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La période de transition entre la fin du glaciaire et le début du glacio-marin dans la vallée de la rivière aux Outaouais : preuve de l'existence d'un lac glaciaire?

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Article 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 Ft. Ann Phase of Glacial Lake Vermont. These phases occurred at depths consistent with the requirements 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 déglaciation rather than the calving bay concept.

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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 Ft. Ann Phase of Glacial Lake Vermont. These phases occurred at depths consistent with the requirements 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.

RÉSUMÉ *La période de transition entre la fin du glaciaire et le début du glacio-marin dans la vallée de la rivière aux Outaouais: preuve de l'existence d'un lac glaciaire?* On trouve tout au long de la vallée des Outaouais des rythmites qui recouvrent soit du sable en stratification oblique, soit un diamicton. On les a d'abord considérées comme des sédiments glacio-lacustres localisés, mais on sait maintenant qu'elles sont répandues et qu'elles témoignent de l'existence d'un grand lac glaciaire qui aurait précédé la Mer de Champlain. Les rythmites sont constituées de lamines de silt et d'argile qui s'affinent vers le haut et qui renferment des structures de glissement, en flamme, de cisaillement (de contact glaciaire?) et d'échappement fluidal. Les matériaux transportés par radeaux de glace sont courants. L'ostracode *Candona* cf. *C. subtriangulata* que l'on trouve en petit nombre témoigne de l'existence d'une nappe d'eau douce d'une profondeur d'environ 200 m. L'alternance de lamines rythmiques de silt et d'argile est caractéristique d'une mise en place par des courants de sous-écoulement et de débordement, respectivement. Pour qu'il y ait sous-écoulement accompagné de concentrations d'épandage fluvio-glaciaire, le déversement doit se faire en eaux douces plutôt qu'en milieu marin. Cet élément de preuve ajouté au fait que l'on trouve des rythmites partout dans la région de la vallée des Outaouais et des lacs Rideau laisse croire qu'un grand lac glaciaire a servi de bassin de sédimentation. À titre d'essai, on a établi la corrélation entre ce lac et la phase Belleville du Lac glaciaire Iroquois et la phase de Fort Ann du Lac glaciaire Vermont. Ces phases correspondent à des profondeurs d'eau conformes à la survie de *Candona*. On nomme ici *Lac Rideau* la nappe d'eau qui occupait la région d'Ottawa, d'après le site de référence où l'on a observé les premières rythmites. L'existence d'un tel lac favorise le modèle classique de retrait graduel des glaces plutôt que l'hypothèse des baies de vêlage.

ZUSAMMENFASSUNG *Die Übergangszeit zwischen dem Ende der Eiszeit und dem Beginn der glazio-marinen Zeit im Tal des Outaouais-Flusses: Nachweis eines glazialen Sees?* Das ganze Outaouais-Tal entlang findet man Rhythmite, die entweder diagonal-geschichteten Sand oder Diamikton überlagern. Zuerst hielt man sie für begrenzte glaziale See-Sedimente, aber jetzt weiss man, dass sie weit verbreitet sind und auf das Vorhandensein eines grossen glazialen Sees hinweisen, der sich dort vor dem Champlain-Meer befand. Die Rhythmite bestehen aus Schlamm- und Ton-Schichten, die sich nach oben verfeinern und Strukturen von Gleiten, Flammen, Abscherung (durch Eis-Kontakt?) und Flüssigkeitsentweichen enthalten. Es gibt häufig durch Eis-Flosse transportiertes Material. Ostracode *Candona* wie auch *C. subtriangulata*, das man in kleinen Mengen findet, weist auf einen Süsswasserspiegel von ungefähr 200 m Tiefe hin. Der Wechsel zwischen rhythmischen Schichten von Schlamm und Ton ist charakteristisch für eine Ablagerung durch Unterstrom- bzw. Überlaufströmungen. Damit Unterstrom mit gleichzeitigen Konzentrationen von fluvio-glazialer Aufschwemmung stattfindet, muss das Abfliessen eher in Süsswasser als in Meereswasser geschehen. Dieser Nachweis und die Tatsache, dass man überall im Gebiet des Outaouais-Tals und der Rideau-Seen Rhythmite findet, erlaubt zu glauben, dass ein grosser glazialer See als Becken für die Ablagerung gedient hat. Versuchsweise wurde eine Korrelation zwischen diesem See und der Belleville-Phase des glazialen Iroquois-Sees und der Fort Ann-Phase des glazialen Vermont-Sees erstellt. Diese Phasen entsprechen Wassertiefen, die mit den Bedingungen für das Überleben von *Candona* übereinstimmen. Rideau-See wird hier nach dem Modell-Standort, wo man die ersten Rhythmite bemerkt hat, die Wasserfläche genannt, die sich im Gebiet von Ottawa befand.

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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-*

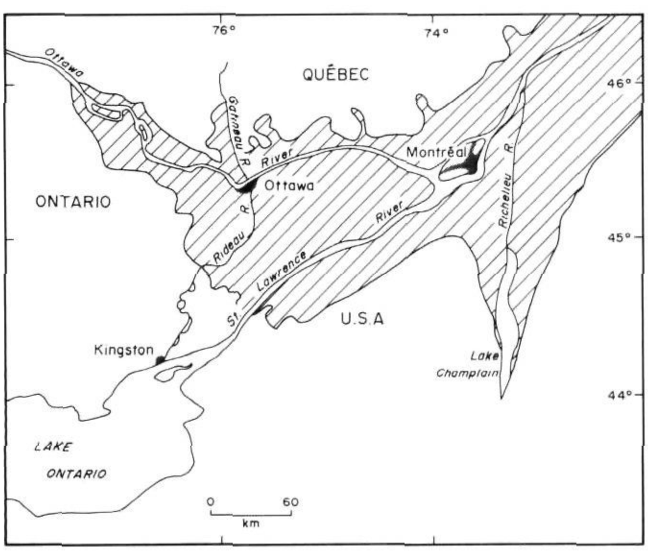

FIGURE 1. Generalized limits of the western portion of the Champlain Sea.

Limites généralisées de la partie ouest de la Mer de Champlain.

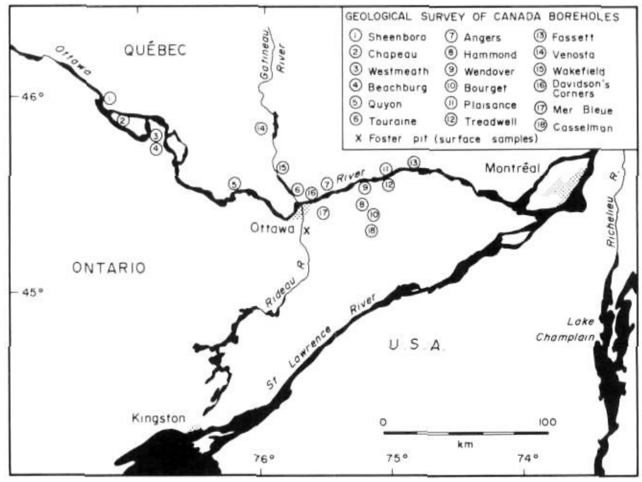

FIGURE 2. Location of the Geological Survey of Canada (GSC) boreholes in the Ottawa Valley.

Localisation des trous de forage de la Commission géologique du Canada dans la vallée des Outaouais.

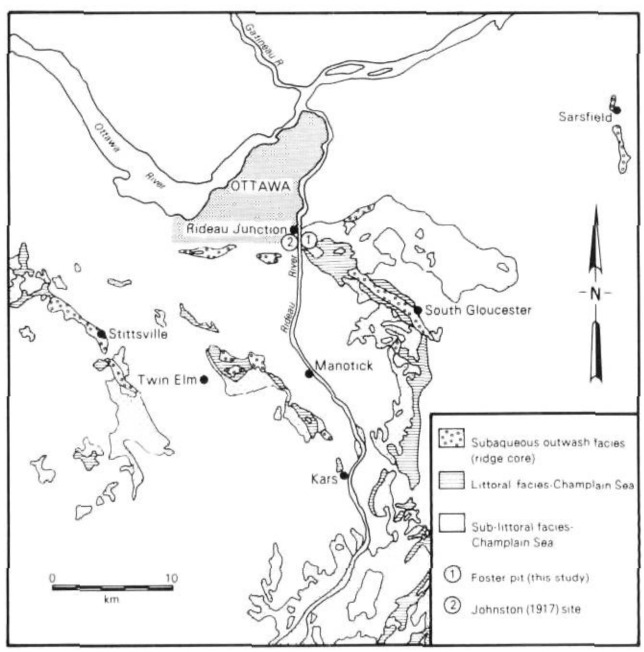

FIGURE 3. Subaqueous outwash and littoral facies of the Ottawa area (after Richard *et al.*, 1977).

Épandages sous-aquatiques et faciès littoraux dans la région d'Ottawa (d'après Richard et al., *1977).*

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 overlying 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, toeset and attenuating bottomset laminae distinctively shown 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, toeset 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.

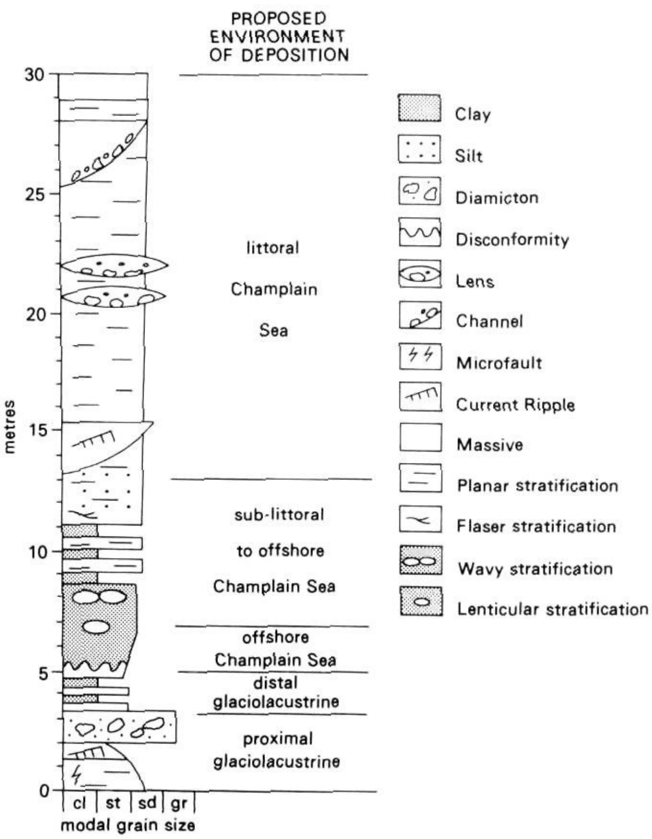

FIGURE 4. Generalized stratigraphic column.
Colonne stratigraphique généralisée.

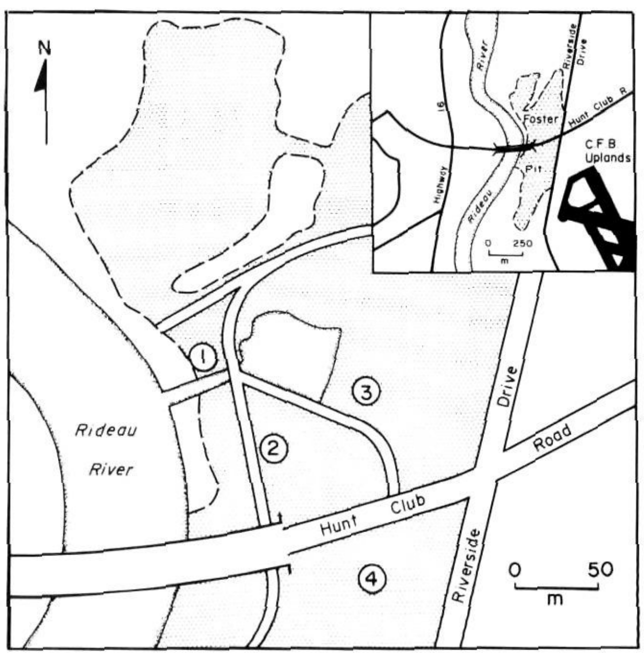

FIGURE 5. Location of sections in the Foster sand pit.
Localisation des coupes à la sablière Foster.

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

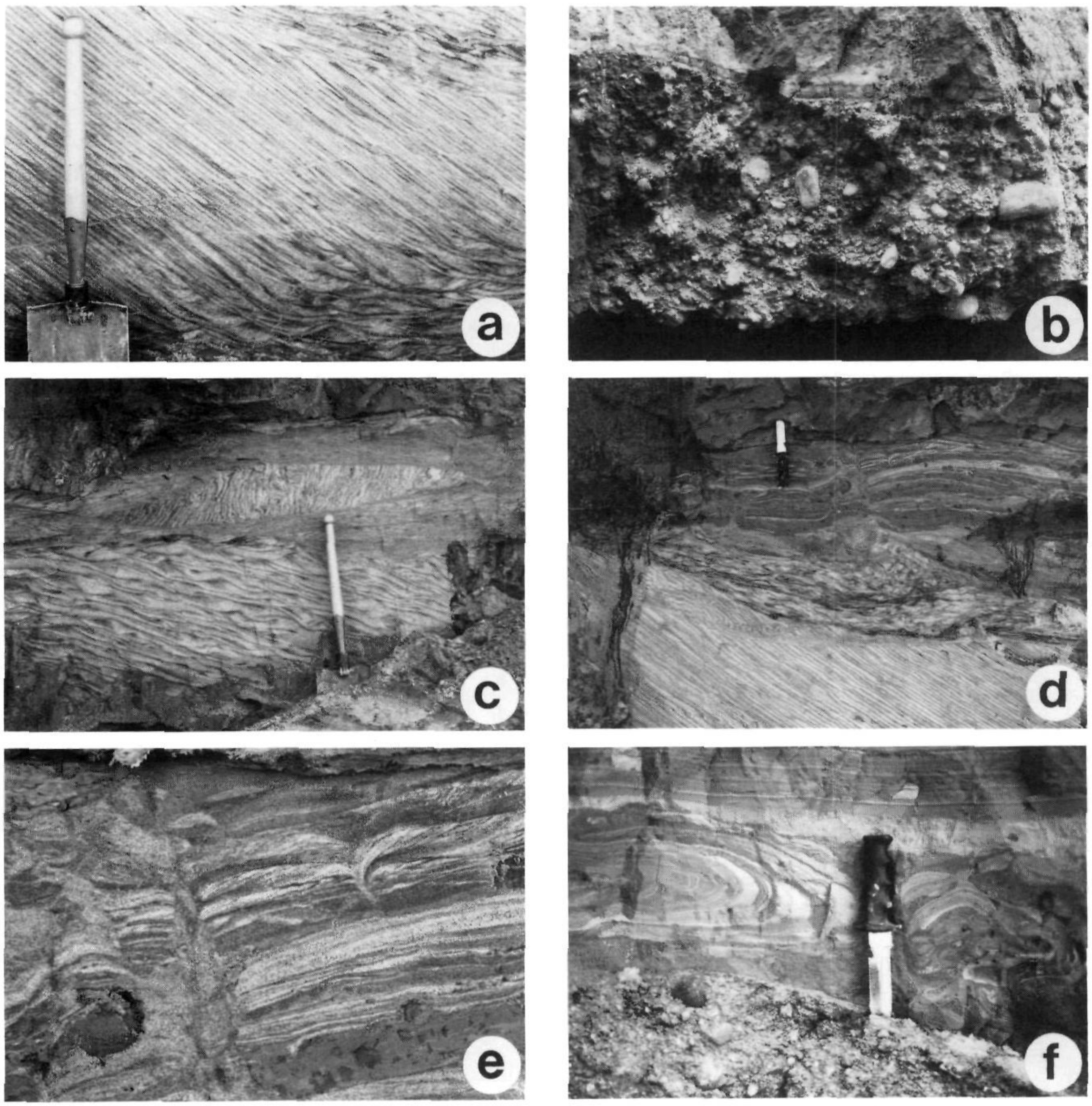

FIGURE 6. Sedimentary structures underlying the rhythmites: a) dune, section 2; b) diamicton, section 1; c) rip-up clast, section 2, bedding shown by heavy mineral accumulations; d) convolute laminations, section 2; e) detail of fluid escape structures from 5d; f) shear (ice-contact) structures, section 1.

Structures sédimentaires sous les rhythmites: a) dune, coupe n° 2; b) diamicton, coupe n° 1; c) fragment d'arrachement, coupe n° 2, les accumulations de minéraux lourds montrent le litage; d) laminations contournées, coupe n° 2; e) détail des structures d'échappement fluidal de 5d; f) structures de cisaillement (de contact glaciaire), coupe n° 1.

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 then 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.

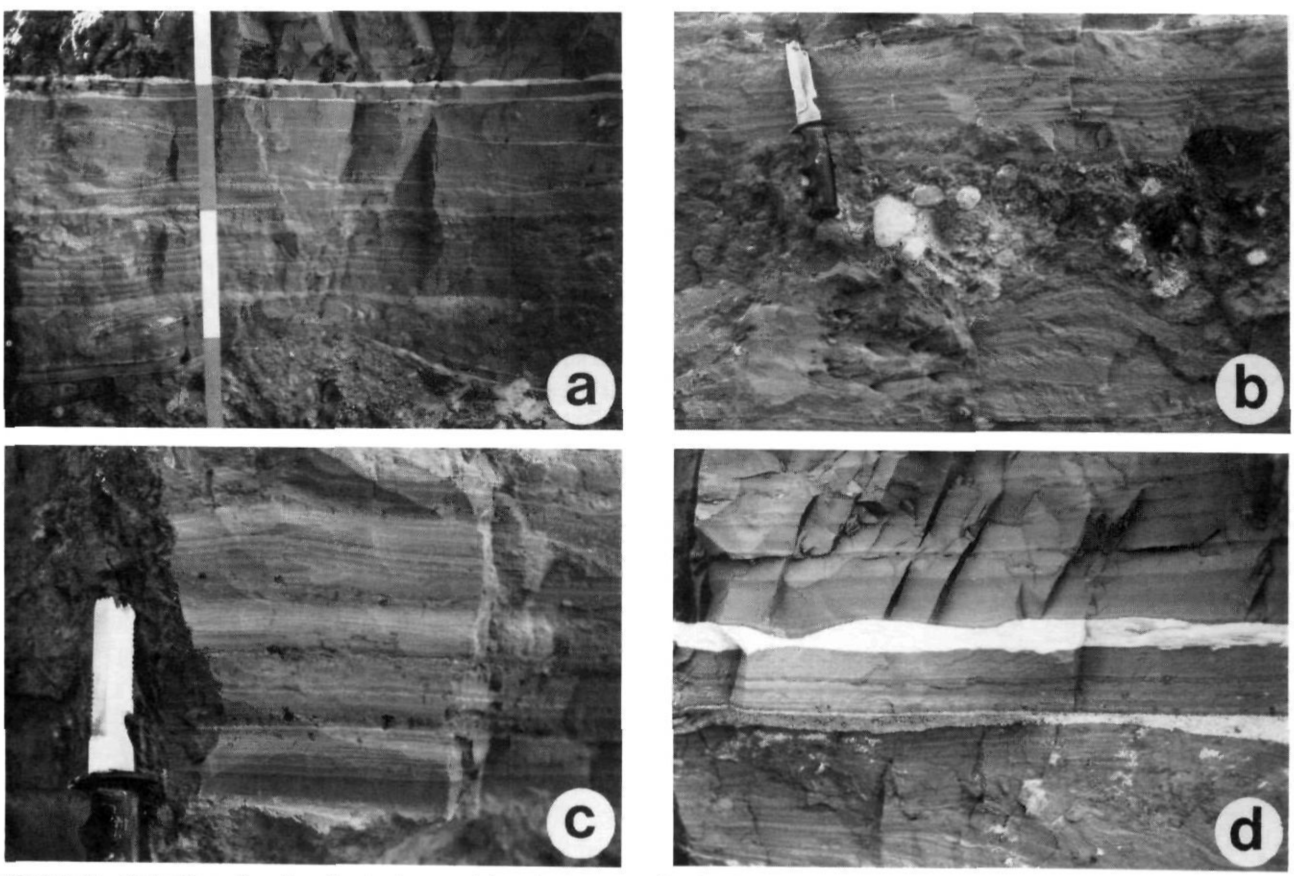

FIGURE 7. Rythmite portion of section 1 : a) general view of rythmites; b) lens of ice-rafted debris; c) details of rythmites laminations; d) rippled silt bed separating rythmites from overlying massive silt.

Partie de la coupe n° 1 contenant des rythmites: a) vue générale des rythmites; b) lentilles de débris transportés par radeaux de glace; c) détail des laminations de rythmites; d) lit de silt ondulé qui sépare les rythmites du silt massif sus-jacent.

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.

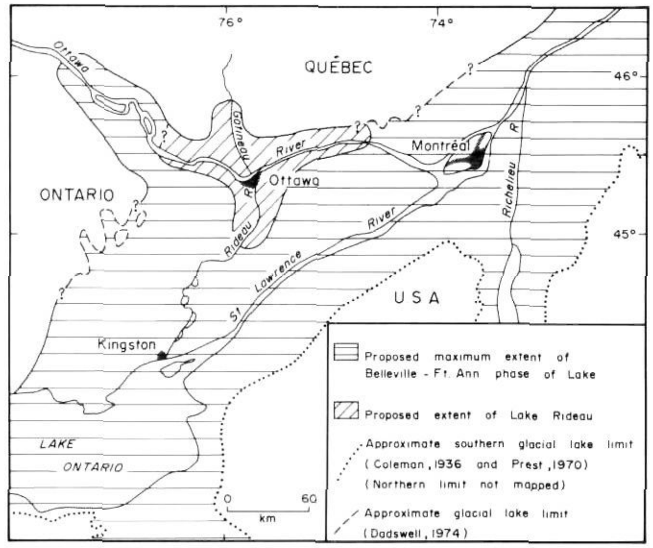

FIGURE 8. Inundation of the Ottawa Valley by a large proglacial lake correlated with the Belleville Phase of Glacial Lake Iroquois and the Ft. Ann Phase of Glacial Lake Vermont.

Inondation de la vallée des Outaouais par un vaste lac glaciaire qu'on a fait correspondre à la phase Belleville du Lac glaciaire Iroquois et à la phase de Fort Ann du Lac glaciaire Vermont.

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) laminations become 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 rippled silt bed between the two units marks the position of a disconformity 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, millipeds, 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.

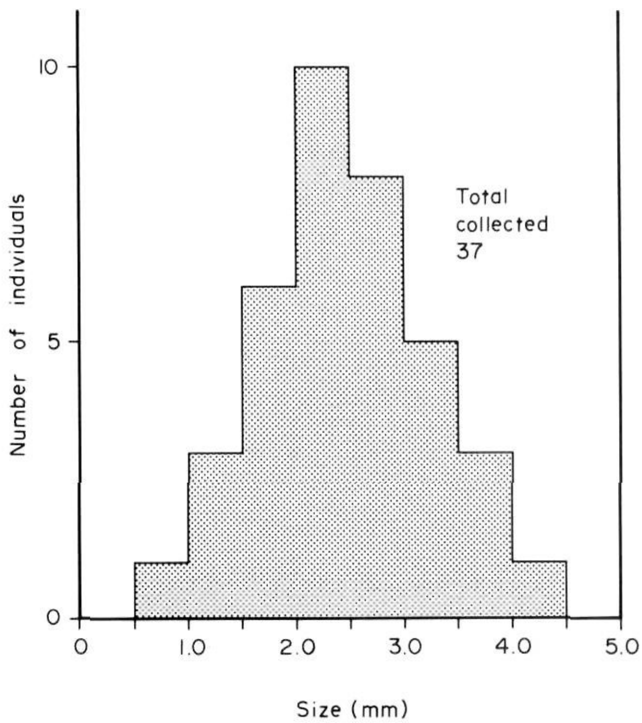

FIGURE 9. Maximum size for spat-killed *Portlandia arctica* collected at section 1.

Taille maximale des Portlandia arctica *recueillis dans la coupe n° 1.*

MICROPALEONTOLOGY

The freshwater ostracode *Candona* cf. *C. subtriangulata* has been reported by Anderson *et al.* (1985), Gadd (1986), Guilbault (1980), Naldrett (1986) and Rodrigues and Richard (1986) in small numbers in rhythmites in the Ottawa and St. Lawrence valleys. Anderson *et al.* (1985) noted this ostracode in association with *Cytheissa lacustris* and *Limnocythere friabilis* in cores from the Rideau Lakes area, and note the presence of *C. subtriangulata* and *C. lacustris* indicates a lake with few dissolved solids and depth up to 180 m. This fauna coincides with the pre-A biofacies of Guilbault (1980), who examined GSC core from Touraine, Québec and found 12 specimens or fragments of oligohaline ostracodes in rhythmites overlying diamicton.

Two surface samples from the Foster pit sites 1 and 2 yielded 4-5 disarticulated *Candona* valves per 200 g sediment sample. *Candona* abundance in the Ottawa surface samples corresponds with numbers found in other studies: Parent (1986) found 4-5 per 100 g sample in the eastern townships of Québec, and Anderson *et al.* (1985) found 1-50 per sample, with average recovery of 8 per sample in samples ranging up to 500 g. The sparsity of the *Candona* fauna indicates harsh conditions. In the Foster pit samples, *Candona* was only recovered from the upper ⅓ of the rhythmite section. The lower ⅔ of the rhythmites shows abundant slump, ice-contact and ice-rafted debris evidence, indicating the importance of ice interactions to early lake conditions. This factor, and high sediment load may have been partly responsible for faunal sparsity.

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: *Protelphidium orbiculare, Elphidium bartletti, Cassidulina 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, Protelphidium orbiculare* and *Cassidulina 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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REFERENCES

Agterberg, F. P. and Banerjee, I., 1969. Stochastic model for the deposition of varves in glacial Lake Barlow-Ojibway, Canada. Canadian Journal of Earth Sciences, 6: 625-652.

Allen, J. R. L., 1982. Sedimentary Structures Their Character and Physical Basis. Developments in Sedimentology, 30A and 30B, Vol. 1, p. 498.

Anderson, T. W., Mott, R. J. and Delorme, L. D., 1985. Evidence for a pre-Champlain Sea glacial lake phase in the Ottawa Valley, Ontario, and its implications. *In* Current Research, Part A, Geological Survey of Canada, Paper 85-1A: 239-245.

Antevs, E., 1925. Retreat of the last ice-sheet in Eastern Canada. Geological Survey of Canada, Memoir 146, 142 p.

Banerjee, I., 1973. Part A: Sedimentology of Pleistocene glacial varves in Ontario, Canada. Part B: Nature of the grain-size distribution of some Pleistocene glacial varves in Ontario, Canada. Geological Survey of Canada, Bulletin 226, 60 p.

Chauvin, L., Martineau, G. and Lasalle, P., 1985. Deglaciation of the Lower St. Lawrence Region, Quebec, p. 111-123. *In* H. W. Borns, Jr., P. Lasalle and W. Thompson, eds., Geological Society of America, Special Paper 197.

Coleman, A. P., 1936. Lake Iroquois, Ontario Department of Mines, Report 45, 36 p.

Clark, P. and Karrow, P. F., 1984. Late Pleistocene water bodies in the St. Lawrence Lowland, New York and regional correlations. Geological Society of America, Bulletin 95, p. 805-813.

Cronin, T. M., 1977. Champlain Sea foraminifera and ostracoda: a systematic and paleoecological synthesis. Géographie physique et Quaternaire, 33: 107-122.

——— 1981. Paleoclimatic implications of Late Pleistocene marine ostracoda from the St. Lawrence Lowlands. Micropaleontology, 27: 384-418.

Dadswell, M. J., 1974. Distribution, ecology and postglacial dispersal of certain crustaceans and fishes in eastern North America. National Museum of Canada, Publications in Zoology, Vol. 11, 110 p.

Delorme, L. D., 1970. Freshwater Ostracodes of Canada. Part III. Family *Candonidae*. Canadian Journal of Zoology, 48: 1099-1127.

French, H. M. and Rust, B. R., 1981. Stratigraphic investigation — South Gloucester special waste disposal site, Final Report, Contract OSU81-00313. Environment Canada, NHRI, 30 p.

Fulton, R. J., 1986. Quaternary geology of the western basin of the Champlain Sea. Geological Association of Canada, Field Trip 7: Guidebook, 36 p.

Gadd, N. R., 1961. Surficial geology of the Ottawa area: Preliminary report. Geological Survey of Canada, Paper 61-19, 14 p.

——— 1962. Surficial geology of the Ottawa map-area, Ontario and Quebec (includes map 16-1962). Geological Survey of Canada, Paper 62-16, 4 p.

——— 1977. Offlap sedimentary sequence in Champlain Sea, Ontario and Quebec. *In* Report of Activities. Part A, Geological Survey of Canada, Paper 77-1A: 379-380.

——— 1980. Late-glacial regional ice flow patterns in eastern Ontario. Canadian Journal of Earth Sciences, 15: 1439-1453.

——— 1986. Lithofacies of Leda clay in the Ottawa Basin of the Champlain Sea. Geological Survey of Canada, Paper 85-21, 44 p.

Graham, B. W. and Jackson, R. E., 1982. Quarterly Progress Report, South Gloucester Project, April 1982. Environment Canada, NHRI River Road Labs, 71 p.

Guilbault, J.-P., 1980. A stratigraphic approach to the study of the late-glacial Champlain Sea deposits with the use of foraminifera. Unpublished Ph.D. thesis, Aarhus University, Denmark, 294 p.

Hillaire-Marcel, C., 1980. Les faunes des mers post-glaciaires du Québec: quelques considérations paléoécologiques. Géographie physique et Quaternaire, 34: 3-59.

Johnston, W. A., 1916. Late Pleistocene oscillations of sea level in the Ottawa Valley. Geological Survey of Canada, Museum Bulletin 24, 16 p.

——— 1917. Pleistocene and Recent deposits in the vicinity of Ottawa with a description of the soils. Geological Survey of Canada, Memoir 101, 69 p.

Jopling, A. V. and Walker, R. G., 1968. Morphology and origin of ripple-drift cross lamination, with examples from the Pleistocene of Massachusetts. Journal of Sedimentary Petrology, 38: 971-984.

Lajtai, E. Z., 1967. Origin of some varves in Toronto, Canada. Canadian Journal of Earth Sciences, 4: 633-639.

Naldrett, D. L., 1986. Glacigenic clays of the Ottawa Valley, Unpublished Ph.D. thesis, University of Ottawa, Ottawa, Ontario, 218 p.

Naldrett, D. L., and Rust, B. R., 1984. Rhythmic sedimentation in early marine deposits of the Champlain Sea near Ottawa, Canada. Geological Association of Canada, Program with Abstracts, 9: 92.

Parent, M., 1986. Late Wisconsinan glaciolacustrine episode and early Champlain history in southeastern Quebec, Geological Association of Canada, Program with Abstracts, 11: 111.

Prest, V. K., 1970. Quaternary geology in Canada, p. 676-764. *In* R. J. W. Douglas, ed., Geology and Economic Minerals of Canada. Geological Survey of Canada, Economic Geology Report No. 1.

Richard, S. H., Gadd, N. R. and Vincent, J.-S., 1977. Surficial materials and terrain features, Ottawa-Hull, Ontario-Quebec. Geological Survey of Canada, Map 1425A.

Romanelli, R., 1970. A study of the Pleistocene sediments in two sand pits near Ottawa. Unpublished B.Sc. thesis, University of Ottawa, Ottawa Ontario, 45 p.

Rust, B. R., 1977. Mass flow deposit in a Quaternary succession near Ottawa, Canada: diagnostic criteria for subaqueous outwash. Canadian Journal of Earth Sciences, 14: 175-184.

——— 1982. Flow tills in Late Quaternary subaqueous outwash deposits of the Champlain Sea near Ottawa, Canada. Geological Association of Canada, Program with Abstracts, 7: 78.

Saunderson, H. C. and Jopling, A. V., 1980. Paleohydraulics of a tabular cross-stratified sand in the Brampton Esker, Ontario. Sedimentary Geology, 25: 169-188.