilus edulis* Coarse features 3 *Hiatella arctica* a. upper sub-community: *Macoma balthica* b. middle sub-community: *Mytilus edulis, Balanus crenatus, B. balanus* c. deep sub-community: *Mya truncata, Balanus hameri* Ultrahaline cold waters 2 *Macoma calcarea* a. upper sub-community: *Astarte* sp. b. middle sub-community: *Chlamys islandicus, Serripes groenlandicus* c. deep sub-community: *Balanus hameri, Nuculana* sp. *Nucula tenuis* Near ice 1 *Portlandia arctica*	Echinoderms: *Crossaster papposus* *Ophiura* sp. *Ophiocoma* sp. or *Amphiura* sp. *Strongylocentrus drobachienois* Demosponge: *Tethya logani* Marine worms: *Nereis pelagica* Crustaceans: *Mesidotea sabini* Euphausiacea (near *Meganyctiphanes*) *Estheria dawsonii* xx Insects: March fly: *Bibio* sp. May fly: Ephemeridae Beetle: *Fornax ledensis* x Beetle: *Tenebrio calculensis* x Beetle: *Byrrhus ottawaensis* x Pill Beetle: Byrrhidae (*Cytilus* or *Byrrhus*) Caddisfly: *Phryganea ejecta* x	-Capelin: *Mallotus villosus* -Lake trout: *Salvelinus namaycush* -Rainbow smelt: *Osmerus mordax* -Lump fish: *Cyclopterus lumpus* -Threespine stickleback: *Gasterosteus aculeatus* (*trachurus* form) -Atlantic cod: *Gadus morhua* -Lake cisco: *Coregonus artedii* -Longnose sucker: *Catostomus catostomus* -Atlantic tomcod: *Microgadus tomcod* -Spoonhead sculpin: *Cottus ricei* -Deepwater sculpin: *Myoxocephalus thompsoni* -Blenny-like fish: *Blennioidea*	Marine mammals: Whales: -*Delphinapterus leucas* -*Megaptera novaengliae* -*Balaena mysticetus* -*Balaenoptera physalus* Seals: -*Phoca groenlandica* -*Phoca hispida* -*Phoca vitulina* -*Erignathus barbatus* Sea-elephant: -*Odobenus rosmarus* Terrestrial mammals: hare: -*Lepus americanus* Marten: -*Martes americana* Chipmunk: -*Tamias striatus* Birds: -*Somateria* cf. *mollissima*	*Laminaria* *Rodymenia* probable *Audouinella membranacea* *Acrochaetium* sp. Sugar maple: -*Acer saccharinum* Alder: -*Alnus* sp. Yellow birch: -*Betula alleghaniensis* (*B. lutea*) Water-shield: -*Brasenia schreberi* (*B. peltata*) Brome grass: -*Bromus ciliatus* Sedge: -*Carex magellanica* Round-leaved sundew: -*Drosera rotundifolia* Water-weed: -*Elodea canadensis* Algae: -*Encyonema prostratum* (*Cymbella prostratum*) Water horsetail: -*Equisetum fluviatile* (*E. limosum*) Dwarf horsetail: -*Equisetum scirpoides* Wood horsetail: -*Equisetum sylvaticum* Aquatic moss -*Fontinalis* sp. Rockweed -*Fucus digitalis*	*Huckleberry* -*Gaylussacia baccata* (*G. resinosa*) Bog moss -*Hypnum fluitans* Rice grass -*Orizopsis asperifolia* Balsam poplar -*Populus balsamifera* Large toothed aspen -*Populus grandidentata* Pondweed -*Potamogeton pectinatus* Pondweed -*Potamogeton perfoliatus* Pondweed -*Potamogeton pusillus* Pondweed -*Potamogeton rutilans* xx Silverweed -*Potentilla anserina* Willow -*Salix* sp. common cattail -*Typha latifolia* American eel-grass -*Valisneria americana* (*V. spiralis*)

x Record requires verification
xx Taxonomic position uncertain

Ostracode assemblages (Cronin, 1977a, b)	Foraminifer biozones from Lake Champlain cores (Fillon and Hunt, 1974; Corliss et al., 1982)	Foraminifer assemblages (Guilbault, 1980)	Diatom assemblages Goldthwait Sea (Lortie, 1983)	Shell assemblages and communities, Foraminifers and Ostracodes, in Ottawa Valley and western Champlain Sea (Rodrigues and Richard, 1983, 1986; Anderson et al., 1985)	Biostratigraphic and paleohydrological synthesis: diachronic composite vertical sequence
Upper stage, cold to temperate, brackish: *Cytheromorpha fuscata* *Cytherura gibba* *Leptocythere castanea* Intermediate phase, cold, euhaline to polyhaline: *Cytheropteron* sp. *Finmarchinella curvicosta* *Baffinicythere emarginata* *Cythere lutea* *Palmanella limicola* *Cytheromorpha macchesneyi* Lower transitional phase, cold, fresh to brackish water: *Candona subtriangulata* *Cytheromorpha macchesneyi*	5 *Elphidium clavatum* 4 *Elphidium clavatum* and *Protelphidium orbiculare* 3 *Protelphidium orbiculare* and *Elphidium bartletti* 2 *Islandiella islandica* and *Islandiella teretis* 1 *Islandiella teretis*	Shallow units: *Elphidium hallandense* or *Elphidium albiumbilicatum* Zone C mesohaline temperate: *Elphidium excavatum* Zone B mesohaline: *Elphidium clavatum* forma *clavata* Zone A arctic: *Cassidulina reniforme* *Islandiella helenae* or *Elphidium excavatum* *Islandiella norcrossi* Pre-A transitional zone, deep waters: *Cassidulina reniforme* *Elphidium* sp.	Upper phase, brackish and shallow waters: *Cyclotella caspia* *Cocconeis costata* *C. scutellum* var. *stauroneiformis* Regressive phase, shallower and more brackish waters: *Cocconeis scutellum* var. *stauroneiformis* *Cocconeis costata* *Nitzschia cylindrus* *Chaetoceros* sp. Full-sea phase, deep and saline waters: *Stephanopyrix furris* var. *intermedia* *Coscinodiscus* sp.	Upper lacustrine phase: *Lampsilis siliquoidea* Shallow water assemblages: *Elphidium albiumbilicatum* *Mya arenaria* *Elphidium clavatum* *Protelphidium orbiculare* *Macoma balthica* *Mytilus edulis* Rare assemblage: *Mya truncata* Deep, cold, high or variable salinity waters assemblages: *Elphidium clavatum* *Hiatella arctica* *Eoeponidella* sp. *Protelphidium orbiculare* *Astronomion gallowayi* *Balanus hameri* *Cassidulina reniforme* *Cibicides lobatulus* *Islandiella norcrossi* *Portlandia arctica* Glacial lake phase, fresh, deep water: *Candona subtriangulata* *Cytherissa lacustris* *Lymnocythere friabilis*	g) *Lampsilis* freshwater lake or fluvial estuary f) temperate, shallow, shore or coastal, brackish waters (summer temperature 20°C; salinity 3 to 18‰) e) arctic to subarctic, mesohaline, moderately shallow waters (18 to 24‰, summer temperature 10-12°C) d) arctic, cold, polyhaline, moderately deep waters (salinity 22 to 28‰) c) arctic, cold, euhaline, deep waters (0-4°C, salinity 30 to 33‰) b) transitional, deep and cold waters, fresh to brackish a) *Candona subtriangulata* fresh waters glacial lake

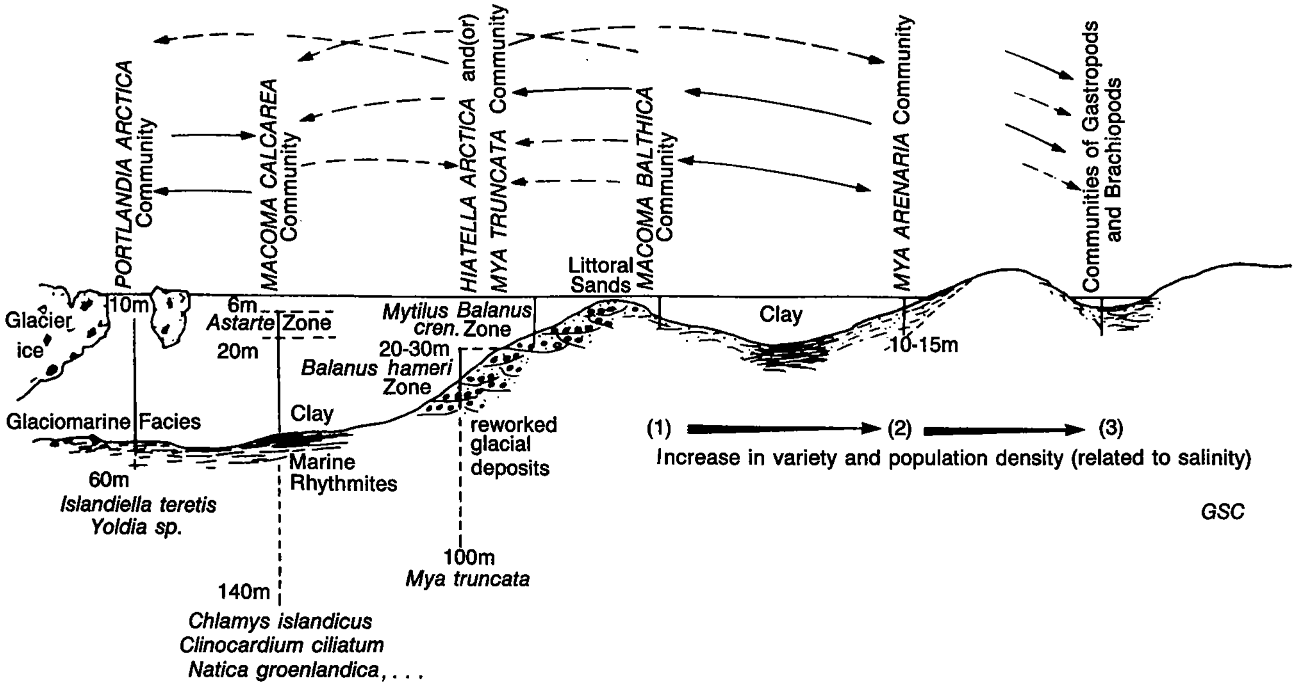

Figure 4.29. Ecological niches of Champlain Sea fossil assemblages, (Hillaire-Marcel, 1979)

The bedrock floor that underlies the pre-St. Pierre Sediments is at or below present base level. Even if residual glacial isostatic compensation is taken into account, it appears that base level of St. Lawrence River during the Sangamon Interglaciation (and possibly older ones) was as low as it is today.

The Sangamonian climatic optimum (equivalent to oxygen isotope stage 5e) apparently is represented by the lower organic-rich sediments at Pointe-Fortune (T.W. Anderson, J.V. Matthews, Jr., and R.J. Mott, Geological Survey of Canada, personal communication, 1987; Veillette and Nixon, 1984; Anderson et al., 1987). Few details are available on these or on the 30 to 40 m of sediments that underlies St. Pierre Sediments near the type section or the more than 60 m that underlies St. Pierre equivalent sediments at Île aux Coudres (J.P. Leroux, Transports Québec, unpublished report, 1986). The discovery of several units underlying the classical St. Pierre Sediments in the Saint-Pierre-les-Becquets area (Lamothe, 1987; Occhietti et al., 1987), however, suggests that a long sequence of events predating the St. Pierre Interval remains to be described.

In the Appalachians, the pre-Johnville sediments are of nonglacial origin and yet contain pebbles from the Canadian Shield; consequently, in addition to being a product of a pre-St. Pierre nonglacial period, they provide evidence of at least one regionally significant glaciation which must have occurred before they were deposited (McDonald, 1971).

Glacial events predating the St. Pierre Interval

There is scattered evidence for as many as three major glaciations prior to the St. Pierre (Ford et al., 1984); however, the nature, extent, and flow pattern of these older glaciers are unknown.

For the Appalachians, the evidence for a glaciation predating the pre-Johnville sediments has already been mentioned. Johnville Till is related to a glaciation immediately predating the St. Pierre but exposures of Johnville Till are extremely rare (McDonald and Shilts, 1971; Shilts, 1981; Parent, 1987).

In an area lying between Montréal and Québec City and between Les Vieilles-Forges and the Appalachian piedmont, there are several tills that may be placed reliably in a stratigraphic position below the St. Pierre Sediments. These are Bécancour, Odanak, Donnacona, Pointe Saint-Nicolas, the lower till at Pointe-Fortune (Table 4.6B), and the till at the base of borings near Saint-Pierre-les-Becquets (Lamothe, 1987). Correlation of these tills, however, is only speculative.

In St. Lawrence Valley varved clay units, in addition to tills, are used as evidence of past glaciations. This is based on the assumption that each glacial lake deposit represents a time when either Laurentide or Appalachian ice was sufficiently extensive to seal off the lower end of St. Lawrence Valley. Glacial events that were extensive enough to fill St. Lawrence Valley with ice were accompanied by lacustrine episodes that both predated and postdated the glacial maximum. However, it can be difficult to distinguish one unit of glacial lake sediments from another and consequently a degree of ambiguity has entered the Quaternary stratigraphy of the lowlands. For example, in the Pierreville section, varved sediments of Pierreville Formation (Lamothe, 1985) underlie St. Pierre Sediments. If a thermoluminescence date of 135 ka (Table 4.9) for these varved sediments is correct, these deposits are late Illinoian (Lamothe, 1985). Gadd (1971) assumed that finely laminated clays of the Rivière aux Vaches Formation exposed on the opposite bank of Rivière Saint-François were correlative. However, thermoluminescence dates of ca. 80 ka on these (Lamothe, 1984a; Table 4.9) suggest that these sediments, which are overlain by nonfossiliferous sand, represent a glacial lake episode that postdates the warmest part of the Sangamonian (oxygen isotope stage 5e), are younger than the Pierreville varves, and directly predate the St. Pierre Sediments. Gadd (1971) interpreted his single varved succession the result of a glacial lake that formed during retreat of the ice which deposited the Bécancour Till. He referred both the till and the varved sediments to the Bécancour Stade which immediately predates the St. Pierre Interval. Dreimanis and Karrow (1972) renamed this stade the Nicolet Stade. Lamothe (1984b, 1985), basing his interpretation on thermoluminescence dates and stratigraphic data, suggested that the Pierreville varves are Illinoian and are separated from what he referred to as the Rivière aux Vaches clays by a hiatus that represents the Sangamon Interglaciation. Hence there is a lack of agreement on the number and timing of glacial and lacustrine units in St. Lawrence Valley.

St. Pierre Interval events

In St. Lawrence Valley, a group of sediments deposited in glacial lacustrine, lacustrine, and fluvial environments is interbedded between the Bécancour Till (or old tills) and the Gentilly Till (or a group of equivalent units) (Table 4.10). The succession of these units was examined and defined in the central part of the valley by Gadd (1960, 1971), partially extended by Occhietti (1980), and re-examined by Lamothe (1984a, b, 1985, 1987), Occhietti (1982), and Occhietti et al. (1987). Similar lithostratigraphic suites are identified at a number of other sites (Fig. 4.22) which can be placed in five groups: Pointe-Fortune (site 1), Saint-François Valley (site 2), Les Vieilles-Forges-Saint-Pierre-les-Becquets (sites 3 and 4), Donnacona-Pointe Saint-Nicolas (sites 5 and 6), and Beauport-Île aux Coudres (sites 7, 8, and 9). Palynostratigraphic studies and absolute dating are currently insufficient to establish definite correlations between the units of these five areas; however, based on the sequence of deposits (Fig. 4.30), the interval appears to have been characterized by two main phases: 1) a nonglacial fluvial episode: St. Pierre Sediments (Gadd, 1960); 2) a lacustrine and deltaic episode: (Gadd, 1971; Occhietti, 1982; Lamothe, 1985).

Nonglacial fluvial episode. The St. Pierre Sediments, characterized by fluvial sand, peat, silt, and clay, suggest a relatively low energy fluvial environment. It appears that St. Lawrence Valley at this time was a broad, flat-floored basin occupied by peat bogs and shallow lakes connected by a relatively large, but low gradient fluvial system.

The study of pollen, plant, and insect macrofossils suggests interstadial climatic conditions, with temperatures generally cooler than at present (Terasmae, 1958). Terasmae's pollen diagram for Les Vieilles-Forges, shows *Picea* and *Pinus* as the dominant genera with temperate deciduous trees, such as *Quercus*, *Fagus*, *Tilia*, and *Carya*, representing the optimum climatic period. The occasional

Table 4.9. Radiocarbon ages for concretions and thermoluminescence ages for lake sediments

Lithostratigraphic unit	Locality	^{14}C age, lab no.	Characteristics of ^{14}C dated material	Thermoluminescence dates	Reference	Comments
Gentilly Till	Pierreville	34 000 +1800/-1400 BP, UQ-312 36 400 +3000/-2400 BP, UQ-494 37 200 +2400/-2500 BP, I-12 894 26 000 ± 2300 BP, UQ-484	Striated calcareous concretions, carried by ice		Lamothe, 1985	Concretions older than ice invasion; age of concretion formation and possibly maximum age for glacier advance
Pierreville Formation varves	Pierreville	34 000 ± 1050 BP, UQ-406 $\delta^{13}C$ = -13.13‰ 36 400 +3000/-2400 BP, UQ-494	calcareous ovoid concretions	135 ± 26 ka >82 ± 15 ka	Lamothe, 1984a, 1985	34 ka could be the age of concretion formation; the sediment is late Illinoian according to thermoluminescence dates
Deschaillons Formation varves	Deschaillons	36 280 ± 2410 BP, QU-279 37 500 +2300/-1800 BP, QC-357 34 900 +1625/-1350 BP, QU-559	deformed, elliptic syngenetic concretions		Hillaire-Marcel and Pagé, 1981	age of concretion formation and probably minimum age for sediments
Gayhurst Formation varves	Old Gayhurst Dam on Rivière Chaudière	32 900 +1450/-1225 BP, QC-508 20 640 ± 640 BP, QC-558 20 600 ± 350 BP, UQ-556	calcareous concretions		Hillaire-Marcel, 1979	age of concretion formation and possibly minimum age for sediment
Rivière aux Vaches Formation varves	Pierreville	28 030 ± 760 BP, UQ-130	disc-shaped concretions	86.3 ± 17 ka >76.7 ± 15 ka	Lamothe, 1984a, 1985	28 ka could be the age of concretion formation; sediment age 86 ka
Stratified silts and sands of Saint-François-du-Lac Formation	Pierreville			61.2 ± 11 ka 61.1 ± 9.2 ka >53.7 ± 8.1 ka	Lamothe, 1984a, 1985	sediment age about 60 ka

abundance of birch (*Betula*) and alder (*Alnus*), and of herbaceous plants such at *Typha*, indicates local variations, particularly in drainage. Because of presence of eastern hemlock (*Tsuga canadensis*) in the flora at the Les Vieilles-Forges site, it is suggested that palynology indicates conditions similar to those of today's southern boreal forest (Clet and Occhietti, 1988).

In the Appalachians, the Massawippi Formation, which has generally been correlated with the St. Pierre Sediments (McDonald and Shilts, 1971) appears to be mainly lacustrine. It contains pollen grains of *Picea*, *Pinus*, and *Betula* — evidence of a boreal forest — and also pollen of some subarctic species.

Considerable controversy has surrounded the age and duration of the nonglacial St. Pierre Interval (see discussion in Occhietti, 1982). The earliest radiocarbon date of ca. 11 ka led Gadd (1953) to correlate this nonglacial with the Allerod and Two Creeks Interval. This date, obtained when the dating method was in its infancy, was soon discounted by a large number of dates beyond the range of radiocarbon dating. The oldest apparently acceptable date is 74 700 +2700/-2000 BP (QL-198; Stuiver et al., 1978) obtained by isotopic enrichment procedures. This date agrees relatively well with thermoluminescence dates of ca. 61 ka (Lamothe, 1984a; Table 4.9). These old dates have led to the designation of the St. Pierre as an Early Wisconsinan interstade which lasted for only a few thousand years (Terasmae, 1958; Dreimanis and Karrow, 1972). Because only one till was found above the St. Pierre near the type section, it was hypothesized that ice advanced over the site in the Early Wisconsinan and did not retreat until the end of the Wisconsinan. Finite radiocarbon dates in the 28 to 38 ka

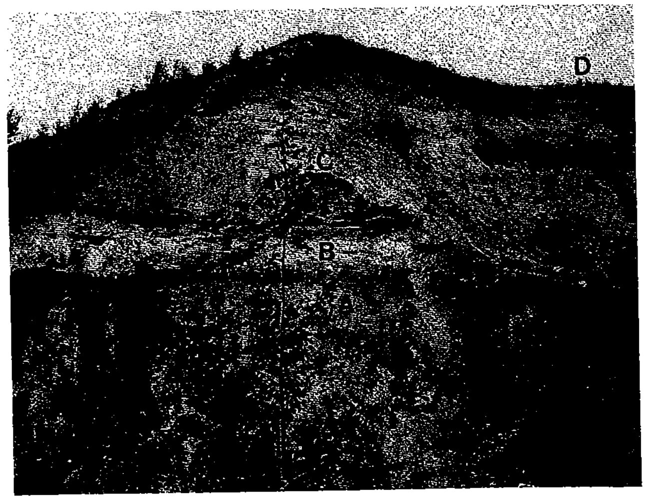

Figure 4.30. Sediments exposed at the Pierreville site: A, Pierreville varves; B, St. Pierre Sediments; C, lacustrine silts and sands; D, Gentilly Till. 200300-V

Table 4.10. Lithostratigraphic correlations

			Upper St. Lawrence Valley (MacClintock, 1958; Clark and Karrow, 1983)	Montréal area and southern Appalachian piedmont (LaSalle, 1981; Prichonnet, 1982a; Veillette and Nixon, 1984)	Central St. Lawrence Valley (Gadd, 1971; Occhietti, 1982; Lamothe, 1985; Parent, 1987)	Québec City and middle St. Lawrence estuary (Gadd, 1971; Karrow, 1957; LaSalle, 1984)	Southern Appalachians: Eastern Townships, upper Beauce (McDonald and Shilts, 1971)	Southern Appalachians: Bois-Francs, Beauce (Chauvin, 1979a)
QUATERNARY	Holocene		Lacustrine, fluvial, eolian, and organic sediments					
	Late Wisconsinan	Trois-Rivières Stade	Marine sediments					
			varved sediments	Lake Chambly varves	varved sediments		glacial Lake Vermont and Memphrémagog sediments	
			Till B (ex-Fort-Covington Till)	Saint-Jacques Till	Gentilly Till (several units)	Gentilly Till, Québec Till	Lennoxville Till	Thetford Mines Till
	Middle Wisconsinan		-varved sediment -intermediate till complex -varved sediment	Lac Châteauguay varves			Gayhurst Formation	Ruisseau Perry Formation (varved sediment)
	Early Wisconsinan		Till A (ex-Malone Till)	Ange-Gardien Till			Chaudière Till	Norbestos Till
			varved sediment		turbidites	Beaupré varves		
	Early Wisconsinan and/or Sangamonian and Illinoian	St. Pierre Interstade		St. Pierre Sediments	Saint-François-du-Lac Formation, St. Pierre Sediments	St. Pierre, Anse aux Hirondelles, and Donnacona sediments	Massawippi Formation	
		Nicolet Stade			Rivière aux Vaches Formation, Pierreville Formation, Deschaillons varves			
				Pointe-Fortune old till	Bécancour Till Odanak Till	Bécancour Till,Pointe Saint-Nicolas Till	Johnville Till	
					pre-Bécancour varved sediment		pre-Johnville sediments	

range on wood and peat from units correlated with the St. Pierre (Table 4.5) have been used to suggest that the St. Pierre Interval extended through much of the Middle Wisconsinan. LaSalle (1984) argued that finite dates from the Québec City area should be disregarded because they were obtained on samples contaminated by modern rootlets and also that the Québec Laboratory (QU) dates and other dates determined by means of the benzene method are unreliable in this dating range. As indicated in Table 4.5, finite radiocarbon dates have been obtained for wood and peat enclosed in nonglacial sediments exposed on Île aux Coudres. Brodeur and Allard (1985) correlated these sediments with the St. Pierre Sediments and, although they were concerned about the validity of the finite dates, tentatively suggested that the St. Pierre Interval might have extended into the Middle Wisconsinan. A nonfinite age has now been accepted for these deposits (M. Allard, Département de géographie, Université Laval, personal communication 1987). Consequently the deposits on Île aux Coudres can be correlated with the St. Pierre Sediments without requiring a change in the generally accepted time span of the St. Pierre Interval.

Lacustrine episode. Stratified silts and clayey silts deposited in a lake (lower part Saint-François-du-Lac formation; Lamothe, 1985) and sediments containing thermophilous pollen at Les Vieilles-Forges (Clet and Occhietti, 1988) overlie the fluvial St. Pierre Sediments. Pollen is abundant in these sediments with 7.6% thermophilous trees (*Tsuga, Tilia, Carya*) at Les Vieilles-Forges (Clet and Occhietti, 1988). The stratified silts grade upward into sands deposited as shallow water fans at Pierreville (upper part of Saint-François-du-Lac formation; Lamothe, 1985) and to prodelta and delta sands at Les Vieilles-Forges (Occhietti, 1980). Going by the highest occurrence of these sediments at Les Vieilles-Forges, this lake reached a level of at least 36 m above present sea level (Occhietti, 1982). The possible extent of this lake is shown (Fig. 4.31), but the reason for this rise in water level is at present not known.

Environmental context of the St. Pierre Interval. During the St. Pierre Interval, the drainage system in which the sediments were deposited was graded to a base level that was between 5 and 27 m above present sea level. The maximum elevation is based principally on the elevation of organic sediments on Île aux Coudres. The paleoenvironmental context implies cool "interstadial"? conditions which may have occurred during the latter cool part of the Sangamonian or early part of the Wisconsinan (Occhietti, 1980, 1982). During these times world sea level was 13 to 18 m below present. The easiest way to explain the discrepancy between the high base level of the sediments and the probable low sea level is isostatic downwarping of St. Lawrence Valley due to an ice load on the Canadian Shield and possibly accentuated by residual downwarping of the possible earlier stade.

In conclusion, cool climate, sedimentation on the floor of a broad valley, isostatic depression, and low relative sea level are all conditions postulated for the St. Pierre Interval. Conditions were possibly similar to those of the early Holocene (ca. 8 ka). At that time the Champlain Sea had regressed from St. Lawrence Valley and the river system was superposed on the flat valley floor which was covered by an open spruce forest (Richard, 1977). Ice still covered about half of Quebec and world mean sea level was around −13 to −15 m, according to the curve of Clark (1980).

Last glacial maximum

The succession of glacial events following the St. Pierre Interval was referred to the Gentilly Stade by Gadd (1971) and renamed Trois-Rivières Stade by Occhietti (1982). This latter is the term used throughout the rest of this report. Table 4.11 illustrates the events that occurred in different parts of the subregion during this episode.

The Trois-Rivières Stade ended at the time of construction of the St. Narcisse Moraine ca. 10.8 ka (LaSalle and Elson, 1975; Occhietti, 1977b, 1982), but there is no consensus on when this stade began. If sedimentation of the lacustrine sediments at Les Vieilles-Forges, which ended deposition of St. Pierre Sediments and heralded advance of the subsequent ice sheet, occurred ca. 75 ka, then this stade began either in the Early Wisconsinan (Dreimanis and Karrow, 1972; Dreimanis, 1977) at the beginning of oxygen isotope stage 4 or in the Middle Wisconsinan during oxygen isotope stage 3 (see discussion in Occhietti, 1982).

The Trois-Rivières Stade is represented by a single till in Ottawa Valley, middle and lower St. Lawrence Valley, and at the margin of the Laurentian Highlands. This unit has been referred to as the Gentilly Till, the Québec Till, and the Matawin Formation (Tables 4.6A, 4.10). Locally this unit may include a till of local lithology at the base and deposits of limited distribution that suggest local glacial fluctuations (Gadd, 1971; Occhietti, 1977b, 1980), but in general it is interpreted to represent a single glacial advance and retreat. In the Appalachians, the Trois-Rivières Stade has three parts: an early glaciation which deposited the Chaudière Till, a period of recession related to the Gayhurst Formation, and a final glaciation that deposited the Lennoxville Till (Tables 4.6C, 4.10). The nature of this stade in the upper St. Lawrence Valley is uncertain because more than one till has been recognized in several places (Table 4.6C) but, because St. Pierre Sediments generally are not present, it is not known whether the lower till predates the St. Pierre or whether it is equivalent to the Chaudière Till.

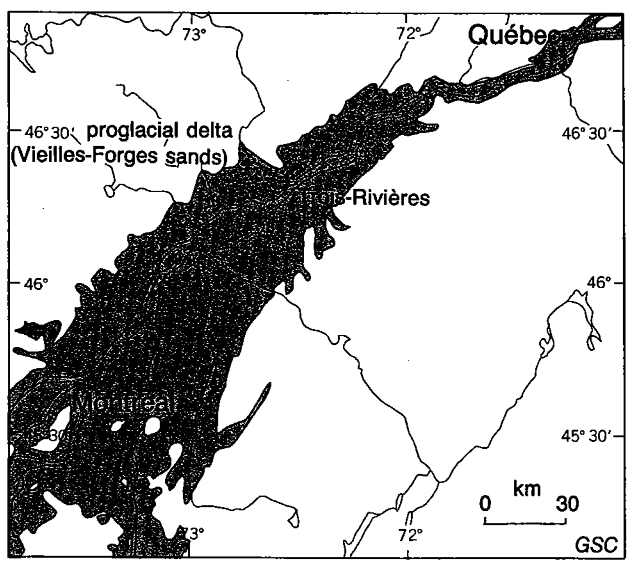

Figure 4.31. Possible extent of glacial lake in which Les Vieilles-Forges sands and silts were deposited at the end of the St. Pierre Interval.

During the Trois-Rivières Stade, it is likely that the dispersal centre of Laurentide ice in Quebec shifted westward between the initiation of glaciation and the major final glacial advances (Occhietti, 1983). It is also possible that one or more Appalachian ice sheets, first autonomous and then coalescent, developed on the high plateaus of Quebec, Maine, and probably Vermont (Fig. 4.32). St. Lawrence Valley functioned as a channel way for a number of glacial lobes and ice streams which moved in different directions at different times. The general flow pattern is apparently as follows: upstream from Québec City early Laurentide ice flow was towards the southwest, up St. Lawrence Valley. Appalachian ice probably also entered the valley at this time flowing north in the east and west in the west (Fig. 4.32). At the time of glacial maximum, flow from the Canadian Shield extended across St. Lawrence Valley into and over the Appalachians, through Lake Champlain Valley, and into the Adirondacks of northern New York. During deglaciation, drawdown into a calving bay, in the Gulf of St. Lawrence, caused reversal of flow in the Appalachians and St. Lawrence Valley and a flow pattern influenced by local topography at the southern edge of the Canadian Shield.

Early Trois-Rivières and Chaudière glaciations

Prior to the maximum of the glacial advance that preceded the Gayhurst lacustrine episode, the Laurentide Ice Sheet covered the entire St. Lawrence Valley and probably abutted against an ice sheet advancing out of the Appalachians. Several till fabrics from the lower part of the Gentilly Till and striations, possibly of this age, suggest a southwesterly flow (up St. Lawrence Valley) for at least the early part of this episode (Gadd, 1971; Occhietti, 1977b; M. Lamothe, Université du Québec à Montréal, personal communication, 1984; Fig.4.32). There is, however, no defined till unit in central St. Lawrence Valley that clearly can be correlated with an early advance as distinct from the maximum Late Wisconsinan advance.

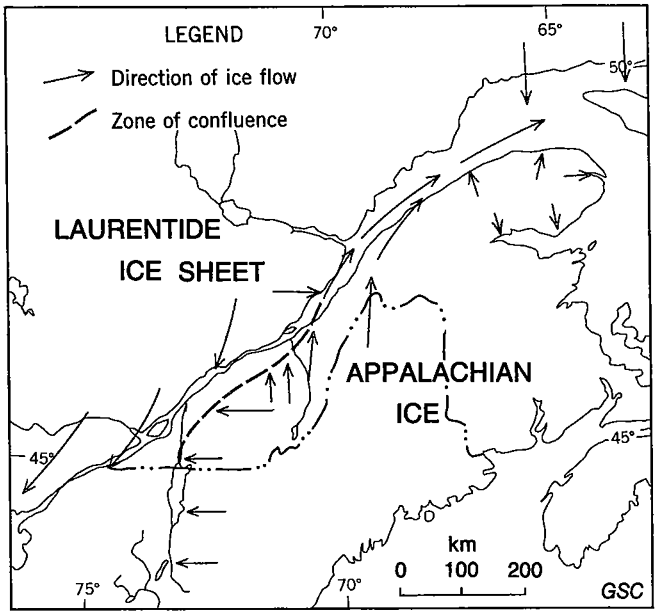

Figure 4.32. Ice flow during Early Wisconsinan buildup.

Table 4.11. Correlation of post-St. Pierre Interval events

Conventional Climatostratigraphy	Age	Southern Laurentians and central St. Lawrence Valley (Gadd, 1971; Occhietti, 1982)	Southern Quebec Appalachians (McDonald and Shilts, 1971; Lortie, 1975; Chauvin, 1979a, b; Shilts, 1981; Parent, 1987)	Upper St. Lawrence Valley, Montreal (MacClintock and Stewart, 1965; Prest and Hode-Keyser, 1977; Prichonnet, 1982a; Clark and Karrow, 1983; LaSalle, 1984)	Vermont, Lake Champlain (Stewart and MacClintock, 1969)	Middle estuary, Lower St. Lawrence, Chaudière Valley (Gadd, 1978a; LaSalle et al., 1979; Martineau et Corbeil, 1983)
	6 ka					
Shawinigan Stade		?Shawinigan Stade Saint-Narcisse episode	Champlain Sea			Goldthwait Sea
	11 ka		glacial Lake Vermont glacial Lake Memphrémagog Bois-Francs reversal	glacial Lake Chambly	glacial Lake Vermont	Notre-Dame Mountains reversal Lake Chaudière Valley
Trois-Rivières		Matawin Formation Till episode Gentilly Till episode	Lennoxville Till episode, *Laurentide*	Till B (ex-Fort Covington Till) episode	Burlington Till episode	Lennoxville Till episode, *Laurentide*
Stade			glacial Lake Gayhurst	glacial Lake Châteauguay	glacial lake	?
		? turbidite episode	Asbestos reversal *Laurentide* Chaudière Till episode *Appalachian*	intermediary Till complex Till A (ex-Malone Till) Ange-Gardien Till episode	Shelburne Till episode	Chaudière Till episode, *Appalachian*
St. Pierre Interstade	40 or 70 ka ?	fluvial and lacustrine episode (St. Pierre)	(Massawippi)			(Vallée-Jonction)

GSC

In the Appalachians on the other hand, Chaudière Till overlies the Massawippi Formation (St. Pierre equivalent) and underlies glacial lake sediments (Gayhurst Formation), all of which are overlain by the Late Wisconsinan Lennoxville Till. This package of two tills and intervening stratified sediments is correlated with the single Gentilly Till of central St. Lawrence Valley because both apparently occupy the same stratigraphic position, that is, overlie deposits of the St. Pierre Interval and underlie postglacial deposits. Lower parts of the Chaudière Till apparently were deposited by ice flowing northwestward and westward from an ice cap in the upper Beauce and northern Maine (Fig. 4.32; McDonald, 1967; Shilts, 1976, 1981; Parent, 1984a). Later flow, however, was from the northwest suggesting that the Appalachian ice was overwhelmed by ice moving southward from the Canadian Shield into the Eastern Townships (McDonald and Shilts, 1971). In contrast with this, Parent (1984a, 1987), reported evidence for occupation only by Appalachian ice in part of this region.

Partial deglaciation episode

During an interval of undetermined age, which is normally placed before the last glacial maximum, a large part of the southern Appalachians in Quebec was apparently deglaciated (McDonald and Shilts, 1971; Fig. 4.33). At this time the Laurentide Ice Sheet apparently remained in central St. Lawrence Valley blocking drainage from the Appalachians and creating glacial Lake Gayhurst. This lake existed for at least 4 ka because this number of varves have been counted in the Gayhurst Formation (Shilts, 1981). This interval may be equivalent to the Plum Point Interstade, between 32 and 23 ka, or less probably to the Port Talbot Interstade, between 53 and 36 ka (Dreimanis and Karrow, 1972). A nonfinite date on disseminated organic matter of >20 ka (McDonald and Shilts, 1971) provides a minimum age for the Gayhurst Formation.

The southern Great Lakes basins are generally considered to have been ice free at this time (Karrow, 1984, 1989). Upper St. Lawrence Valley and the Lake Champlain depression, are also generally considered to have been ice free, but there is no direct stratigraphic proof of this. Deposits in this region that might be related to a period of Middle Wisconsinan deglaciation are the glaciolacustrine sediments intercalated between Shelbourne and upper Burlington tills in the Lake Champlain trough; Lac Châteauguay sediments south of Montréal (LaSalle, 1984); the sediments between the Ange-Gardien Till and the upper till in the Granby area (Prichonnet, 1984a); and varves lying in the upper part of the "middle till complex" of the Montréal area (Prest and Hode-Keyser, 1977). These correlations give a paleogeographic picture for this deglacial episode which may have been similar to that at the end of the Late Wisconsinan just prior to incursion of the Champlain Sea (Fig. 4.33).

Late Wisconsinan glacial maximum

The surface tills of the area (upper part of Gentilly, Lennoxville, and their equivalents, Tables 4.6A, C) are correlated with the Late Wisconsinan maximum and the deglaciation which followed. These units all contain evidence of a general flow from the Canadian Shield towards the southeast and south (Fig. 4.34a). During this advance Laurentide ice covered Gaspésie (David and Lebuis, 1985) and filled the Great Lakes basin (Karrow, this chapter, 1989); the ice margin lay off the coast of Maine and on Long Island. The ice may have reached its maximum extent on Long Island before 21.3 ka (Sirkin, 1981) and had begun to retreat from its margin in northern New Jersey by 18.5 ka (Cotter et al., 1985).

Two main factors, topography and development of a calving bay (or of a major ice stream) in the Gulf of St. Lawrence, influenced ice dynamics during retreat. The calving bay cut into the Laurentide Ice Sheet, producing a saddle over St. Lawrence Valley (Thomas, 1977; Lebuis and David, 1977; LaSalle et al., 1977a, b), and induced a northerly gradient on the part of the Laurentide Ice Sheet covering the Appalachians of Quebec and northwestern Maine (Lowell, 1985; Fig. 4.34b). This gradient caused a brief reversal of flow which transported little debris but produced an abundance of north and westward trending flow features in an area inside the Appalachian front (Lamarche, 1971, 1974; Gauthier, 1975; Lortie, 1976; Rencz and Shilts, 1980) reaching from Rivière Saint-François to Gaspésie. Ice thickness was appreciably greater over the valleys of the Appalachians than it was over the adjacent highlands. Consequently, late flow followed the valleys, and during downwasting, highlands appeared through the ice first, leaving thick stagnant ice tongues in the valleys (Gerath et al., 1985). This resulted in a complex pattern of ice marginal features, stagnation deposits, and local glacial lakes which are difficult to correlate from one valley to the next. This in turn has left considerable leeway for interpretation and has led to controversy about the paleogeography during deglaciation (Gadd, 1983, 1984; Parent, 1984b; Dubois et al., 1984).

As much as 5 ka may have passed between retreat from the terminal moraine and the start of the final deglaciation of the Appalachians of Quebec; this interval included the Erie Interstade, Port Bruce Stade, Mackinaw Interstade, and much of the Huron Stade (Karrow, 1989). Many recessional and advance moraines were built in Hudson-Champlain valley (Connally and Sirkin, 1973); the calving bay in the Gulf of St. Lawrence had separated ice in Gaspésie from the main ice sheet on the Quebec north shore; and ice flow in the Quebec Appalachians had reversed and

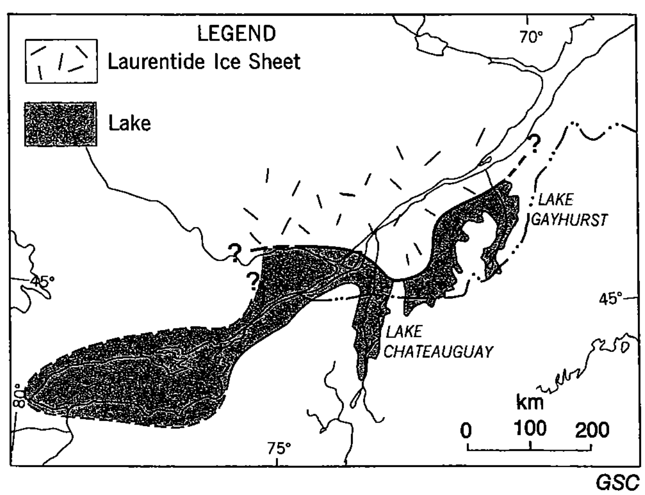

Figure 4.33. Paleogeography during maximum Middle Wisconsinan ice recession.

the Appalachian remnant had stagnated as this ice became too thin to sustain regional flow. After this time, ice retreat involved: extension of the Gulf of St. Lawrence calving bay, retreat of stagnant ice in the Appalachians, retreat of the ice from the Lake Ontario basin and the upper St. Lawrence Valley, and retreat across central St. Lawrence Valley.

Progress of the calving bay

Considerable controversy surrounds timing of development and the ultimate extension of the Gulf of St. Lawrence calving bay. Most workers agree that such a feature occupied St. Lawrence Valley as far upstream as Québec City but there is no unanimity on its speed and direction of propagation from that point. The chronology of this major feature of deglaciation is based on the earliest dates of marine incursion of various parts of the St. Lawrence system. These dates indicate that by 13.4 ka the calving bay had passed Sainte-Marthe-de-Gaspé and had reached Trois-Pistoles (Locat, 1977; David and Lebuis, 1985). By 12.4 ka it had passed Québec City and, according to Gadd (1980b) and Richard (1975b), reached Ottawa by 12.7 ka. This is, however, based on a controversial date from Clayton, Ontario (GSC-1859) which has been discounted by Karrow et al. (1975), Karrow (1981b), and Hillaire-Marcel (1981b); a subsequent accelerator date on this same material gave an age of 12 180 ± 90 BP (TO-245). In addition, Karrow (1981b) disputed the concept of a calving bay entering Ottawa Valley and, based on Great Lakes chronology, stated that marine waters could not have reached the western basin of the Champlain Sea before the end of Lake Iroquois (later than 12 ka). Additional discussion of this controversy is included in the *Chronology* subsection of the *Postglacial marine episode.*

Ice retreat in the Quebec Appalachians. As mentioned above, the ice retreat picture in the Appalachians was complex and lacks good chronological control. In the Upper Beauce region, ice contact features indicate a retreat of the glacial front towards the north-northwest, transverse to Chaudière Valley (Gadd, 1978a). West of this valley, on the low plateaus of the Beauce and Bois-Francs regions, the ice mass in the Appalachians appears to have acted independently and, according to glacial striation patterns, to have dissipated in a complex fashion (Fig. 4.34b; Lortie, 1976). This probably explains the ablation till in the Thetford Mines region (Chauvin, 1979b), which suggests in situ melting of a stagnant ice mass, and the absence of well differentiated recessional moraines as has been suggested by M. Parent (Geological Survey of Canada, personal communication, 1985). Farther south, in the Lac Mégantic area and in the Sherbrooke region of the Appalachians, the northward retreating ice front was oriented more or less east-west but was strongly controlled by local topography (Shilts, 1981; Fig. 4.23). Ice flowed towards the south-southeast and, between 13.5 and 12.5 ka, built the Cherry River Moraine (McDonald, 1967), Stoke Mountain interlobate moraine (McDonald, 1967; Clément and Parent, 1977), Ditchfield, Mégantic, La Guadeloupe (Shilts, 1981); and Tingwick-Ulverton (Parent, 1987) morainic systems. Following this time topography strongly controlled flow of the remaining ice masses, notably on the Appalachian piedmont to the east of the Lake Champlain-Rivière Richelieu axis (Prichonnet, 1977, 1982, b, 1984a). A series of small glacial lakes (Clément and Parent, 1977; Larocque et al., 1983a, b) and the larger glacial Lake Memphrémagog formed between the ice front and divides in west and north draining valleys during retreat of the glacier (McDonald, 1967; Boissonnault and Gwyn, 1983; Parent, 1984b).

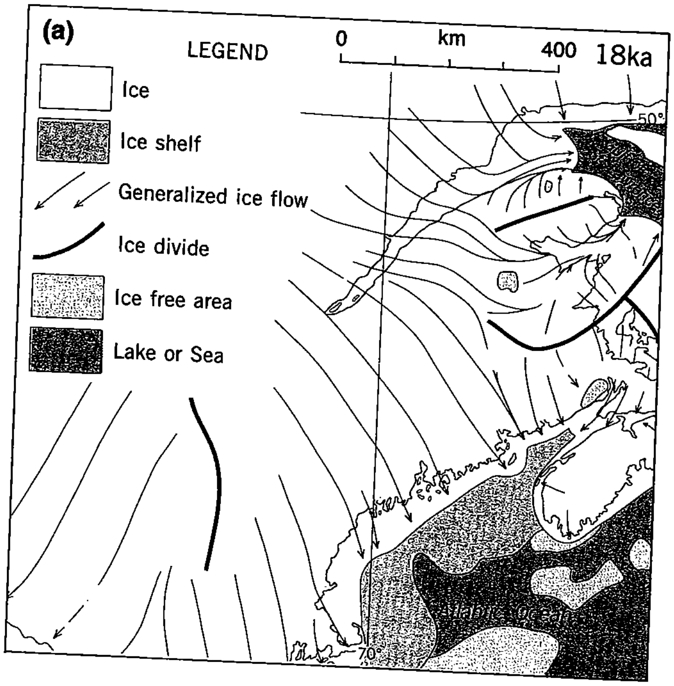

Figure 4.34a. Ice flow at Late Wisconsinan maximum.

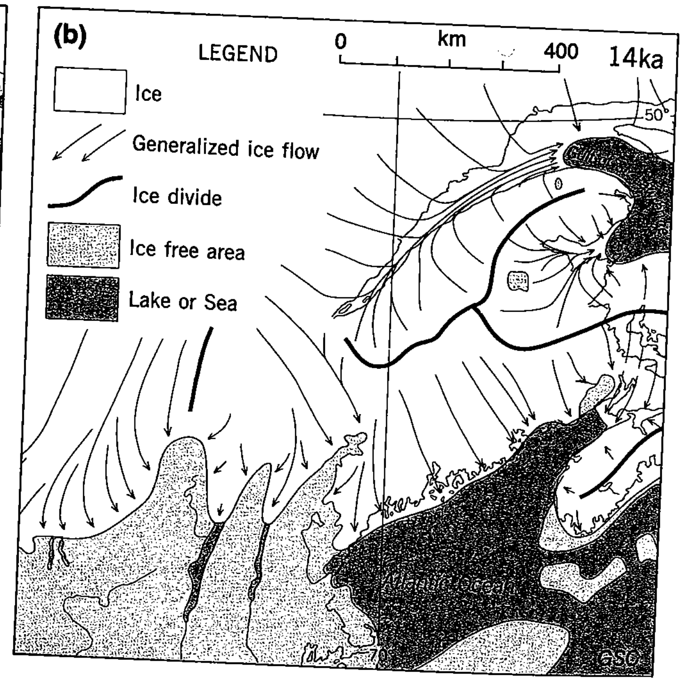

Figure 4.34b. Ice flow during inception of a calving bay in the Gulf of St. Lawrence.

Retreat from Lake Ontario basin and upper St. Lawrence Valley. Distinct patterns of flow features in the upper St. Lawrence Valley indicate that several ice lobes developed during deglaciation (Gadd, 1980a, b). One lobe flowed southward into the Lake Champlain-Hudson trough. Glacial lakes, draining southward into Hudson River, occupied the valley south of this lobe and expanded northward as the ice retreated (Connally and Sirkin, 1973; Fig. 4.35a). The last glacial lake was the Fort Ann phase of glacial Lake Vermont; this ended with invasion of the Champlain Sea which probably occurred ca. 12 ka (Cronin, 1979b).

Late glacial south and southwest flowing ice occupied upper St. Lawrence Valley between Montréal and the Frontenac Arch. This ice abutted against the Adirondack Mountains, to the south, precluding glacial lakes from this segment of the valley during most of deglaciation. In addition, it separated lakes in the Ontario basin from those in the Lake Champlain basin almost until the time of marine invasion.

A major flow of ice extended south from the vicinity of Ottawa and swung southwest into the Lake Ontario basin. As this lobe retreated, Lake Iroquois developed and expanded to the northeast (Muller and Prest, 1985). Lake Iroquois, which emptied east into Mohawk River at Rome, New York, was in existence ca. 12.5 ka. Ice retreat from the Covey Hill area permitted drawdown of Lake Iroquois and developed a single, southward draining, water body joining the Lake Ontario basin with the Lake Champlain basin. This confluent phase combined the Fort Ann phase of glacial Lake Vermont in the Champlain trough, Lake Chambly south of Montréal (LaSalle, 1981), and Belleville phase of the eastern Ontario basin (Fig. 4.35b). Anderson et al. (1985) used the presence of freshwater ostracodes, mostly *Candona subtriangulata*, in sediments overlying glacial deposits to suggest that this lake extended into the Ottawa area. Rodrigues and Richard (1986) are not certain that a single lake occupied the entire Ottawa-upper St. Lawrence region. The water level was lowered and the fresh water was replaced by marine when ice retreat in middle St. Lawrence Valley permitted the Champlain Sea to invade the area, probably about 12 ka.

To the west of Ottawa ice flowed southward across Ottawa Valley and over the Algonquin Highlands towards the Ontario basin (Fig. 4.35a). Early during retreat this ice separated from that in the Lake Ontario basin, and the Oak Ridges Moraine formed between the two lobes. When this ice thinned to the point where it could no longer overtop the Algonquin Highlands, flow was diverted southeastward to form a local Ottawa Valley ice lobe which left a series of small moraines as it retreated up valley from Renfrew (Gadd, 1980b; Barnett and Kennedy, 1987). The chronology of deglaciation of Ottawa Valley is not well dated but the Champlain Sea had reached Westmeath (20 km east of Pembroke) by 11 000 ± 160 BP (GSC-1664, Lowdon and Blake, 1979), and ice had receded from Ottawa Valley downstream from Lake Timiskaming so that drainage from the Great Lakes could use the North Bay outlet before 10.1 ka (Harrison, 1972).

Retreat from central St. Lawrence Valley. In central St. Lawrence Valley several of the Monteregian Hills became nunataks prior to 12.5 ka and the Champlain Sea apparently invaded the south shore of St. Lawrence Valley a few centuries later (Prichonnet, 1977). As the ice retreated across the lowlands there is no evidence of significant stillstands or readvances. Scattered glaciofluvial deposits and moraine ridges, however, suggest deposition was occurring at the margin of a north to northwest retreating arcuate ice

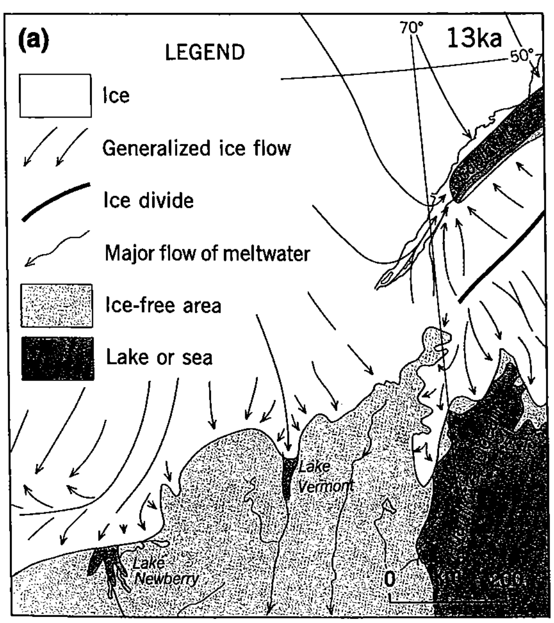

Figure 4.35a. Pattern of ice flow when front had receded to approximately Quebec-United States border.

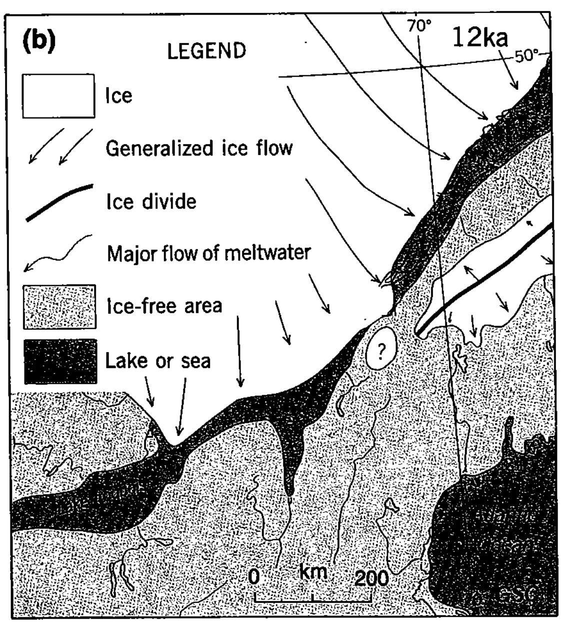

Figure 4.35b. Paleogeography immediately prior to invasion of Champlain Sea into upper St. Lawrence Valley.

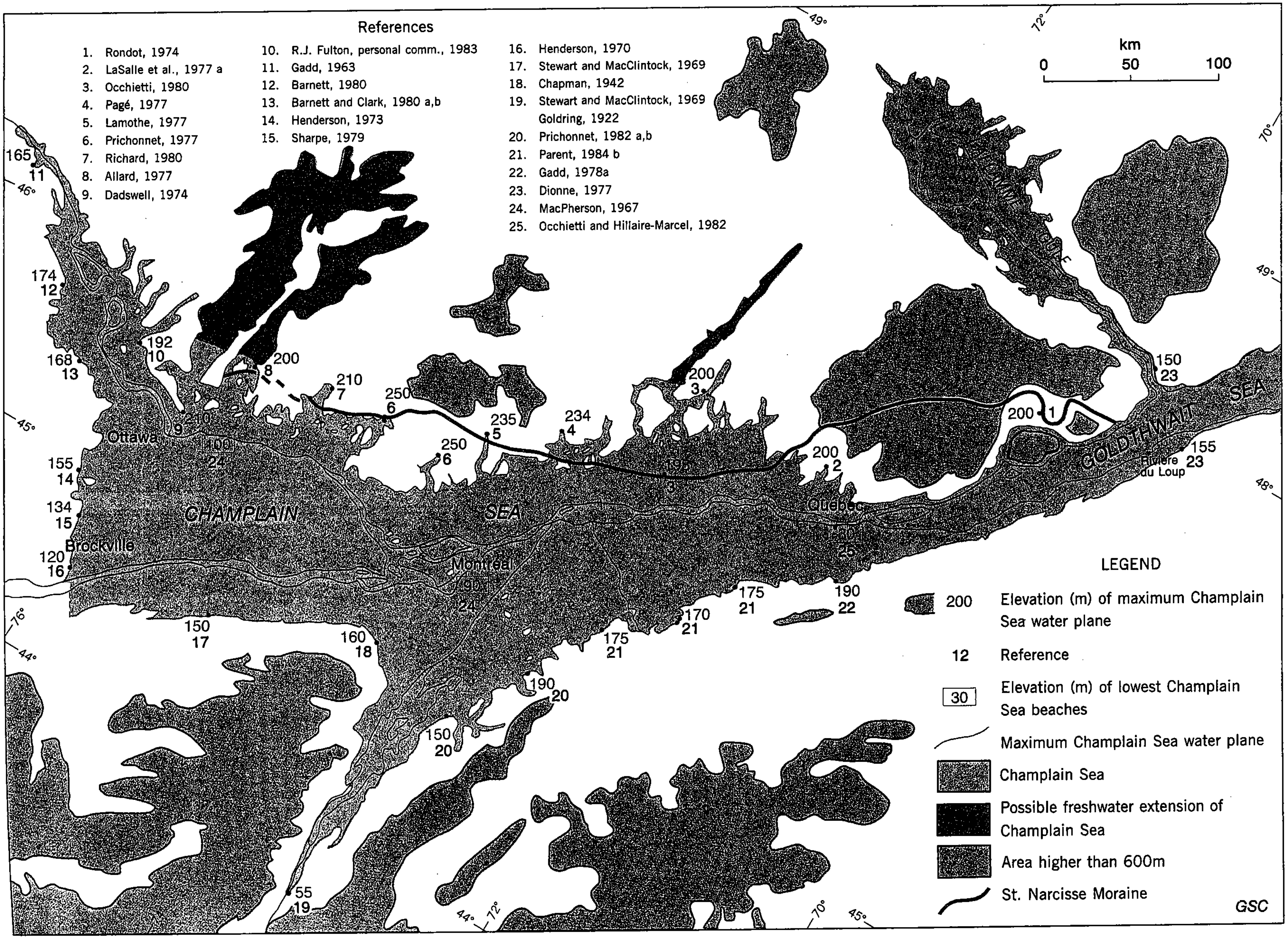

Figure 4.36. Extent and maximum water plane of the Champlain Sea.

front (Prichonnet et al., 1982b; Prichonnet, 1984b). Ice recession halted near the margin of the Canadian Shield north and northwest of the valley and at least locally readvanced, overriding marine sediments, to build the St. Narcisse Moraine (Parry and Macpherson, 1964; Fig. 4.36) between 11 and 10.6 ka (Occhietti, 1980). This period of moraine building and the following deglaciation has been referred to as the Shawinigan Stade (Occhietti, 1980; Table 4.11). According to LaSalle and Elson (1975) this moraine may represent a period of ice margin stability that was climatically controlled. Hillaire-Marcel et al. (1981) on the other hand referred to the St. Narcisse Moraine as a re-equilibrium feature formed where the ice became anchored following rapid retreat within the Champlain Sea. The ice left St. Lawrence Valley for the last time when it retreated from the St. Narcisse Moraine. The ice had apparently retreated from the St. Narcisse Moraine and from the Lac Saint-Jean area to the north, where marine waters had breached the St. Narcisse Moraine and occupied the Lac Saint-Jean basin by 10.3 ka (LaSalle and Tremblay, 1978; Vincent, 1989).

Postglacial marine episode

As described above, areas adjacent to the Gulf of St. Lawrence, St. Lawrence Valley, and lower Ottawa Valley were submerged by the sea at the time of the Late Wisconsinan deglaciation. The postglacial sea in the Gulf of St. Lawrence downstream from Québec City is referred to as the Goldthwait Sea. The ephemeral sea which occupied as much as 55 000 km^2 of valley system upstream from Québec City between 12 and 9.5 ka is called the Champlain Sea (Elson, 1969a; Fig. 4.36).

Lithostratigraphy

The sediments of the Champlain Sea have already been described in the section on marine sediments. The lithostratigraphic suite within the Champlain Sea basin includes sediments deposited during ice retreat, glaciolacustrine and glaciomarine sediments, followed by quiet or deep water sediments and by marine regression sediments. The glacial retreat and quiet water sediments are time transgressive from east to west and from south to north; the regression sequence is time transgressive from the margins towards the centre of the basin. Mixed facies of the glacial margin and of marine incursion were deposited in a narrow zone near the retreating ice front. Littoral and offlap sediments were deposited at the retreating margins of the sea as the basin shrank because of glacial isostatic uplift and sediment deposition.

Biostratigraphy

The Champlain Sea sediments contain a wide variety of marine vertebrates and invertebrates which attest to the variety of ecological niches present (Table 4.8). Cold water communities tolerant of salinity variations followed the retreat of the ice; cold euryhaline communities were associated with the main period of submergence; littoral, sublittoral, and brackish communities developed along the margins of the basin. This variety of communities is a complete reconsideration of the *Hiatella arctica* and *Mya arenaria* phases proposed by Elson and Elson (1959) which do not reflect the total biostratigraphy of the basin (Hillaire-Marcel, 1979; Occhietti, 1980; Rodrigues and Richard, 1983, 1985, 1986). The picture of evolving biostratigraphic zonation in response to environmental change in the basin as established by macrofossils (Hillaire-Marcel, 1980; Rodrigues and Richard, 1983), by ostracodes (Gunther and Hunt, 1977; Cronin, 1977a, b, 1979a, 1981; Rodrigues and Richard, 1986), by foraminifera (Cronin, 1977a, 1979 a, b; Guilbault, 1980; Corliss et al., 1982; Rodrigues and Richard, 1986), and by diatoms (Lortie, 1983; Lortie and Guilbault, 1984) are all similar. This evolution follows the sequence of type communities defined by Hillaire-Marcel (1980; Fig. 4.29, Table 4.8) and indicates the gradual change from ice proximal facies to deep water facies to shallow water facies.

Water conditions in the Champlain Sea

Analysis of the stable isotopes of ^{18}O and ^{13}C, supported by biostratigraphy, have permitted an analysis of the water conditions of the marine basin (Hillaire-Marcel, 1977, 1981a; Corliss et al., 1982). The closed basin of the Champlain Sea received substantial amounts of water from land and was characterized by steep vertical temperature and salinity gradients (Hillaire-Marcel, 1979). During the middle part of the marine episode, the water of the basin was stratified, with cold, saline water at depth and brackish water with seasonal temperature variations near the surface. Species living in the deep water, particularly *Balanus hameri* and *Portlandia arctica*, have high (positive) isotopic values (Fig. 4.37). Littoral shells, such as *Macoma balthica*, *Mya arenaria* and *Mytilus edulis*, on the other hand, have much lower (negative) isotopic values, which are related to temperature and to dilution of ocean water by glacial meltwater depleted in ^{18}O (Hillaire-Marcel, 1981a). As uplift occurred, the depth of water decreased and the proportion of fresh water increased. The general oceanographic conditions are interpreted as being similar to those of James Bay today, with salinity values of 10 to 30‰ and temperatures between −1 and 8°C.

Chronology

Based on fossil-bearing diamicton at Petite-Matane (south shore of the St. Lawrence about 100 km northeast of Rimouski), Lebuis and David (1977) have postulated that a glaciomarine phase existed between Laurentide and Appalachian ice sheets in an area downstream from Trois-Pistoles. The age of the shells from this diamicton, and from shells in marine deposits at other sites between Petite-Matane and Trois-Pistoles-Saint-Fabien (13.4 and 13.4 ka,

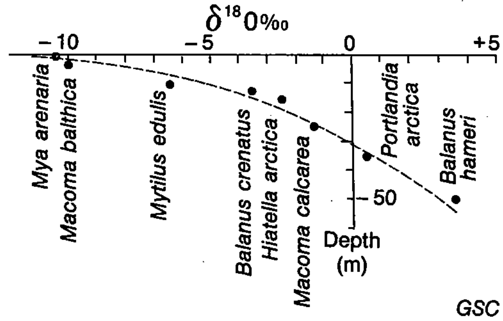

Figure 4.37. Oxygen isotope content of Champlain Sea shells related to water depth (Hillaire-Marcel, 1979).

Table 4.12; Locat, 1977) suggests inception of marine conditions in that area around 13.5 ka . The opening of the western arm of the Goldthwait Sea into the middle estuary, upstream from Trois-Pistoles, must have occurred by around 12.8 ka, according to a date from shells of *Portlandia arctica* from the Saint-Antonin Moraine at Trois-Pistoles (Table 4.12; Lee, 1962).

The timing of invasion of the Champlain Sea is controversial. Radiocarbon dates of 12.7 to 12.1 ka on marine shells in the Ottawa area (Table 4.12; Rodrigues and Richard, 1986), a shell date of 12.5 ka from near Saint-Dominique (Prichonnet, 1982a), and two dates on gyttja from Mont Saint-Bruno (LaSalle, 1966; Terasmae, 1968) are from 200 to 800 years older than dates on similar materials from surrounding areas. Gadd (1980b) proposed rapid extension of a calving bay, limited to the deepest part of the valley, as a means of getting marine waters into a relatively limited area near Ottawa at a time significantly earlier than they arrived in the Montréal and the upper St. Lawrence area. Hillaire-Marcel et al. (1979) and Karrow (1981b) proposed that the ^{14}C equilibrium of the Champlain Sea waters was upset by incorporation of old carbon derived from meltwaters, and consequently the shells provide dates older than their actual ages. It is also proposed that aging of the sea water during the 400 to 600 km flow from the Atlantic into the closed basin may in part be responsible for "old" dates (Mangerud and Gulliksen, 1975; Hillaire-Marcel, 1981b).

It is the author's view that marine incursion at ca. 12 ka best fits available evidence. Several authors have proposed extensive development of glacial lakes in the southern part of Ottawa and upper St. Lawrence valleys prior to Champlain Sea incursion (Prest, 1970; Anderson et al., 1985; Parent et al., 1985; Muller and Prest, 1985). They placed the ice margin at the time of invasion on a line running approximately from Ottawa to Bois-Francs (Fig. 4.35b). Anderson (1987) used pollen stratigraphy of Champlain Sea sediments to suggest that the Champlain Sea probably reached the Ottawa area about 11.7 ka. In addition, Karrow (1981b) and Karrow et al. (1975) argued that the Champlain Sea formed in the upper St. Lawrence after Lake Iroquois had drained, and because Lake Iroquois probably did not drain until shortly after 12 ka, the Champlain Sea could not have reached Ottawa earlier. Dates on shells from the upper St. Lawrence-Lake Champlain valleys suggest that the Champlain Sea reached its southern limit about 12 ka (Table 4.12).

Table 4.12. Radiocarbon ages for marine shells referred to in text. (A more complete list of dates for the western basin of the Champlain Sea may be found in Rodrigues and Richard, 1985.)

Area	Age years BP	Laboratory number	Species	Elevation m	Locality	Reference	Comments
Lower estuary	13 360 ± 320	QU-264	*Hiatella arctica*	98-126	Saint-Donat, Quebec	Locat, 1977	
	13 390 ± 690	QU-271	*Hiatella arctica*	138-155	Saint-Fabien, Quebec	Locat, 1977	
Middle estuary	12 720 ± 170	GSC-102	*Portlandia arctica*	167	Trois-Pistoles, Quebec	Gadd et al., 1972a	Minimum age for Goldthwait Sea in middle estuary
Québec City	12 400 ± 160	GSC-1533	*Portlandia arctica*	109	Charlesbourg, Quebec	Gadd et al., 1972a	Beginning of Champlain Sea in Québec City area
	12 230 ± 250	QU-93			Saint-Henri-de-Lévis, Quebec	LaSalle, in Richard, 1978b	
South shore of central St. Lawrence Valley	12 000 ± 230	GSC-936	several species	121	L'Avenir, Quebec	Lowdon and Blake, 1970	Beginning of Champlain Sea in main basin
	12 480 ± 240	QC-475	*Mya* sp.	90	Saint-Dominique, Quebec	Prichonnet, 1982a	Date not consistent with species and elevation: new date 11 250 ± 100 BP, UQ-1429 (Occhietti, unpub.) on *Mya arenaria* same site but slightly different position
Western part of Champlain Sea basin	12 700 ± 100	GSC-2151	*Macoma balthica*	168	Clayton, Lanark County, Ontario	Richard, 1978b	Date verified twice but on same material as T0-245 (below)
	12 180 ± 90	T0-245	*Macoma balthica*	168	Clayton	unpublished	
	12 200 ± 160	GSC-1646	*Macoma balthica*	192	Cantley, Gatineau County, Quebec	Lowdon and Blake, 1973	
	12 100 ± 100	GSC-3110	*Macoma balthica*	170	White Lake, Renfrew County, Ontario	Rodrigues and Richard, 1983	
	12 000 ± 200	—			Massena, New York	Kirkland and Coates, 1977	Lab number not available
	11 900 ± 200	GSC-1772	*Macoma balthica*	176	Martindale, Gatineau County, Quebec	Lowdon and Blake, 1973	
	11 900 ± 120	GSC-2338	*Macoma balthica*	101	Peru, New York	Lowdon and Blake, 1979; Cronin, 1979b	
	11 900 ± 100	GSC-3767	*Portlandia arctica*	76	Sparrowhawk Point, New York	Rodrigues and Richard, 1985	
	11 800 ± 210	GSC-1013	several species	104	Maitland, Ontario	Lowdon and Blake, 1970	
	11 800 ± 100	GSC-3523	*Macoma balthica*	120	Merrickville, Grenville County, Ontario	Rodrigues and Richard, 1985	
	11 800 ± 100	GSC-2366	*Macoma balthica*	96	Plattsburg, New York	Lowdon and Blake, 1979; Cronin, 1979b	
North shore of central St. Lawrence Valley	11 300 ± 160	GSC-1729	*Portlandia arctica*	81	Rivière la Fourche, Quebec	Occhietti, 1976	Glaciomarine sediments predating St. Narcisse event
Québec	9 355 ± 185	UQ-64	*Hiatella arctica*	64	Saint-Nicolas	Occhietti and Hillaire-Marcel, 1982	LaSalle (1984) reported dates as young as 9730 ± 190 BP (GSC-1726), from this same site

The oldest marine shell date at Yamachiche on the north side of central St. Lawrence Valley is 11.3 ka (Occhietti, 1980). The distance across valley from Bois-Francs to Yamachiche is about 65 km. If the Champlain Sea breached the ice dam at Bois-Francs at 12 ka, then 700 years were required for retreat across the valley (a rate of ca. 90 m/a).

Isostatic uplift caused a progressive shoaling which in turn pushed the lower highly saline waters from the Champlain Sea basin. This led to the formation of a shallow lake upstream from Québec ca. 10 ka (*Lampsilis* Lake Phase of Elson, 1962, 1969b) but the youngest marine fauna in the Québec region at Saint-Nicolas has provided dates as young as 9.4 ka (Occhietti and Hillaire-Marcel, 1982).

Marine limits and emergence

The age and level of marine limit vary throughout the basin but there is insufficient chronological information to establish consistent patterns (Fig. 4.36). About the only general comment that can be made is that the highest limits are on the northern margin of the basin, nearest the centre of ice loading.

Old shorelines, marine terraces, and terrace scarps provide evidence that emergence rates were variable and that uplift included periods of little relative sea level change. Unfortunately few of the small number of regional emergence curves available are complete (Elson, 1969a; Dionne, 1972a; Hillaire-Marcel, 1974, 1979; Locat, 1977; Fulton and Richard, 1987; Fig. 4.38). What data are available suggest that emergence was at times rapid, reaching rates of 115 m/ka.

Postglacial and postmarine episode

The beginning of the postglacial nonmarine history of St. Lawrence Valley and the adjacent Appalachians is time transgressive. It began as areas were deglaciated and as glacial lakes and postglacial seas drained. The ice disappeared from areas of the Appalachians as early as 13 ka but remained in some valleys north of the St. Narcisse Moraine until after 10.5 ka. Glacial lakes in the area drained when ice retreat opened St. Lawrence Valley to the Champlain Sea ca. 12 ka. Crustal rebound caused emergence of marine inundated areas, beginning at the time of marine submergence of the Gaspésie coast about 13.5 ka and ending with retreat of marine waters from the Québec City area before 9 ka.

Vegetation colonization and evolution

The postglacial history of the vegetation of St. Lawrence Valley and adjacent Appalachians has been reconstructed by analysis of pollen and macrofossils from the bottom of lakes and peat bogs (Potzger and Courtemanche, 1956; LaSalle, 1966; Terasmae and LaSalle, 1968; Richard, 1971, 1973, 1975a, 1978a; Richard and Poulin, 1976; Mott, 1977; Savoie and Richard, 1979; Mott and Farley-Gill, 1981; Anderson, 1987; Table 4.13). Plant colonization prior to the Holocene was influenced by the proximity of the ice front, by the dampening effect that the large, cold Champlain Sea had on climate, by the migration barrier formed by the Champlain Sea, and to a lesser degree by changes in climate. Subsequent vegetation development depended on climate and regional and local conditions.

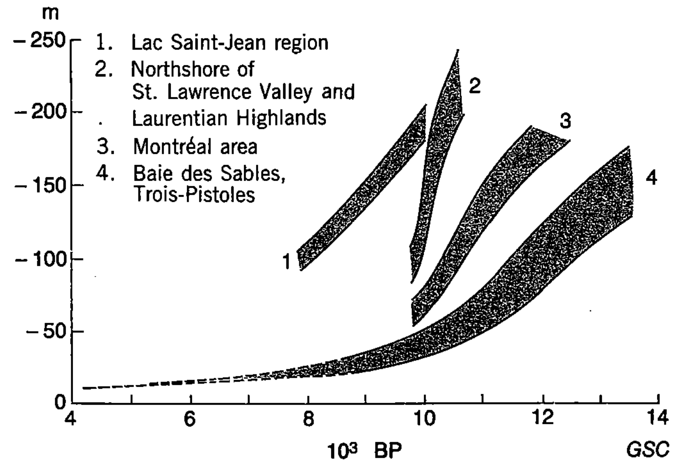

Figure 4.38. Shoreline relation diagrams for Champlain Sea.

The same general vegetation sequence may be observed in all regions. The Mont Shefford succession (Richard, 1978a) may be taken as an example of southern regions. It comprises a periglacial desert at the base, then a shrub tundra which seems to have lasted 400 years and ended 11 ka. Afforestation led to open spruce woods, dominated by *Picea mariana* and *Populus tremuloides*, lasting about a thousand years. This was succeeded by a spruce forest including white birch, which persisted from the early Holocene to around 7.5 ka, followed by a climax maple forest. Despite what is indicated by this example, locally the tundra period may have lasted for some time, due to the persistence of stagnant ice, the presence of glacial lakes, and the slow migration of vegetation (Richard, 1977). The modern climax vegetation zones in St. Lawrence Valley and the adjacent Appalachians are distributed according to a latitudinal gradient, ranging from maple forest with hickory in the south, to maple forest with basswood, to maple forest with yellow birch and, farther north, spruce forest with yellow birch and white birch (Grandtner, 1966).

Landforms and sediments related to evolution of drainage

Since ice retreat, drainage systems have become incised. In areas where streams have been superimposed on Quaternary sediments, series of terraces have been formed. Where streams have been superimposed on bedrock, channels cut in rock with abundant rapids and waterfalls have resulted.

In the southern Quebec Appalachians region, notable fluvial terraces have been formed in the Chaudière and Saint-François river valleys. Charny Falls on Chaudière River is one example of a locality where the river has been superimposed on rock. In other places old valleys, such as the buried valley of Rivière Eaton northeast of Sherbrooke (Dubois, 1973), have not been reoccupied by streams.

In the Montréal area of St. Lawrence Valley, Lampsilis Lake (Elson, 1962) developed as the Champlain Sea regressed. This lake existed ca. 9.8 ka (Richard, 1978b) and was part of an extensive, evolving lacustrine and fluvial system that was slowly but continually downcutting and prograding seaward. Present day lakes Saint-Louis, Saint-François, and Saint-Pierre are lake basin remnants of this system. Extensive terrace systems developed as the lakes were filled and paleochannel systems were left behind by incising streams (MacPherson, 1967). Peat bogs and marshes developed in many of the abandoned channels. Dating of the lowest organic bed of peat bogs on high terraces puts the minimum age for marine regression and high terrace abandonment in central St. Lawrence Valley at ca. 9.5 ka (Terasmae, 1960b).

Extensive and locally thick sandy and silty fluvial sediments overlie marine deposits in lower Ottawa Valley (Gadd, 1986). These sediments were deposited in a deltaic system that prograded from Petawawa through to St. Lawrence River. The deposited materials were of several origins: glacial meltwaters flowing directly from the receding ice front, drainage from the glacial Great Lakes, drainage from glacial lakes to the north (Vincent, 1989), and erosion of marine and deltaic sediments exposed as isostatic uplift raised recently deposited sediments above base level. *Lampsilis* shells locally occurring near the top of this succession indicate that freshwater conditions dominated in later periods of delta building (Rodrigues and Richard, 1983). Dates on *Lampsilis* from Ottawa Valley suggest freshwater conditions in that area as early as ca. 10.3 ka. Marine shells at higher elevations in this same area have, however, been dated as young as 10 ka and consequently there appears to be a problem with shell dates in this region (Fulton and Richard, 1987).

Several major deltas are still being formed in the region. Several rivers join the St. Lawrence, at the head of Lac Saint-Pierre and have built a delta consisting of several islands. Rivière Saint-Maurice is building a delta of three islands at its mouth, from which the city of Trois-Rivières takes its name. In addition at low tide, mud flats as much as 1000 m wide occupy the shore zone of the present middle estuary of the St. Lawrence and clay, silt, and sandy mud are being transported within the St. Lawrence estuary (D'Anglejean, 1971, 1981). All shores of the present system of lakes and rivers are affected by the "glaciel" phenomena (Dionne, 1969). Spring ice breakup sweeps the banks bare of vegetation and the ice transports blocks and other debris downstream.

Periglacial processes

Ice-wedge casts, cryoturbation, and niveo-eolian accumulations have been identified in the Appalachians and St. Lawrence Valley (Hamelin, 1961; Gangloff, 1970, 1973; Dionne, 1971; Cailleux, 1972). These structures and accumulations are characteristic of periglacial processes developed under conditions in which there was discontinuous permafrost. This activity is compatible with the rigorous climate, indicated by the presence of tundra vegetation as late as 11 ka on Mont Shefford and 10 ka in the Charlevoix area (Richard and Poulin, 1976; Richard, 1978).

Mass movements

During recession of the sea and during development of drainage channels in the Champlain Sea basin massive landslides occurred in saturated marine clays (Fransham and

Table 4.13. Late glacial and Holocene pollen assemblage zones (Richard, 1977)

Age ka	Southern Laurentians PAZ	Southern Laurentians Sub-PAZ	Southern Laurentians Taxon guide		Lowlands PAZ	Lowlands sub-PAZ	Lowlands Taxon guide	Age ka
0	*Betula-Pinus*				*Betula-Pinus*; *Betula-Picea* (in peat bogs)			0
0.3		(*-Ambrosia*)				(*-Ambrosia*)		0.4
4		*-Fagus*	*Acer saccharum*			*-Fagus*		4
		-Tsuga		4.8 minimum *Tsuga*		*-Tsuga*	*Acer saccharum*	
5						*Betula-Pinus*		5
	Pinus-Betula	*-Tsuga*				(*-Tsuga*)		
7		*-Quercus*			*Pinus-Betula* or *Pinus* (west and central)	(*-Quercus*)		7
		-Picea				(*-Picea*)		
		Betula arborescent — *Picea*				*Betula* arborescent — *Picea*		
		Betula arborescent — (*Alnus crispa*)				(*Picea*)		10
10		*Populus* — *Picea* — *Juniperus*				(Cyperaceae)		
		Betula (shrub)						
		Cyperaceae-Gramineae						
11.5		Trees — minimal pollen						

( ) may be absent
PAZ pollen assemblage zone

Gadd, 1976). Downcutting enhanced by glacial isostatic uplift, steadily deepened channels and gullies causing slope failures and many individual and multiphase landslides (Karrow, 1972). The triggering of landslides in these thixotropic clays can be caused by several different means. Earthquakes triggered the 1663 landslides in Saint-Maurice Valley described in the Jesuit Relations and confirmed by ^{14}C dating (Desjardins, 1980). Heavy spring rains were a major factor in the Saint-Alban landslide (on Rivière Sainte-Anne) in 1894 (Chalmers, 1900; Occhietti et al., 1975). The catastrophic Nicolet landslide in 1955 showed that landslides constitute a permanent and continuing threat in the densely populated St. Lawrence Valley (Hurtubise et al., 1957).

In the Quebec Appalachians, small slumps and solifluction flows occur in the soft rocky slopes and debris slopes following periods of heavy rain. These are insignificant on a regional scale but locally cause road maintenance problems.

Eolian phenomena

Immediately following glacial retreat or emergence, and before vegetation colonization, the surface of unconsolidated deposits was vulnerable to eolian processes. Osborne (1950) and Clark and Elson (1961) reported finding ventifacts, which probably date from this time, on the top of the St. Narcisse Moraine at Mont-Carmel. All the high and middle terraces and perched deltas of St. Lawrence Valley are covered with stabilized dunes. Parabolic dune systems have formed "crête de coq" structures on the south (Gadd, 1971; Dubé, 1971) and north shores of the St. Lawrence (Occhietti, 1980). The deflation areas are at present commonly filled in by peat bogs. Niveo-eolian sediments (Cailleux, 1972) and loess have been deposited by eolian processes in the lower Saint-Maurice region (Occhietti, 1980) and in the Montréal region (Gangloff, 1973).

Earthquakes and neotectonics

St. Lawrence Valley is frequently affected by earthquakes of low, medium or, rarely, high magnitude (Basham et al., 1979). These shocks are concentrated in the area of the Charlevoix Astrobleme, in the area of Montréal, and in Gatineau Valley. It has been suggested that the Charlevoix activity may be related to residual stress release associated with a Devonian impact feature (Rondot, 1968). In addition, recent vertical crustal movements have been proposed for the southern Laurentians (Gale, 1970). There is other evidence of neotectonic, possibly residual glacial isostatic uplift, in the area. For example, we know that Samuel de Champlain would not now be able to launch his ships in Rivière Saint-Charles (at Québec), as he was able to in 1603 and that postglacial faulting has been reported in southern Quebec (Oliver et al., 1970).

ACKNOWLEDGMENTS

This chapter has been critically reviewed by W.H. Mathews (University of British Columbia), J.B. Bird (McGill University), N.R. Gadd, V.K. Prest (Geological Survey of Canada), P. LaSalle (Ministère de l'Énergie et des Ressources), J.A. Elson (McGill University), G.P. Prichonnet (Université du Québec à Montréal), E.V. Sado and P.J. Barnett (Ontario Geological Survey).

Table 4.14. An alternative interpretation of central St. Lawrence Lowlands stratigraphy.

Approximate age (Ka)	Oxygen Isotope Stages	Chronostratigraphic	Classification (as used in this volume)	Climatic Interpretation	Stratigraphic units
	1	Holocene			
13	2	Wisconsinan	Late		Gentilly Till (with stratified interbeds)
32	3	Wisconsinan	Middle	Cool / Cold / Cool	
65	4	Wisconsinan	Early		
80	5a	Sangamonian		Cool	St. Pierre Sediments; St. Francois-du-Lac Formation(2); silts and sands at Les Vieilles Forges(3); unnamed till(1)
	5b	Sangamonian		Cold	Lévrard Till?(2); Deschaillons Varves(1)
	5c	Sangamonian		Cool	pre-Deschaillons sand(1)
	5d	Sangamonian		Cold	
	5e	Sangamonian		Warm	lower sand at Pointe-Fortune(4)
130	6	Illinoian			unnamed varves(1) and clay(4,5); Bécancour Till?(1); lower till at Pointe-Fortune(5)

(1) Lamothe, 1987
(2) Lamothe, 1985
(3) Occhietti et al, 1987
(4) Anderson, T.W., Matthews, J.V.Jr. and Mott, R.J., personal communication 1987
(5) Veillette and Nixon, 1984

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Editor's Note. In the time between completion of the first draft of this chapter (1984) and final editing (1987), a number of papers were published which questioned some of the earlier Quaternary stratigraphy. Some of this preliminary work has been incorporated into the chapter and Table 4.14 has been added to give a clear picture of new ideas on the Quaternary stratigraphy of the central St. Lawrence Lowlands.

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