Late Quaternary deglaciation of the southwestern St. Lawrence Lowland, New York and Ontario

DONALD L. PAIR *Department of Geology, University of Dayton, Dayton, Ohio 45469-2364*
CYRIL G. RODRIGUES *Department of Geology, University of Windsor, Windsor, Ontario, Canada N9B 3P4*

ABSTRACT

The style of deglaciation and maximum extent of earliest proglacial lakes have been reconstructed for the southwestern St. Lawrence Lowland of New York and Ontario using ice-marginal sediments and landforms, strandline features, and the areal distribution of *Candona subtriangulata*-bearing rhythmites. An important recessional position, the Carthage-Harrisville ice border, fronted proglacial Lake Iroquois in the eastern Lake Ontario Basin. Subsequent ice retreat, probably earlier than 12,500 yr B.P., allowed Lake Iroquois to expand along the northwestern flank of the Adirondack Mountains and into the St. Lawrence Lowland. Contrasting styles of deglaciation, controlled primarily by water depth, resulted in a land-based ice margin which withdrew gradually off the northern slope of the Adirondack Mountains, while the ice margin in the western St. Lawrence Lowland retreated rapidly in the deep waters of Lake Iroquois.

The maximum extent of ice retreat during the early phases of Lake Iroquois has been estimated on the basis of the distribution of the ostracode *Candona subtriangulata* in Lake Iroquois and younger sediments in New York, and by northward projections of Iroquois shoreline elevations to the region bounded by the Madawaska Highlands (Ontario). Results indicate that the southwestern St. Lawrence Lowland was rapidly deglaciated during the highest phases of Lake Iroquois. The distribution and radiocarbon chronology of fossiliferous sediments relating to lower post-Iroquois levels also confirm that these extensive proglacial lakes occupied the Lowland well before the Champlain Sea incursion.

INTRODUCTION

A great deal of controversy remains regarding the timing and style of glacial retreat from the St. Lawrence Lowland and surrounding regions (compare Karrow, 1981; Clark and Karrow, 1984; Pair and others, 1988a; Gadd, 1980, 1981, 1987, 1988a, 1988b; Sharpe, 1988; Naldrett, 1990, 1991; Rodrigues, 1991, 1992). Models for the area (Prest, 1970; Gadd, 1980) differ substantially in (1) the duration of ice cover in the Lowland, (2) mechanisms of ice retreat, and (3) the sequence of lacustrine and marine (Champlain Sea) levels. These questions persist primarily because of the absence of a detailed account of ice retreat from the Adirondack Mountains and adjacent Lowlands. In addition, studies of the late-glacial water bodies have been hampered by discontinuous strandline data, and a lack of objective indicators of lacustrine and marine conditions which are *independent* of sedimentological interpretations. The timing of deglaciation and the succession of water levels in the Lowland is of particular importance in view of the recent emphasis on late Quaternary events along the eastern margin of the Laurentide Ice Sheet (Ruddiman and Wright, 1987), and the proposed route and timing of proglacial lake drainage to the North Atlantic Ocean via the St. Lawrence Lowland (Teller, 1988, 1990; Lewis and Anderson, 1989; Broecker and others, 1989).

The purpose of this paper is to evaluate the proposed models for the deglaciation of the St. Lawrence Lowland. We present new evidence from ice-marginal sediments, strandline features, and well-exposed fossiliferous lacustrine and marine sediments in the southwestern St. Lawrence Lowland. This information is used to trace the retreat of the ice margin and associated expansion of proglacial lakes from the Lake Ontario Basin into the St. Lawrence Lowland.

SETTING

The western St. Lawrence Lowland is bounded to the south by the northwestern Adirondack Mountains, the lower Black River Valley, the promontory of the Tug Hill Plateau, and the adjacent Lake Ontario Lowland (Fig. 1). Relief in the south rises from 76 m on the flat-lying Paleozoic sedimentary rocks of the Lake Ontario plain to more than 579 m on the upper Tug Hill Plateau and northwestern Adirondack slope.

The northern boundary of the western Lowland is marked by the Madawaska Highlands in Ontario. The Frontenac Axis bridges the south and north sides of the western St. Lawrence Lowland. It consists of low-relief, northeast-southwest–trending, ridge-and-valley topography resulting from differential erosion of the Precambrian bedrock. The rest of the Lowland is underlain by flat-lying sedimentary rocks.

PREVIOUS STUDIES

Fairchild (1907, 1919), Taylor (1924), and Coleman (1937) first discussed the spatial and temporal relationships between deglaciation, proglacial water bodies, and the Champlain Sea in the western St. Lawrence Lowland. More recent work began with regional studies by Stewart (1958), Mirynech (1962), and MacClintock and Stewart (1965) in the Lake Ontario Basin and St. Lawrence Lowland.

Subsequent research has resulted in the development of two contrasting models for the deglaciation of the St. Lawrence Lowland. The proglacial lake model of Prest (1970) depicted an ice front that retreated from south to north, a style described as "windowblind" deglaciation by Gadd (1981, p. 1393). In this model, ice retreat was accompanied by a series of proglacial lakes that flooded the St. Lawrence Lowland. Subse-

Data Repository item 9321 contains additional material related to this article.

Geological Society of America Bulletin, v. 105, p. 1151–1164, 9 figs., September 1993.

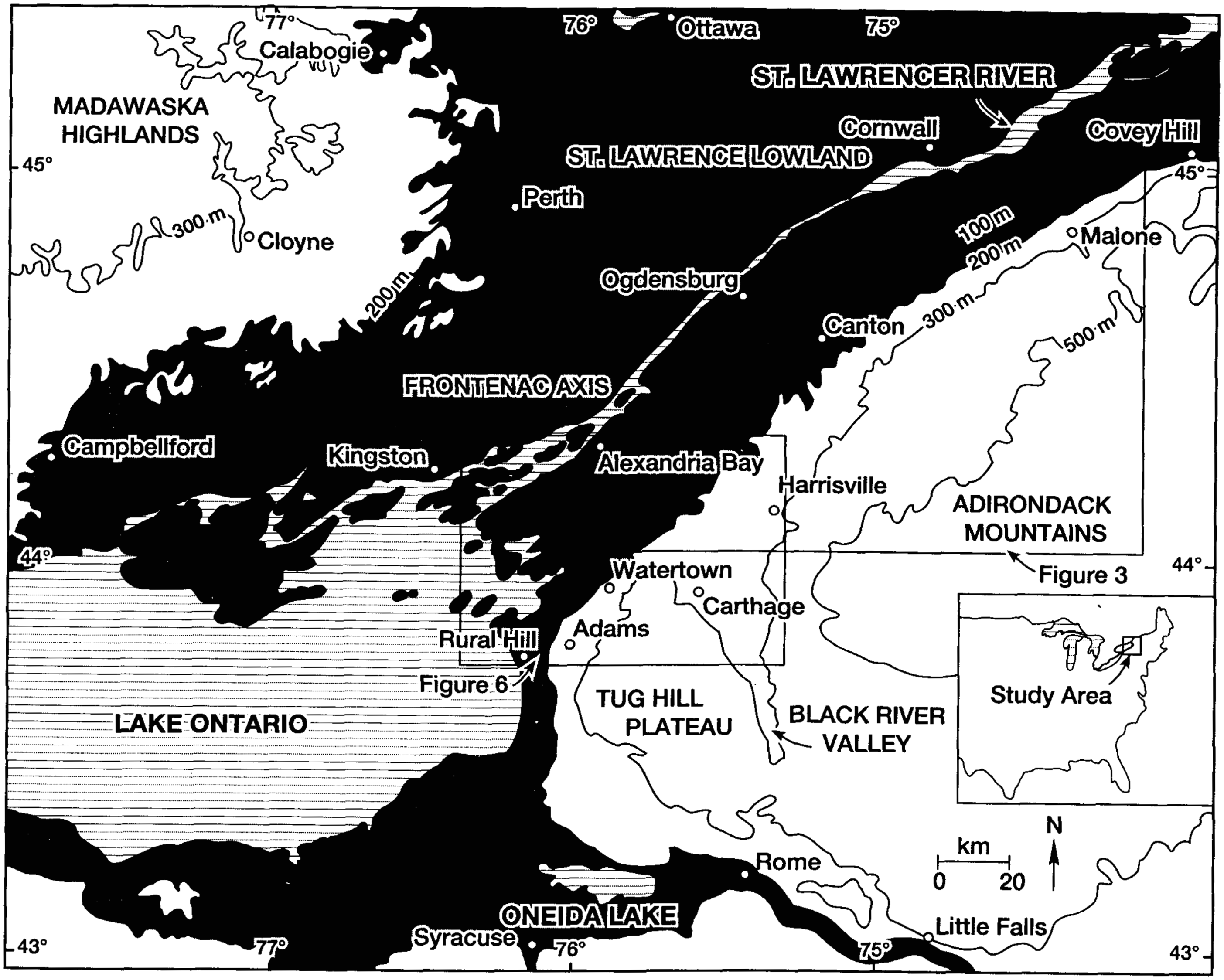


Figure 1. Map of the southwestern St. Lawrence Lowland. Shaded area is below 200 m.

quent incursion by the Champlain Sea was believed to have followed the last of these lacustrine water bodies (Henderson, 1967, 1973; Denny, 1974; Kirkland and Coates, 1977).

Gadd (1980, 1987, 1988a) proposed an alternate hypothesis based on the mathematically derived calving-bay model of Thomas (1977), which suggested that a calving-bay migrated up the St. Lawrence Valley into the upper St. Lawrence and Ottawa Valleys, allowing marine waters to encroach, while an ice dam retained proglacial lakes in the Lake Ontario Basin. Karrow (1981) pointed out the physical difficulties in maintaining such an ice dam. Based on reconstructed lake levels in the region around Covey Hill, Clark and Karrow (1984) proposed that an active ice margin at Covey Hill was responsible for the deglacial events, and concluded that "the 'windowblind' style of ice-marginal retreat remains the most attractive and realistic interpretation of deglaciation for the St. Lawrence Lowland" (Clark and Karrow, 1984, p. 813). Anderson and Lewis (1985) and Muller and Prest (1985) supported the concept of progressive ice retreat during glacial lake stages followed by the marine incursion.

Several studies along the southern margin of the former lacustrine and marine basins outlined the sequence and nature of the regional water levels and discussed ice-marginal positions marking retreat from the flank of the Adirondack Mountains and St. Lawrence Lowland (Clark and Street, 1985; Clark and Davis, 1988; Street, 1988; Pair and others, 1988b; Pair and Rodrigues, 1989; Gurrieri and Musiker, 1990). These studies, however, did not address the nature and timing of initial ice retreat out of the Ontario Basin.

Investigation of the age, origin, and depositional environments of the water bodies considered in this study have been approached through examination and radiocarbon dating of the biota present in the glaciolacustrine and marine sediments. Anderson and others (1985), and Anderson (1987, 1988) proposed ages for events based on pollen zones. Rodrigues (1987, 1988, 1992) reported ages on invertebrate marine fossil assemblages and reconstructed the paleoenvironments of the glaciolacustrine and marine water bodies.

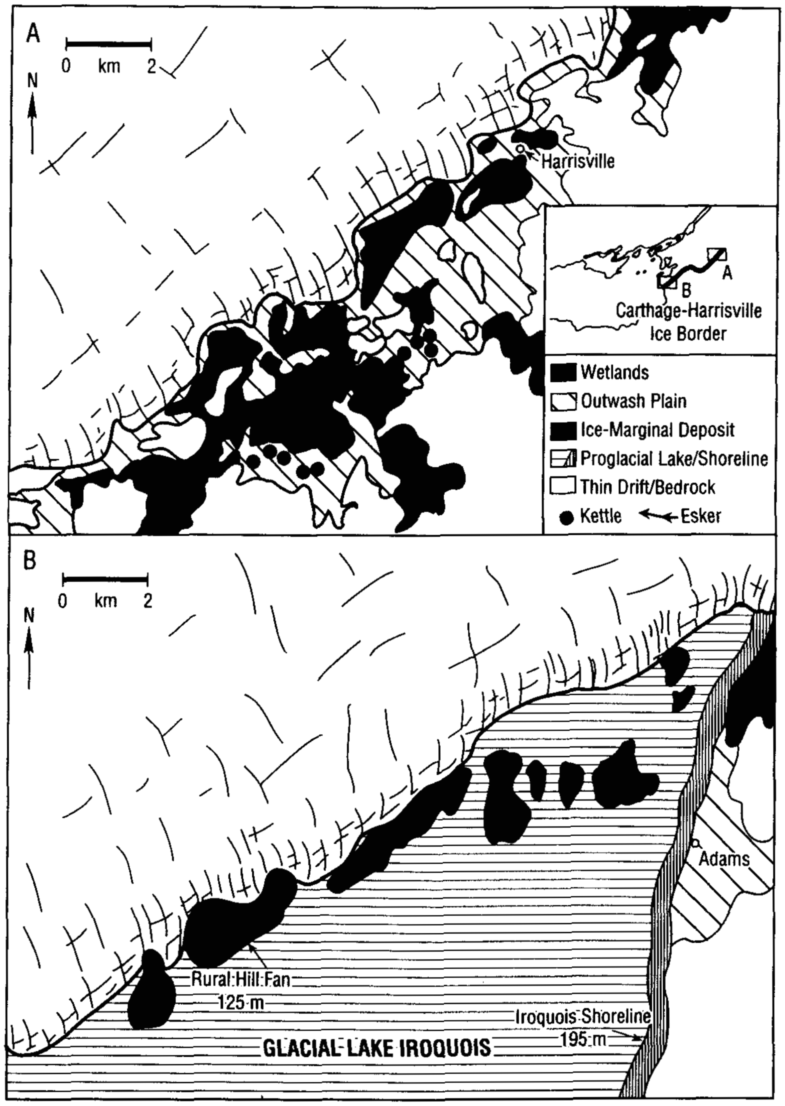


Figure 2. (A) Landforms and sediments associated with a land-based ice margin along the northwest flank of the Adirondack Mountains near Harrisville, New York. (B) Landforms and sediments associated with an ice margin terminating in Glacial Lake Iroquois near Rural Hill, New York.

Sedimentological analyses of ice-marginal sediments associated with deglaciation of portions of the St. Lawrence Lowland and Ottawa Valley yield significantly different interpretations of depositional environments and late glacial events (Rust and Romanelli, 1975; Rust, 1977, 1988; Cheel and Rust, 1982; Naldrett, 1988; Burbidge and Rust, 1988; Sharpe, 1988; Gadd, 1988b; Pair and others, 1988b). Gadd (1988b) continued to attribute a glaciomarine origin to rhythmites in the Ottawa Valley.

ICE-MARGINAL AND LAKE-BASIN DEPOSITS

Recessional Deposits

Interpretations of ice-marginal depositional environments and water depths are based on detailed surficial mapping (scale of 1:24,000) completed in association with the New York State Geological Survey's Surficial Geology Mapping Program—Adirondack Sheet (Cadwell and Pair, 1991). This regional mapping program permitted identification of ice-marginal landforms through the western St. Lawrence Lowland. A‹ tional sedimentologic study of recessional posits and analyses of elevations of drain thresholds, shoreline features, and rebo‹ history have been reported elsewhere (I and others, 1988a, 1988b; Pair, 1991) and not discussed in this paper.

Glacial features found in upland areas c sist of moraine-esker complexes, associa outwash plains, and a series of well-defi ice-marginal channels (Denny, 1974; Cl and Street, 1985; Clark and Davis, 1988; F and others, 1988b; Street, 1988; Gurrieri a Musiker, 1990; Cadwell and Pair, 1991). T distribution of landforms and sediments in cates that the margins of northward-retre ing lobes constructed moraines with ice-c tact slopes and deposited extensive outw sediment on valley floors (Fig. 2A). I posures in ice-marginal landforms reveal p dominantly stratified ice-contact and g ciofluvial sediments. Landform-sedim associations indicate a grounded, subaerial locally ponded ice margin, similar to ice-m ginal settings outlined by Gustavson a Boothroyd (1987) for Malaspina Glaci Alaska.

Unlike the uplands, where ice-marginal c posits are restricted to bedrock valleys, cessional sediments in the Lowland are d tributed mainly along broad bands align with bedrock highs and scarps (Cadwell a Pair, 1991). Borrow pits expose sedimen exhibiting consistent proximal to distal faci changes from cobble and boulder uni through largely ripple-drift sand, to laminat silt-clay sequences (Pair, 1991). These ha been mapped as subaqueous fans (Cadw and Pair, 1991) and were built along the i margin in proglacial lakes associated with i retreat from the western St. Lawrence Lo land (Fig. 2B). This ice-marginal setting consistent with other subaqueous depositi models described for the St. Lawrence Lo land (see Rust, 1988). These fan systems m have been fed by subglacial meltwaters f cused into bedrock valleys up-ice from be rock scarps (Pair and Muller, 1990). E. Henderson (1967) and P. J. Henderson (198 also suggested bedrock control of subglaci discharge near Kingston, Ontario. The alig ment of ice-marginal materials in the weste St. Lawrence Lowland with bedrock hig and scarps may indicate that they acted temporary pinning points along a retreatin floating or at least buoyant, ice margin. Sha low water depths at bedrock highs wou have decreased ice-calving rates and allowe sediment to accumulate preferentially dow

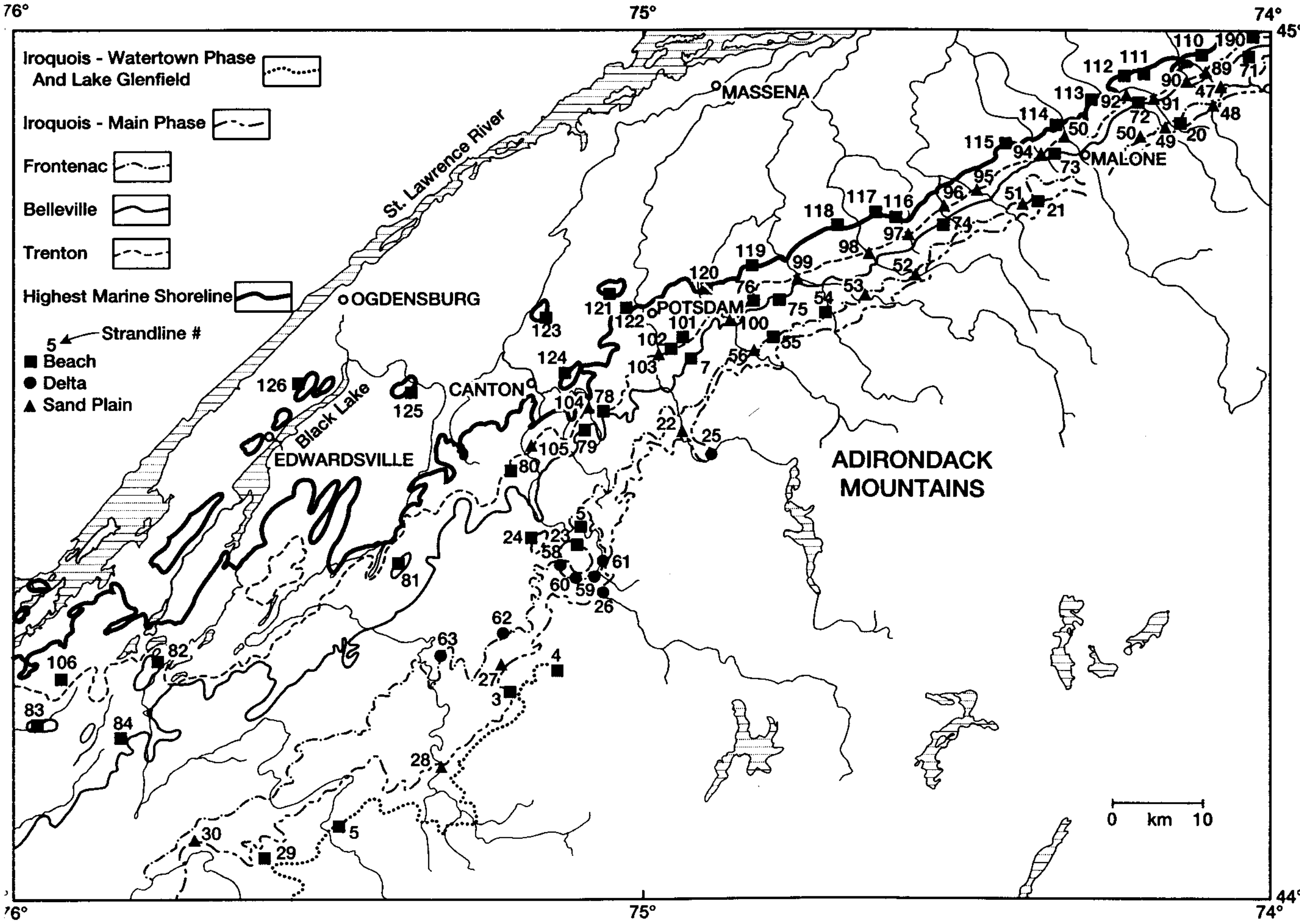


Figure 3. Iroquois and younger shorelines on the Ogdensburg map sheet (scale 1:250,000). Strandline numbers correspond to those listed in Appendix A.

from bedrock highs. Crossen (1991) noted similar relationship between subaqueous posits and bedrock ridges studied in aine.

ythmites and Massive Silt and Clay

Exposures of rhythmically laminated silt d clay underlain by till or ice-marginal maials are common in the western St. wrence Lowland (Pair, 1991; Rodrigues, 92). Deposition of these fine-grained sedints occurred either in the deeper areas of lake basin or as part of the distal portions ice-marginal subaqueous fans. Sharp conts between silt and clay laminae and the sence of trace fossils along some bedding nes suggest an annual cycle (that is, ves), but deposition by sporadic underws cannot be ruled out as a formative chanism for some of the rhythmites.

Sediments exposed along riverbanks near Ogdensburg, New York, and northwest of Canton, New York (Fig. 1) consist of diamicton, rhythmites, and overlying massive mud typical of the stratigraphy found at other locations in the St. Lawrence Lowland (Rodrigues, 1992). Both sites are below the highest marine shoreline in the region, and maximum marine water depths exceeded 30 m.

The lowest unit exposed at both sites is a massive, stony diamicton with striated clasts. Disconformably overlying the diamicton are silt and clay couplets consisting of alternating, finely laminated, green and gray silt/clay couplets which are up to 2.5 cm thick at the base of the unit. In the lowest meter of the rhythmites, silt laminae are graded, and lack distinct boundaries between couplets. Dropstones are common, and unlithified sediment clasts that fell through the water column, perhaps as frozen debris, are embedded in silt laminae. Clay inclusions are present in the silt laminae of some of the couplets.

Rhythmites overlying those of the lowest meter display micro-laminated silt beds, sharp contacts between silt and clay, and uniform clay-bed thicknesses. Dropstones and sediment clasts are rare. In places the beds are tilted, perhaps due to the slumping of the sediment as competent blocks. The upper rhythmites thin progressively to less than 1-cm-thick laminae at their upper contact with the overlying unit.

The thin, uppermost couplets of the rhythmites grade conformably into sediment referred to here as the "transitional unit." It consists of ~.5 m of thick, faintly laminated clays with prominent, discontinuous silt beds, rare massive clay beds, and several well-defined silt/clay couplets. Several of the contacts between the massive clays and silt/clay couplets are distinctly erosional and in-

clude c
The upp
a shell l
continu
is conf
blocky,
this unit
capped

WATEF

Form
from str
ing crit
ability):
shorebl
channel
Shoreli
and ana
Pair (19
Strandli
were pr
tain eq
and oth

[1]GSA
data App
uments S
CO 80301

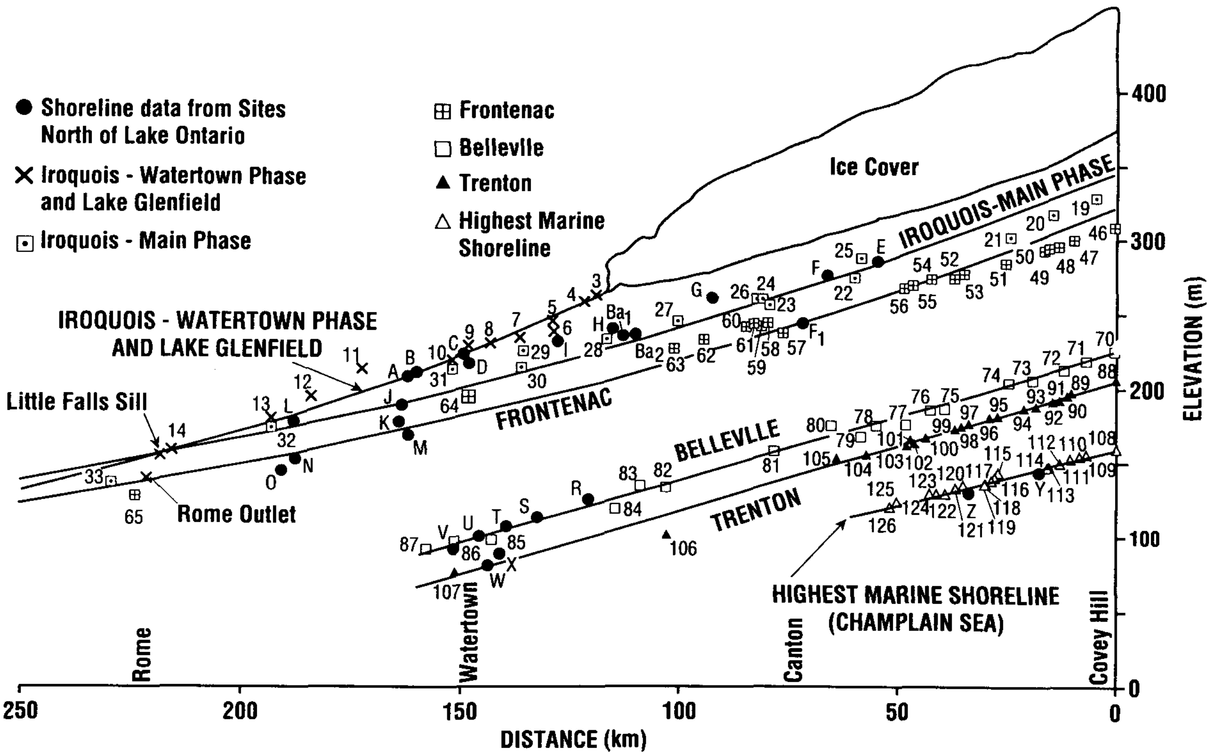


Figure 4. Strandline diagram for Iroquois and younger water levels from Covey Hill, Quebec, to Rome, New York.

clude clay rip-up clasts in the silt laminae. The upper contact at both sites is defined by a shell bed lying directly above the last discontinuous silt stringer. The transitional unit is conformably overlain by fossiliferous, blocky, massive gray clay. The upper part of this unit has thin red and gray laminae and is capped by faintly laminated silt.

WATER LEVELS

Former water levels were reconstructed from strandline evidence using the following criteria (in order of decreasing reliability): glaciolacustrine deltas; beaches, shorebluffs, or terraces; drainage cols or channels; and subaqueous sand plains. Shoreline characteristics, isobase trends, and analysis methods were described by Pair (1986) and Pair and others (1988a). Strandline data (Fig. 3 and Appendix A[1]) were projected onto curved profiles to obtain equidistant diagrams (compare Pair and others, 1988a). The orientation of these profiles permits direct evaluation of shoreline data from both the southern and northern margins of the former water bodies and is the basis for recognition of six distinct water levels (Fig. 4). The gradients of the Iroquois and post-Iroquois Frontenac water planes increase exponentially to the northeast, but shorter segments used in this study are essentially linear.

Watertown Phase of Lake Iroquois

The highest water plane identified on the strandline diagram is related to an early level of Lake Iroquois in the Ontario Basin referred to here as the "Watertown phase." It is identified from shoreline features that can be traced from Watertown southward along the eastern Lake Ontario shoreline toward the Rome region (Figs. 3, 4). Correlative with this phase are strandlines northeast of Watertown and in the lowermost portion of the Black River Valley that are equivalent to the lowest levels of Lake Glenfield (Strandlines 3–5 in Fig. 3). The Watertown phase represents an early stabilized level of Lake Iroquois. The gradient of this water plane is ~1.1 m/km. Coleman (1937), Mirynech (1962), and Sly and Prior (1984) identified high-level strandlines on the north shore of Lake Ontario (Appendix A). These shorelines are found on the high ground on the north shore of Lake Ontario and may correlate with the Watertown phase (A, B, C, and D in Figs. 4, 5).

Main Lake Iroquois Phase

The shoreline of the Main Lake Iroquois phase (gradient 0.9 m/km), the next lowest water plane on the strandline diagram (Fig. 4), is marked by a series of deltas and beaches (Figs. 3, 4) extending from the Covey Hill region to the Ontario Basin (Clark and Karrow, 1984; Pair, 1986; this study). The Main Lake Iroquois shoreline can be traced south of the study area and is approximately parallel to the present shoreline of Lake Ontario. Muller and Prest (1985) reported strandlines and projected lake-level elevations extending as far north as Cloyne, Ontario. The shore features they reported fall generally on the Main Lake Iroquois water plane reconstructed from strandlines on the southern margin of the Lowland. Shore features on the north shore of Lake Ontario may also be correlative with the Main Lake Iroquois level.

[1]GSA Data Repository item 9321, strandline-data Appendix, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

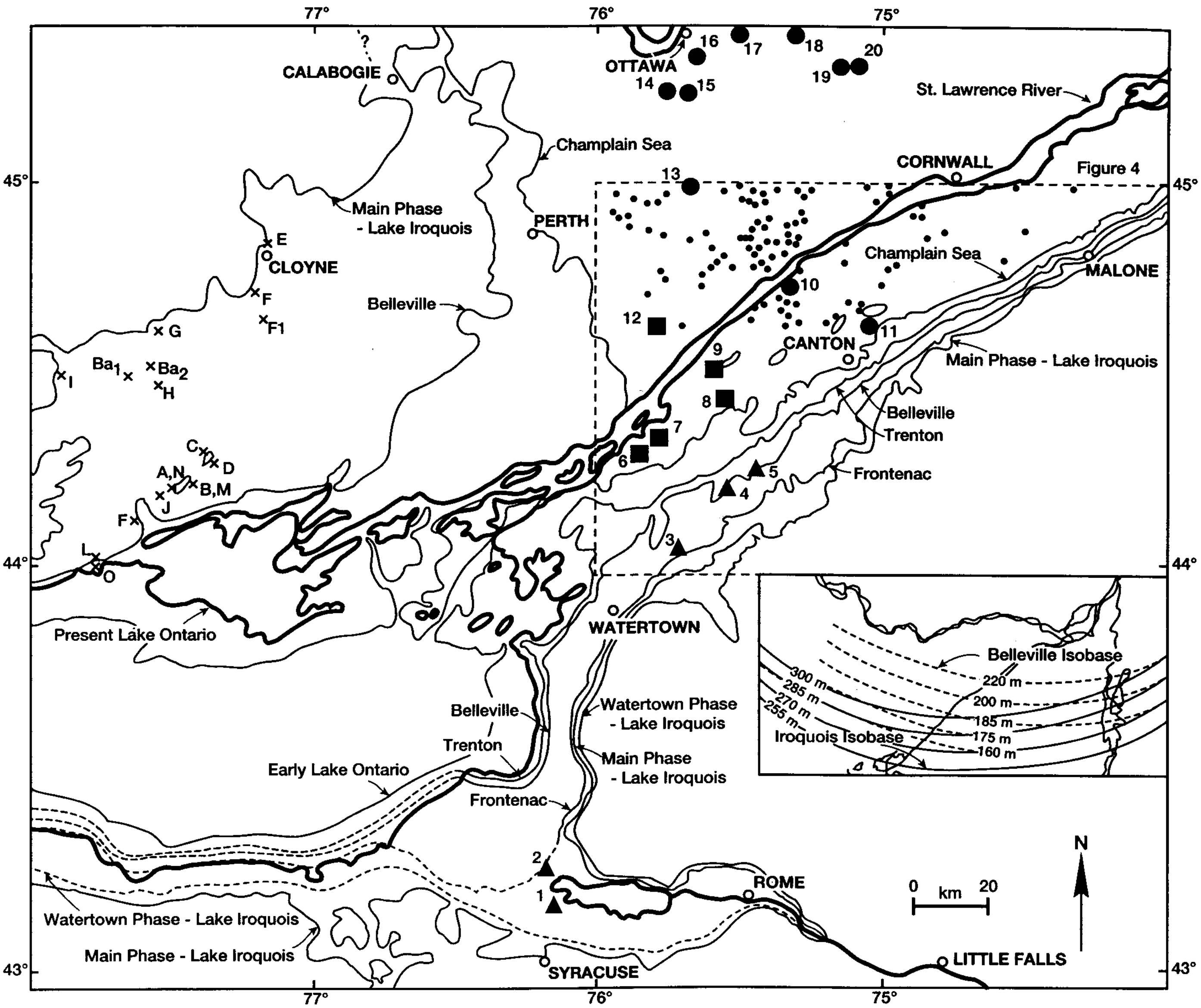


Figure 5. Shorelines, isobase trends, occurrences of *Candona subtriangulata* assemblages in the study area, and occurrences of marine fossils on the Ogdensburg map sheet (scale 1:250,000). Shorelines dashed where insufficient data prevent exact location from being indicated. Regional isobase trends from Muller and Prest (1985), Pair (1986), and Parent and Occhietti (1988). Curved profiles for strandline diagram (Fig. 4) were drawn perpendicular to isobases.

Post-Iroquois Phases

Shorelines from the southern margin of the Lowland related to the post-Iroquois Frontenac level plot as a distinct lower water plane (gradient 0.9 m/km) below the Main Lake Iroquois level (Figs. 3, 4). The northern margin of the Frontenac water body is represented by terraces and beach gravels at elevations well below the Main Lake Iroquois strandlines (Figs. 3, 4). Henderson (1967) identified a delta belonging to the Frontenac level at Flinton, Ontario (F1 in Figs. 4, 5), which also appears to correspond to the Frontenac level.

Pair (1986) and Pair and others (1988a) discussed post-Iroquois (Belleville and Trenton) levels. The next lower water level in the St. Lawrence Lowland, the highest marine shoreline, falls below the Belleville and Trenton levels in Figure 4. There are no intermediate shoreline features between the Trenton water plane and the highest marine shoreline (Fig. 4).

DEGLACIATION, PALEOGEOGRAPHY, AND DEPOSITIONAL ENVIRONMENTS

Ice-Marginal History and Lake Iroquois

We have identified a number of former ice borders in the Adirondack Mountains and adjacent St. Lawrence Lowlands from ice-marginal materials, landforms, and channels (Fig. 6). Recession of the ice margin to the base of the Tug Hill Scarp opened spillways for glacial Lake Glenfield in the Black River

FIGURE 5 LEGEND

Fossil Sites

1 - BREWERTON
2 - CAUGHDENOY
3 - WESTWOOD CORNERS
4 - SPRAGUEVILLE
5 - GOUVERNEUR
6 - CLAYTON
7 - ALEXANDRIA BAY
8 - BLACK LAKE
9 - MORRISTOWN
10 - SPARROWHAWK POINT
11 - BUCKS BRIDGE
12 - LAMBS POND CORE
13 - MERRICKVILLE
14 - TWIN ELM
15 - BRAZEAU PIT
16 - FOSTER SAND PIT
17 - MER BLEUE BORE HOLE
18 - BEARBROOK
19 - CASSELMAN BORE HOLE
20 - CASSELMAN

Shorelines- North Shore Lake Ontario

A - OAK LAKE
B - OAK LAKE
C - PANCAKE HILL
D - PANCAKE HILL
E - CLOYNE
F - NORTH BROOK
G - COOPER
H - MADOC
I - ROUND LAKE
J - OAK LAKE
K - OAK LAKE
L - BRIGHTON
M - OAK LAKE
N - OAK LAKE
O - PRESQUILE
F1 - FLINTON
Ba_1 - MADOC
Ba_2 - HAZZARDS CORNERS

▲ *Candona subtriangulata* — Above Highest Marine Shoreline

■ *Candona subtriangulata* (Not overlain by marine sediments)
● *Candona subtriangulata* (Overlain by Marine Sediments)
— Below Highest Marine Shoreline

• Marine Fossils [only sites on Ogdensburg map sheet (1:250,000) are shown]

Valley. The location of these spillways provides a means of identifying the position of the ice margin along the northwest Adirondack flank and northern scarp of the Tug Hill. Water carried by these spillways drained west along or under the ice margin into northward-encroaching Lake Iroquois (Fig. 6A).

Following retreat from the Tug Hill scarp, the ice margin stabilized and deposited sediments that can be traced from the northwestern flank of the Adirondack Mountains to the Lake Ontario Lowland (Cadwell and Pair, 1991). This position, referred to as the "Carthage-Harrisville ice border," provides an important link between the deglaciation of the region and expansion of Lake Iroquois into the St. Lawrence Lowland.

We relate differences in landforms and deposits along this ice margin to contrasts in water depth. Water depths were estimated by comparing the elevation of nearby shoreline features to the ice-marginal landforms. At Harrisville, the Carthage-Harrisville ice margin is represented by moraines with subaerial outwash plains that are graded to a late Lake Glenfield level in the Black River Valley (Cadwell and Pair, 1991). Along the Carthage portion of the ice border, the glacial lake in front of the ice margin was <60 m deep. The ice margin was grounded, and hummocky topography dominates the landscape. Ice-marginal sediments associated with the westernmost edge of the Carthage-Harrisville ice border were deposited in the deeper waters of northeastward-encroaching Lake Iroquois. The western edge of the ice border was in water about 90 to 120 m deep, and deposition along the margin was in the form of subaqueous fans built into Lake Iroquois (Figs. 2B, 6A).

Correlation of strandlines from the high ground on the north shore of Lake Ontario (Figs. 4, 5) with Watertown phase shorelines from the southern margin of the Lowland suggests that the Watertown phase may have been related to a stage in the deglaciation of the Lake Ontario Basin when the ice margin stood north of the Lake Ontario shoreline. This indicates that a significant portion of the Lake Ontario Basin was ice free (compare Fairchild 1919; Dyke and Prest, 1987).

The next prominent recessional positions are represented by the Deferiet–North Wilna and Philadelphia-Antwerp moraines (Fig. 6B). The proximity of these moraines to bedrock highs (Cadwell and Pair, 1991) suggests that they were constructed when the retreating ice margin was temporarily stabilized. Northward retreat of the ice margin to these positions allowed Lake Iroquois to expand into the St. Lawrence Lowland and along the northwest flank of the Adirondack Mountains. Water depth in front of these ice margins was at least 91 m.

Deglaciation of the western St. Lawrence Lowland continued until the ice margin became stabilized again by a bedrock scarp at LaFargeville (Fig. 6C). Deposition at the ice margin built subaqueous fans in about 90 m of water. A beach associated with the Belleville water plane is developed on the crest of these features at 136 m (Fig. 6C), indicating that ice had retreated from the southwestern St. Lawrence Lowland *before* the post-Iroquois Belleville and Trenton phases.

The Role of the Rome Outlet

The relationship of the outlet at Rome (Figs. 1, 5) to the levels of Lake Iroquois is poorly understood. The elevation of the sill, commonly quoted as being at 140 m, has not been re-examined since it was first proposed by early workers. Fullerton (1980) questioned the role of the Rome Outlet in controlling Lake Iroquois water levels. He inferred that the threshold may not have been at Rome, but east down the Iromohawk River (in the Mohawk River Valley) at the bedrock sill near Little Falls (as first suggested by Brigham, 1898). The sill at Little Falls may have controlled initial water levels and downcutting of the Rome outlet. The present elevation of the Little Falls sill is estimated here to be about 155 m. The position of this sill on the equidistant diagram (Fig. 4) and the convergence of the water levels suggest that it indeed may have influenced Iroquois water levels.

Maximum Northward Expansion of Lakes Iroquois and Frontenac

Determination of the maximum northward expansion of Lake Iroquois during the retreat of the ice from north of the Lake Ontario shoreline is based on (1) shoreline data from the Cloyne, Ontario, region (Muller and Prest, 1985); (2) strandlines identified by P. J.

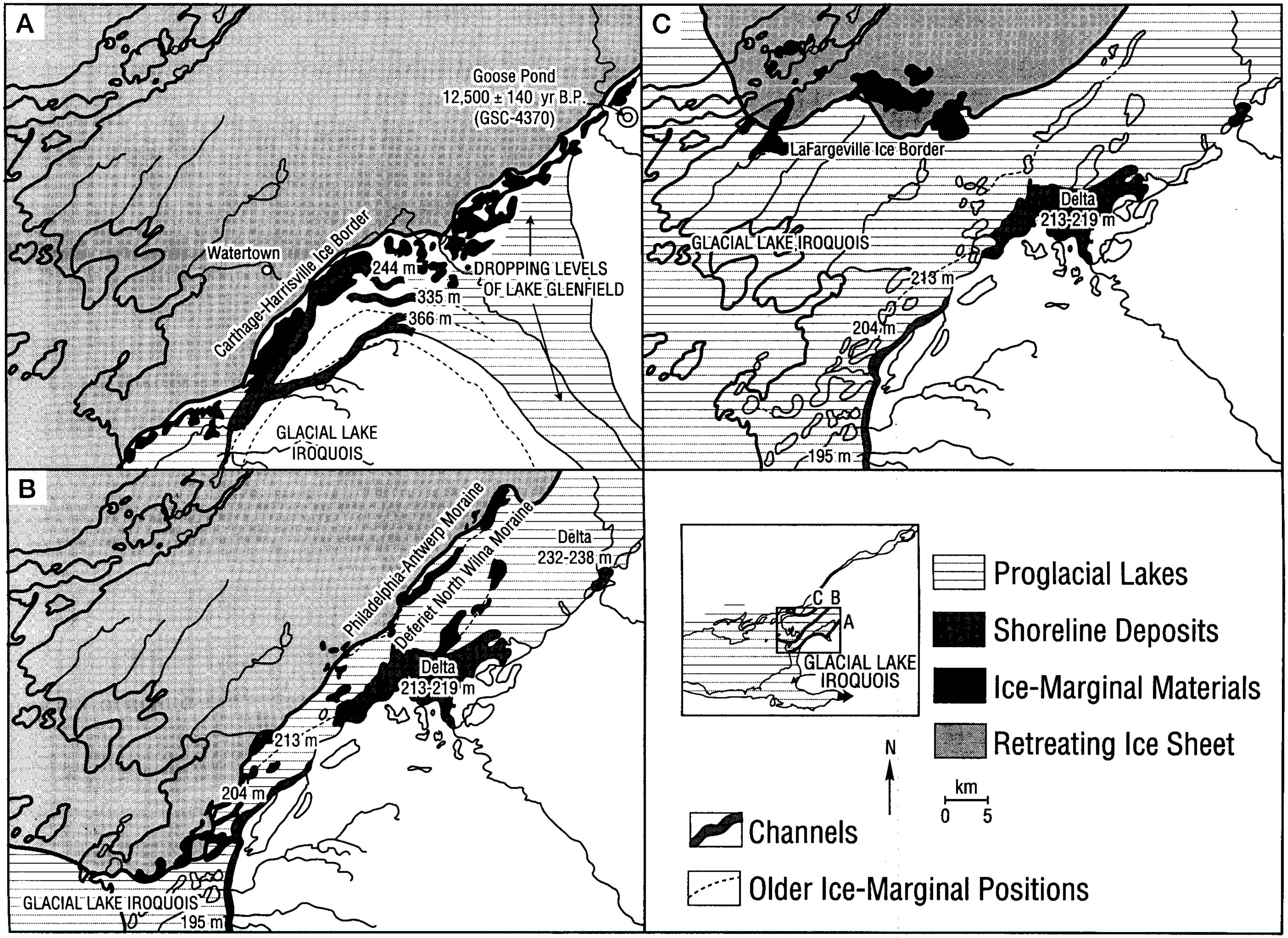


Figure 6. (A) The Carthage-Harrisville ice border, drainage channels, and related proglacial lakes. (B) The Deferiet–North Wilna and Philadelphia-Antwerp moraines and Glacial Lake Iroquois. (C) The LaFargeville ice border and Glacial Lake Iroquois.

Figure 6. (A) The Carthage-Harrisville ice border, drainage channels, and related proglacial lakes. (B) The Deferiet-North Wilna and Philadelphia-Antwerp moraines and Glacial Lake Iroquois. (C) The LaFargeville ice border and Glacial Lake Iroquois.

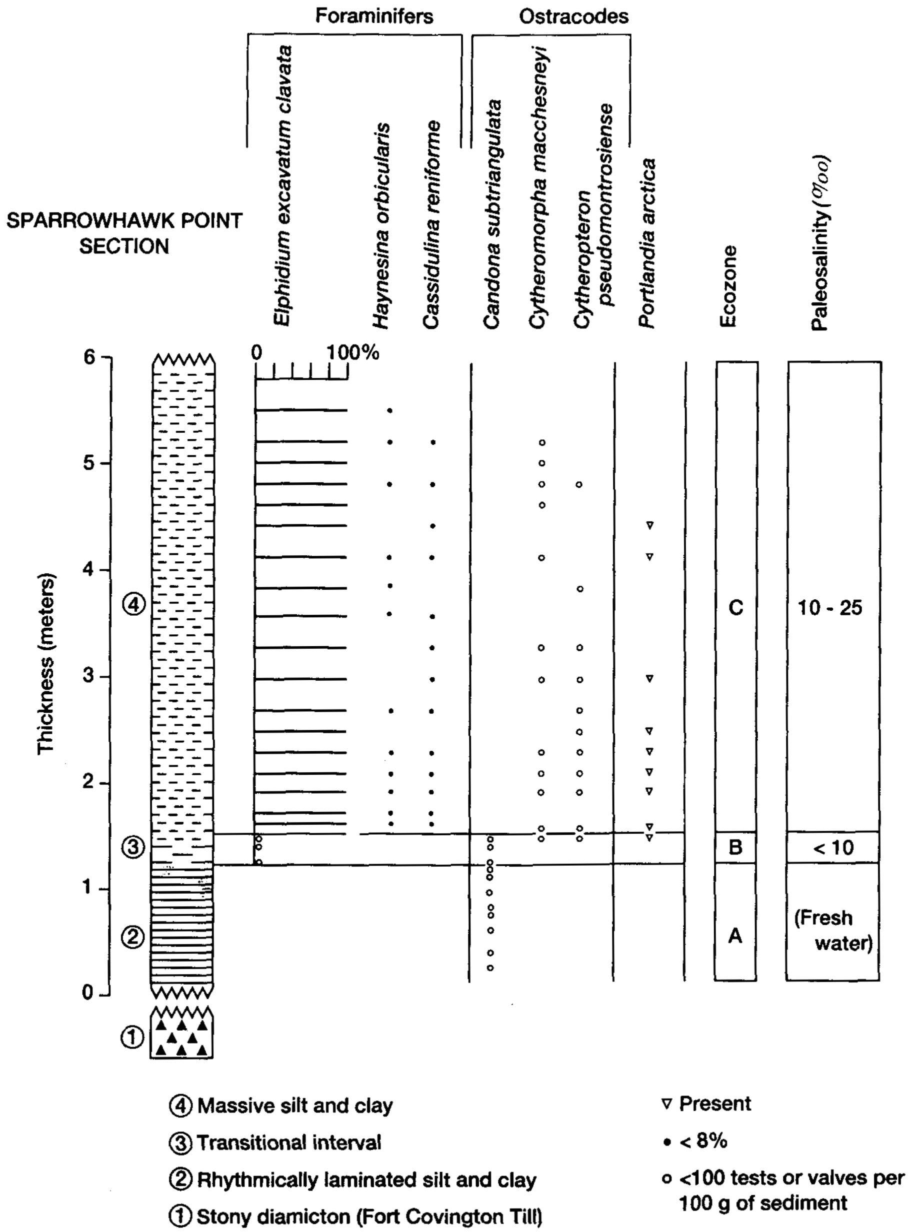


Figure 7. Stratigraphy and invertebrate fossils at Sparrowhawk Point Site (no. 10 in Fig. 5).

Barnett (1986, oral commun.) north of Madoc, Ontario; and (3) projection to the northwest of strandline elevations from well-developed shoreline features from the Adirondack flank described by Clark and Karrow (1984), Pair (1986), Pair and others (1988a), and this study. These data were plotted on the strandline diagram to establish the maximum area submerged by lacustrine water bodies on the northern edge of the St. Lawrence Lowland. These reconstructions indicate that the northern margin of high-level water bodies could have reached the edge of the Madawaska Highlands at elevations as high as 300 m.

Main Lake Iroquois persisted until drainage was initiated via a col across Covey Hill. Shorelines of the post–Iroquois Frontenac phase are well developed on the southern margin of the former lake basin (Fig. 5). The water plane of the Frontenac phase falls at least 6 m below the elevation given for the Rome Outlet (140 m) (Fig. 4).

Belleville, Trenton Phases, and the Champlain Sea

Post-Frontenac lakes continued to occupy the western St. Lawrence Lowland at lower levels, representing significant drops in regional water levels controlled by outlets in the lower Champlain Valley of New York. The 20-m difference in elevation, and parallel trend of the Belleville and Trenton water planes (both ~.9 m/km) (Fig. 4), indicate that these levels were close in time. The absence of intermediate shoreline features between the Trenton water plane and the highest marine shoreline (Fig. 4) indicates that the drop to sea level was rapid. Pair and others (1988a) showed that the highest shoreline of the Champlain Sea on the southern shore of the basin exceeded the elevation of the Lake Ontario threshold and was, therefore, confluent with Early Lake Ontario.

Sediments at the Sparrowhawk Point and Bucks Bridge sites (nos. 10 and 11; Figs. 5, 7, and 8) illustrate the succession of water bodies and depositional environments. Rhythmites overlying the glacial diamicton were deposited in a glacial lake preceding the marine transgression. Graded transitions from silt to clay beds indicate surge-deposit origin for some of the couplets. These graded beds are particularly common at the base of the unit and at the upper contact with the overlying marine sediments. The majority of the rhythmites, however, display sharp contacts between silt and clay beds and consistent clay thicknesses. The number of couplets (~60) present at both sections may provide an estimate of the duration of the last lake level in this area preceding the Champlain Sea.

The alternating massive and laminated fine-grained sediment which overlies the rhythmites represents the transition from lacustrine to marine conditions. The change from thin couplets to clays with irregular banding is probably related to mixing of marine and fresh water during the early stages of the marine transgression. Sporadic underflows may account for the occasional silt/clay couplets at the base of the transitional zone. As marine conditions developed, suspension and flocculation dominated sedimentation, resulting in deposition of the overlying massive clays. Underflows in the marine environment require significant fluctuations in meltwater output and sediment load to maintain density stratification, conditions that are usually associated with an ice-proximal setting (Mackiewicz and others, 1984; Domack, 1984; Stevens, 1985, 1986). The absence of glaciomarine deposits at these sites (Figs. 7, 8) indicates that the marine sediments were deposited some distance from the retreating ice margin. The few rhythmically laminated beds intercalated with massive marine clay of the transitional zone may be related to surge

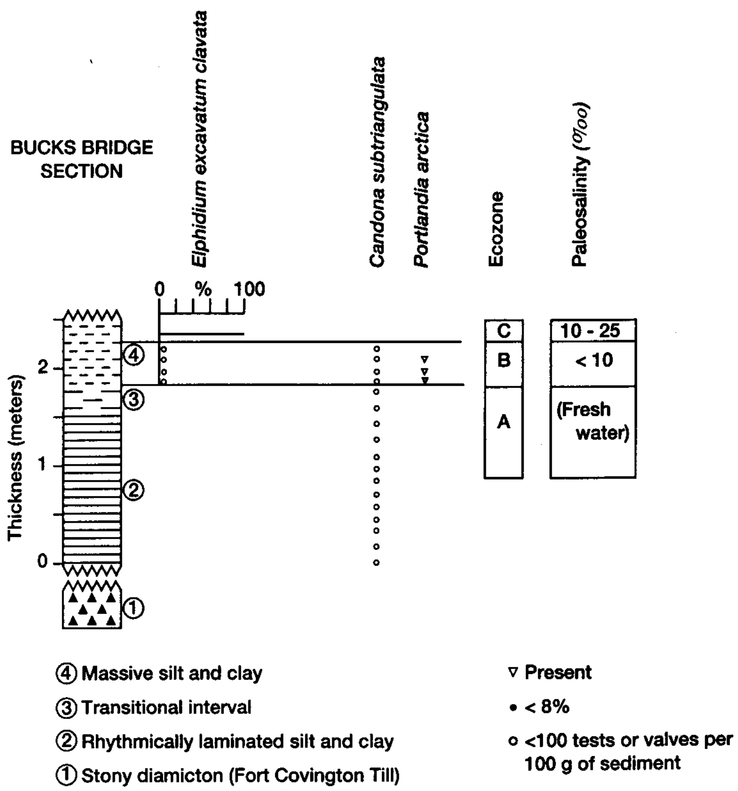


Figure 8. Stratigraphy and invertebrate fossils at Bucks Bridge Site (no. 11 in Fig. 5).

deposits triggered by episodic slumping or debris flows. The drop to sea level was a minimum of 18 to 37 m and may well have initiated such mass movements in the basin. Massive silt and clay in the upper parts of the two sections (Figs. 7, 8) represent establishment of marine conditions in the study area.

DISTRIBUTION AND SIGNIFICANCE OF INVERTEBRATE FOSSILS

We sampled exposures of rhythmically laminated and massive silt and clay for foraminiferal and ostracode analyses to interpret paleoenvironmental conditions during deposition of the fine-grained sediments. The results reported here are part of a regional study (Rodrigues, 1992) based on a total of 166 samples from 10 sites within both the western and central St. Lawrence Lowland. Ice-marginal deposits or diamicton are overlain by rhythmically laminated silt and clay at sites 1–9 (Fig. 5). Trace fossils were observed along parting planes in the rhythmites at some sites. Monospecific ostracode assemblages consisting of <25 valves of *Candona subtriangulata* per 100 g of sediment are present in the fine-grained sediments. Sites 1–5 are above the highest shoreline of the Champlain Sea, whereas sites 6–9 are below.

The rhythmically laminated silt and clay to massive clay successions at the Sparrowhawk Point and Bucks Bridge sites (nos. 10 and 11; Fig. 5) are divided into three ecozones on the basis of ostracode and foraminiferal assemblages (Figs. 7 and 8). Monospecific *Candona subtriangulata* assemblages are present in ecozone A. The foraminifer *Elphidium excavatum clavata* and *Candona subtriangulata* characterize Ecozone B. Ecozone C is characterized by *Elphidium excavatum clavata*–dominant assemblages.

The *Candona subtriangulata* assemblages of Ecozone A at Sparrowhawk Point and Bucks Bridge are identical to those from rhythmically laminated silt and clay at sites 1–9 (Fig. 5). The rhythmites at sites 1–5 (Fig. 5) were deposited in glacial lakes associated with the Iroquois and Frontenac levels, and those of Ecozone A at Sparrowhawk Point and Bucks Bridge (sites 10 and 11) are related to the Belleville and Trenton levels. Ecozone B at sites 10 and 11 represents a transition from glaciolacustrine to marine conditions. Bottom-water salinity ranged from <10‰ in Ecozone B to between 10‰ and 25‰ in Ecozone C.

Anderson and others (1985), Naldrett (1988), and Rodrigues (1984, 1987, 1988, 1992) also reported the succession from rhythmically laminated silt and clay to Champlain Sea sediments in the Ottawa Valley north of the St. Lawrence River (sites 14–19, Fig. 5). They concluded that the *Candona subtriangulata* assemblages in the rhythmites are evidence for a proglacial lake extending from Lake Ontario into the Ottawa Valley preceding the Champlain Sea. Gadd (1987, 1988a, 1988b) and Sharpe (1988), however, proposed that the rhythmites in the Ottawa Valley were deposited in a glaciomarine environment.

Candona subtriangulata lives in the Great Lakes at depths ranging from 8 to 363 m and in temperatures ranging from 2.6 to 19.2 °C, and can tolerate high turbidity (Delorme, 1970, 1978, 1989; Westgate and others, 1987). The species has been reported from Holocene lacustrine deposits in Lake Michigan (Colman and others, 1990), and from late Pleistocene glaciolacustrine deposits in the Metro-Toronto region of southern Ontario (Westgate and others, 1987). The presence of *Candona subtriangulata* in rhythmites above the Frontenac level, south of the eastern end of the Lake Ontario Basin (sites 1 and 2; Fig. 5), and between the Frontenac and younger Belleville levels east of the Lake Ontario Basin (sites 3–5) shows that the rhythmites overlain by marine sediments and characterized by *Candona subtriangulata* at sites in the western St. Lawrence Lowland (sites 10, 11, 14–19) were deposited in a glaciolacustrine environment. Rodrigues (1988) concluded that *Candona subtriangulata* migrated from the Lake Ontario Basin into the Ottawa Valley before the marine transgres-

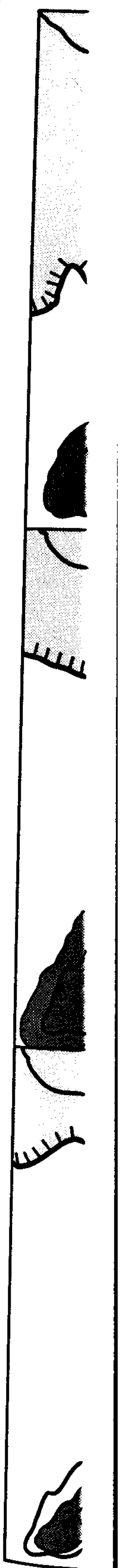
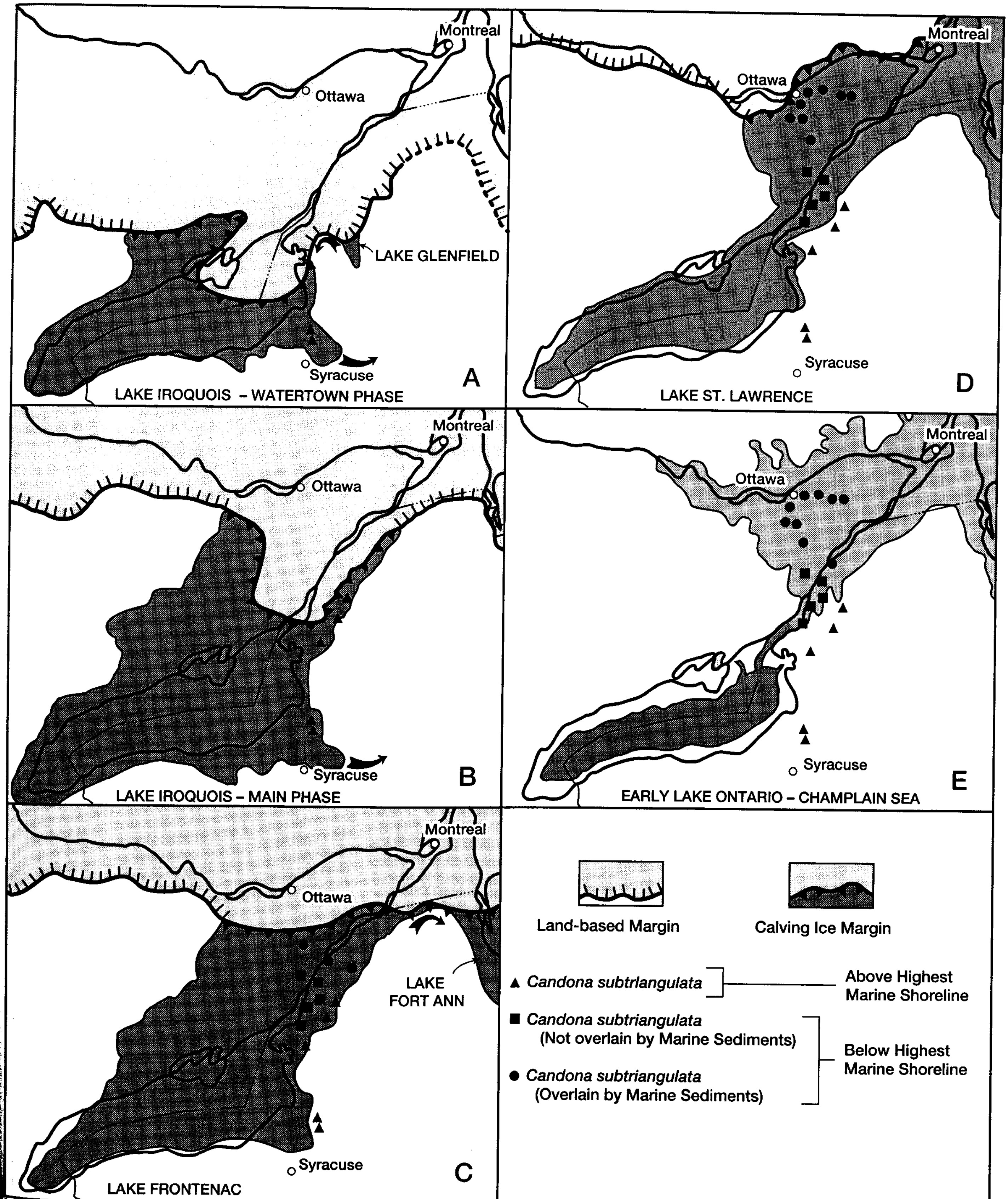


Figure 9. Possible configuration of the ice margin during deglaciation of the southwestern St. Lawrence Lowland. Ice-margin position, in part, after Dyke and Prest (1987). Arrows indicate discharge routes of glacial lakes. Occurrences of *Candona subtriangulata* assemblages indicated by solid circles, squares, and triangles. (A) Carthage-Harrisville ice border and Watertown Phase of Lake Iroquois. (B) LaFargeville ice border and Main Phase of Lake Iroquois. (C) Frontenac and Fort Ann Lake phases. (D) Lake St. Lawrence. (E) Highest level of the Champlain Sea and Early Lake Ontario.


Montreal
Ottawa
LAKE GLENFIELD
Syracuse
A
LAKE IROQUOIS - WATERTOWN PHASE
Montreal
Ottawa
Syracuse
D
LAKE ST. LAWRENCE
Montreal
Ottawa
Syracuse
B
LAKE IROQUOIS - MAIN PHASE
Montreal
Ottawa
Syracuse
E
EARLY LAKE ONTARIO - CHAMPLAIN SEA
Montreal
Ottawa
LAKE
FORT ANN
Syracuse
C
LAKE FRONTENAC
Land-based Margin
Calving Ice Margin
▲ Candona subtrlangulata
Above Highest
Marine Shoreline
■ Candona subtriangulata
(Not overlain by Marine Sediments)
● Candona subtriangulata
(Overlain by Marine Sediments)
Below Highest
Marine Shoreline

sion. The presence of monospecific *Candona subtriangulata* assemblages in rhythmites above the highest Champlain Sea shoreline in New York and the succession from *C. subtriangulata*–bearing rhythmites to marine sediments in New York and Ontario confirm the migration route proposed by Rodrigues (1988).

DISCUSSION

Ice-Marginal Controls on Deglacial History

The results of our study suggest that water depths along the retreating ice margin in the St. Lawrence Lowland controlled the mode of ice-marginal deposition. Previous ice-marginal correlations (for example, Taylor, 1924; MacClintock and Stewart, 1965) were based on morphologic evidence between "moraines" in the Lowlands and those on the northwestern slope of the Adirondack Mountains. These correlations imply time-equivalency between moraine segments, without recognition that the ice margin may have responded differently along various portions of the ice border. Our model for the region is based on the distribution and characteristics of ice-marginal sediments, and estimated water depths in front of the ice margin. Thus, the causes of ice-marginal stabilization may have differed between the uplands of the Adirondack Mountains and the St. Lawrence Lowland.

We propose that the land-based margin of the ice sheet retreated slowly by backwasting off the Adirondack slope with ice-marginal sediments accumulating during climatically and/or topographically controlled stillstands. At the same time, the ice sheet retreated rapidly out of the Lake Ontario Basin by actively calving in the deep water of Glacial Lake Iroquois. Consequently, the retreat of the ice margin in the Lowland would have paused only when calving rates slowed in the shallow water near bedrock highs.

Discussions of regional ice-border geometry and deglacial history (for example, Clark and Karrow, 1984; Gadd, 1988a) for this region should consider these different controls. The concept of "windowblind ice retreat," with straight ice margins extending for great distances, should be re-evaluated using the details of ice retreat reconstructed from studies in the southwestern St. Lawrence Lowland. We suggest that a topographically controlled and slowly retreating land-based ice margin pinned against the northern slope of the Adirondack Mountains at Covey Hill retained high water levels by blocking lower outlets, while the eastern Lake Ontario and southwestern St. Lawrence Lowlands were rapidly evacuated of ice by calving retreat in the deep waters of Lake Iroquois.

Chronology of Deglaciation and Water Bodies

Basal organic material from the bottom of a kettle lake adjacent to the Carthage-Harrisville ice border (Fig. 6A) yielded a radiocarbon age of 12,500 ± 140 yr B.P. (GSC-4370) and provides a minimum age for deglaciation of the northwestern Adirondack flank and subsequent incursion by Lake Iroquois (Pair and others, 1988b). We correlate the Carthage-Harrisville ice border with the Star Lake moraine to the east, where a radiocarbon age of 12,640 ± 430 yr B.P. (GX-13278) was obtained from organic material in the bottom of another kettle in the outwash plain south of the Star Lake Moraine (Clark and Davis, 1988).

The age of the lacustrine-marine transition indicates that considerable time separated the northeastward expansion of Lake Iroquois into the western St. Lawrence Lowland and incursion of the Champlain Sea. Pollen analyses of a core at Mer Bleue near Ottawa, Ontario, and of sediment at Sparrowhawk Point (sites 17 and 10, Fig. 5) identified the rise in *Picea* across the contact between the lacustrine and marine sediments (Anderson, 1987, 1988). This same rise in *Picea* was dated at 11,200 ± 190 yr B.P. (GSC-3429) at Boyd Pond, New York. Thus, Anderson (1987, 1988) concluded that marine waters arrived in the western part of the basin between about 11,000 to 11,500 yr B.P. Rodrigues (1992) used radiocarbon ages to determine the arrival of the salt-water wedge in the central St. Lawrence Lowland and placed the beginning of the Champlain Sea between 11,400 and 11,600 yr B.P. Both of these estimates are consistent with the sequence of water levels and estimates on the age of the confluence between the westernmost Champlain Sea in the St. Lawrence Lowland and Early Lake Ontario in the Ontario Basin by Anderson and Lewis (1985).

Major Ice Borders and Paleogeography of Water Bodies

Ice-marginal features and shorelines in New York (Cadwell and Pair, 1991), and locations of *Candona subtriangulata* in the western and central St. Lawrence Lowland (Rodrigues, 1992) were used to reconstruct former ice borders and the sequence and extent of water bodies in the region (Fig. 9). Ice-margin positions in Ontario are based on the distribution of pre–Champlain Sea glaciolacustrine deposits summarized by Rodrigues (1992). The configuration of the ice lobe in the Lake Ontario Basin is adapted from Dyke and Prest (1987). Pending detailed glaciological reconstructions which are beyond the scope of this study, the actual geometry of this lobe must be considered speculative.

The Watertown phase of Lake Iroquois corresponded to the Carthage-Harrisville ice border in New York and to a position north of high-level strandlines on the Lake Ontario shoreline in Ontario. Such a position may correspond to the Dummer Moraine in Ontario as indicated by Dyke and Prest (1987), or if this feature is subglacial in origin as suggested by Shulmeister (1989) and Shaw and others (1991), this region of till and hummocky topography (Barnett and others, 1991) may be unrelated to the ice border. The paleogeography of Watertown phase, however, indicates that a significant portion of the Lake Ontario Basin was ice free (Fig. 9A).

The ice margin then retreated to LaFargeville, where it stabilized at a bedrock high (Fig. 9B). Ice-marginal sediments were deposited in a series of subaqueous fans into Main Lake Iroquois in about 90 m of water. If calving rates at the ice margin were high, the remaining ice in the Lake Ontario Basin may have been removed very quickly. Correlation of the best available shoreline data from the area north of Lake Ontario with the Main Lake Iroquois strandline along the northwest Adirondack flank has established the maximum extent of lacustrine water bodies on the northern edge of the St. Lawrence Lowland. Results of this reconstruction show that the northern margin of Lake Iroquois may have reached the edge of the Madawaska Highlands at elevations as high as 300 m while drainage continued through the Iromohawk River system east of Rome, New York.

Ice retreat uncovered a lower outlet on Covey Hill, and Main Lake Iroquois drainage was through the Covey Hill gap and into a Fort Ann level in the Champlain Valley (Fig. 9C). Deep water in front of the retreating ice margin may have resulted in rapid retreat and a relatively straight ice margin. Expansion of Lake Iroquois from the Lake Ontario Basin allowed the migration of *Candona subtriangulata* into the western St. Lawrence Lowland (Figs. 5, 9A, 9B). The presence of this ostracode in the lacustrine sediments throughout the region (Rodrigues,

1992) indicates that water bodies in the St. Lawrence Lowland were extensions of glacial lakes in the Lake Ontario Basin rather than discontinuous, locally ponded, water bodies as stated by Gadd (1988a). The maximum northern extent of the glacial lake preceding the Champlain Sea was determined from the distribution of rhythmites containing *Candona subtriangulata* overlain by marine sediments (Figs. 5 and 9D). Rodrigues (1992) pointed out that the name "Glacial Lake St. Lawrence" (Upham, 1895) has priority over other names.

Glacial lakes were followed by the Champlain Sea (Fig. 9E). The absence of marine assemblages in the extreme western part of the area (Figs. 5 and 9E) submerged by the Champlain Sea is probably related to freshwater outflow from the Lake Ontario Basin into the western Champlain Sea. Such a relationship was described by Fairchild (1907) (his Gilbert Gulf) and discussed by Clark and Karrow (1984), Anderson and Lewis (1985), Muller and Prest (1985), and Pair and others (1988a). Drainage of fresh water from Early Lake Ontario through a narrow strait at the Thousand Islands (Fig. 9E) (Pair and others, 1988a) diluted marine water in the southwestern Champlain Sea. The presence of fresh water to the west of the Sparrowhawk Point and Bucks Bridge sites prevented migration of marine organisms beyond Ogdensburg, New York.

SUMMARY

In this paper, we have used new data from the southwestern St. Lawrence Lowland of New York and Ontario to determine the style of deglaciation, timing of the expansion of Glacial Lake Iroquois into the St. Lawrence Lowland, and the extent of the proglacial lakes preceding the marine transgression. The distribution of shoreline features and lacustrine and marine faunal assemblages were used to delimit these water bodies.

Extremes in bedrock relief appear to have determined the character and orientation of deglacial ice borders in the southwestern St. Lawrence Lowland. Ice retreat off the northern Tug Hill scarp, the northwestern Adirondack slope, and out of the Black River Valley allowed Glacial Lake Iroquois to expand northeastward from the Lake Ontario Basin into the St. Lawrence Lowland. With northward encroachment of Glacial Lake Iroquois, ice-border morphology was also influenced by deep water at the ice margin.

An important recessional position, the Carthage-Harrisville ice border has been identified. The western margin of this ice border terminated in Glacial Lake Iroquois, and subsequent recession, perhaps as early as 12,500 yr B.P., allowed Lake Iroquois to expand along the northwestern flank of the Adirondack Mountains and into the St. Lawrence Lowland. Contrasting styles of deglaciation, controlled primarily by water depth at the ice margin, resulted in a land-based ice margin pinned against the northern slope of the Adirondack Mountains, which maintained high-water levels of Lake Iroquois while Covey Hill was covered by ice. Simultaneously, an actively calving ice front in the deep waters of Lake Iroquois was rapidly evacuating the western St. Lawrence Lowland of ice.

The early deglaciation of the southwestern St. Lawrence Lowland has been supported by field evidence, including shoreline features and lacustrine sediments characterized by the ostracode *Candona subtriangulata*, which indicates the maximum extent of pre–Champlain Sea lakes (Rodrigues, 1992). Documentation of the maximum extent of the highest lakes in the Lowland and the distribution of the fossiliferous sediments relating to the lower post-Iroquois levels were used to reconstruct the paleogeography of proglacial lakes that occupied the St. Lawrence Lowland prior to the Champlain Sea incursion. Models requiring contemporaneous lacustrine and marine events in the western St. Lawrence Lowland are considered improbable in light of the overwhelming evidence for extensive pre–Champlain Sea glacial lakes. Low-salinity assemblages from the Sparrowhawk Point and Bucks Bridge sections and the absence of marine fossils west of Ogdensburg establish that fresh-water outflow from Early Lake Ontario resulted in very low salinities in the southwestern Champlain Sea basin.

ACKNOWLEDGMENTS

The authors thank E. A. Romanowicz and T. A. Payne for assistance with field work. Helpful discussions and unpublished information were provided by T. W. Anderson, P. J. Barnett, P. U. Clark, and J. S. Street. Comments by E. H. Muller and H. T. Mullins, and thorough reviews by P. U. Clark, P. J. Fleisher, D. R. Sharpe, and an anonymous reviewer led to significant improvements in this manuscript. Funding to the first author was provided by grants from the Geological Society of America, Senate Research Committee of Syracuse University, the Department of Geology of Syracuse University, New York State Geological Sur Honorarium Program, and the Universit Dayton Research Institute. Support of work through the New York State Geolog Survey's Surficial Mapping Program, un the direction of D. H. Cadwell, is gratef acknowledged. Support to Rodrigues provided by an operating grant from the N ural Sciences and Engineering Resea Council of Canada.

REFERENCES CITED

Anderson, T. W., 1987, Terrestrial environments and age o Champlain Sea based on pollen stratigraphy of the Ot Valley–Lake Ontario region, *in* Fulton, R. J., ed., Quater geology of the Ottawa region, Ontario and Quebec: Ge ical Survey of Canada Paper 86-23, p. 31–42.

Anderson, T. W., 1988, Late Quaternary pollen stratigraphy o Ottawa Valley–Lake Ontario region and its application in ing the Champlain Sea, *in* Gadd, N. R., ed., The late ternary development of the Champlain Sea Basin: Geolo Association of Canada Special Paper 35, p. 207–224.

Anderson, T. W., and Lewis, C.F.M., 1985, Postglacial water- history of the Lake Ontario Basin, *in* Karrow, P. F., Calkin, P. E., eds., Quaternary evolution of the Great La Geological Association of Canada Special Paper p. 231–253.

Anderson, T. W., Mott, R. J., and Delorme, L. D., 1985, Evid for a pre–Champlain Sea glacial lake phase in Ottawa Va Ontario, and its implications: Current Research, Part A, ological Survey of Canada Paper 85-1A, p. 239–245.

Barnett, P. J., Cowan, W. R., and Henry, A. P., 1991, Quater geology of Ontario, southern sheet: Ontario Geological vey, Map 2556, scale 1:1,000,000.

Brigham, A. P., 1898, Topography and glacial deposits of the hawk Valley: Geological Society of America Bulletin, p. 183–210.

Broecker, W. S., Kennett, J. P., Flower, B. P., Teller, J. T., Tr bore, S., Bonani, G., and Wolfli, W., 1989, Routing of m water from the Laurentide Ice Sheet during the You Dryas cold episode: Nature, v. 341, p. 318–321.

Buddington, A. F., 1934, Geology and mineral resources of Hammond, Antwerp, and Lowville quadrangles: New Y State Museum Bulletin 296, 255 p.

Burbidge, G. H., and Rust, B. R., 1988, A Champlain Sea subw fan at St. Lazare, Quebec, *in* Gadd, N. R., ed., The late C ternary development of the Champlain Sea Basin: Geolog Association of Canada Special Paper 35, p. 47–62.

Cadwell, D. H., and Pair, D. L., 1991, Surficial geologic map of N York: Adirondack sheet: Albany, New York State Muse Geologic Survey Map and Chart Series No. 40, 1 sheet, s 1:250,000.

Cheel, R. J., and Rust, B. R., 1982, Coarse grained facies of gl omarine deposits near Ottawa, Canada, *in* Davidson-Arn R., Nickling, W., and Fahey, B. D., eds., Research in gla glaciofluvial, and glaciolacustrine systems: Norwich, C necticut, Geobooks, p. 279–295.

Chute, N. E., 1979, Glacial Lake Iroquois in central New Y Northeastern Geology: v. 1, p. 69–105.

Clark, P., 1980, Late Quaternary history of the Malone area, N York [M.Sc. thesis]: Waterloo, Ontario, University of terloo, 188 p.

Clark, P., and Karrow, P. F., 1984, Late Pleistocene water bo in the St. Lawrence Lowland, New York, and regional relations: Geological Society of America Bulletin, v. p. 805–813.

Clark, P. U., and Davis, P. T., 1988, Deglacial chronology of northwestern Adirondack Mountains: Geological Societ America Abstracts with Programs, v. 20, p. 12.

Clark, P. U., and Street, J. S., 1985, Deglaciation of the northw Adirondack Mountains and northward encroachment of L Iroquois: Geological Society of America Abstracts with P grams, v. 17, p. 11.

Coleman, A. P., 1937, Lake Iroquois: Ontario Department of Mi 45th Annual Report. pt. 2., p. 1–36.

Colman, S. M., Jones, G. A., Forester, R. M., and Foster, D. 1990, Holocene paleoclimatic evidence and sedimentat rates from a core in southwestern Lake Michigan: Journa Paleolimnology, v. 4, p. 269–284.

Crossen, K. J., 1991, Structural control of deposition by Pleistoc tidewater glaciers, Gulf of Maine, *in* Anderson, J. B., Ashley, G. M., eds., Glacial marine sedimentation; Paleo matic significance: Geological Society of America Special per 261, p. 127–135.

Delorme, L. D., 1970, Freshwater ostracodes of Canada. Part Family Candonidae: Canadian Journal of Zoology, v. p. 1099–1127.

Delorme, L. D., 1978, Distribution of freshwater ostracodes in La Erie: Journal of Great Lakes Research, v. 4, p. 216–220.

Delorme, L. D., 1989, Methods in Quaternary ecology 7—Fre water ostracodes: Geoscience Canada, v. 16, p. 85–90.

Denny, C. S., 1974, Pleistocene geology of the northeast Adir

dack region, New York: U.S. Geological Survey Professional Paper 786, 50 p.
mack, E. W., 1984, Rhythmically bedded glaciomarine sediments on Whidbey Island, Washington: Journal of Sedimentary Petrology, v. 54, p. 589–602.
ke, A. S., and Prest, V. K., 1987, Late Wisconsinan and Holocene retreat of the Laurentide Ice Sheet: Geological Survey of Canada Map 1702A, scale 1:5,000,000.
irchild, H. L., 1907, Gilbert Gulf: Geological Society of America Bulletin, v. 17, p. 712–718.
irchild, H. L., 1919, Pleistocene marine submergence of the Hudson, Champlain, and St. Lawrence Valleys: New York State Museum Bulletin 209–210, 76 p.
rster, S. W., 1971, Pleistocene geology of the Carthage 15′ quadrangle [Ph.D. thesis]: Syracuse, New York, Syracuse University, 129 p.
illerton, D. S., 1980, Preliminary correlation of post-Erie Interstadial events (16,000–10,000 radiocarbon years before present), central and eastern Great Lakes region, and Hudson, Champlain, and St. Lawrence Lowlands, United States and Canada: U.S. Geological Survey Professional Paper 1089, 52 p.
add, N. R., 1980, Late-glacial regional ice flow patterns in eastern Ontario: Canadian Journal of Earth Sciences, v. 17, p. 1439–1453.
add, N. R., 1981, Late-glacial regional ice flow patterns in eastern Ontario: Reply: Canadian Journal of Earth Sciences, v. 18, p. 1390–1393.
add, N. R., 1987, Geological setting and Quaternary deposits of the Ottawa region, *in* Fulton, R. J., ed., Quaternary geology of the Ottawa region, Ontario and Quebec: Geological Survey of Canada Paper 86-23, p. 3–9.
add, N. R., 1988a, The basin, the ice, the Champlain Sea, *in* Gadd, N. R., ed., The late Quaternary development of the Champlain Sea Basin: Geological Association of Canada Special Paper 35, p. 15–24.
add, N. R., 1988b, Lithofacies relationships in freshwater-marine transition of the Champlain Sea, *in* Gadd, N. R., ed., The late Quaternary development of the Champlain Sea Basin: Geological Association of Canada Special Paper 35, p. 83–90.
iurrieri, J. T., and Musiker, L. B., 1990, Late Wisconsinan ice margins and recessional events in the north-central Adirondack mountains, New York: Northeastern Geology, v. 12, p. 185–197.
iustavson, T. C., and Boothroyd, J. C., 1987, A depositional model for outwash, sediment sources, and hydrologic characteristics, Malaspina Glacier, Alaska: A modern analog of the southeastern margin of the Laurentide Ice Sheet: Geological Society of America Bulletin, v. 99, p. 187–200.
Henderson, E. P., 1967, Surficial geology north of the St. Lawrence River, Kingston to Prescott, *in* Guidebook, Geology of parts of eastern Ontario and western Quebec: Geological Association of Canada, p. 199–208.
Henderson, E. P., 1973, Surficial geology of the Kingston (north-half) map area, Ontario: Geological Survey of Canada Paper 72-48, 6 p.
Henderson, P. J., 1988, Sedimentation in an esker system influenced by bedrock topography near Kingston, Ontario: Canadian Journal of Earth Sciences, v. 25, p. 987–999.
Karrow, P. F., 1981, Late-glacial regional ice-flow patterns in eastern Ontario: Discussion: Canadian Journal of Earth Sciences, v. 18, p. 1386–1390.
Kirkland, J. T., and Coates, D. R., 1977, The Champlain Sea and Quaternary deposits in the St. Lawrence Lowland, New York, *in* Newman, W. S., and Salwen, B., eds., Amerinds and their paleoenvironments in North America: New York Academy of Sciences Annals, v. 288, p. 70–89.
Lewis, C.F.M., and Anderson, T. W., 1989, Oscillations of levels and cool phases of the Laurentian Great Lakes caused by inflows from glacial Lakes Agassiz and Barlow-Ojibway: Journal of Paleolimnology, v. 2, p. 99–146.
MacClintock, P., and Stewart, D. P., 1965, Pleistocene geology of the St. Lawrence Lowland: New York State Museum Bulletin 394, 152 p.
Mackiewicz, N. E., Powell, R. D., Carlson, R. P., and Molnia, B. F., 1984, Interlaminated ice-proximal glacimarine sediments in Muir Inlet, Alaska: Marine Geology, v. 57, p. 113–147.
Mirynech, E., 1962, Pleistocene geology of the Trenton-Campbellford map-area, Ontario [Ph.D. thesis]: Toronto, Canada, University of Toronto, 176 p.
Muller, E. H., and Prest, V. K., 1985, Glacial lakes in the Ontario Basin, *in* Karrow, P. F., and Calkin, P. E., eds., Quaternary evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 213–229.
Naldrett, D. L., 1988, The late glacial–early glaciomarine transition in the Ottawa Valley: Evidence for a glacial lake?: Geographie physique et Quaternaire, v. 42, p. 171–179.
Naldrett, D. L., 1990, Locomotion and feeding traces in Champlain Sea subaqueous outwash deposits near Ottawa, Canada: Canadian Journal of Earth Sciences, v. 27, p. 1495–1503.
Naldrett, D. L., 1991, Locomotion and feeding traces in Champlain Sea subaqueous outwash deposits near Ottawa, Canada: Reply: Canadian Journal of Earth Sciences, v. 28, p. 833–834.
Pair, D., 1986, Reconstruction and history of ice retreat, proglacial lakes, and the Champlain Sea, central St. Lawrence Lowlands, New York [M.Sc. thesis]: Waterloo, Ontario, University of Waterloo, 201 p.
Pair, D. L., 1991, Late Pleistocene glacial history and magnetic chronostratigraphy, western Adirondack borderland, New York [Ph.D. thesis]: Syracuse, New York, Syracuse University, 126 p.
Pair, D. L., and Muller, E. H., 1990, Regional flow patterns and subglacial conditions of the St. Lawrence–Lake Ontario ice lobe, western Adirondack borderland, New York: Geological Society of America Abstracts with Programs, v. 22, p. 61.
Pair, D. L., and Rodrigues, C. G., 1989, Late Quaternary deglaciation of the southwestern St. Lawrence Lowland, NY: Geological Society of America Abstracts with Programs, v. 21, p. 55.
Pair, D. L., Karrow, P. F., and Clark, P. U., 1988a, History of the Champlain Sea in the central St. Lawrence Lowlands, New York, and its relationship to Lake Ontario water levels, *in* Gadd, N. R., ed., The late Quaternary development of the Champlain Sea Basin: Geological Association of Canada Special Paper 35, p. 107–124.
Pair, D. L., Muller, E. H., and Anderson, T. W., 1988b, Glacial morphostratigraphic relationships and ice recession on the northwest Adirondack slope and adjacent lowlands, New York: Geological Society of America Abstracts with Programs, v. 20, p. 60.
Parent, M., and Occhietti, S., 1988, Late Wisconsinan deglaciation and Champlain Sea invasion in the St. Lawrence Valley, Quebec: Geographie physique et Quaternaire, v. 42, p. 215–246.
Prest, V. K., 1970, Quaternary geology of Canada, *in* Douglas, R.J.W., ed., Geology and economic minerals of Canada: Geological Survey of Canada Economic Geology Report 1 (5th edition), p. 675–764.
Rodrigues, C. G., 1984, Faunal successions in late Pleistocene sediments of the Ottawa–St. Lawrence Lowlands: 1984 Canadian Paleontology and Biostratigraphy Seminar Program with Abstracts, p. 7.
Rodrigues, C. G., 1987, Late Pleistocene invertebrate macrofossils, microfossils, and depositional environments of the western basin of the Champlain Sea, *in* Fulton, R. J., ed., Quaternary geology of the Ottawa region, Ontario and Quebec: Geological Survey of Canada Paper 86-23, p. 16–23.
Rodrigues, C. G., 1988, Late Quaternary invertebrate faunal associations and chronology of the western Champlain Sea Basin, *in* Gadd, N. R., ed., The late Quaternary development of the Champlain Sea Basin: Geological Association of Canada Special Paper 35, p. 155–176.
Rodrigues, C. G., 1991, Locomotion and feeding traces in Champlain Sea subaqueous outwash deposits near Ottawa, Canada: Discussion: Canadian Journal of Earth Sciences, v. 28, p. 831–832.
Rodrigues, C. G., 1992, Successions of invertebrate microfossils and the late Quaternary deglaciation of the central St. Lawrence Lowland, Canada and United States: Quaternary Science Reviews, v. 11, p. 503–534.
Ruddiman, W. F., and Wright, H. E., eds., 1987, North America and adjacent oceans during the last deglaciation: The Geology of North America, Volume K-3: Boulder, Colorado, Geological Society of America, 501 p.
Rust, B. R., 1977, Mass flow deposits in a Quaternary succession near Ottawa, Canada: Diagnostic criteria for subaqueous outwash: Canadian Journal of Earth Sciences, v. 14, p. 175–184.
Rust, B. R., 1988, Ice-proximal deposits of the Champlain Sea at south Gloucester, near Ottawa, Canada, *in* Gadd, N. R., ed., The late Quaternary development of the Champlain Sea Basin: Geological Association of Canada Special Paper 35, p. 37–46.
Rust, B. R., and Romanelli, R., 1975, Late Quaternary subaqueous outwash deposits near Ottawa, Canada, *in* Jopling, A. V., and McDonald, B. C., eds., Glaciofluvial and glaciolacustrine sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 23, p. 177–192.
Sharpe, D. R., 1988, Glaciomarine fan deposition in the Champlain Sea, *in* Gadd, N. R., ed., The late Quaternary development of the Champlain Sea Basin: Geological Association of Canada Special Paper 35, p. 63–82.
Shaw, J., Naldrett, D., and Vreeken, W., 1991, The late glacial and post-glacial environment of the Kingston area: The Canadian Association of Geographers field trip, 10 p.
Shulmeister, J., 1989, A conceptual model for the deposition of the Dummer Moraine, southern Ontario: Geomorphology, v. 2, p. 385–392.
Sly, P. G., and Prior, J. W., 1984, Late glacial and post glacial geology in the Lake Ontario Basin: Canadian Journal of Earth Sciences, v. 21, p. 802–821.
Spencer, J. W., 1892, The Iroquois shore north of the Adirondacks: Geological Society of America Bulletin, v. 3, p. 488–491.
Stevens, R., 1985, Glaciomarine varves in Late-Pleistocene clays near Goteborg, southwestern Sweden: Boreas, v. 14, p. 127–132.
Stevens, R., 1986, Glaciomarine varves and the character of deglaciation, Savean valley, southwestern Sweden: Boreas, v. 15, p. 289–299.
Stewart, D. P., 1958, The Pleistocene geology of the Watertown and Sackets Harbor quadrangles, New York: New York State Museum Bulletin 369, 79 p.
Street, J. S., 1988, Glacial meltwater channels associated with deglaciation: Geological Society of America Abstracts with Programs, v. 20, p. 285.
Sutton, R. G., Lewis, T. L., and Woodrow, D. L., 1972, Post-Iroquois lake stages and shoreline sedimentation in eastern Ontario Basin: Journal of Geology, v. 80, p. 346–356.
Taylor, F. B., 1924, Moraines of the St. Lawrence Lowland: Journal of Geology, v. 32, p. 641–667.
Teller, J. T., 1988, Lake Agassiz and its contribution to flow through the Ottawa–St. Lawrence system, *in* Gadd, N. R., ed., Quaternary evolution of the Champlain Sea Basin: Geological Association of Canada Special Paper 35, p. 281–290.
Teller, J. T., 1990, Volume and routing of late-glacial runoff from the southern Laurentide Ice Sheet: Quaternary Research, v. 34, p. 12–23.
Thomas, R. H., 1977, Calving bay dynamics and ice sheet retreat up the St. Lawrence Valley system: Geographie physique et Quaternaire, v. 31, p. 347–356.
Upham, W., 1895, Late glacial or Champlain subsidence and reelevation of the St. Lawrence River basin: American Journal of Science, v. 49, p. 1–18.
Westgate, J. A., Chen, F. J., and Delorme, L. D., 1987, Lacustrine ostracodes in the late Pleistocene Sunnybrook diamicton of southern Ontario, Canada: Canadian Journal of Earth Sciences, v. 24, p. 2330–2335.
Wright, F. M., 1972, The Pleistocene and Recent geology of the Oneida-Rome district, New York [Ph.D. thesis]: Syracuse, New York, Syracuse University, 181 p.

Manuscript Received by the Society July 1, 1992
Revised Manuscript Received February 5, 1993
Manuscript Accepted February 12, 1993

Printed in U.S.A.