The Late Glacial-Early Glaciomarine Transition in the Ottawa Valley: Evidence for a Glacial Lake?

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THE LATE GLACIAL-EARLY GLACIOMARINE TRANSITION IN THE OTTAWA VALLEY: EVIDENCE FOR A GLACIAL LAKE?

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ABSTRACT Rhythmites overlying either cross-bedded sand or diamicton are found throughout the Ottawa Valley. Previously thought to be restricted glacial lake sediments, they are now known to be widespread, and represent a large proglacial lake which preceded the Champlain Sea. The rhythmites consist of thin silt and clay laminae which fine upwards and contain slump, flame, shear (ice-contact?) and fluid escape structures. Ice-rafted material is common. The ostracode *Candona* cf. *C. subtriangulata* occurs in low numbers and indicates a freshwater body with depth of approximately 200 m. The alternation of silt and clay rhythmite laminae is characteristic of deposition by underflow and overflow currents, respectively. To produce underflows with typical glacial outwash concentrations may require discharge into fresh rather than marine water. This evidence and the widespread occurrence of rhythmites throughout the Ottawa Valley and the Rideau Lakes area suggests a large proglacial lake as the sedimentary basin. The lake is tentatively correlated with the Belleville Phase of Glacial Lake Iroquois and the Fort Ann Phase of Glacial Lake Vermont. These phases occurred at depths consistent with the requirement for *Candona* survival. The water body which existed in the Ottawa area is here called Lake Rideau after the type locality where rhythmites were first observed. Generation of such a lake favours the more conventional "window blind" model for deglaciation rather than the calving bay concept.
INTRODUCTION

Cronin (1977, 1981) identified a Transitional Phase of the Champlain Sea (Fig. 1) which represents the period from late-glacial to early glaciomarine time. This phase was identified on the basis of ostracodes tolerant of fresh to brackish water. Cronin gave no detailed description of the sediments, or interpretation of the depositional environment.

The purpose of this paper is to examine similar sediments from the Ottawa Valley in surface exposure and in cores, and to critically examine the evidence for either a glaciolacustrine or glaciomarine origin. This will provide new insight into the transition from late-glacial to early glaciomarine environments in the Ottawa Valley.

Recent construction activity and a drilling program by the Geological Survey of Canada (GSC) Terrain Sciences Division (Fig. 2) allowed excellent surface and subsurface examination of these deposits, and provided surface control to validate findings from core analysis.

PREVIOUS STUDIES

Previous studies have focussed on the proximal subaqueous outwash facies of the ridges in the Ottawa area (e.g. Rust, 1977), and on the littoral deposits of the receding Champlain Sea (Fig. 3). Little attention has been paid to the early deposits, characterized by rhythmically laminated and massive silt and clay.

Johnston (1916, 1917) studied the clay in detail. He noted its occurrence and distribution, accurately describing and dividing it into upper and lower clay. Johnston (1917) showed photographs of the upper and lower clay in sections in Ottawa (Plate III) and on the Rideau River near Rideau Junction (Plate VII; location shown on Fig. 3). Antevs (1925) noted "varved" clay at the base of several exposures in the Ottawa Valley, and attributed it to deposition in glacial Lake Frontenac. Gadd (1961, 1962) began modern work on the rhythmites exposed along the Rideau River near Uplands. He postulated that the late-glacial Rideau Valley was blocked by the Bowesville Moraine (now termed the South Gloucester Ridge, Fig. 3), and drained southward, presumably toward the St. Lawrence Valley. Gadd suggested that in a stage just prior to marine submergence, the valley contained a glacial lake. Romanelli (1970) identified the marine foraminifera Elphidium bartletti, Protelphidium orbiculare, Cassidulina islandica and Pseu...
dopolymorphina novanglie in the upper clay at this locality. Banerjee (1973) named the lower, laminated silt and clay the Rideau River varves, and showed structures indicative of slumping and turbidite-type deposition.

SEDIMENTOLOGY AND STRATIGRAPHY

FACIES DESCRIPTIONS

The laminated and massive fine-grained facies comprise only a small portion of the Quaternary sediments of the Ottawa Valley. Facies were observed in sections located in the Foster sand pit (Fig. 5). Sediments were exposed during sand pit operation, and occurred naturally in a deeply incised gully which cut into the complete marine sequence of offshore and nearshore deposits of the Champlain Sea overlain by laminated silt and clay (Fig. 4). Figure 4 shows a generalized stratigraphic column based on surface exposures at the Foster pit, with laminated and massive facies located between 3 m and 6 m. Facies correspond to similar sediments observed in all GSC cores (Gadd, 1977, 1986; Naldrett, 1986). Complete core logs and sediment description is given by Gadd (1986). To simplify discussion, sediments are described below by lithofacies, in order of stratigraphic appearance.

Facies 1

Facies 1 consists of large-scale tabular sets of cross-bedded sand overlain by small-scale cross-laminations. The large tabular sets are 0.8 m thick and consist of well defined and preserved foreset, toset and attenuating bottomset laminae distinguished by heavy mineral accumulations. In places, dune foresets can be traced through toesets into bottomsets (Fig. 6a). Similar deposits from the Brampton esker have been described by Saunderson and Jopling (1980). The rate of sedimentation of the suspended load was sufficient to form a fine sandy to silty drape over the dune front, in places merging into regressive ripples of the bottomset. The silt indicates periods of quiescence of the sand wave followed by reactivation (Allen, 1982). The continuity between the foreset, toset and bottomset bedding indicates that deposition must have been contemporaneous.

In the upper portion of facies 1, transitional ripples (Jopling and Walker, 1968) have low angle erosional scours merging into a lens of deformed ripples (Fig. 6c). The lens may be a large rip-up clast, although its origin is problematic. Large cross-beds are exposed in section 1, with large and small cross-beds exposed in section 2.

Facies 2

Facies 2 is composed of matrix-supported diamicton with smaller maximum clast size than proximal gravel. Based on qualitative fabric observations, there is no preferred orientation of the larger clasts.

A possible till flow origin is indicated for the diamicton on the basis of stratigraphic position, fabric, poor sorting and the lack of sedimentary structures. Till flow facies have been observed in association with interchannel sand facies of the Ottawa area ridges (Rust, 1982). Other coarse-grained facies such as proximal gravel are clast-supported with large, imbricate clasts.
Drilling studies (French and Rust, 1981; Graham and Jackson, 1982) show similar diamicton at the base of the South Gloucester Ridge, immediately to the south in the direction of subaqueous outwash paleoflow. In all sections, the basal unit is either tabular cross-bedded to rippled medium-grained sand (facies 1, Fig. 6a), or poorly sorted diamicton (facies 2, Fig. 6b). In section 1, sand is overlain by diamicton; in section 2, the diamicton is absent.

Facies 3

Facies 3 consists of convoluted interbeds of fine silt or clay and silty sand. These beds appear to have been deposited as the ripples in facies 1, but they have been disrupted (Fig. 6d) by loading and slumping. Figure 6e shows details of these features. At least two complete cycles occur where ripple amplitude decreases upward and laminations change from...
small thickness type C ripple drift cross-lamination at the base to nearly planar lamination at the top. Banerjee (1973) described similar structures and attributed them to slumping, whereby turbidity currents may have been generated. Figure 6e illustrates the downslope movement, where flow was from left to right. Parts of the clay bed became detached when slumping silty sand cut into the clay, separating part of the underlying bed. The cohesiveness of the clay caused the detached sediment to form small spheres.

In section 1, directly overlying the diamicton is a lens of convolute laminated silt and clay which pinches out. Thickness reaches up to 200 mm, and in places the convolutions form crude pseudonodules. In contrast to the obvious slump features of section 2, these features occur in a variety of orientations rather than the unidirectional deformation produced as a result of slumping. The disrupted bedding may be the result of grounded ice shearing the underlying sediment, producing deformation in several directions (Fig. 6f).

Facies 4

Facies 4 consists of rhythmically laminated silt and clay, termed rhythmites. Undulose bedding and ripples are the dominant sedimentary structures in facies 4. Lenses of ice-rafted material (Fig. 7b) are common and restricted to the central portion of the rhythmite sequence. Figure 7c illustrates a typical rhythmite series roughly 200 mm thick. The rhythmites are predominantly silt with occasional sand and rare clay layers. The bulk of the textural variation occurs in the silt range, from very fine to medium or coarse. Coarse (sandy) layers are poorly graded and have a sharp contact with the overlying silt. Small clasts up to 3-4 mm diameter commonly occur at the top of the sand laminations, and never occur in the clay. These are interpreted as dropstones deposited from summer melt of surface ice. In the rhythmite classifications of Banerjee (1973) and Lajtai (1969), the rhythmites of this facies are silty or graded to complex, respectively.

All contacts are smooth and gradational. The silt layers are often undulose and appear to form long wavelength ripples. Banerjee (1973, Fig. 3e) noted ripples 50 mm high and 390 mm long at this locality. In rare cases, fine-grained sediments display small load structures when overlain by coarser material. Microfaults are also found distributed randomly throughout the silt layers. Displacements are usually a few mm; generally these are two to three times lamination thickness and faults are restricted to single beds. It is thus concluded that the faults are of syndepositional origin.

Rhythmites, previously termed varves by Banerjee (1973) and Gadd (1961, 1962), are restricted to a 1 m thick section overlying the sediments described above. Details are shown in Figure 7a, which shows rhythmites at section 1.
Conformably overlying the disrupted bedding of facies 3 is a thin (100 mm) drape of laminated sand and silt which represents the first rhythmite deposition. The drape consists of massive to faintly laminated medium sand with the middle 50 mm of laminated silt and clay. Pseudonodules composed of laminated silt and clay occur in the sand. The structures are completely isolated, and rarely exceed 100 mm in largest dimension.

Rhythmite Distribution and Correlation

Rhythmites have been identified in similar stratigraphic position to those exposed at the Foster pit in all GSC boreholes (Fig. 2). Anderson et al. (1985) have identified rhythmites from Ottawa through the Rideau Lakes area to the Lake Ontario basin. It thus appears that an extensive proglacial lake preceded the Champlain Sea, and covered the area known to have been inundated by the Champlain Sea as well as the Rideau Lakes area and the Lake Ontario basin. Correlation of rhythmites from these different areas is speculative, since no conclusive marker bed or sediment package has been found which can demonstrate deposition took place in a single basin.

If similar rhythmite deposits in these areas are correlated with the Belleville Phase of Glacial Lake Iroquois and the Ft. Ann Phase of Glacial Lake Vermont, a high level (> 200 m) water body would have flooded the area, creating a large lake, as shown in Figure 8.

The highly variable nature of the episodic rhythmites makes correlation over a large area difficult. Minor facies changes occur within 100 m, making correlation and analysis of sedimentation patterns difficult. In subsurface analysis, the problem becomes more complex. Individual sedimentation units do not correlate well, if at all, between cores. There appears to be no basin-wide depositional marker or event which can be used to correlate depositional history: close examination of selected GSC cores has shown that while the depositional pattern is similar in all cores, each displays its own particular sedimentation rhythm. Under normal conditions, if turbidite-type deposition is assumed, the rhythmites should become more distal and thin and fine as the ice front recedes. Agterberg and Banerjee (1969) and Banerjee (1973) presented a complex stochastic model for deposition, but core from the Ottawa Valley does not conform to this model.

The following characteristics of the rhythmites appear in all sections and in cores examined, and may be used as a general guide to correlation:

1) lower contacts are always with either diamicton or sand, and sharp;
2) the basal 200-300 mm contain convolute lamination: in places resulting from slumping;
3) lenses of diamicton are restricted to the central portion of the rhythmite sequence;
4) lamination becomes less common and beds more widely spaced in the upper part of the deposit; close examination, however, reveals that lamination is present in the apparently massive upper clay.

Facies 5

Facies 5 consists of massive clay with rare silt stringers and lamination. Bulk grain size distribution is similar to the underlying facies 4, however, silt and clay are not separated into distinct laminations in this facies. The massive clay is part of a well documented (Gadd, 1977) coarsening upward sequence. The portion described here represents the fine-grained facies where muds (mainly clay) predominate. Figure 7d illustrates the transition from laminated lower clay (facies 4) to apparently massive upper clay (facies 5). A ripples bed between the two units marks the position of a discontinuity separating non-marine rhythmite deposition and marine deposition of the overlying massive silt and sand. Fossil insects and plants found in the silt unit include flies, wasps and ants, sowbugs, weevils, beetles, millipedes, and the maxillae of a fish (Naldrett and Rust, 1984). Subsequent examination of faunal and floral evidence (GSC Plant Macrofossil Report No. 84-25 by J. V. Matthews Jr.; GSC Fossil Arthropod Report No. 84-24 by J. V. Matthews Jr.) indicates this material is younger than its stratigraphic position would suggest, although the exact temporal relationship has yet to be determined.

1.5 m above the contact with massive clay, a number of juvenile *Portlandia arctica* occur. Of 35 individuals collected, all were less than 5 mm long, with the majority between 2-3 mm long (Fig. 9). The close range in size and the small size itself suggests a high juvenile mortality rate: spat kill must have occurred at an early stage, eliminating an entire generation of individuals. No adult remains were found. Hillaire-Marcel (1980) noted *Portlandia arctica* is typical of early glaciomarine environments, however the early Champlain Sea must have been too harsh for even this hardy species.
The possibility of ostracode valves being washed into the depositional area was considered and rejected, since the surface of *Candona* showed no evidence of abrasion. Like other freshwater ostracodes, *Candona* valves are fragile, and would be easily abraded or broken during transport. It is thus assumed that all ostracodes, even though disarticulated, are found in place. The preference of *Candona* for deep freshwater bodies (Delorme, 1970) eliminates the possibility of *Candona* being washed into a marine basin from small ice-marginal ponds of fresh water.

 Cronin (1981) noted *Candona* in Transitional Phase Champlain Sea sediments where fresh and marine waters mixed to produce a brackish environment. *Candona*, therefore, must be salinity-tolerant to some extent, however Delorme (1970) noted that *Candona* will not live exclusively in a marine environment and is most commonly found in deeper waters of the Great Lakes. It is quite tolerant of sulphate-rich brackish water and less tolerant of water with high chlorinity. It appears that *Candona* is a useful indicator of deep, freshwater, but may tolerate brackish water under certain conditions.

In the massive clay (facies 5), faunal diversities are low: usually the populations are restricted to less than 7 or 8 species with 1 or 2 species dominant. Within the dominant species, abundance is also low. Variation in microfossil abundance is a function of the rate of sedimentation, diagenetic processes, and adverse environmental conditions at the time of deposition (Cronin, 1977). Low salinity, poor nutrient supply or strong currents may also affect abundance. Dominant species, however, are considered representative of the depositional environment.

The following foraminifera were found in the massive clay: *Protephidium orbiculare*, *Elphidium bartletti*, *Cassidula islandica*, *Cassidulina crassa*, *Islandiella islandica* and *Dentalina pauperata*. As with other fine-grained facies, the foraminifera dominate the ostracodes, which are often completely absent. Dominant species are: *Elphidium bartletti*, *Protephidium orbiculare* and *Cassidula crassa*. Based on the information available, the massive clay facies was deposited in brackish water (18-28 ppt) of shallow to moderate depth (10-30 m). Care must be exercised in bathymetric estimates, however, since restricted faunas could be washed into deeper water in times of high meltwater input. Where a great bathymetric range seems evident, faunal mixing may have occurred.

**DISCUSSION**

The laminated silt and clay (rhythmite) facies differs from varves. Normally, as an ice front recedes, successively deposited units are more distal and finer-grained: sediment supply diminishes and individual unit thickness decreases with time. The result is that the sequence fines upward and unit thickness decreases toward the top. This does not occur in the Ottawa Valley rhythmites, and sedimentary evidence suggests episodic deposition by density current underflows.

The freshwater event was most likely shortlived. Rust (pers. comm., 1986) estimated deposition time to be roughly 20 years and Gadd (1986) proposed a period of 30-50 “varve years”. These estimates are based on the assumption that
major depositional breaks represent annual breaks in sedimentation. Although the rhythmites cannot be proven annual, these seem to be the best estimates to date for the duration of the lake.

Assuming maximum thickness of 1.0 m and minimum deposition time gives a sedimentation rate of 50 mm/yr. Gadd (1986) estimated a sedimentation rate of 35-50 mm/yr for the overlying Champlain Sea clay, based on thicknesses observed in the Ottawa Valley boreholes and radiocarbon dates giving marine maximum and freshwater minimum (post-Champlain Sea) ages. Rapid distribution and deposition over an uneven lake-bottom topography led to various fluid escape structures, slumping and microfaulting. The result is a chaotic depositional style, and poor correlation of units.

Presently, only the beginning and the end of rhythmites can be traced through the subsurface. With further study, individual depositional packages may be identified and traced through the Ottawa Valley. Further work is needed to better determine the sedimentology, stratigraphy and extent of the rhythmites. This may help determine whether a single basin was involved (as is suggested by the high elevation of the water plane) or several smaller water bodies coexisted.

Surface and subsurface evidence indicates the presence of a proglacial lake covering at least the area within the Ottawa Valley. It is proposed here that this water body be called Lake Rideau (Fig. 8). This name is taken from the type location on the Rideau River where Banerjee (1973) first described the rhythmites, calling them the Rideau River varves. It is possible that the maximum extent of the freshwater body was larger, however only the known extent is shown here, with possible connection to the Belleville Phase of Glacial Lake Iroquois and the Ft. Ann Phase of Glacial Lake Vermont producing the larger water body shown in Figure 8.

Creation of such a large lake would require deglaciation in the more conventional “window blind” model proposed by Clark and Karrow (1984) and Prest (1970) rather than the calving bay model proposed by Gadd (1980). The style of deglaciation in this area is a point of controversy. The conventional idea is that ice in the lowland areas retreated in a roughly south to north direction with proglacial lakes extending into the centre of the area from the Lake Iroquois basin to the west and the Lake Vermont basin to the east. The alternative view is that a calving bay moved up the lower St. Lawrence Valley from the east and into the Ottawa area, isolating ice between Cornwall and Kingston in the upper St. Lawrence Valley. In this model, the rhythmites were deposited in a temporary freshwater phase which occurred at the head of the calving bay. The calving bay concept thus provides a mechanism for retaining freshwater in the Lake Ontario basin while the Champlain Sea occupied the Ottawa Valley. Chauvin et al. (1985), however, argue that ice did not calve upstream past Québec City. The conventional “window blind” model appears to better explain the distribution of glaciolacustrine deposits underlying the Champlain Sea deposits, and the pattern of subaqueous outwash ridges (Fig. 2) found in the Ottawa area (Fulton, 1986).

CONCLUSIONS

The previous discussion points to the existence of a transient, early freshwater body preceding the Champlain Sea in the Ottawa Valley. Faunal and sedimentological evidence indicate periodic influx of glacial meltwater, significant ice interaction, and a brief period of rapid sedimentation by episodic underflow currents following an uneven lake-bottom topography. In the Ottawa Valley, this event is represented by rhythmic sediments of Glacial Lake Rideau. Correlation of the Ottawa Valley rhythmites with sediments from the Belleville Phase of Glacial Lake Iroquois and the Ft. Ann Phase of Glacial Lake Vermont would produce a large lake up to 200 m deep. The freshwater body apparently existed at a higher elevation than the Champlain Sea, and occupied a larger area, as shown in Figure 8. This is in possible agreement with Clark and Karrow (1984) who proposed a coeval Trenton Phase of Lake Iroquois and the Champlain Sea, and with Cronin (1977) who proposed a Transitional Phase of the Champlain Sea (12,500 BP to 11,600 BP).

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