Géographie physique et Quaternaire

Significance of Sedimentological Studies on the Wisconsinan Stratigraphy of Southern Ontario

L'importance des études de sédimentologie en vue de l'établissement de la stratigraphie du Wisconsinien dans le sud de l'Ontario

Die Bedeutung der sedimentologischen Studien für die Stratigraphie von Süd-Ontario während des Wisconsin

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Volume 39, Number 3, 1985

URI: https://id.erudit.org/iderudit/032607ar
DOI: https://doi.org/10.7202/032607ar

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Publisher(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (print)
1492-143X (digital)

Explore this journal

Cite this article

Sharpe, D. R. & Barnett, P. J. (1985). Significance of Sedimentological Studies on the Wisconsinan Stratigraphy of Southern Ontario. *Géographie physique et Quaternaire*, *39*(3), 255–273. https://doi.org/10.7202/032607ar

Article abstract

Detailed facies mapping along Lake Erie and Lake Ontario Bluffs, plus other studies illustrate that sedimentological studies, especially those with geomorphic or landform control, have had three main effects on the Wisconsinan stratigraphy of Ontario: (1) improved understanding of depositional processes and environments of several major rock stratigraphic units, without altering the stratigraphic framework, (2) aided correlation of drift sequences, and (3) questioned previous interpretations and stratigraphic correlations of drift sequences. Thus sedimentological analysis can not be separated from stratigraphy because the interpretation of depositional environnments of many mapped strata relies on their geometry and the inclusion of regional data. The geomorphic control provided by sedimentological study of surface landforms is also important because assessment of older buried sediments such as those at the Scarborough Bluffs has been hampered by the failure to determine landform control. The Late Wisconsinan stratigraphy of Southern Ontario generally remains unchanged, except for questions on the role of climate versus ice margin dynamics. The pre-Late Wisconsinan stratigraphy is scarce and not well defined, yet sedimentary studies support the presence of glacial ice in the Ontario Lake basin for all of the Middle Wisconsinan and possibly earlier, including the formation of the Scarborough delta. Large channel cut and fill sequences in the Toronto area (Pottery Road Formation), initially interpreted as resulting from subaerial erosion, were probably formed by subaqueous or subglacial meltwater erosion. If so, the pre-Late Wisconsinan stratigraphy in southern Ontario changes because the Pottery Road Formation may not be an Early Wisconsinan correlative of the St. Pierre beds. The channel example illustrates that stratigraphie correlation without sedimentological investigations may be misleading.

Géographie physique et Quaternaire, 1985, vol. XXXIX, nº 3, p. 255-273, 18 fig., 2 tabl.

SIGNIFICANCE OF SEDIMENTOLOGICAL STUDIES ON THE WISCONSINAN STRATIGRAPHY OF SOUTHERN ONTARIO*

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ABSTRACT Detailed facies mapping along Lake Erie and Lake Ontario Bluffs, plus other studies illustrate that sedimentological studies, especially those with geomorphic or landform control, have had three main effects on the Wisconsinan stratigraphy of Ontario: (1) improved understanding of depositional processes and environments of several major rock stratigraphic units, without altering the stratigraphic framework, (2) aided correlation of drift sequences, and (3) questioned previous interpretations and stratigraphic correlations of drift sequences. Thus sedimentological analysis can not be separated from stratigraphy because the interpretation of depositional environnments of many mapped strata relies on their geometry and the inclusion of regional data. The geomorphic control provided by sedimentological study of surface landforms is also important because assessment of older buried sediments such as those at the Scarborough Bluffs has been hampered by the failure to determine landform control. The Late Wisconsinan stratigraphy of Southern Ontario generally remains unchanged, except for questions on the role of climate versus ice margin dynamics. The pre-Late Wisconsinan stratigraphy is scarce and not well defined, yet sedimentary studies support the presence of glacial ice in the Ontario Lake basin for all of the Middle Wisconsinan and possibly earlier, including the formation of the Scarborough delta. Large channel cut and fill sequences in the Toronto area (Pottery Road Formation), initially interpreted as resulting from subaerial erosion, were probably formed by subaqueous or subglacial meltwater erosion. If so, the pre-Late Wisconsinan stratigraphy in southern Ontario changes because the Pottery Road Formation may not be an Early Wisconsinan correlative of the St. Pierre beds. The channel example illustrates that stratigraphic correlation without sedimentological investigations may be misleading.

RÉSUMÉ *L'importance des études de sédimentologie en vue de l'établissement de la stratigraphie du Wisconsinien dans le sud de l'Ontario.* La cartographie détaillée des faciès le long des falaises du lac Erié et du lac Ontario ainsi que d'autres études ont démontré que les études de sédimentologie, qui tiennent compte du contexte géomorphologique, ont eu des résultats bénéfiques pour l'établissement de la stratigraphie du Wisconsinien en Ontario, notamment: 1) une meilleure compréhension des processus et des environnements sédimentaires de plusieurs unités stratigraphiques, sans qu'il y ait modification du cadre stratigraphique général; 2) une meilleure corrélation entre les séquences de dépôts; 3) une remise en question de certaines interprétations antérieures et de certaines corrélations entre les séquences de dépôts. Ces résultats démontrent que l'analyse sédimentologique est fortement liée à la stratigraphie étant donné que les milieux de dépôts ne peuvent s'expliquer qu'en tenant compte de leur géométrie et du contexte régional. La connaissance de la géomorphologie qu'on obtient grâce aux études de sédimentologie des formes est aussi très importante, car on constate que certaines interprétations des sédiments anciens enfouis ont été erronées pour ne pas avoir tenu compte du rôle de la morphologie. La stratigraphie du Wisconsinien supérieur du sud de l'Ontario demeure à peu près inchangée, sauf en ce qui a trait au rôle du climat et à celui de la marge glaciaire. La stratigraphie d'avant le Wisconsinien supérieur est encore mal définie, mais les études de sédimentologie indiquent que les glaciers ont occupé le bassin du lac Ontario, y compris le delta de la Formation de Scarborough, pendant tout le Wisconsinien moyen, peut-être même avant. Certaines séries de grands chenaux d'érosion et de comblement dans la région de Toronto (Formation de Pottery Road), interprétés d'abord comme ayant été formés par érosion subaérienne, le furent plus vraisemblablement par l'action érosive des eaux de fonte sous-aquatiques et sous-glaciaires.

ZUSAMMENFASSUNG *Die Bedeutung der sedimentologischen Studien für die Stratigraphie von Süd-Ontario während des Wisconsin.* Die detaillierte kartographie der Fazies entlang des Erie-Sees und der Steilufer des Ontario-Sees veranschaulichen zusammen mit anderen Studien, daß die sedimentologischen Studien, insbesondere diejenigen mit geomorphologischer oder Landform-Kontrolle, drei Haupt-auswirkungen auf die Erstellung der Wisconsin-Stratigraphie von Ontario hatten: 1) ein besseres Verständnis der Ablagerungsprozesse und -umbegungen von einigen wichtigen stratigraphischen Fels-einheiten ohne Änderung des stratigraphischen Rahmens, 2) eine verbesserte Korrelation der Aufeinanderfolge der Ablagerungen und 3) eine Infragestellung von früheren Interpretationen und stratigraphischen Korrelationen der Aufeinanderfolge von Ablagerungen. Also kann eine sedimentologische Analyse nicht von der Stratigraphie getrennt werden, weil die Interpretation der Ablagerungs-umgebungen vieler kartographisch festgehaltener Strata auf ihrer Geometrie beruht, sowie auf der Einbeziehung regionaler Daten. Die geomorphologische Kontrolle, die durch die sedimentologische Studie der Oberflächenlandformen gewährt wird, ist auch wichtig, weil die Einschätzung älterer vergrabener Sedimente, wie die an den Steilufern von Scarborough behindert wurde, weil die Landform-Kontrolle nicht durchgeführt wurde. Die Stratigraphie von Süd-Ontario im späten Wisconsin bleibt im allgemeinen unverändert mit Ausnahme von Fragen, die die Rolle des Klimas gegenüber der Dynamik der Eisgrenze betreffen. Die Stratigraphie vor dem späten Wisconsin ist spärlich und nicht gut definiert, doch bekräftigen Sediment-Studien das Vorkommen von glazialem Eis im Becken des Ontario-Sees und auch in der Ausformung des Scarborough Deltas für das ganze mittlere Wisconsin und möglicherweise auch früher. Die Folgen von breiten Rinneneinschnitten und Aufschüttungen im Gebiet von Toronto (Pottery Road Formation), die man ursprünglich auf die subaërische Erosion zurückführte, wurden wahrscheinlich durch subaquatische oder subglaziale Schmelzwasser-Erosion gebildet.

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INTRODUCTION

The Wisconsinan stratigraphy of southern Ontario and of other regions has traditionally relied on stratigraphic correlation based on lithostratigraphy and chronology (DREIMANIS and KARROW, 1972; KARROW, 1984b; FULLERTON, 1980; MICKELSON *et al.*, 1983). The stratigraphic framework and interpretation of Quaternary geology of southern Ontario has not changed substantially in the last fifteen years when these techniques have been emphasized (compare DREIMANIS and KARROW, 1972, and KARROW, 1984). The sedimentological analysis of Pleistocene sequences on the other hand, has generally been overlooked (especially stratified sediments) in stratigraphic interpretation. Recently, stratigraphic interpretation has included more works emphasizing sedimentological observations. Interesting questions are now being raised concerning the environment of deposition and the sedimentary association of many adjacent or continuous strata. Thus, those studies that adopted a sedimentological approach to Quaternary studies in southern Ontario are highlighted in the present review of the stratigraphy of southern Ontario. This review of the Quaternary Wisconsinan stratigraphy of southern Ontario was requested to complement a summary of the Quaternary stratigraphy of Québec presented in Sherbrooke, October, 1984.

Sedimentological studies have had three distinct effects concerning a reassessment of the Wisconsinan stratigraphy: (1) sedimentological analysis of many well known strata has improved the interpretations and understanding of processes and of environments of deposition such as Catfish Creek Drift (EVENSON *et al.*, 1977; GIBBARD, 1980; DREIMANIS, 1982b; GIBBARD and DREIMANIS, 1984); (2) sedimentological study has improved the correlation of drift sequences such as Lake Bluffs between Oshawa and Port Hope (MARTINI *et al.*, 1981; BROOKFIELD *et al.*, 1982; MARTINI *et al.*, 1984); and (3) interpretation of sedimentary features has lead to challenges to the current stratigraphic interpretation (EYLES and EYLES, 1983). In addition, the concept of relating sediment analysis closely to an identifiable landform is emphasized.

A clear result of increased sedimentological interpretation of many key features (*e.g.* diamictons, channels) is an improved interpretation of the stratigraphy and the correlation of strata from one region to another. It is also apparent that the depositional environments of many deposits need to be known more thoroughly before valid stratigraphic interpretation can be proposed. The present paper stresses selected examples of studies showing the impact of sedimentologic study and Figure 1 identifies other sequences or strata that are in need of sedimentologic studies, but they will not all be discussed here. Results from dating and paleoecological investigations have not been common in Ontario in the last ten years and they are not discussed here either.

PRESENT STATUS

The present status of Wisconsinan stratigraphy in southern Ontario is based primarily on the correlations presented by DREIMANIS and KARROW (1972) and this stratigraphy has been only slightly altered in recent accounts (Fig. 1a, KARROW, 1984b). The Wisconsinan stratigraphy of Southern Ontario has been subdivided into three major (glacial) substages (Early, Middle and Late Wisconsinan). Early and Late Wisconsinan substages were characterized by an extensive ice cover over most of Ontario while Middle Wisconsinan was a lengthy cool, essentially nonglacial interval in parts of the Great Lakes.

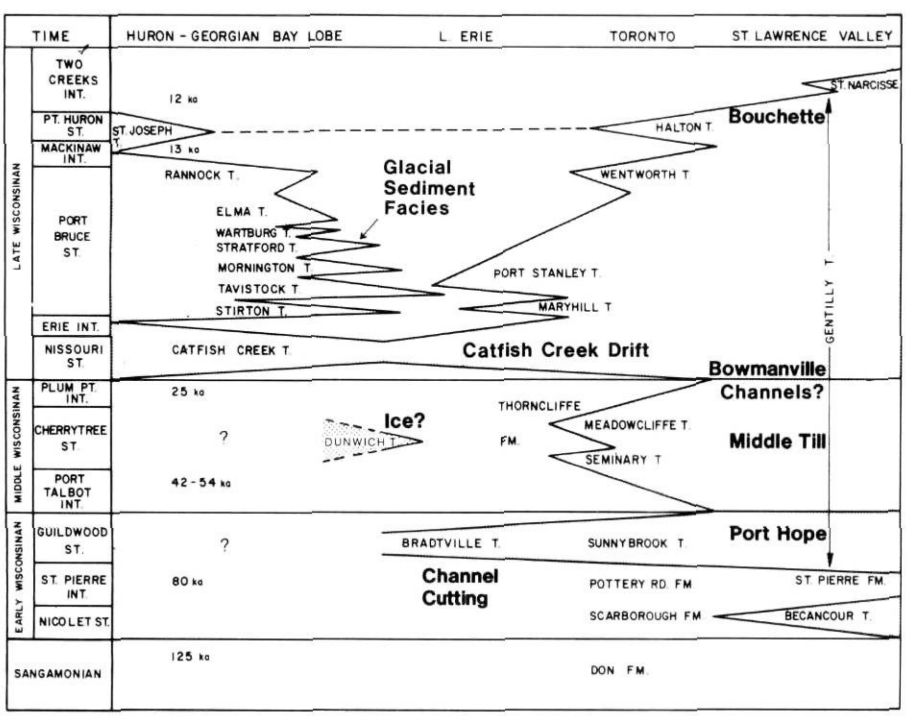


FIGURE 1a). Time-distance diagram of Wisconsinan stratigraphy of southern Ontario and Québec (after KARROW, 1984). Those units that are in bold type or underlined are discussed in this report. Glacial sediment facies refer to ice marginal deposits not necessarily climatically controlled (SHARPE, 1984b).

Diagramme chrono-spatial de la stratigraphie du Wisconsinien du sud de l'Ontario et du Québec (d'après KARROW, 1984). Seules les unités qui sont en caractères gras ou qui sont soulignées sont expliquées dans le texte. Les faciès de sédiments glaciaires proviennent de dépôts de marge glaciaire qui ne résultent pas nécessairement de fluctuations climatiques (SHARPE, 1984b).

FIGURE 1b). Location figure of major sites discussed in report.

Carte de localisation des sites les plus importants analysés dans le texte.

TABLE I

Lithostratigraphic parameters useful in stratigraphic correlation

Lithostratigraphic parameter	Examples in Ontario literature
1. Texture	Cowan, 1978; Dreimanis and Vagners, 1969
2. Mineralogy	Gwyn and Dreimanis, 1979
3. Geochemistry	Barnett, 1982; May and Dreimanis, 1973
4. Clast Petrology	Cowan, 1978
5. Geotechnique	Milligan, 1976; Quigley and Ogumbadejo, 1976
6. Structures	Dreimanis, 1976; Hicock and Dreimanis, 1985
7. Fabric	Harrison, 1957; Stankowski, 1977; May *et al.*, 1980
8. Weathering	Quigley and Dreimanis, 1972
9. Colour	Karrow, 1974

Note: 1. Lithostratigraphic parameters are best used together, as multiple-criteria and in combination with sedimentary facies for stratigraphic correlation.
2. Harrison's paper is not from Ontario but he studied many clay tills (melt-out) similar to the common fine-textured tills in Ontario.

However glacial ice probably occupied portions of the Lake Erie basin during the Middle Wisconsinan (DREIMANIS, 1981 and pers. comm. 1984) and glacial ice clearly occupied the St. Lawrence River Valley in order to support the thick raised lakes sequences in the Ontario basin at Toronto (KARROW, 1967, 1969, 1984a; SHARPE, 1980).

Wisconsinan stratigraphy and in particular the Late Wisconsinan stratigraphy of Southern Ontario was founded on lithostratigraphic correlation of major till unit that were assigned to the influence of glacial ice lobes moving from different areas of ice accumulation and different provenance areas. Many useful lithostratigraphic methods have been considered including the techniques outlined in Table I. Multiple criteria yield the best results, however, the most common techniques frequently used for correlation have been matrix texture and lithologic composition of various till sheets; these can be identified by careful field mapping primarily and by laboratory analysis. The fact that till sheets often show uniform matrix composition (texture) is a property that is widely used and it allows for glaciological interpretations (KEMMIS, 1981). Matrix texture may remain very uniform over large areas (100-400 km^2) and this allowed strata such as subglacial Catfish Creek till facies to be traced from river bank to river bank (Fig. 2a). Not all till sheets have homogeneous matrix properties because till may undergo rapid lateral facies changes. These facies changes may be due to changes in source material, englacial mixing or sediment differentiation at time of deposition (*e.g.* flow till, melt-out, lodgement, etc.). The Wentworth Till shows a rapid textural change along the Paris Moraine (Fig. 2b) reflecting change from incorporation and deposition of terrestrial debris to the incorporation and deposition of lacustrine debris. A similar facies change occurs within the St. Joseph Till along the Banks moraine near Paisley (COWAN *et al.*, 1978). These examples of textural properties serve to point out that lithostratigraphic methods work well in many areas of southern Ontario, yet multiple criteria (Table I) provide the best results for correlation (*cf.* BARNETT, 1982).

The complex pre-Late Wisconsinan record in southern Ontario is only exposed at a few locations however, and correlation by traditional lithostratigraphic methods is correspondingly difficult, and thus knowledge of the local environments of deposition may aid in the interpretation of paleogeographic setting prior to correlation.

SEDIMENTOLOGICAL STUDIES AND THEIR EFFECT ON STRATIGRAPHY

The sedimentological approach to Quaternary studies in Ontario has been on the increase since 1970 (Table II). The earliest sedimentologic studies paid particular attention to stratified sequences of nonglacial sediments: varves (ANTEVS, 1925; LAJTAI, 1967; BANJEREE, 1973), glaciofluvial sediments (COSTELLO and WALKER, 1972); esker sediments (SAUNDERSON, 1975), moraines (COWAN *et al.*, 1978). Later sedimentologic studies emphasized the inter-relationship between tills (diamictons) and other stratified sediments. Sedimentology was first used as a significant aspect of stratigraphic correlation in a comprehensive study by MARTINI *et al.* (1981) and BROOKFIELD *et al.* (1982). Three main findings arose from the above studies including improved understanding of (a) environments of deposition, (b) stratigraphic correlation and (c) the need for re-evaluation of the existing stratigraphy.

The stratigraphic position of a few examples used to discuss these three findings are highlighted in Figure 1a (*e.g.* Catfish Creek Drift, Port Hope-Bouchette sequence, Sunnybrook-Halton sequence, channels, and glacial sediment facies).

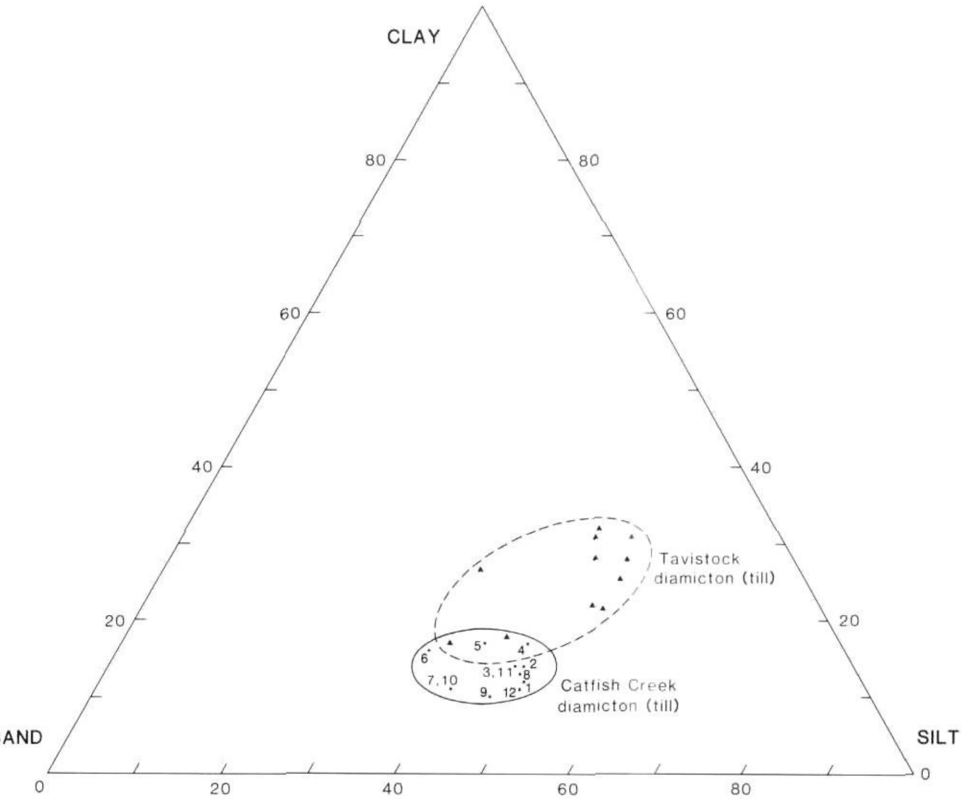


FIGURE 2a). Ternary diagram showing the uniform till texture (matrix) characteristic of subglacial Catfish Creek Till and Tavistock Till for comparison. Data are from 12 areas in southern Ontario (SHARPE, 1981). While average textural data may be misleading this plot serves to illustrate that clearly distinguishable lithologic units can be traced out with careful field mapping.

Diagramme triangulaire montrant la texture uniforme de la matrice du till caractéristique du Till sous-glaciaire de Catfish Creek et celle du Till de Tavistock (donné en comparaison). Les données proviennent de 12 régions différentes du sud de l'Ontario (SHARPE, 1981). Bien que la moyenne des valeurs des données texturales puisse induire en erreur, ce diagramme démontre que l'identification et la répartition d'unités lithologiques bien distinctes peuvent être reconnues par une bonne cartographie de terrain.

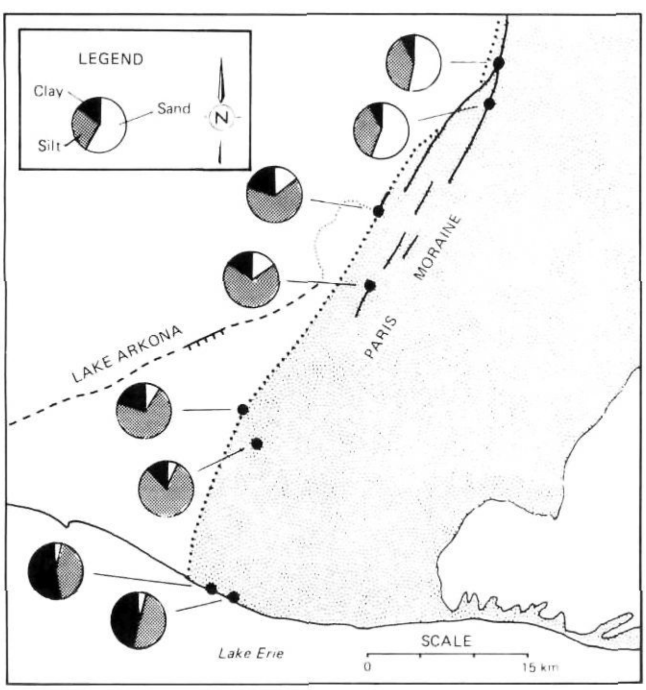


FIGURE 2b). Facies change in Wentworth Till (pattern) along the Paris Moraine indicated by sharp decrease in sand content from north to south. This reflects a change from incorporation and deposition of terrestrial debris (north) to the incorporation and deposition of lacustrine debris in the Lake Erie basin (south).

Changement de faciès dans le Till de Wentworth (figuré) le long de la Moraine de Paris indiqué par une diminution rapide de la proportion de sable dans la matrice en allant du nord vers le sud. Ceci reflète un changement où, dans le nord, la moraine est formée de dépôts glaciaires d'origine continentale exclusivement, alors que, dans le sud, la moraine est constituée de dépôts glaciaires formés en partie à partir de dépôts lacustres incorporés par le glacier lors de son avancée dans le bassin du lac Érié.

1) ENVIRONMENTS OF DEPOSITION

Detailed analysis of the sedimentary sequences along the Erie Bluffs between Port Talbot and Plum Point (Fig. 1b) has yielded a series of studies that refined our understanding of the processes and environments of deposition responsible for forming the Catfish Creek Drift — a major marker bed throughout southern Ontario (EVENSON *et al.*, 1977; GIBBARD, 1980; DREIMANIS, 1982b; GIBBARD and DREIMANIS, 1984).

EVENSON *et al.* (1977) demonstrated that stratified Catfish Creek Till at lake bluffs near Plum Point could reasonably be explained by deposition as subaquatic flow till. Important sedimentological criteria used to establish this model included detailed mapping and field survey of: (i) interstratified diamicton and current-bedded sediment, (ii) flow folding structures (Fig. 3) and the buoyant competence of debris flows, (iii) the apparent presence and geometry of large, flat debris cones consisting of flow tills and glaciofluvial sediment, (iv) the presence of micro-laminated silt-clay rip-up clasts within stratified sediment identified as flows.

TABLE II

Sedimentological study of Pleistocene sediments, Southern Ontario

Author		Deposit	Comment
Lajtai, E.Z.	1967	Toronto Varves	Glaciolacustrine sediments
Mörner, N.-A.	1971	Scarborough Bluffs	Glaciolacustrine sediments
Martini, I.P.	1972	Campbellford Outwash	Facies description
Banerjee, I.	1973	Ontario Varves	Turbiditic origin
Eynon, G. and Walker, R. G.	1974	Caledon Outwash	Bar facies
Pinch, J. J.	1974	Georgian Bay Sections	Gravel beach facies
Rust, B. and Romanelli, R.	1975	Champlain Sea Subaquatic Fans	Dish structures
Saunderson, H. C.	1975	Brampton Esker	Facies analysis
Evenson, E. B. *et al.*	1977	Catfish Creek Drift	Subaquatic sediment flow
Cowan, W. R. *et al.*	1978	Tara Moraine	Ice-marginal delta fan
Gibbard and Dreimanis	1978	Rhythmic or varved strata	Trace fossils
Pinch, J.	1979	McKittrick Drift Section	Depositional environments
Duckworth, P. B.	1979	Oak Ridges Moraine	Glaciofluvial character
Gibbard, P.	1980	Catfish Creek Drift	Undermelt deposition
Sharpe, D. R.	1981	Allan Park Delta	Ice-marginal delta
Martini, I. P. *et al.*	1981	Newcastle Bluffs	Environmental analysis
Kelly, R. I. and Martini, I. P.	1982	Scarborough Formation	Facies analysis
Cheel, R. J. and Rust, B. R.	1982	Champlain Sea	Coarse fan facies
Fraser, J. Z.	1982	Caledon Outwash	Facies assemblages
Stewart, R. A.	1982	Port Stanley Drift	Subaquatic flow tills
Eyles, C. H. and Eyles, N.	1983	Scarborough Bluffs	Lake bottom sedimentation
Brookfield, M. E. *et al.*	1982	Oshawa — Port Hope	Sedimentology/stratigraphy
Barnett, P. J.	1984	Lake Erie Bluffs	Proglacial/Subglacial model

FIGURE 3. Photopraph of the stratified Catfish Creek Drift at Waite Farm section (near Plum Point), Lake Erie, showing flow cone structure suggestive of a subaquatic flow origin.

Photo du Till stratifié de Catfish Creek à la coupe de Waite Farm (Plum Point), lac Erié, montrant une structure en forme de cône d'écoulement suggérant une mise en place par écoulement sous-aquatique.

FIGURE 4. Photopraph of the stratified Catfish Drift at the Boy Scout pit (Plum Point), Lake Erie considered by Gibbard to represent basal undermelt.

Photo du Till stratifié de Catfish Creek dans la sablière Boy Scout (Plum Point), lac Érié, que Gibbard considère comme ayant été mis en place par des processus de fonte sous-glaciaire.

In addition GIBBARD (1980), studying similar sequences along Lake Erie, suggested an alternate depositional model consisting of the undermelt deposition of stratified drift by a partially floating ice sheet (Fig. 4). He considered the following features to be important: (i) paucity of flow structures, (ii) abundance of drop stones, (iii) uniform compositional changes over 200 m intervals, (iv) wide compositional variability and lack of grading within individual laminae, (v) lack of sole or erosional marks at the base of units. Gibbard also considered bodies of cross-stratified sand to have originated from current flow of meltwater released from tunnels in the ice that may have scoured channels while locally washing and eroding till deposits. Gibbard reasoned that no ice marginal compressive flow is possible in a floating ice sheet and this supports his suggestion that undermelting rather than ice-marginal debris flow was the major agent of deposition.

DREIMANIS (1982b) considered that there was evidence for both a subaquatic flow origin and an undermelt origin depending upon the local environment of deposition. Advance of grounded ice into water could have produced silty subaquatic till flows that are interbedded with sand in an ice marginal setting. A readvance of a thinner, partially floating glacier into deeper water led to deposition of subglacial sediment by undermelt that formed the upper part of the stratified Catfish Creek Drift. Subsequently the advancing glacier became grounded as indicated by deformational structures, shears, and strong parallel fabric in the overlying lodgement till (Fig. 5). A detailed multiple criteria study (lithologic, textural and fabric) was done on the dominantly massive variety of Catfish Creek till (STANKOWSKI, 1977; MAY *et al.*, 1980). In all, the Catfish Creek Drift, in the 8 km long Port-Talbot-Plum Point section, has been subdivided into four genetic varieties of till (lodgement, undermelt, flows, deformation) separated by interbedded meltwater deposits, sands, gravels and silts, and stratified diamicton (*viz.* GIBBARD and DREIMANIS, 1984). To the southwest these tills interdigitate with deltaic deposits or with fan deposits. In summary, these studies have improved the environmental interpretation of stratified Catfish Creek Drift without altering its stratigraphic position. They also serve as a model of ice-marginal sedimentation in western Lake Erie Basin and as norms to compare other stratified diamicton sequences (*e.g.* BARNETT, 1985, eastern Lake Erie; EYLES and EYLES, 1983, Lake Ontario, and JUNG and POWELL, 1985, Lake Michigan).

FIGURE 5. Lodgement facies of Catfish Creek Drift with prominent boulder pavement at Plum Point, Lake Erie.

Vue du faciès massif du Till de Catfish Creek et du remarquable pavage de blocs erratiques qui l'accompagne à Plum Point, lac Érié.

2) STRATIGRAPHIC CORRELATION

The detailed sedimentology by MARTINI *et al.* (1981), BROOKFIELD *et al.* (1982) and MARTINI *et al.* (1984) on the Lake Ontario coastal bluffs east of Oshawa is probably the best Quaternary sedimentology carried out to date in Ontario for stratigraphic correlation. Their sedimentological analysis defined several environments of deposition to support correlation of major rock-stratigraphic units. The stratigraphic units here show strong lateral variations in lithology and thickness; however several diamicton (till) and rhythmic and varved lacustrine sequences show consistent characteristics over large areas to be termed marker beds.

Local diamicton and other stratified facies are more variable and more restrictive depositional models were established to aid in correlation with the rock units at Scarborough Bluffs. Two lacustrine sequences (upper and lower), four major diamicton units (tills) and complex channel sand fills are recognized (Fig. 6). A lower lacustrine sequence (2a), shows complex sedimentation patterns. Distal clayey varves (containing intraformational slumping) were observed to grade laterally from sandy proximal varves and ripple-drift cross laminated and cross bedded sands.

The transitional nature of the sediment contacts (where there varved clays are interbedded with diamictons and other rhythmites) show that sedimentation was at the margin of a grounded ice sheet fronted by a large lake. In the lowest lacustrine facies common thin diamictons consist of glacial silt debris. The rhythmites with less thick diamicton layers show diamictic varves within a larger rhythmic sediment package. Higher energy currents and deposition occur as scours and fills that are situated below massive pebbly and sandy diamictons (middle till). In summary, MARTINI *et al.* (1981) and BROOKFIELD *et al.* (1982) interpreted the sedimentary features (northwest paleocurrent directions in gravel, interbedded debris flows, cross-laminated sand and diamictic varves) as all supporting an interpretation of subaqueous deposition from a partially floating, advancing ice sheet.

In addition to an ice-marginal depositional model, evidence is presented for major glaciofluvial (subaqueous) units and channel erosion and fill (MARTINI, 1982) within an upper lacustrine sequence (MARTINI *et al.*, 1981, 1984). Small-scale channels are filled with irregular massive sands and they may represent high-energy scour and fill turbidity events. Larger channels are cut into the underlying glaciolacustrine sediments down to the base of unit 2 (Fig. 6). The sediments within the larger channels show little lateral variation and at the base poorly sorted pebbly sand is common due to channel-side slumping. Massive sand bodies, thick tabular cross-bedded sand sets and cross-cutting channels are all found higher in the fill (Fig. 7). Current directions are to the north and west and these paleoflows resulted from ice occupying the basin to the south and east. These directions are not compatible with a subaerial origin of cut and fill and support the earlier suggestion of MARTINI *et al.* (1981) that the cut and fill sequences are subaqueous in origin if not subglacial in origin (MARTINI, 1982).

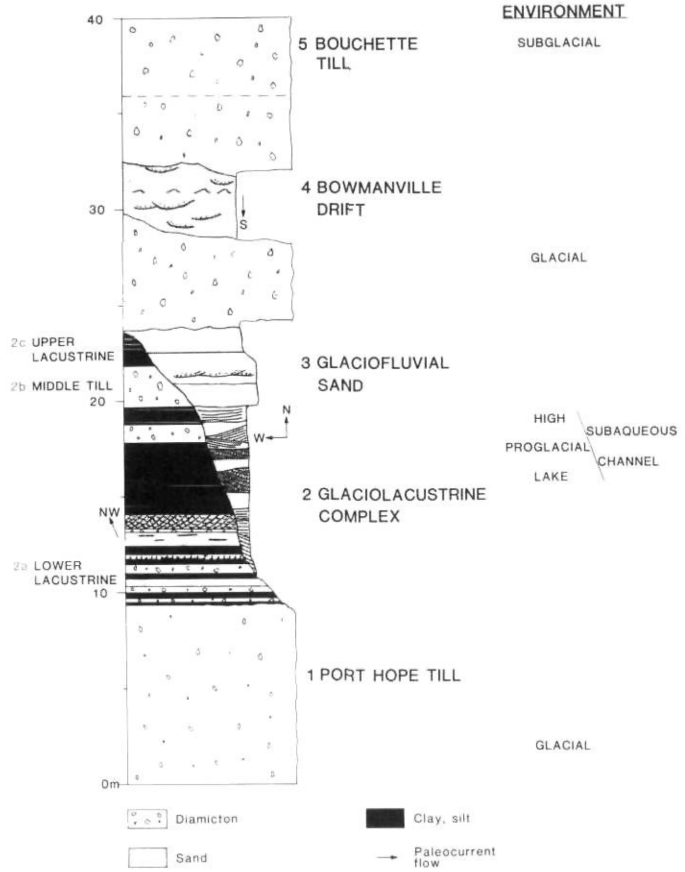


FIGURE 6. Composite sections showing summary facies for Lake Ontario bluff sediments in the Oshawa-Port Hope area. Note that unit 2 (a. lower lacustrine; b. middle till; c. upper lacustrine) is cut by a deep channel that goes close to present lake level and the channel is filled with a sandy sequence (unit 3). The section represents about 40 m of sediment. (After MARTINI *et al.*, 1981.)

Coupes composites montrant les principaux faciès des sédiments formant les falaises le long de la rive nord du lac Ontario dans la région d'Oshawa-Port Hope. Il est important de noter que l'unité n° 2 (a. lacustre inférieur; b. till moyen; c. lacustre supérieur) a été érodée par un chenal profond qui s'est encaissé presque jusqu'au niveau du lac actuel et qui a été par la suite comblé par une séquence de sables (unité n° 3). La coupe représente une épaisseur d'environ 40 cm de sédiments. (D'après MARTINI et al., *1981.)*

Figure 7. Photograph of planar tabular cross-bedded sand, with channel scour and fill, unit 3, fluvio-glacial sand, from Oshawa Port-Hope area (Fig. 6).

Photo des sables fluvio-glaciaires de l'unité n° 3 dans la région d'Oshawa-Port Hope, montrant la structure tabulaire horizontale des lits de sables entrecroisés à l'intérieur du chenal d'érosion et de comblement.

The significance of the study by MARTINI *et al.* (1981, 1984) and BROOKFIELD *et al.* (1982) is that detailed sediment analysis identified a thick package of glaciolacustrine sediments and these beds are probably analogous to the thick ice-supported glaciolacustrine sediments represented by the Thorncliffe Formation at Scarborough. The units below and above these thick stratified sequences, the Port Hope diamicton (till) and the Bowmanville and Halton diamictons (till), may be tentatively correlated with the Sunnybrook and the Halton diamictons (till) at Scarborough by facies association. This correlation may strengthen the tentative correlations made by BROOKFIELD *et al.* (1982). That different facies assemblages occur at the Oshawa-Port Hope Bluffs than those occurring at the Scarborough Bluffs does not alter the fact that both sequences represent high lake sequences of varied sedimentation into an ice-marginal glacial lake system. These sediments occur between Early(?) and Late Wisconsinan diamictons (tills).

3) RE-EVALUATION OF THE STRATIGRAPHY

A third significant aspect of recent sedimentological investigations of Ontario Quaternary sequences are that they have raised serious questions about current stratigraphic interpretation and understanding of late Quaternary (Wisconsinan) sequences (EYLES and EYLES, 1983). The current view, based on KARROW (1967, 1969), suggests that massive diamictons (Sunnybrook, Meadowcliffe and Seminary) above the Pottery Road channels are glacial sediments (tills) separating interstadial (cool, nonglacial) stratified sediments all capped by a subglacial diamicton (Halton till). Sediment logging (based on a lithofacies coding method) was used by EYLES and EYLES (1983) to suggest that multiple stratified and diamicton units at the Scarborough Bluffs are the preserved bottom stratigraphy of a large lake and that these beds were deposited by floating glacial ice or possibly lake ice. Many of the salient features used to reach this interpretation include sedimentary structures such as: loaded contacts, flame structures, diapirs, dewatering structures, balls and clasts of diamictic sediment, channel cut and fill, laminated sand, ripple cross-laminated, intercalated and graded sand bedding. An absence of buried landforms, major erosive contacts and structural deformation (considered by EYLES and EYLES, 1983, to be a requirement for lodgement and melt-out processes at an ice base-bed interface) are cited in support of the lake bottom depositional model. In addition, the lateral and vertical variability of sediments at the Scarborough Bluffs plus a literature review are used to suggest a three-part depositional model of rain-out (from a floating ice shelf or lake ice), current re-working and "re-sedimentation". A major conclusion of the study is that the original sediment boundaries of KARROW (1967) are considered to be artificial subdivisions of a depositional sequence, and that this distorts the importance of individual lithofacies by ignoring lateral facies changes. These suggested oversights in the original study are used to conclude that the Scarborough Bluffs is not appropriate as a chronostratigraphic model for mid-latitude glaciation. While not all these views are shared by others (KARROW, 1984a; DREIMANIS, 1984a; SHARPE, 1984a; GRAVENOR, 1984; KEMMIS and HALLBERG, 1984) this sedimentological analysis of a complex Late Quaternary sequence has renewed interest in these classic sections (KELLY and MARTINI, 1982, in press) and in landform sediment assemblages displayed at the Scarborough Bluffs (SHARPE, 1985).

THE SIGNIFICANCE OF LANDFORM-SEDIMENT STUDIES IN THE INTERPRETATION OF SEDIMENTARY SEQUENCES AND STRATIGRAPHY

The importance of the relationships between landforms and their internal structure (contained sediments) has long been a subject of geological study. However, many of these landform-sediment relationships, long accepted to be true, need further investigation (SHAW, 1983b; LAWSON, 1984; McCABE *et al.*, 1984; SHAW and KVILL, 1984). Two examples of landform-sediment studies from the writers own works will be presented, one from the Scarborough Bluffs, and the second from the Lake Erie Bluffs.

1) SUNNYPOINT SECTION AT SCARBOROUGH BLUFFS

In reviewing the recent reinterpretation of the Scarborough Bluffs, it was noticed that the upper part of the sequence (Halton drift) was not considered or discussed (EYLES and EYLES, 1983). This is unfortunate because many similar sedimentary features to those discussed by Eyles and Eyles and considered by them to be indicative of nonglacial lake bottom processes are present in the upper sequence, Halton drift (Fig. 8), and these sedimentary features can be related to surface landforms (Fig. 11).

One of the most interesting suggestions of the Eyles and Eyles study is that the Scarborough sequence could represent a continuous depositional sequence comprising variable facies (Fig. 8). For example the Sunnybrook diamicton is clearly transitional within itself, comprising several diamicton units interbedded with the sand at its base (Fig. 9a). The lower and upper Sunnybrook diamicton assemblage of Eyles and Eyles comprises many interbedded members (massive and rhythmic beds, flows and breccias). The central Sunnybrook diamicton is generally massive and thick followed by thin multiple flow units (Fig. 9b) above the massive thick diamicton and similar to the thin lower flow units. The higher diamictons (Meadowcliffe, Seminary) also show loaded, transitional and interbedded contacts within the Thorncliffe sands (Fig. 9c).

Similar evidence for continuous sedimentation is found above the Thorncliffe sediments (Fig. 8) and includes the Halton drift that caps the entire sequence (Fig. 10). The contact between the Thorncliffe sand and the Halton diamictons (till) shows interbedded, transitional and loaded relationships (Fig. 10 a,b,c). These features indicate a close depositional relationship between such diverse sediments as massive silt and clay, varved clay silt, laminated silt, rippled sands, small sand-filled channel sand (Fig. 10c) and massive thin and thick diamictons (Fig. 10a). The diamicton in this case can be shown however, to be till, by association with the surface landforms of the Halton drift (Fig. 11). The Halton drift comprises a large till plain with fluting patterns and drumlins, features generally

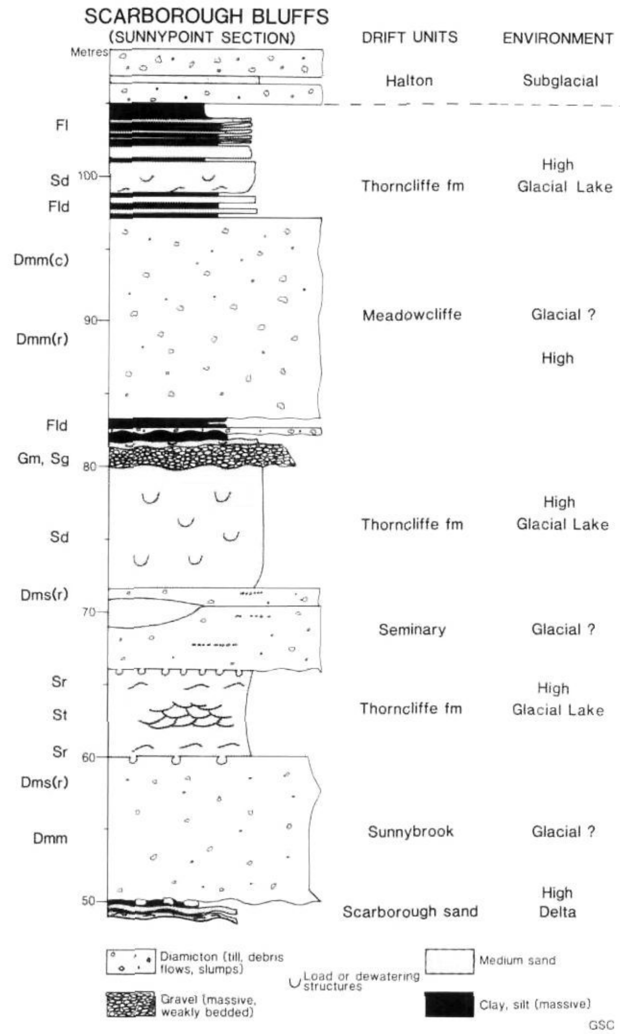


FIGURE 8. Summary facies diagram of the sedimentary sequence at the Sunnypoint Section, Scarborough Bluffs (after KARROW, 1967; coding from EYLES and EYLES, 1983); including transitional sedimentation from the Sunnybrook up to and including the Halton drift. The dashed line represents the top of the section studied by EYLES and EYLES (1983).

Diagramme sommaire des faciès des unités sédimentaires présentes dans la coupe de Sunnypoint, aux falaises de Scarborough (d'après KARROW, 1967; symboles d'après EYLES et EYLES, 1983); la coupe comprend les unités sédimentaires depuis l'unité de Sunnybrook à la base jusqu'à et y compris le Till de Halton au sommet. La ligne interrompue marque la limite supérieure de la coupe étudiée par EYLES et EYLES (1983).

FIGURE 9a). Transitional nature of lower part of Sunnybrook diamicton (till) sequence showing interbedded diamictons and sand.

Vue de la nature diversifiée des faciès dans la partie inférieure du diamicton (till) de Sunnybrook montrant des lits interstratifiés de diamictons et de sable.

FIGURE 9c). Loaded contact at base of Sunnybrook diamicton (till).

Contact de type encaissant à la base du diamicton (till) de Sunnybrook.

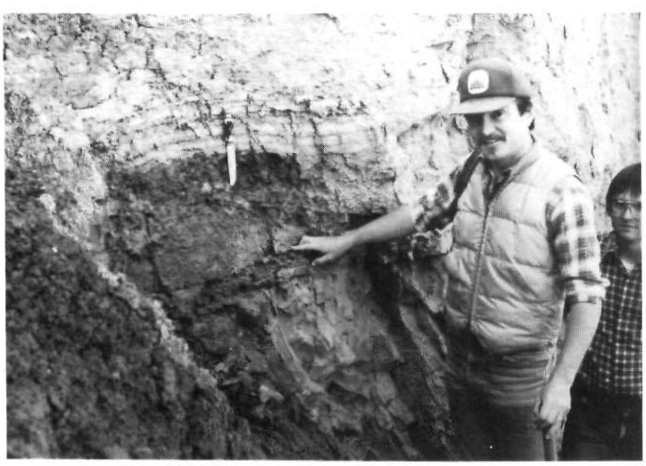


FIGURE 9b). Flow units of Sunnybrook diamicton found within the overlying Bloor Member rhythmic sediments.

Lits formés de coulées du diamicton de Sunnybrook trouvés interstratifiés avec les sédiments rhythmiques sus-jacents du Membre de Bloor.

considered to be indicative of subglacial sedimentation. The Halton drift was deposited by ice occupying the Lake Ontario basin and its northern margin of deposition is defined by the Palgrave and Oak Ridges moraines.

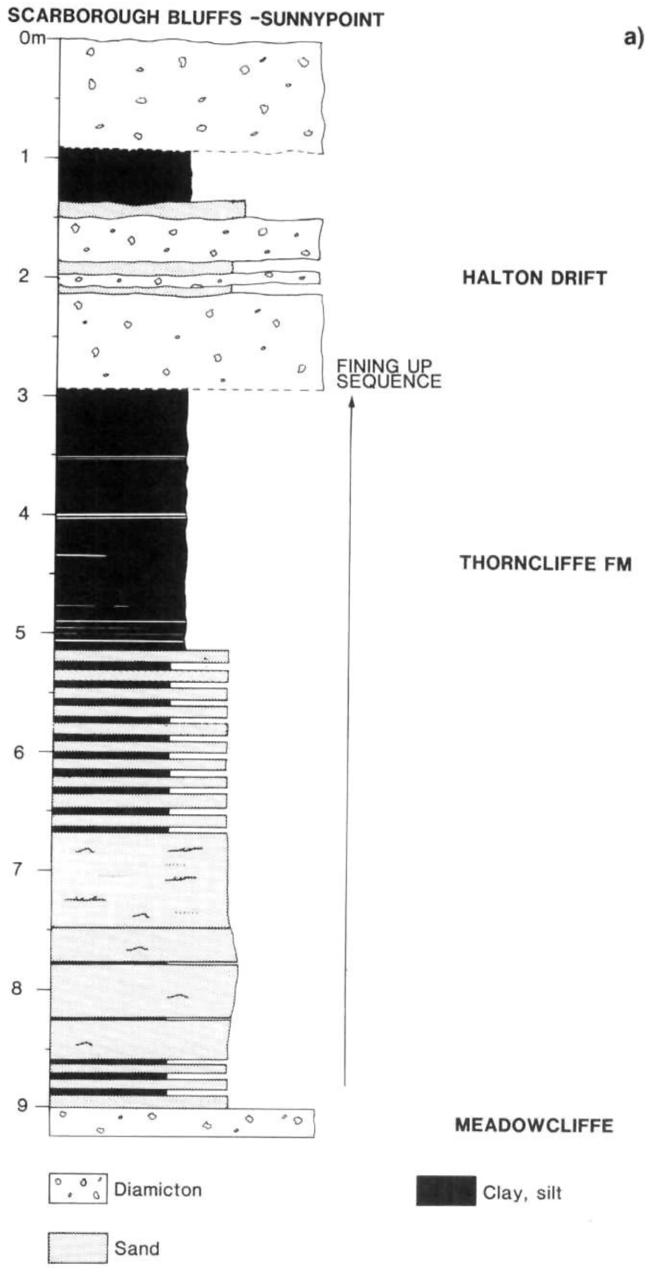
The diamicton sequence within the Halton till plain consists of massive diamicton to multiple thin diamictons deposited as till flows interbedded with silt and clay lacustrine sediment (Fig. 11b,c,). A special point about the sedimentary association within the Halton drift is the occurrence of boulder scour features at Scarborough (Fig. 12a). These scour features are diagnostic of a subglacial melt-out origin of diamicton (SHAW, 1982, 1983a). Similar boulders (with equivocal scour structures) are found at the basal contact of the Sunnybrook diamicton (till). This indicates the clear possibility that the Sunnybrook diamicton consists of subglacial till, in part (Fig. 12b,c).

In summary, the same sedimentary structures and sedimentary features (contact relationships) that are used to indicate a depositional environment of nonglacial lake bottom processes to construct the lower Scarborough sequence (EYLES and EYLES, 1983), are found in the Halton drift and its lower contact. Landforms that are formed subglacially (streamlined forms and a till plain) comprise a stratified sediment assemblage, with diamictons, that were deposited subaquatically and contemporaneously with ice (Fig. 12a). A recognition of the significance of the surface landform relationships (Fig. 11) is therefore crucial to considering that the lower sequence at Scarborough was probably deposited subaqueously near a glacier ice margin rather than by nonglacial lake conditions. The significance of landform-sediment studies has been investigated at other lake bluff sections (Lake Huron, SHARPE, 1982a) and documented by BARNETT (1984, 1985) for Lake Erie sections.

2) LAKE ERIE BLUFFS (PORT BRUCE TO PORT BURWELL)

Landform-sediment studies along the Lake Erie shorebluffs between Port Bruce and Port Burwell, Ontario, also help evaluate buried sedimentary sequences. Here, excellent exposures through several end moraines which were deposited in large proglacial lakes provide information on lateral and vertical facies changes in complex lacustrine and diamicton sequences (Fig. 13). These sediment sequences were deposited by ice occupying the eastern portion of the Lake Erie basin as it fluctuated towards the northwest. Both massive and stratified diamictons are associated with the end moraines: massive diamicton on the proximal side, stratified diamictons are abundant on the distal side.

A general facies model from the eastern Lake Erie bluffs contains the following sequence of sediments from the base (Fig. 14): (a) rhythmically bedded sand, consisting of ripple cross-laminated fine sand grading upwards through silt to a thin clay layer at the top; (b) rhythmically bedded silt and



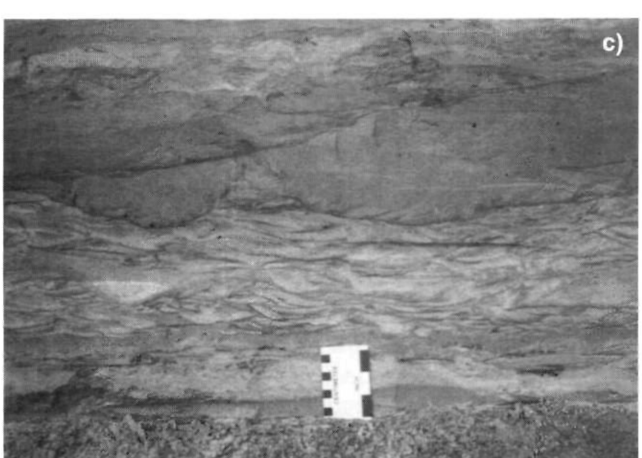


FIGURE 10 Contact relationships between Halton drift and the Thorncliffe Formation as shown by (a) detailed facies diagram showing the transitional nature of the Thorncliffe Formation and Halton drift at Sunnypoint section, Scarborough. The lower Halton contact is gradational and sharp and marked by load structures and boulder scours in places; (b) sharp, loaded contacts are found above the coarsening upward sequence from rhythmites to ripped sand cut by small subaqueous channels (c) below load structures.

Divers aspects des contacts marquant le passage de la Formation de Thorncliffe au Till de Halton illustrés par (a) un diagramme détaillé des faciès montrant le passage graduel de la Formation de Thorncliffe au Till de Halton à la coupe de Sunnypoint, à Scarborough. Le contact à la base de la nappe du Till de Halton est graduel et net et il est caractérisé par des structures sédimentaires de type encaissant et par des formes de creusement par bloc glaciaire par endroits; (b) des contacts nets dans des structures sédimentaires encaissantes situées au-dessus d'une séquence sédimentaire de granulométrie plus grossière en allant vers le haut et qui va de rythmites dans le bas à des sables ayant été partiellement érodés par de petits chenaux sous-aquatiques dans le haut; (c) en-dessous de structures sédimentaires encaissantes.

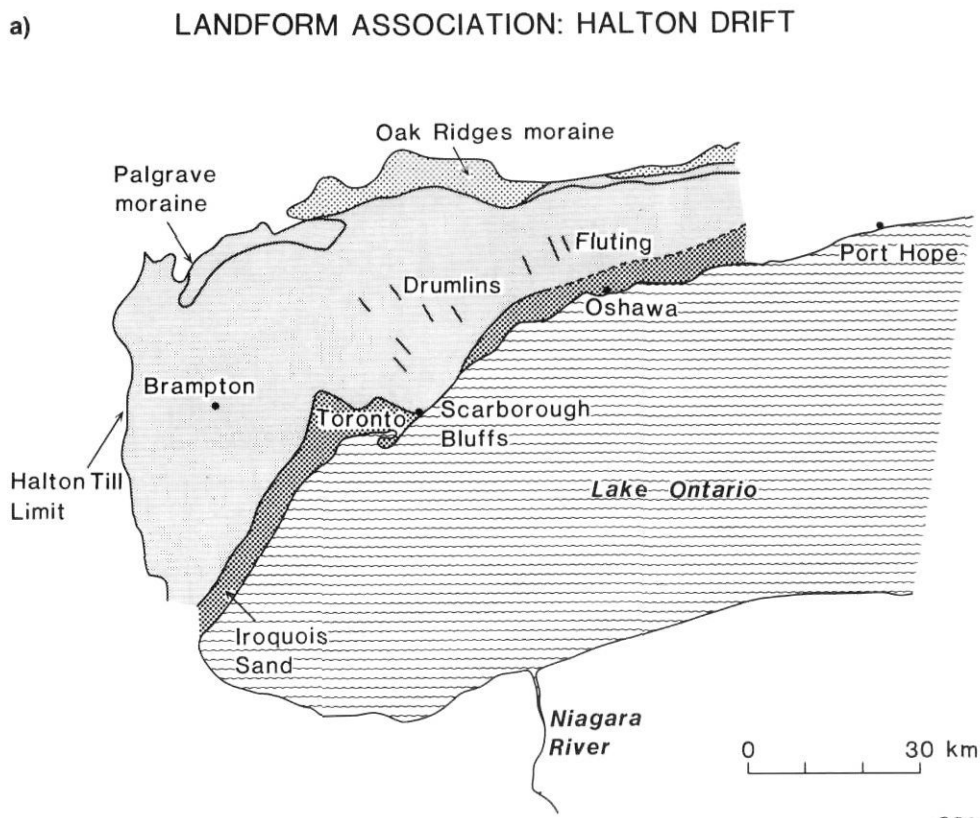
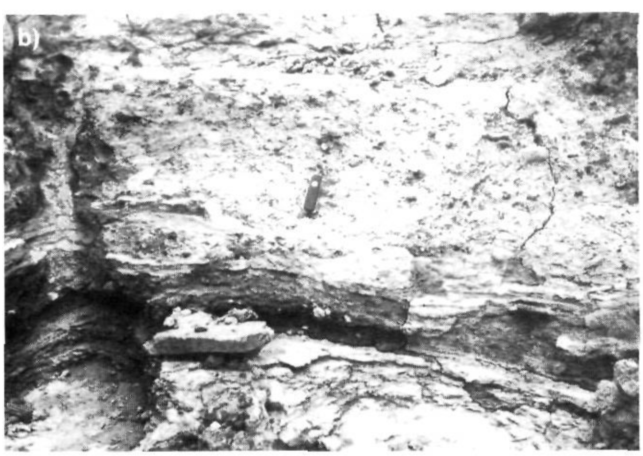


FIGURE 11. (a) Halton drift in the Scarborough Bluffs area of Lake Ontario showing surface landforms (drumlins, flutings, till plain) that comprise the sedimentary assemblage. The Halton drift was deposited by ice occupying the Lake Ontario basin and its northern *margin of deposition is defined by* the Oak Ridges and Palgrave moraines. (b) Photographs of thick interbedded Halton diamicton (debris flows or till flows) and (c) minor diamictons and fine sediment within the Halton drift near Brampton.

(a) Till de Halton dans la région des falaises de Scarborough, le long de la rive du lac Ontario, montrant les formes de terrain (drumlins, cannelures, plaine de till) qui la caractérisent. Le Till de Halton fut déposée par un glacier qui occupait le bassin du lac Ontario et la limite septentrionale de son extension est marquée par les moraines frontales de Oak Ridges et de Palgrave. (b) Photographies montrant des diamictons épais de Halton (coulées de débris ou coulées de till) et (c) des diamictons plus minces interstratifiés avec des sédiments fins à l'intérieur du Till de Halton, près de Brampton.



clay, with an upwards increase in the number of pebbles, silt clasts and thin discontinuous bands of massive diamicton; (c) stratified diamicton, generally thin beds of massive, matrix-supported sediment (Fig. 15a) separated by thin discontinuous silt and fine sand laminations; (d) massive diamicton, matrix-supported diamicton with lower contact sharp to gradational (Fig. 15a), *in places showing loaded, erosional, or sheared* relationships with underlying sediments; (e) stratified diamicton similar to facies (c); and (f) rhymically bedded silt and clay with an upwards decrease in the number of thin discontinuous bands of massive diamicton, pebbles and silt clasts. Bedding in the lower part of this unit (f) can be highly deformed due to loading and dewatering (BARNETT, 1985).

All facies except (d) are interpreted as proglacial lake deposits and facies (d), massive diamicton, is interpreted as subglacial till (Fig. 14). Diamicton beds within facies (b),(c),(e) and (f) are interpreted mainly as glacially derived debris flows or subaquatic flow tills (Fig. 15b). Their massive nature may be attributed to high viscosity differences between the high-density (fine-textured) debris flow material and the proglacial lake water.

Transitions through facies (a),(b) and (c) represent the advancing ice margin, (d) overriding of the site by the glacier, and in facies (e) and (f) Fig. 14), the ice margin is in recession (BARNETT, 1984, 1985a,b).

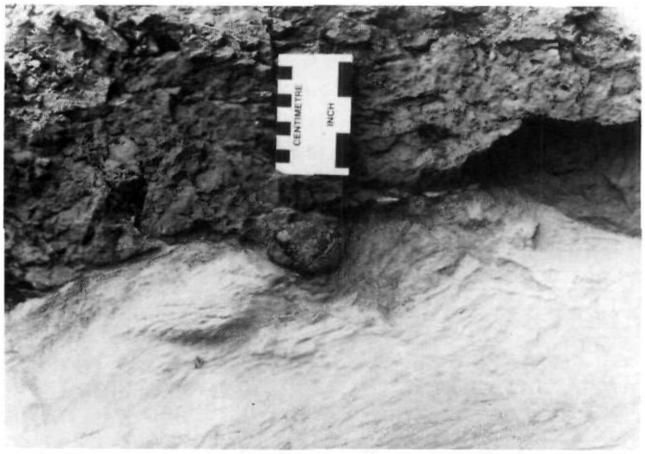


FIGURE 12a). Boulder scour feature found at the base of the Halton Drift near the Sunnypoint section, Scarborough Bluffs. Scour beneath the clast occurs if it is projecting into the current that deposited the coarser sand within the scour (SHAW, 1983). Shaw suggested that a subglacial cavity, with a clast projecting from basal ice, is required to meet this condition. The cavity fills with sand prior to melt-out till formation.

Forme de creusement par bloc glaciaire trouvée à la base du Till de Halton près de la coupe de Sunnypoint, dans les falaises de Scarborough. Le travail de creusement sous le bloc s'effectue si sa partie inférieure est présente dans le courant d'eau qui a déposé le sable grossier dans la rigole excavée dans le lit de sable (SHAW, 1983). Shaw a exprimé l'opinion que la présence d'un bloc affleurant au plafond d'une cavité ou tunnel sous-glaciaire est nécessaire pour qu'un tel phénomène puisse se produire. La cavité est graduellement comblée par de nouvelles arrivées de sable avant le dépôt du till de fusion sus-jacent lors de la fonte de la glace.

FIGURE 12b). Boulder located at the base of the Sunnybrook diamicton (till) that may also be considered to be diagnostic of melt-out till.

Bloc glaciaire à la base du diamicton (till) de Sunnybrook que l'on peut aussi considérer comme étant caractéristique d'un till de fusion glaciaire.

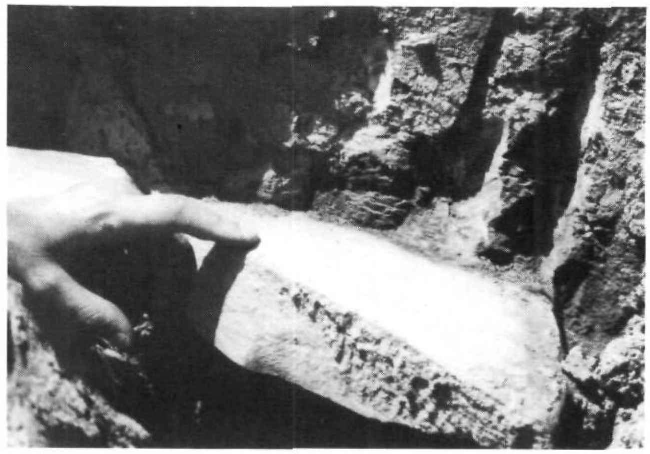


FIGURE 12c). Striated boulder at the base of the Sunnybrook diamicton (till) confirming a subglacial origin of deposition.

Bloc glaciaire strié à la base du diamicton (till) de Sunnybrook démontrant l'origine sous-glaciaire lors du dépôt du till.

It is interesting to note the similarities in the sediment sequences along the eastern Lake Erie bluffs (where an end moraine landform association is known) and the Sunnybrook sedimentary sequences which also contain stratified to massive sequences of diamictons at Scarborough described by EYLES and EYLES (1983).

THE SIGNIFICANCE OF INTERPRETATION OF SEDIMENTARY FEATURES

With the increased use of sedimentological analysis in presenting local stratigraphic interpretation it is clear that the environmental interpretation of key sedimentary structures and features has a great bearing on regional correlation. There are several key units, for example the Bradtville Drift, Dunwich Drift, Erie Interstadial gravels, the Pottery Road Formation and channel cutting in the present Ontario stratigraphy that require further analysis (Fig. 1). Channel cutting features however, are the only example to be discussed in this report. The channel features exposed along the Scarborough Bluffs and exposed in the Toronto (Don Valley) Brickyard (Pottery Road Formation) and interpreted as the Pottery Road Formation (KARROW, 1974) are key limits to the Ontario stratigraphy.

1) CHANNELS AT TORONTO

The large channels in the Toronto area (Pottery Road Formation, KARROW, 1974) are central links in the current stratigraphy of Southern Ontario and Québec (Fig. 1). These channels, cut into the Scarborough delta, have been interpreted as subaerially cut and filled gullies (KARROW, 1969) that required ice to be absent from the St. Lawrence Valley. These low-stage channels are correlated to the St. Pierre peat beds that indicate low-level subaerial organic accumulations 75 000 years BP (LASALLE, 1984).

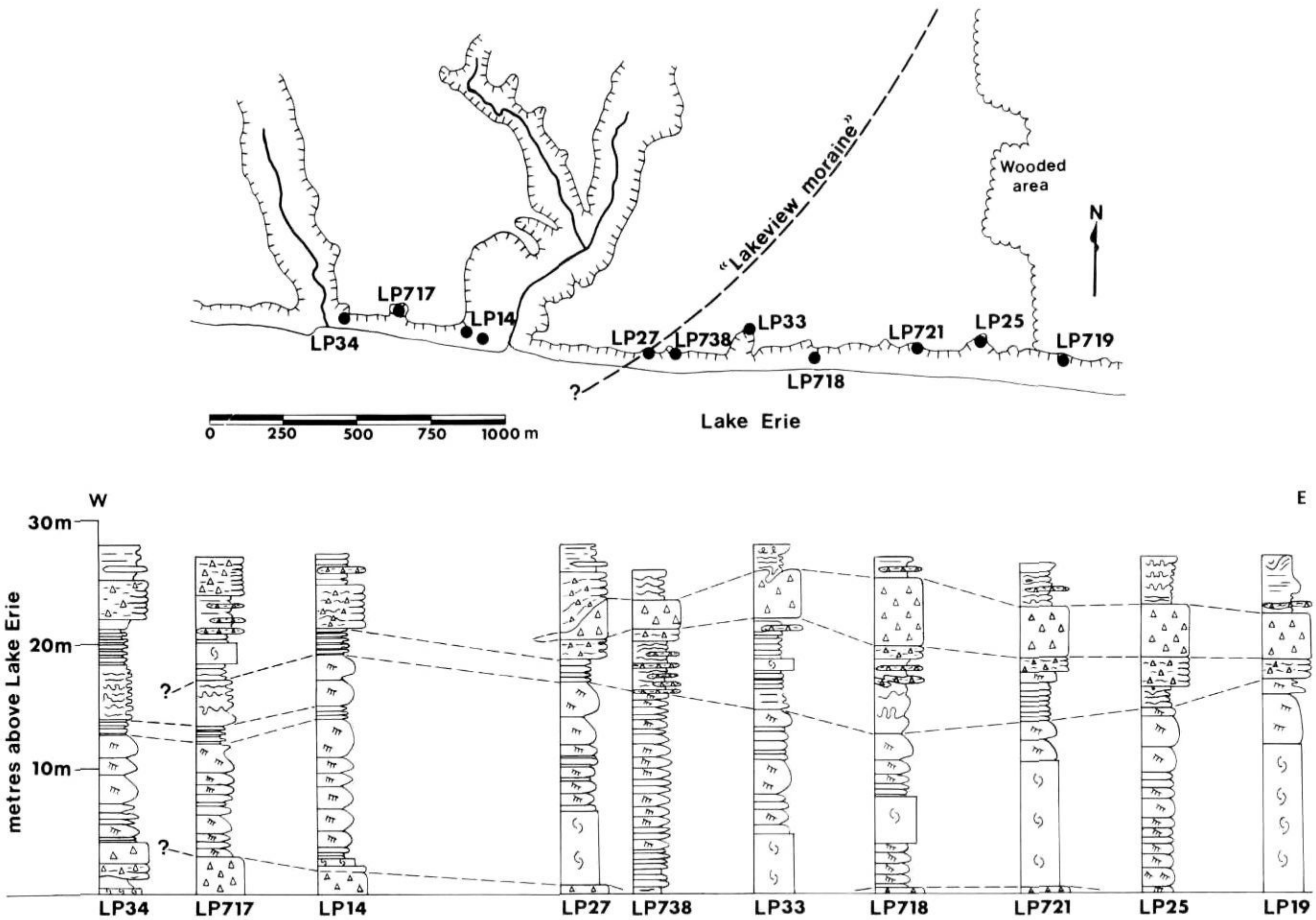


FIGURE 13. End Moraine stratigraphy within and adjacent to the Lakeview Moraine along Lake Erie Bluff, McConnell's Nursery area (BARNETT, 1984). The key is massive diamicton (triangles), stratified diamicton (triangles and lines), greater thickness of column represents a coarser texture of sediment and diamicton is plotted as gravel; slump covered interval (offset brackets). Diamicton was deposited by ice occupying the eastern portion of Lake Erie basin. Notice that more massive diamicton is associated with the proximal side of the moraine, while more stratified diamicton is found on the distal side of the moraine. Reproduced with the permission of GAC from BARNETT (1984).

Stratigraphie de moraine frontale à l'intérieur et au voisinage immédiat de la moraine de Lakeview le long des falaises du lac Érié, dans la région de McConnell's Nursery (BARNETT, 1984). Les diamictons massifs sont représentés par des triangles, les diamictons interstratifiés par des triangles et des lignes. Les sédiments plus grossiers sont représentés par une épaisseur plus grande de l'unité dans la coupe et les diamictons sont représentés par le symbole des graviers; la partie recouverte par des éboulis est représentée par le symbole des parenthèses en échelons. Le diamicton a été déposé par un glacier qui occupait la partie orientale du bassin du lac Érié. Il est important de noter que les diamictons les plus massifs se trouvent dans la partie proximale de la moraine, alors que les diamictons interstratifiés se trouvent dans la partie distale de la moraine. Reproduit avec la permission de l'AGC, d'après BARNETT (1984).

An alternative view suggests that the large channels in the Toronto area (below Sunnybrook unit at Bluffer's Park, Scarborough) were not cut by nonglacial subaerial streams that required low base levels and that required the absence of glacial ice in the St. Lawrence River valley. The channels could have been cut and filled subaqueously and, or subglacially by high-energy discharges that created high velocity currents and sediment gravity flows (LOWE, 1975,1976,1982; POTSMA *et al.*, 1983).

The contact between sediments of the Scarborough Delta and the overlying Sunnybrook (diamicton) Till is one key to the interpretation. In places this contact appears to be gradational and interbedded suggestive of continuous sedimentation (Fig. 9a). KELLY and MARTINI (1982) however have evidence of the contact being sharp (Fig. 9), erosional and not at the base of the diamicton. If, as they suggest, silty clay and sandy lenses immediately under the Sunnybrook diamicton (till) are part of the Sunnybrook drift, then, the critical contact would occur at the top of sandy beds associated with the Scarborough delta.

In addition KELLY and MARTINI (1983) have evidence of subaerial exposure on this high delta surface as represented

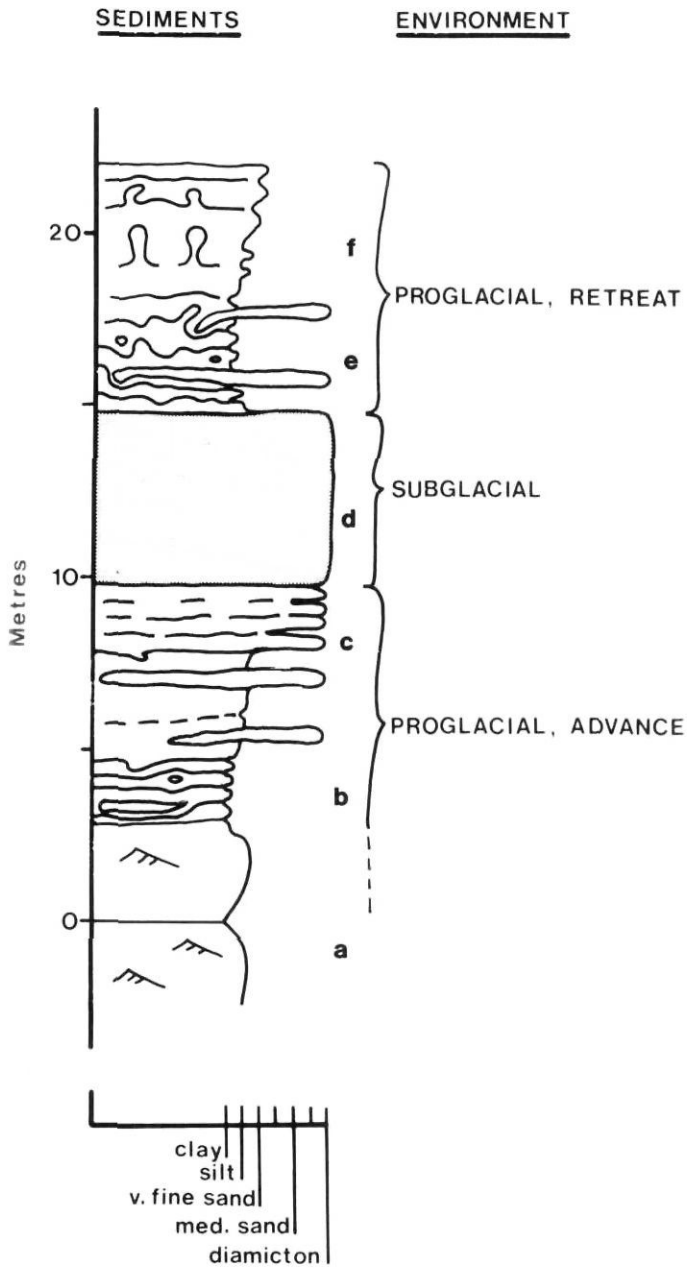


FIGURE 14. Model of Glacial-Glaciolacustrine Sedimentation developed from eastern Lake Erie massive (subglacial) diamicton and interbedded (proglacial) diamictons. The model is probably applicable to many ponded ice-marginal settings. Reproduced with permission of GAC from BARNETT (1984).

Modèle de sédimentation glaciaire-glaciolacustre élaboré à partir de l'observation de diamictons massifs d'origine sous-glaciaire et de diamictons lités alternant avec d'autres sédiments d'origine proglaciaire dans la partie orientale de la région du lac Érié. Ce modèle est probablement valable pour plusieurs autres régions d'anciennes marges glaciaires ayant eu leur terminus dans des lacs de barrage glaciaires. Reproduit avec la permission de l'AGC, d'après BARNETT (1984).

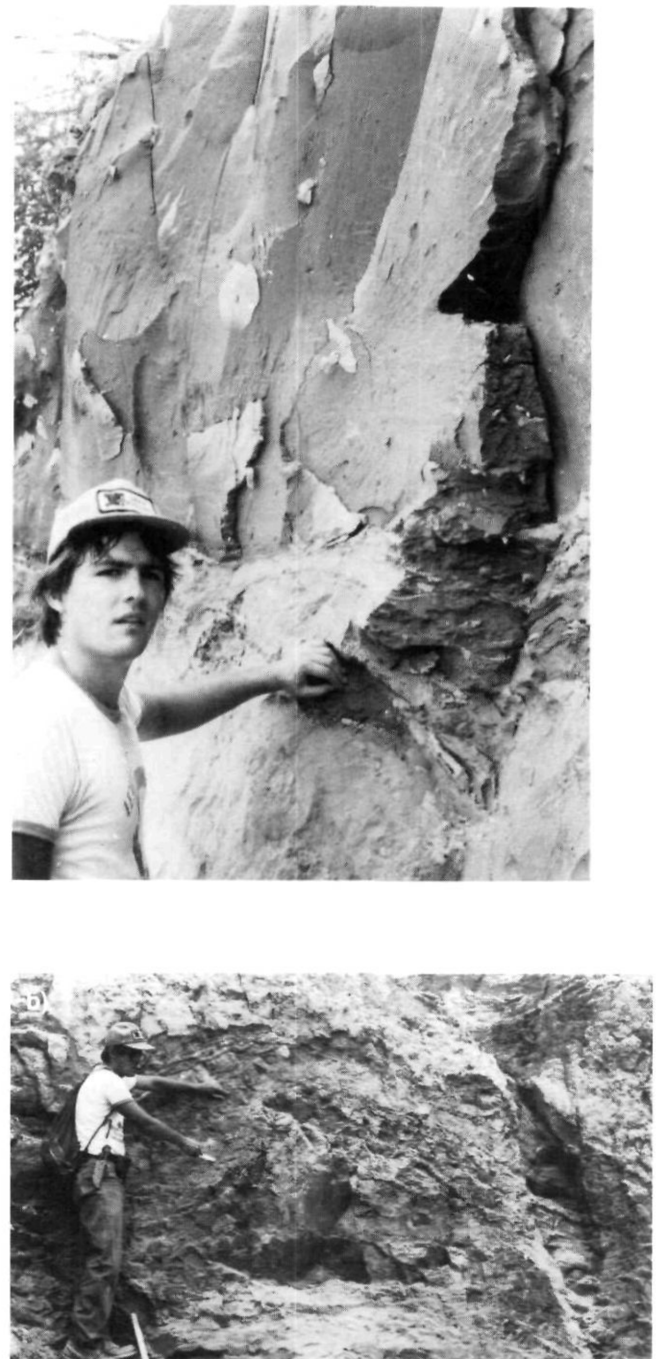


FIGURE 15. (a) Stratified diamicton in the lower portion of the photograph and massive diamicton in the upper portion; (b) flow cones of stratified diamicton; from the Lake Erie sections within the Lakeview Moraine.

(a) Diamicton lité dans la partie inférieure de la photographie et diamicton massif dans la partie supérieure; (b) cône de déjection formé de diamictons lités dans des coupes de la Moraine de Lakeview dans la région du lac Érié.

by mud-crack marks. These observations tend to support a delta top subaerial environment, while not necessarily indicating the extremely low water levels suggested by KARROW (1967). The cutting of large channels could have been achieved by subaquatic density currents on the delta slope (SMITH and ASHLEY, 1985). In fact KELLY and MARTINI (in press) have documented channels up to 50 m wide filled with subaqueously deposited massive sand in the upper Scarborough delta sequence. They interpreted the Scarborough Formation as a classical lacustrine-deltaic sequence strongly affected by a nearby glacier.

A preliminary evaluation of the channel fill (Pottery Road Formation) exposed at the Toronto (Don Valley) Brickyards 11 km east of the Scarborough Bluffs suggests that the erosion and fill of this channel by high energy ice-proximal meltwater discharges can not be ruled out. Here, the channel is filled with clast to matrix supported massive and stratified gravel and sand which become interbedded with discontinuous diamicton beds (debris flow) towards the top of the channel fill (Fig. 16).

A more complete sedimentological appraisal of the channel cut and fill exposure at the Scarborough Bluffs area is necessary to refine the above possibilities. If the sedimentological arguments for higher lake levels than those proposed by KARROW (1967) are probable, then the correlation of the Scarborough channel with the St. Pierre peat beds is questioned. The result implies that there is no precise timing for channel formation postdating the deltaic Scarborough Sands and that high ice-marginal lakes may have occupied much of the western Lake Ontario basin during Wisconsinan time. This conclusion is at odds with interpretations from the Hudson Bay Lowlands (ANDREWS *et al.*, 1983) that suggest several nonglacial (marine and therefore limited ice extent) episodes during Wisconsinan time based on amino acid results.

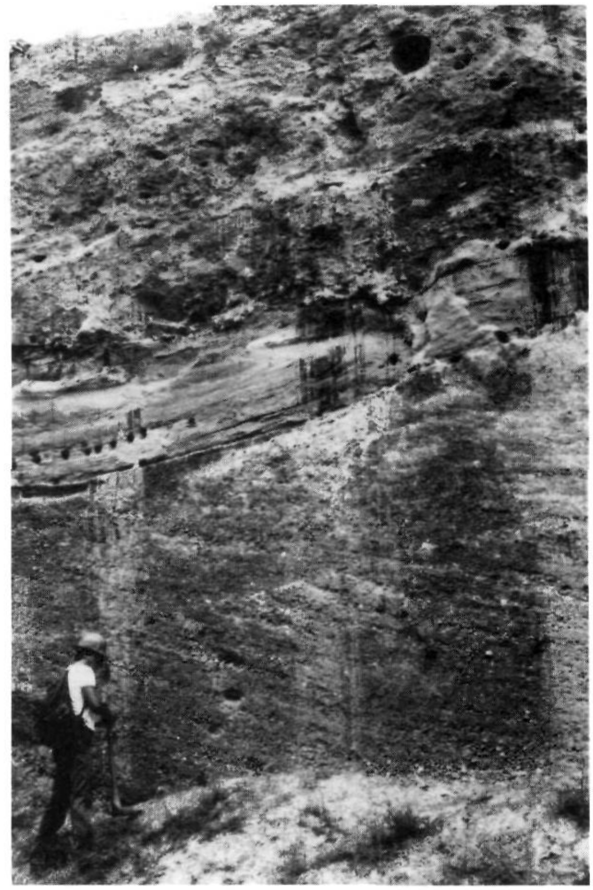


FIGURE 16. Large-scale foreset sand and gravel overlain by ripple-drift sand and interbedded diamictons from a channel fill sequence in the Don Valley brickyards, Toronto.

Couches frontales sableuses et graveleuses de grande épaisseur surmontées de lits de sable avec rides de courant et de diamictons interstratifiés dans un ancien chenal comblé et fossilisé à la briqueterie de Don Valley, Toronto.

2) OTHER CHANNELS

Other channel features have been recognized as probably relating to subaqueous formation. Several clear examples are present in the Ottawa Valley. The identification of structures suggesting subaqueous processes (CHEEL and RUST, 1982) in the Champlain Sea deposits are important to this interpretation (Fig. 17a,b). The subaqueous channel cut and fills (Fig. 17a) are defined by accompanying mass flow and grain flow deposits (massive sands) that show dewatering structures (Fig. 17b) common in rapidly sedimented subaqueous environments (LOWE, 1975, 1976, 1982).

Other channel features have been found in important glaciolacustrine sequences across Ontario highlighted in Figure 18. A valley cut and fill feature in Middle Wisconsinan deposits at Pointe Fortune, Québec, on the Ontario-Québec border may not be a low water stage feature (VEILLETTE and NIXON, 1984). It comprises large-scale trough-cross bedded sands that thin and fine upwards to ripple drift cross-laminated sands that subtely become interbedded and that are conformably overlain by diamicton (Fig. 18). The relationship between the sand body and the overlying till indicates deposition by meltout (SHAW, 1982) and possible simultaneous deposition of underlying sand in a subglacial tunnel or cavity.

A similar channel cut into Middle Wisconsinan (glaciolacustrine) deposits is present in the Oshawa-Port Hope lake bluffs (MARTINI *et al.*, 1981, 1982; BROOKFIELD *et al.*, 1982). BROOKFIELD *et al.* (1982) interpreted this channel as a local subaerial downcutting of deep valleys and tentatively correlated the event with the Plum Point interstadial. The possibility that it may represent a channel cut in a subglacial environment was considered (MARTINI, 1982). The valley fill is currently viewed as a glaciofluvial or possibly a glaciolaustrine sequence formed during readvance (BROOKFIELD *et al.*, 1982). It is more probable however, that the glaciofluvial sequence was deposited by high discharge meltwater following a contemporaneous channel cutting event from subglacial outflow. This is because flow directions indicated from cross-beds are inland to the west and north (Fig. 6). This later interpretation fits the distribution of channels better in that they are rare compared to the high potential for subaerial gullies as seen along the modern shoreline.

STATUS OF THE QUATERNARY STRATIGRAPHIC FRAMEWORK OF ONTARIO

Sedimentological studies of Quaternary strata in southern Ontario have clearly improved our understanding of the origin and depositional environment of some of the major stratigraphic units. The studies on the origin of stratified Catfish Creek Drift till (EVENSON *et al.*, 1977; GIBBARD, 1980; DREIMANIS, 1982b; GIBBARD and DREIMANIS, 1984) are good local models for ice proximal sedimentation within a lake basin or depression. Other studies (DALRYMPLE, 1971; STEWART, 1982; BARNETT, 1984, 1985; in the Lake Erie basin, SHARPE, 1982a, 1982b, in the Lake Huron basin, and MARTINI *et al.*, 1981; BROOKFIELD *et al.*, 1982; EYLES and EYLES, 1983; in the Lake Ontario basin) provide additional information on sediment sequences (and associations) deposited in ice proximal lacustrine environments. These studies plus the numerous studies on modern and ancient glaciolacustrine sedimentation outside Ontario (*e.g.* JUNG and POWELL, 1985) must be distilled to obtain a norm that will aid in the reas-

FIGURE 17a). Channel feature formed subaqueously in sandy facies of an ice marginal fan within the Champlain Sea Basin.

Chenal sous-marin comblé et fossilisé dans un des faciès sableux d'un cône d'eaux de fonte de marge glaciaire dans le bassin de la Mer de Champlain.

FIGURE 17b). Dewatering structure in channel sands found in Champlain Sea ice-marginal fan.

Lits de sable déformés par l'expulsion de l'eau lors du comblement d'un chenal fossilisé dans un cône d'eaux de fonte de marge glaciaire mis en place dans la Mer de Champlain.

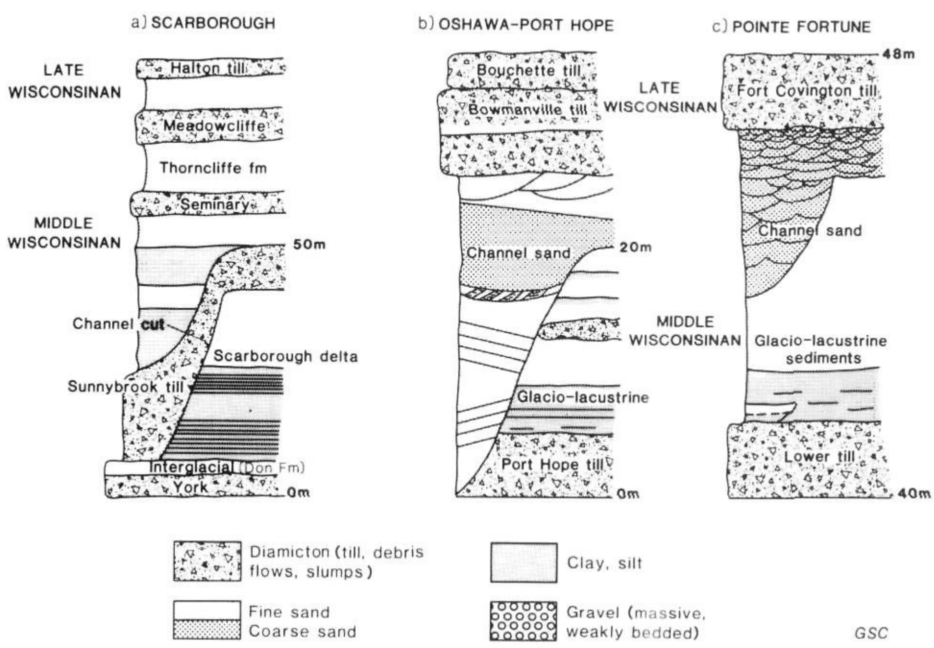


FIGURE 18. Major sections with large channel features in or adjacent to southern Ontario. a) The Scarborough section shows a large channel cut into the Scarborough delta. Elevations are approximate positions above the present Lake Ontario levels (75 m a.s.l.); b) the Oshawa-Port Hope section has a channel cut into possible middle Wisconsinan stratified sediments below Late Wisconsinan tills. The scale is approximate elevation above Lake Ontario level; c) the Pointe-Fortune, Québec section is a sequence with a channel cut below Late Wisconsinan till. Elevations are m.a.s.l.

Coupes les plus importantes du sud de l'Ontario à travers des dépôts comportant de grands chenaux comblés et fossilisés. (a) La coupe de Scarborough montre un grand chenal creusé dans le delta de Scarborough avant d'avoir été comblé et fossilisé par la suite. Les cotes d'altitude indiquent les hauteurs approximatives au-dessus du niveau actuel des eaux du lac Ontario (75 m a.n.m.). (b) La coupe d'Oshawa-Port Hope montre la présence d'un chenal creusé dans des sédiments lités datant probablement du Wisconsinien moyen sous des nappes de till mises en place au cours du Wisconsinien supérieur. L'échelle montre l'altitude approximative au-dessus du niveau du lac Ontario. (c) La coupe de Pointe-Fortune, Québec, montre un chenal creusé dans une séquence de sédiments fluviatiles, puis comblé et fossilisé sous un till du Wisconsinien supérieur. Les altitudes sont en mètres au-dessus du niveau moyen de la mer.

sessment of Great Lake basinal sediments. Studies of sediments in other depositional environments also need to be continued.

It must be cautioned that misinterpretation of "objective" sedimentary descriptions (codes) can occur, resulting in erroneous or the least parsimonious explanations being presented for the origin and depositional processes of buried sedimentary sequences. Therefore, further landform-sediment studies are needed. An improved correlation of drift sequences through a greater appreciation of the three dimensional nature of facies transitions and associations is gained through such study. The complex suites represented by the Thorncliffe formation at Scarborough (Fig. 8) and the middle glaciolacustrine and glaciofluvial unit at Oshawa-Port Hope (Fig. 6) are more readily correlated on the bases of their deposition into a high proglacial lake environment whose sediments are found below Late Wisconsinan tills and above probable Early Wisconsinan till. The complex facies associations of these units precludes bed by bed matching but mineralogical tracing of drift units should allow matching of any anomalous suites of the sediments.

The importance of sedimentological analysis is highlighted by the interpretation of key sedimentary features. Thus the interpretation of large channels at Toronto as subaqueous rather than subaerial implies that the St. Pierre peat beds are not correlative events with the channels. The lack of chronological control on the channel cutting means that clear Wisconsinan chronological control at Toronto is lacking as most of the Thorncliffe Formation is dated by dates that are infinite.

One further note of caution is that facies analysis applied to glacial drift sequences is only one aspect of sedimentology and stratigraphy. The techniques of facies analysis (Table II) must be used in concert with as many other techniques as possible to maximize stratigraphic interpretation and understanding.

Sedimentological re-evaluation has affected the Wisconsinan stratigraphic framework of Ontario, although the complete scrapping of the Middle or Late Wisconsinan stratigraphy as proposed by EYLES and EYLES (1983) and FORD *et al.* (1984) is not supported as their analyses have proven to be incomplete. Certainly the Wisconsinan sequence in southern Ontario is not in a state of confusion due to sedimentological assessment (FORD *et al.*, 1984) but rather due to lack of dating controls. The recent sedimentological work has helped strengthen the understanding of well studied strata. Many previously studied sections obviously need further sedimentological study and they will no doubt shed further light on the late Quaternary stratigraphy and sedimentology of southern Ontario.

ACKNOWLEDGMENTS

The authors wish to thank Dr. I. P. Martini and Dr. A. Dreimanis for very helpful comments on earlier versions of the manuscript. R. Kelly provided unpublished data and comments concerning the Scarborough Bluffs. S. H. Richard kindly translated the abstract and captions (checked by J.-S. Vincent). L. Kraus, J.P. Coriveau and D. Clow produced the lines drawings.

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