Géographie physique et Quaternaire

Wisconsinan Inter-Lobal Stratigraphy in Three Quarries Near Woodstock, Ontario

Stratigraphie interlobaire du Wisconsinien dans trois carrières des environs de Woodstock, en Ontario

Interloben-Stratigraphie in der Zeit des Wisconsin in drei Steinbrüchen in der Nähe von Woodstock, Ontario

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Résumé de l'article

La zone interlobaire des lacs Huron et Érié peut être étudiée dans la région de Woodstock. Trois grandes carrières de calcaire (Zorra, Beachville West et Beachville East) offrent des coupes jusqu'à 30 m de haut dans du matériel détritique. La granulométrie, la teneur en carbonate, la couleur, la structure, la fabrique, la lithologie et la séquence, ainsi que le tracé continu des contacts et des changements de faciès, ont permis de reconnaître dix tills et les sédiments lacustres reliés en corrélation avec la stratigraphie déjà connue dans les régions avoisinantes. On a identifié quatre principaux événements glaciaires, dont trois du Wisconsinien supérieur. Trois langues de Till de Canning rouge (âge inconnu) du lobe du lac Érié sont recouvertes par le Drift de Catfish Creek (deux langues de till d'écoulement sud-ouest) du Stade de Nissouri (22 à 17 ka). Des séquences de sédiments glaciaires et non glaciaires similaires et apparamment corrélatives à l'intérieur du complexe de Catfish Creek (membre de Centreville), à Zorra et Beachville West, laissent supposer l'existence d'une marge glaciaire de direction nord-ouest vers le sud-est. Recouvrant ces séquences, on trouve les sédiments glaciolacustres (couches de Rayside) de l'Interstade d'Érié (16 ka), le Till de Port Stanley du Stade de Port Bruce (15-14 ka) du lobe du lac Érié, les couches glaciolacustres de Zorra, le Till de Tavistock du Stade final de Port Bruce du lobe du lac Huron (trois langues) et enfin un épandage de retrait glaciaire (graviers de Dunn's Corner). La sédimentation glaciolacustre répétée entre les dépôts pourrait être associée à la diminution glacioisostatique des gradients et aux marges glaciaires avoisinantes. L'existence de conditions interlobaires au Catfish Creek est peu probable ; il y a plutôt eu des récurrences locales de type lobaire par la suite.

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WISCONSINAN INTER-LOBAL STRATIGRAPHY IN THREE QUARRIES NEAR WOODSTOCK, ONTARIO

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ABSTRACT The Huron-Erie interlobate zone passes near Woodstock, Ontario. Three large limestone quarries (Zorra, Beachville West, Beachville East) provide exposures up to 30 m high of the drift stratigraphy. Grain size, matrix carbonate, color, structure, fabric, lithology, and sequence, along with continuous tracing of contacts and facies changes, allowed recognition of ten tills and related water-laid sediments correlated with the known stratigraphy in surrounding areas.Four major glacial events are recognized, three of Late Wisconsinan age. Three tongues of red, Erie lobe Canning Till (unknown age) are overlain by a Nissouri Stadial (22-17 ka) Catfish Creek Drift complex (two till tongues, regional southwest ice flow). Similar, apparently correlative, glacial and non-glacial sediment sequences within Catfish Creek Drift at Zorra and Beachville West (Centreville Member) suggest a northwest-southeast-trending ice margin. Overlying this are Erie Interstadial (16 ka) glaciolacustrine sediments (Rayside beds), Port Bruce Stadial (15-14 ka) Erie lobe Port Stanley Till, glaciolacustrine Zorra beds, and final Port Bruce Stadial Huron lobe Tavistock Till (three tongues), and deglacial outwash (Dunn's Corner gravels). Repeated glaciolacustrine sedimentation between tills may relate to glacioisostatically reduced gradients and nearby ice lobe margins. There is little evidence of Catfish Creek interlobate conditions and only independent lobal glacial advances later.

RÉSUMÉ *Stratigraphie interlobaire du Wisconsinien dans trois carrières des environs de Woodstock, en Ontario.* La zone interlobaire des lacs Huron et Érié peut être étudiée dans la région de Woodstock. Trois grandes carrières de calcaire (Zorra, Beachville West et Beachville East) offrent des coupes jusqu'à 30 m de haut dans du matériel détritique. La granulométrie, la teneur en carbonate, la couleur, la structure, la fabrique, la lithologie et la séquence, ainsi que le tracé continu des contacts et des changements de faciès, ont permis de reconnaître dix tills et les sédiments lacustres reliés en corrélation avec la stratigraphie déjà connue dans les régions avoisinantes. On a identifié quatre principaux événements glaciaires, dont trois du Wisconsinien supérieur. Trois langues de Till de Canning rouge (âge inconnu) du lobe du lac Érié sont recouvertes par le Drift de Catfish Creek (deux langues de till d'écoulement sud-ouest) du Stade de Nissouri (22 à 17 ka). Des séquences de sédiments glaciaires et non glaciaires similaires et apparamment corrélatives à l'intérieur du complexe de Catfish Creek (membre de Centreville), à Zorra et Beachville West, laissent supposer l'existence d'une marge glaciaire de direction nord-ouest vers le sud-est. Recouvrant ces séquences, on trouve les sédiments glaciolacustres (couches de Rayside) de l'Interstade d'Érié (16 ka), le Till de Port Stanley du Stade de Port Bruce (15-14 ka) du lobe du lac Érié, les couches glaciolacustres de Zorra, le Till de Tavistock du Stade final de Port Bruce du lobe du lac Huron (trois langues) et enfin un épandage de retrait glaciaire (graviers de Dunn's Corner). La sédimentation glaciolacustre répétée entre les dépôts pourrait être associée à la diminution glacioisostatique des gradients et aux marges glaciaires avoisinantes. L'existence de conditions interlobaires au Catfish Creek est peu probable ; il y a plutôt eu des récurrences locales de type lobaire par la suite.

ZUSAMMENFASSUNG *Interloben-Stratigraphie in der Zeit des Wisconsin in drei Steinbrüchen in der Nähe von Woodstock, Ontario*. Drei große Kalkstein-Steinbrüche (Zorra, Beachville West, Beachville East) liefern Aufschlüsse bis zu 30 m Höhe von der glazialen Schotter-Stratigraphie. Korngröße, Matrix-Karbonat, Farbe, Struktur, Textur, Lithologie und Stadium zusammen mit der kontinuierlichen Aufzeichung der Kontakte und Fazies-Änderungen ließen 10 Tills und damit zusammenhängende Seen-Sedimente erkennen, die mit der bekannten Stratigraphie der angrenzenden Gebiete korrelieren.Man erkennt vier glaziale Hauptereignisse, drei davon aus der Zeit des Spät-Wisconsin.Drei Zungen roten Canning-Tills (Alter unbekannt) von der Lobe des Erie-Sees sind von dem Catfish Creek-Drift (zwei Till-Zungen, regionaler Eisfluss nach Südwest) aus dem Nissouri-Stadium (22-17 ka) überlagert. Ähnliche, offenbar entsprechende glaziale und nichtglaziale Sediment-Stadien innerhalb des Catfish Creek-Drifts bei Zorra und Beachville West (Glied von Centreville) lassen auf einen von Nordwesten nach Südosten gerichteten Eissaum schließen. Über diesem befinden sich glaziallimnische Sedimente (Schichten von Rayside) aus dem Erie-Interstadial (16 ka), Port Stanley-Till der Erie-Lobe aus dem Port Bruce-Stadial (15-14 ka), glaziallimnische Schichten von Zorra, Till von Tavistock des Endstadials von Port Bruce der Lobe des Huron-Sees (drei Zungen) und schließlich Anschwemmung von glazialem Rückzug (Kiesel von Dunn's Corner). Wiederholte glaziallimnische Sedimentierung zwischen den Tills könnte mit der Abnahme der glazioisostatischen Gefälle und den nahe gelegenen Säumen der Eislobe zusammenhängen. Es gibt wenig Beweise für die Existenz von Catfish Creek-Interloben-Bedingungen. Es gab eher später unabhängige glaziale Rückvorstöße des Loben-Typs.

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INTRODUCTION

Hydrogeological concern over water resources and groundwater protection has stimulated an upsurge of attention to interlobate glaciofluvial deposits in southern Ontario. The Oak Ridges moraine, formed between the Simcoe and Ontario lobes in the northern Greater Toronto Area, became a major mapping, drilling, and geophysics project to define the geometry and spatial relationships of aquifers and aquitards (Sharpe *et al*., 1996; Barnett *et al*., 1998) (Fig. 1). The Waterloo moraine, formed between the Huron-Georgian Bay and Erie-Ontario lobes, and a major groundwater source for the Waterloo region, has also been studied (Karrow and Paloschi, 1996). Evidence indicates both glaciofluvial complexes formed late in the history of glaciation. Questions remain as to whether similar lobate patterns of ice flow existed during earlier glaciations, how and where lobes interacted, and the nature of resulting sediments and paleogeography.

In contrast, the Woodstock area (Fig. 1) is not known to have major meltwater sediment bodies in the interlobate zone; study of such an area could provide a different perspective on inter-lobal relationships to compare with areas of major glaciofluvial sedimentation. The Woodstock area is particularly accessible for study of interlobate stratigraphy and sedimentation because of the existence of three large bedrock quarries that are among the most extensive excavations through relatively thick drift into bedrock in southern Ontario. Also, the surrounding area is relatively well known from several decades of glacial stratigraphic study and many reference data are available for correlation.

Exposures at three active quarries (Fig. 1) are reported here: Zorra, where about 25 % of the exposures available in 1964, now concealed by slump and dumped fill, were described by Westgate and Dreimanis (1967); Beachville West (Stelco quarry of Cowan, 1975), previously undescribed; and Beachville East (Domtar quarry of Cowan, 1975), partly described by Dilabio (1971), Cowan (1975), and Piotrowski (1985). In the 25 to 30 years since most of the previous studies were undertaken, improved understanding of glacial sedimentology has been achieved, warranting reexamination and extension beyond the older work.

From these considerations, our prime purpose is to describe and interpret the stratigraphy and sedimentary facies of the Woodstock interlobate area. Observations in the three quarries are placed in the stratigraphic framework of the surrounding area.

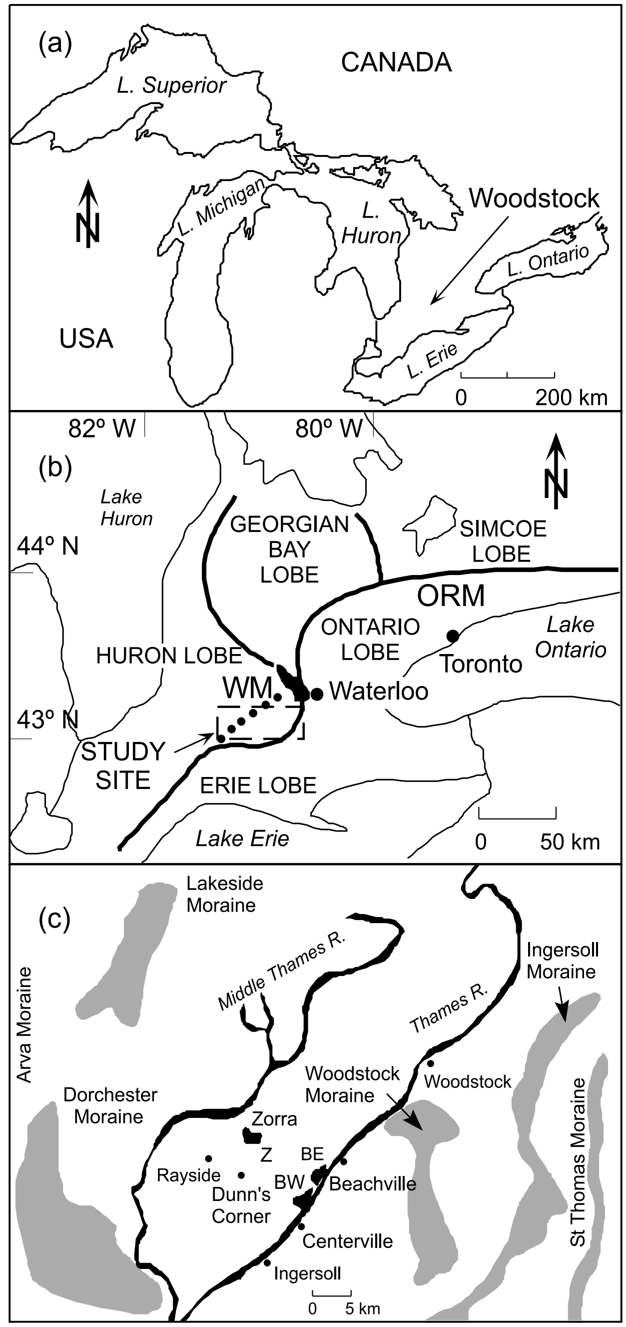


FIGURE 1. Location map. (a) Location in the Great Lakes area. (b) Location relative to ice lobes and Waterloo (WM) and Oak Ridges (ORM) moraines. Dotted line = inferred buried Port Stanley Drift margin. (c) Location map showing quarries in relation to local places and moraines (BE – Beachville East Quarry, BW – Beachville West quarry, Z – Zorra Quarry).

Carte de localisation : (a) localisation par rapport aux Grands Lacs ; (b) localisation relativement aux lobes glaciaires et aux moraines de Waterloo (WM) et d'Oak Ridges (ORM). Le pointillé identifie la marge enfouie du Drift de Port Stanley ; (c) localisation des carrières par rapport aux localités et aux moraines (BE = carrière de Beachville East, BW = carrière de Beachville West, Z = carrière de Zorra).

PREVIOUS WORK

Study of the Quaternary geology of the Woodstock district had a comparatively late start. Although Taylor (1913) delineated the Ingersoll moraine along the south side of the Thames River and indicated it was formed at the margin of the Erie ice lobe, surface landforms were first described and mapped comprehensively by Chapman and Putnam (1951), including the Lakeside, Ingersoll, Westminster and St. Thomas moraines, the Woodstock drumlin field, and a network of meltwater channels across the area. The interlobate setting of the Woodstock-Thames Valley area was also depicted.

Dreimanis (1961) related till characteristics to bedrock and drift deposits overridden by the ice in southern Ontario; he related till facies changes to areal variations in substrate and provided a better basis for correlating till stratigraphy. His stratigraphic work in Lake Erie coastal cliffs established the till sequence of the central Erie lobe (Dreimanis, 1958; de Vries and Dreimanis, 1960), later carried into the Woodstock area in the first local stratigraphic study (at the Zorra quarry) by Westgate and Dreimanis (1967). The Woodstock area was included in the systematic mapping program of the Ontario Geological Survey in 1969-70 (Cowan, 1975). The developing stratigraphy of tills in the interlobate Waterloo area, northeast of Woodstock, was presented by Karrow (1974), with subsequent reviews of deposits and their inferred history of formation by Karrow (1984), Karrow and Occhietti (1989), and Barnett (1992). Further study of the Woodstock drumlin field was carried out by Piotrowski (1987).

These prior studies provided a general context for the detailed studies reported here. As the most widespread, continuous, and traceable units, tills provide the stratigraphic framework for working out the sequence of glacial events. Till provenance has been established by areal mapping and three-dimensional stratigraphy supported by various kinds of analytical work. The latter includes matrix grain size to refine field description, matrix carbonate content and pebble lithology to relate to Paleozoic bedrock sources, and till fabric to deduce ice flow directions. As Paleozoic bedrock is widely uniform, and opposing ice lobes crossed similar bedrock, far-travelled heavy minerals from the Precambrian shield can help distinguish tills from different ice lobes (Gwyn and Dreimanis, 1979), as may certain indicator rock types (Fig. 2).

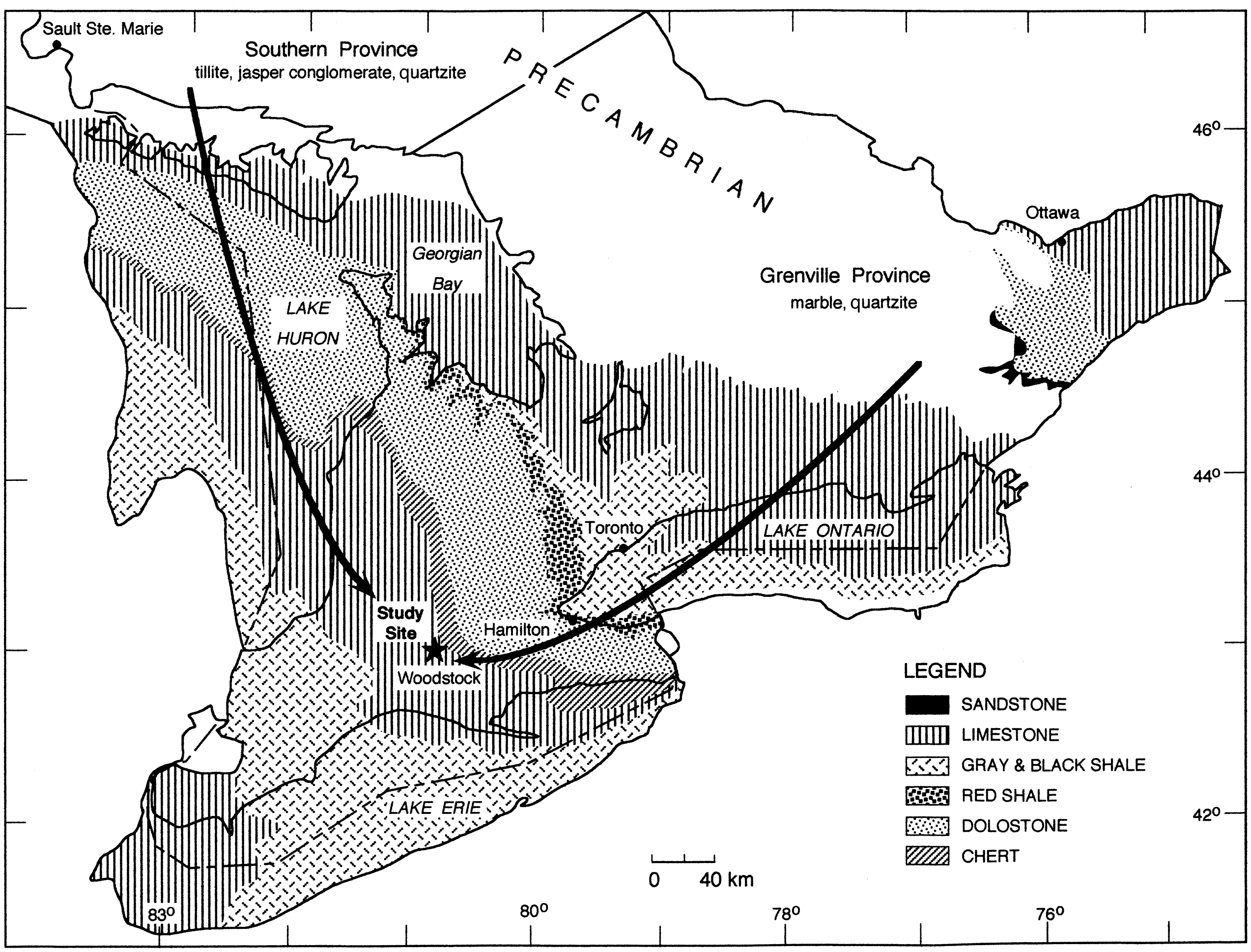


FIGURE 2. Bedrock geology of southern Ontario and some bedrock indicators.

Géologie du substratum rocheux du sud de l'Ontario et quelques indicateurs.

GEOLOGICAL SETTING

Four till units represent separate ice advances into the area. The oldest is the fine-grained Canning Till, thought to have been deposited by a northwestward advance of the Erie ice lobe. Its characteristic reddish color is attributed to the Ordovician Queenston shale of the western Lake Ontario basin, which provided reddish glaciolacustrine clays to the eastern Erie basin, reworked by advancing ice to form the fine red till. The age of the ice advance is unknown.

Next youngest is the Catfish Creek Till, the widespread deposit of the main Late Wisconsinan ice advance into the northern U.S.A. Typical characteristics are coarse grain-size, high matrix carbonate and low carbonate ratio (calcite/dolomite: C/D), hardness, and fabric indicating regional ice flow from the northeast and north, although early and late ice flow from the Erie lobe has been noted, relating to thinner ice more affected by topography (Karrow, 1988). This till is a widely recognized stratigraphic marker, with relatively constant characteristics (Cowan, 1978). It has an estimated age of 22 000 to 17 000 years BP

The youngest Erie lobe till, Port Stanley Till, overlies the Catfish Creek Till. Markedly finer south into the Erie basin from overriding of glaciolacustrine clay, on the north flank of the Erie lobe advance this till becomes coarser, and matrix carbonate and C/D ratio vary proportionately – higher carbonate content and lower C/D ratio to the north. Ontario basin provenance is indicated by erratics of Precambrian Grenville marble (Fig. 2).

From the Huron-Georgian Bay ice lobe flowing from the northwest, and overlapping the Port Stanley Till, is the Tavistock Till, also fine-grained but coarsening into the Woodstock area from overriding of underlying coarser deposits. Moderate matrix carbonate content and C/D ratios again vary with grain size – higher content and lower C/D ratio southward. Clasts of tillite, quartzite, and jasper conglomerate from Huronian rocks north of Lake Huron indicate its provenance (Fig. 2). Port Stanley and Tavistock tills are similar in age, having been deposited 15 000 to 14 000 years ago.

The surface near the quarries is a drumlinized till plain (axes NW-SE) of Tavistock Till, with shallow valleys partly filled by glaciofluvial sand and gravel (Cowan, 1975). Recessional Erie lobe moraines (Ingersoll, St. Thomas) lie to the southeast, and moraine patches (Lakeside, Woodstock, Dorchester) to the northwest are within the area of the Huron-Georgian Bay lobe Tavistock Till. Cowan (1975) mapped the Zorra till (= Tavistock Till) boundary as northwest of the Ingersoll moraine, whereas Piotrowski (1985, 1987) placed it 3 to 10 km farther southeast at the St. Thomas moraine (Fig. 1).

Subsequently, fluvial erosion by the Thames River exposed high-purity Devonian limestone, which became the site for several quarries between Woodstock and Ingersoll (Fig. 1). Later quarry expansion extended into adjacent till plain where drift is about 30 m thick. The quarry exposures described herein display the relationships of multiple till tongues and associated glaciofluvial and glaciolacustrine deposits.

METHODS

Field study June through August of 1995 comprised describing vertical logs of fresh exposures in the three quarries and observations in two gravel pits near the Beachville West quarry (Fig. 1). There are 22 vertical logs at Zorra (Fig. 3), 8 at Beachville West (Fig. 4), and 19 at Beachville East (Fig. 5). Observations included lithology and grain size, structures, color, thickness, till fabrics (50 clasts each, at 43 sites) and paleoflow measurements from cross bedding and ripple marks. Bulk samples (about 2.5 L) were taken of all types of deposits.

In the laboratory, grain size (matrix only for tills: ASTM, 1996), carbonate content (Dreimanis, 1962), and fine (4-12 mm; 100-600 clasts) pebble lithology were determined. Sand, silt, and clay percentages and statistical parameters were determined from plotted cumulative curves.

LITHOSTRATIGRAPHY AND SEDIMENT CHARACTERISTICS

Diamictons identified as tills form a major part of the quarry sequences. As they are the most correlatable units in the Quaternary stratigraphy of southern Ontario, they form the stratigraphic framework and are described first. Interpretations and correlations from this study are covered in the Discussion section. Tables I and II summarize their analytical data.

TILLS

Till A

Till A, informally named by Westgate and Dreimanis (1967) at the Zorra quarry (Fig. 3), was only found at that quarry in this study. It is 0.3-0.8 m thick, laterally continuous on the bedrock surface, massive, coarse grained, carbonate-rich with a relatively high C/D ratio, and has a yellowish brown color (5Y5/3). It is clast-supported, with mostly angular clasts (maximum observed 20 cm, average 2-7 cm). Most clasts are of the underlying cream limestone. Westgate and Dreimanis (1967) found organic inclusions in this unit with molluscs and seeds, the only buried organics found in the sequence by them or us. Pebble fabrics are random. Westgate and Dreimanis (1967) found striae on the bedrock underneath oriented just east of south, but the bedrock was too broken where observed in this study.

Canning Till

This till was defined by Karrow (1963) from the Nith River section at Canning, northeast of Woodstock. It was recognized in this study only at the Zorra quarry (Fig. 3), but occurs there as three layers of till separated by 0.2-1.0 m of gravel, the whole totalling 2-5 m. All till layers are reddish and mostly fine grained (Table II), as it is at the type section.

The lowest bed (Canning Till 1) lies directly on till A or is separated from it by a lag of angular blocks. It occurs throughout Zorra quarry with a thickness of 0.2 m. It is massive, reddish brown (5YR5/3 - 5YR4/3), silty, and matrix-supported with few large clasts. Canning Till 2 also occurs throughout Zorra quarry with a thickness of 1.5-2.5 m. Color and carbonate content are similar to the lower bed and it is also massive and matrix-supported with few large clasts. It differs in being coarser (silty sandy). Canning Till 3 occurs only in the northwest corner of Zorra quarry and is 1.5 m thick. It is massive, matrix-supported, reddish-brown (5YR3/3), with lower carbonate content and C/D ratio. Its grain size is finer, like the lower Canning Till 1 bed.

Pebble long axes in Canning Till form clusters shallowly plunging to the southeast indicating northwestward ice flow. Westgate and Dreimanis (1967) noted bedrock striae under this till oriented southeast. Clast compositions grade upward from dominantly cream limestone at the base, locally derived, and minor black (more distant Ordovician) limestone, with increased black and some dolostone upward (Table II).

Dilabio (1971) and Cowan (1975) identified till in the Beachville East quarry below Catfish Creek Till as Canning by correlation with Zorra quarry Till B of Westgate and Dreimanis (1967). Near the location described by Dilabio (1971) (Fig. 4), 0.5 m of gray till resting on bedrock and having some similar characteristics to his description, was found below 4 m of gravel underlying gray Catfish Creek Till. This lowest till has a grain size like Canning but still within the range of Catfish Creek Till (Table I), pebble lithology more like Catfish Creek than Canning, and lacks the red color typical of Canning Till at Zorra and elsewhere (Karrow, 1963). We have then concluded this till is more likely part of Catfish Creek Till 1.

Catfish Creek Drift

Catfish Creek Drift was defined by deVries and Dreimanis (1960) from Lake Erie shorebluff exposures. Two similar till beds occur in all three quarries, often separated by 0.5 to 0.8 m of fine lacustrine sediments and/or gravel. The lower till bed (Catfish Creek Till 1) is up to 18 m thick in the northeast part of Zorra quarry (Fig. 3), where it overlies Canning Till, but is absent in the central and northwest parts. In Beachville West (Fig. 4) it is up to 20 m thick, resting on gravel or, more often, on bedrock. In Beachville East (Fig. 5) its base is concealed by talus but is believed to rest on bedrock with thicknesses of 2-10 m. This till layer is very hard, gray to dark gray (10YR5/1 to 10YR3/3), has moderate to high carbonate (particularly at Beachville) and higher carbonate ratios than are regionally typical, likely affected by underlying limestone. It is matrix-supported but clast-rich (sizes up to 1.5 m). Pebbles are usually well rounded but larger clasts less so. The matrix is sandy to silty and poorly sorted. Although usually massive, stony clusters and small sand lenses are present. At Zorra this bed is finer in the upper metre. Fabrics range from west of north to east of north. Its stoniness, coarseness, and compactness ("hardpan") compare well with published descriptions (deVries and Dreimanis, 1960; Dreimanis, 1982; Karrow, 1988).

The upper bed (Catfish Creek Till 2) is like the lower but with fewer clasts. It is up to 3 m thick and discontinuous at Zorra (Fig. 3), forming one layer in the northeast that splits into two or three thin layers southwestward with intervening silts, sands, and gravels, then wedges out. It is up to 12 m thick in the Beachville quarries (Figs. 4 and 5) and continuous. It is gray to dark gray (10YR3/2 to 10YR7/2), has similar carbonate content (highest at Beachville East), again with higher than usual C/D ratios, and is also massive and matrix-supported. It is not as hard as the lower layer. Although less stony than Catfish Creek Till 1, it is still much more so than most other tills. Texture is more variable, from the usual sandy silty to even clayey silty. In some Beachville exposures upper and lower units merge and become indistinguishable. Fabrics again indicate ice flow from the north. Clasts include Precambrian Gowganda tillite (Georgian Bay source), Ordovician Queenston green siltstone, local Devonian cream limestone, Ordovician dark limestone, and Silurian dolostone (Table II).

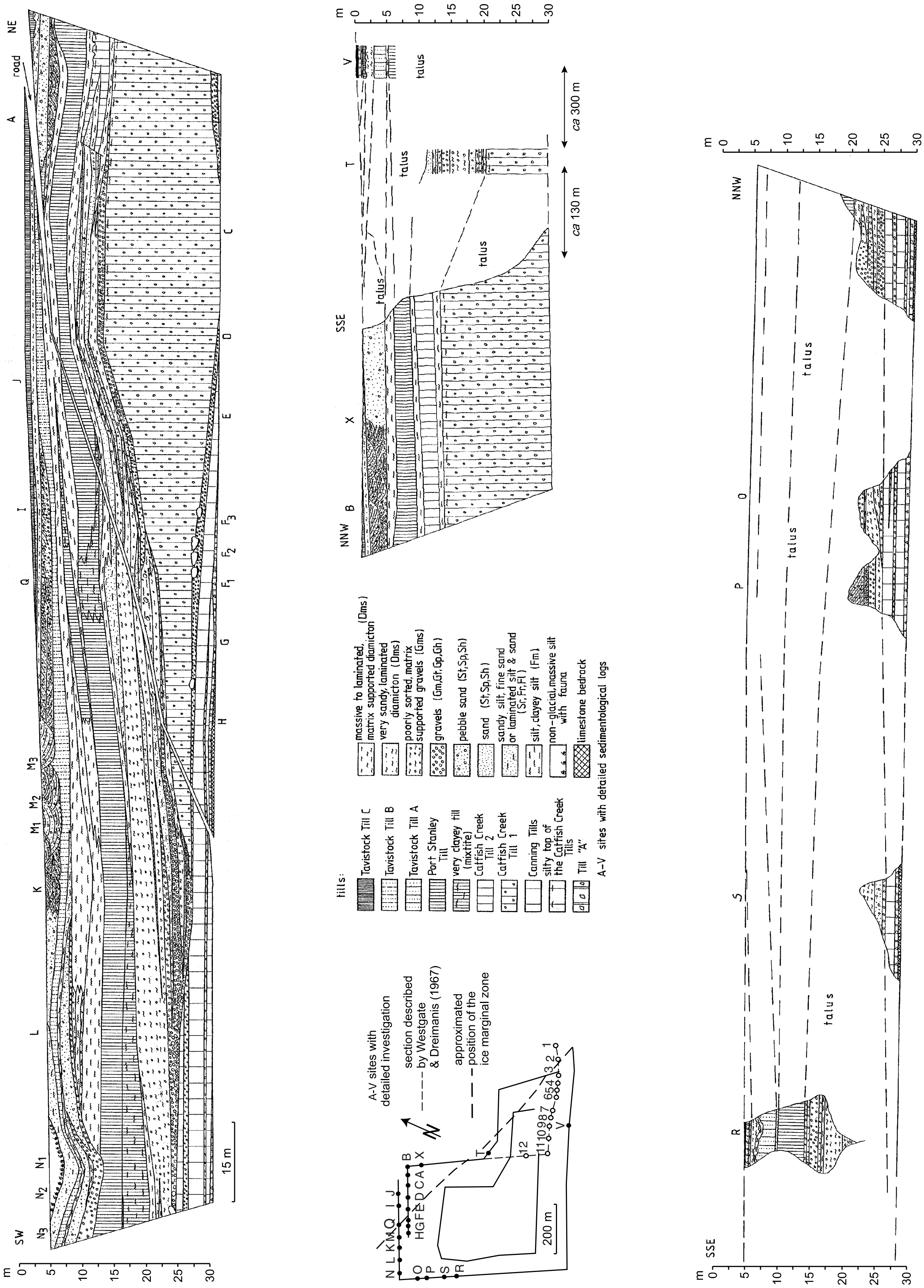
Port Stanley Drift

This unit was also defined in the type section at Lake Erie shorebluffs (deVries and Dreimanis, 1960). Completed mapping between there and Woodstock has established it as a widespread Erie lobe surface till of Port Bruce age (Cowan, 1975). Port Stanley Till is present as a single layer at Zorra (Fig. 3) 1.5-5.5 m thick and Beachville West (Fig. 4) 1-4 m thick, but as one to several beds at Beachville East (Fig. 5). It is variable in character within and between quarries, partly reflecting substrate variation (more clayey over glaciolacustrine clay at Zorra, more sandy over sand and gravel at Beachville West). Still, it is generally the least stony and most clayey of the quarry tills. It contains moderate carbonate amounts and C/D ratios are all over 1.0. Port Stanley Till is usually massive in the quarries and matrix-supported. It sometimes displays textural and color layering, as at Beachville East, and may contain inclusions of glaciolacustrine silt and clay with original lamination, laminated clays may be brecciated, or clays may be more or less homogenized. This variability suggests characteristics of an immature till (Karrow, 1976), *i.e.* local material not transported far enough to be uniformly mixed as in a mature till.

At Zorra, (Fig. 3) this till is dark gray to black (10YR3/1 - 10YR5/2) and is usually a clayey silt, with coarser local lenses. Rare clasts are up to 7 cm in size. At Beachville West (Fig. 4) it is brown (10YR5/4) with less clay and more clasts. This till is most complex at Beachville East (Fig. 5), with black facies C (10YR3/2 - 10YR4/2), brown facies B (10YR5/8), and gray to dark gray facies G (10YR5/1 - 10YR4/2), the latter being similar to Catfish Creek 2 in hardness and coarseness. The multiple layers and variations and their vertical displacements and dips (Fig. 6) suggest glaciotectonic stacking, with some reworking of underlying Catfish Creek Till. This mechanism was suggested by Schwartz (1968) for similar till (Dorchester till) southeast of London. The provenance and ice flow direction for Dorchester till are unresolved (Dreimanis *et al*., 1998).Equivalent till in the quarries has fabrics indicating ice flow from the south to southeast, whereas other Port Stanley fabrics are often random but sometimes similar to the Dorchester facies. Overall clast lithologies are like averages of other tills (Table II).

Tavistock Till

Karrow (1974) defined Tavistock Till as a Huron-Georgian Bay lobe till of Port Bruce age derived from the northwest.


tills:
Tavistock Till C
Tavistock Till B
Tavistock Till A
Port Stanley Till
very clayey till (mixtite)
Catfish Creek Till 2
Catfish Creek Till 1
Canning Tills
silty top of the Catfish Creek Tills
Till "A"
A-V sites with detailed sedimentological logs
massive to laminated, matrix supported diamicton (Dms)
very sandy, laminated diamicton (Dms)
poorly sorted, matrix supported gravels (Gms)
gravels (Gm,Gt,Gp,Gh)
pebble sand (St,Sp,Sh)
sand (St,Sp,Sh)
sandy silt, fine sand or laminated silt & sand (Sr,Fr,Fl)
silt, clayey silt (Fm)
non-glacial, massive silt with fauna
limestone bedrock
A-V sites with detailed investigation
section described by Westgate & Dreimanis (1967)
approximated position of the ice marginal zone
200 m
15 m
ca 300 m
ca 130 m
talus
SW
NE
SSE
NNW
road

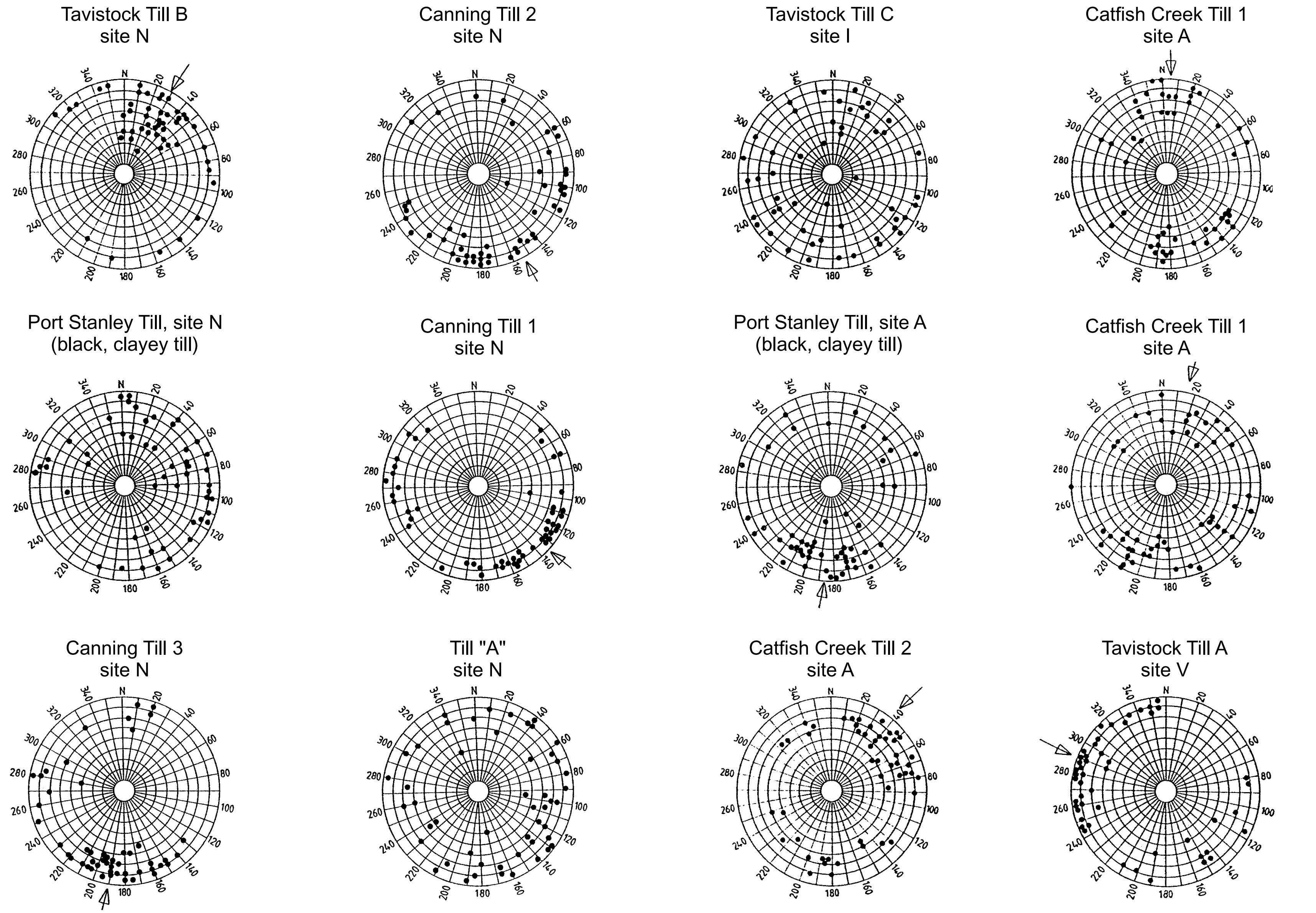


FIGURE 3. Quaternary stratigraphy at Zorra quarry. All tills are represented by various vertical line patterns with specific identifications: A - till A, C - Canning Till, CC - Catfish Creek Till, PS - Port Stanley Till, T - Tavistock Till. Letters along section designate position of vertical sediment logs. Selected till fabrics are shown, with arrow at edge for average direction.

Stratigraphie du Quaternaire à la carrière de Zorra. Tous les tills sont représentés par diverses configurations de lignes verticales bien identifiées : A - till A, C - Till de Canning, CC - Till de Catfish Creek, PS - Till de Port Stanley, T - Till deTavistock. Les lettres apparaissant le long des coupes donnent l'emplacement des enregistrements verticaux des sédiments. La flèche en bordure de certaines fabriques de till donne la direction moyenne.

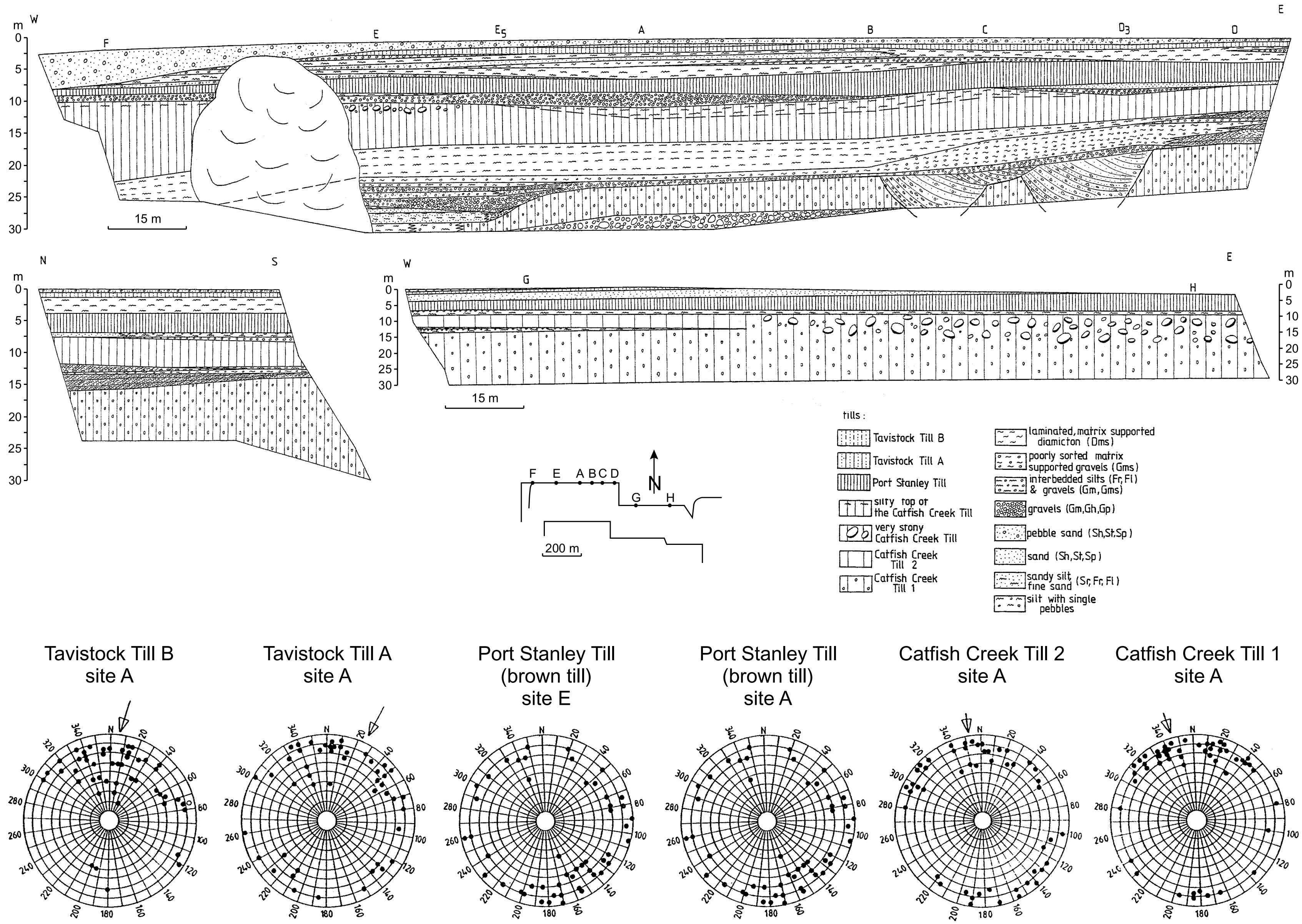


FIGURE 4. Quaternary stratigraphy at Beachville West quarry. Designations as for Figure 3.

Stratigraphie du Quaternaire à la carrière de Beachville West. Les caractéristiques sont celles de la figure 2.

Near its southeastern margin it is commonly coarser, probably reflecting incorporation of underlying Catfish Creek Till (Cowan, 1975: Zorra till; Sado, 1980; Karrow, 1993), and then the two are sometimes difficult to distinguish. Piotrowski (1985, 1987) distinguished three tongues (A, B, C) of the till in the marginal zone, and layers tentatively correlated with his three tongues have been recognized in the quarries. At Zorra (Fig. 3), C is over B and over A, at Beachville West (Fig. 4), B is over A at one site, and elsewhere in the Beachville quarries only A is present. Tavistock clasts are lithologically distinctive in having higher chert, shale, sandstone, and crystalline rocks, whereas Queenston siltstone is lower (Table II). Tillite and chert are related to Georgian Bay lobe sources.

Tavistock Till A is 3-4 m thick at Zorra (Fig. 3), 0.5-1.5 m at Beachville West (Fig. 4), 1-4 m at Beachville East (Fig. 5), and is the most continuous of Tavistock units. It is grayish brown to brown (10YR5/4 - 10YR5/3) and has moderate carbonate content and carbonate ratios. It is matrix-supported and usually massive with moderate stoniness (clasts up to 10 cm). Sand and silt lenses are sometimes present. Fabrics indicate ice flow from the northwest (Zorra) to northeast (Beachville). The matrix is a sandy silt and resembles Catfish Creek Till 1, except for being much softer.

Tavistock Till B is generally continuous at Zorra (Fig. 3), 0.5-1.0 m thick, and is present at one site in Beachville West (Fig. 4), 0.5 m thick. It is yellow to yellowish brown (2.5Y7/2 - 10YR6/4), has moderate carbonates with a lower C/D ratio (< 1.0) and the matrix is sandy silty with clasts to 10 cm, but usually 2-5 cm. This unit is poorly mixed or immature (Karrow, 1976), with lenses of stratified sand and granules and numerous small clasts of silt/clay. Fabrics indicate ice flow from the northeast.

Tavistock Till C is known only at Zorra (Fig. 3), where it is 0.1-1.5 m thick. When at the ground surface it is much altered by weathering, but under postglacial sediments its original character shows as containing moderate carbonate content and C/D ratio < 1.0. It is mottled yellowish brown to dark brown (10YR3/6 - 10YR7/2) and the matrix is sandy silty. Aside from weathering, it resembles Tavistock Till A. Fabrics tend to be random, but could be affected by surface processes.

WATERLAID SEDIMENTS

Waterlaid sediments commonly separate the various till sheets and beds of the same till in the quarries. These sediments vary in thickness and are more generally discontinuous than the tills. The largest waterlaid sediment body is contained within Catfish Creek Drift and is given formal status as the Centreville Member. Other waterlaid sediment bodies are subsidiary in their thickness and extent and are only given informal designations at this time.

Canning Drift

Description: Layers of gravel 0.1 to 1.0 m thick occur between the various Canning Till units (Fig. 3). The gravels are moderately to moderately well sorted and up to 20 cm size (average 3-5 cm). Their composition resembles that of the Canning tills; lower gravels are white and black limestone with some dolostone, whereas middle gravels are mainly black limestone and some dolostone (Table II).

Interpretation: Upward changes in lithology reflect similar changes in Canning Till pebbles, with lowest sediments reflecting most the underlying bedrock and upper reflecting longer distance transport. These gravels are thus interpreted as local outwash related to Canning ice.

Beachville gravels

Description: There are two occurrences of gravel at the base of Catfish Creek Till 1. At Beachville West (Fig. 4), a lens of gravel 2-3 m thick and 50 m long separates Catfish Creek Till 1 from underlying bedrock. The gravel is poorly sorted with clasts up to 0.6 m and a coarse sand matrix. Well rounded boulders dominate the lower part with matrix dominant in the upper part. Limestone and dolostone predominate with some crystalline rock present. Fine gravel composition is like Catfish Creek Till 1. Some silty balls and lenses are present near the top.

At Zorra quarry (Fig. 3), gravels similar in position to the Beachville gravels, containing black and other limestones and green Queenston siltstone, separate Canning Till 3 and Catfish Creek Till 1 (Table II).

Interpretation: Both gravel bodies under Catfish Creek Till 1 are believed to represent proglacial outwash deposited during the Catfish Creek ice advance and are thus part of Catfish Creek Drift. Those at Zorra (Fig. 3) are interpreted as Catfish Creek proglacial gravels containing reworked Canning material.

Centreville Member

Description: This fining-upward sediment complex ranges from gravels, sands, silts, and diamictons to clay-silt rhythmites, occurs between Catfish Creek tills 1 and 2, and has a maximum thickness of up to 15 m. It is named here formally after the hamlet of Centreville, 1 km southwest of Beachville. Where Catfish Creek Till 1 is eroded away from beneath the unit, it overlies older tills (at Zorra: Fig. 3) or bedrock (Beachville West: Fig. 4). It is overlain by Catfish Creek Till 2 in northeast Zorra (Fig. 3) and at both Beachville quarries (Figs. 4 and 5) but by post-Catfish Creek sediments (Rayside silts) in northwest Zorra (Fig. 3). The unit thins and wedges out eastward in Beachville West and East as Catfish Creek tills 1 and 2 converge into a single till (Figs. 4 and 5). As it has its major development at Zorra and Beachville West, it will be described there from northeast to southwest.

The thin sediment edge (up to 1.5 m) consists of massive to laminated silt, with dispersed pebbles at Zorra (Fig. 3); at Beachville West (Fig. 4) there is a thin cap of clay-silt rhythmites. The unit thickens rapidly westward to 5 to 7 m. At Zorra (Fig. 3), two tongues of Catfish Creek Till 2 interdigitate with massive silt and/or cross- to planar-bedded, well sorted pebbly sands. As the tills wedge out westward, silts and sandy diamicton grade into rippled fine sands; 0.5 m of massive gravel floors the sequence (Fig. 7). At Beachville West (Fig. 4), large-scale planar cross-bedded pebbly sands

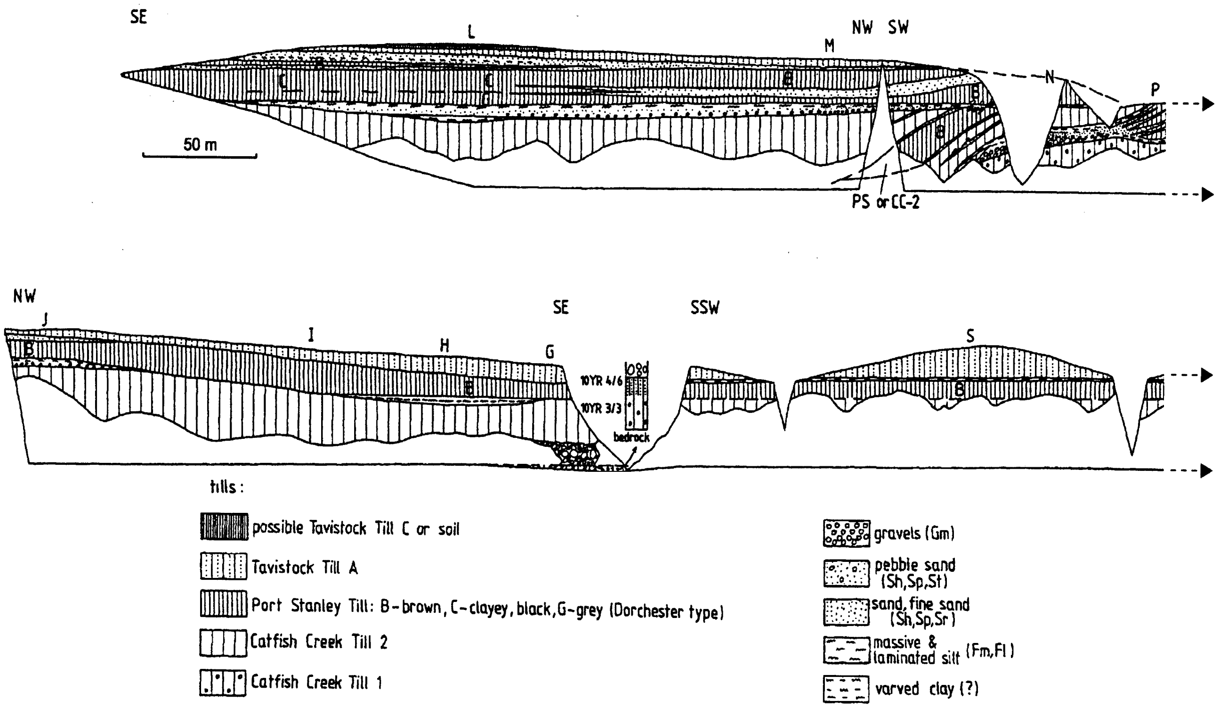


FIGURE 5. Quaternary stratigraphy at Beachville East quarry. Designations as for Figure 3.

Stratigraphie du Quaternaire à la carrière de Beachville East. Les caractéristiques sont celles de la figure 3.

dominate, with seven planar sets 0.5 to 2.5 m thick. Dispersed single cobbles and boulders to 0.4 m are present. Interdigitated are massive, well sorted gravels (size to 0.3 m), rippled sands, and matrix-supported, poorly sorted gravels; the last of these thicken westward and downslope over Catfish Creek Till 1 (Fig. 4).

At Zorra (Figs. 3 and 7), continued thickening of the Centreville Member to about 10 m is accompanied by coarsening, with increasing amounts of poorly sorted, matrix-supported (silt to coarse sand matrix) gravel. Silts disappear westward, being replaced by 5 m of the aforementioned gravel. At least three depositional cycles become evident, with basal medium to large trough cross-bedded gravels (size to 1 m, average 0.2-0.5 m), middle massive gravels (size up to 0.3 m), and upper matrix-supported gravels (0.3-1.0 m). At the western limit of exposure the sequence thins to 5 m as the basal trough-bedded gravels wedge out and only the two overlying massive and poorly sorted gravels remain (Fig. 3).

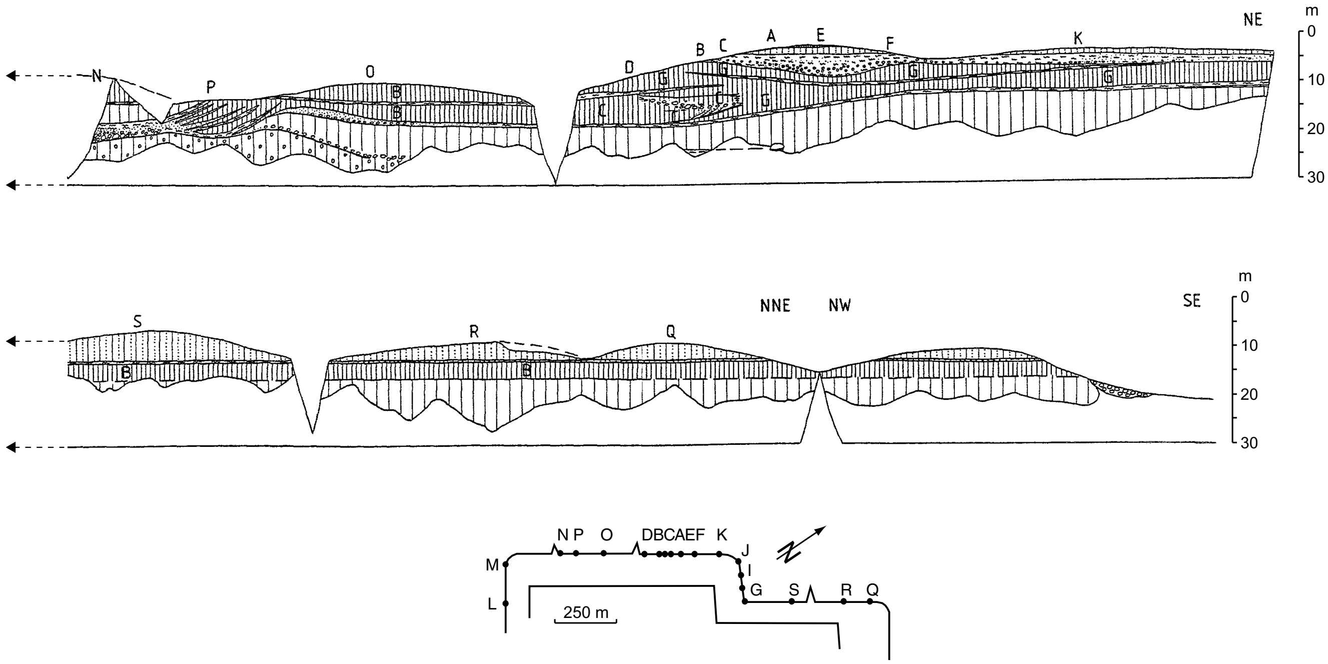
At Beachville West (Fig. 4), similar basal large scale trough-bedded pebbly sands and gravels (troughs 15-20 m wide and 5-10 m deep incised into Catfish Creek Till), and middle massive and matrix-supported gravels, are overlain by 5 m of clay-silt rhythmites (100-150 couplets: varves?). In some places the rhythmites are brecciated below Catfish Creek Till 2. In the westernmost exposures, the upper two parts are similar (rhythmites over gravels), but the lower sands and gravels are replaced by massive sandy silts, poorly sorted massive to horizontally bedded sands, and well sorted, rippled fine sands. The lowermost sediments grade eastward into pebbly silts, then into Catfish Creek Till 1; sandy and gravelly beds occur at the till margin. The upper part of the lower unit is gravelly, with alternating massive and horizontally bedded layers (size to 0.2 m) (Fig. 3). At Beachville East (Fig. 5), lenses of equivalent sediment are up to 4 m thick, with massive basal gravel, alternating gravel, sand, and silt, and upper massive to laminated silt.

Interpretation: Overall, the Centreville Member shows evidence of a three-phase depositional history in a deltaic setting near a northwest-southeast margin of the Catfish Creek ice. Vigorous channelized meltwater flows formed the large trough crossbedding, followed by braided stream outwash with longitudinal bars. Near the ice margin, debris flows formed interbedded diamictons, and subaqueous mass movements generated poorly sorted, reworked sediments. In the final phase, particularly evident at Beachville West, glaciolacustrine conditions prevailed, with deposition of clay-silt rhythmites. Paleoflow indicators from trough crossbedding and sand rpples are northwesterly or widely variable.

Rayside beds

Description: This informal name is taken from a place 3 km southwest of Zorra, for silts and/or gravels that commonly occur between Catfish Creek Till 2 and Port Stanley Till (Fig. 7). The gravels may occur alone or, more commonly, below silts; they are most prominent at Beachville West (Fig. 4), where 0.5-2.5 m of massive to horizontally and cross-bedded gravels with some sand contain clasts ranging up to 0.2-0.3 m and occasionally 0.5 m. Gravels are sporadic and thinner (up to 0.6 m) at Beachville East (Fig. 5).

Gray (10YR6/2 - 10YR6/1) silts 1.0-2.5 m thick at Zorra (Fig. 3), 0.3-1.4 m at Beachville West (Fig. 4) and 0.1-3 m in the western part of Beachville East (Fig. 5), are most continuous at Zorra. Mainly massive silt, there are thin clay laminae,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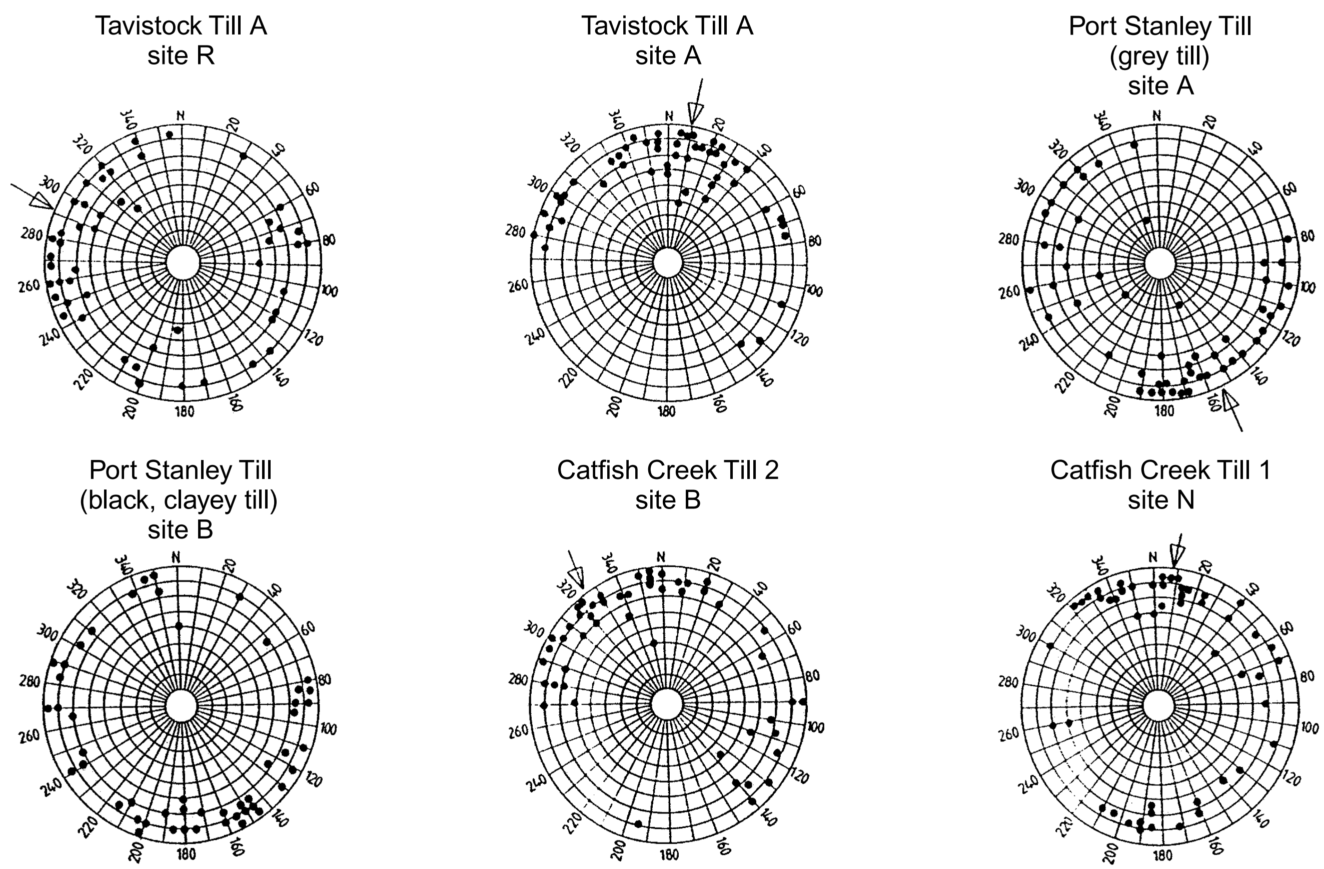
Tavistock Till A
site R
Tavistock Till A
site A
Port Stanley Till
(grey till)
site A
Port Stanley Till
(black, clayey till)
site B
Catfish Creek Till 2
site B
Catfish Creek Till 1
site N

TABLE I

Main lithological properties of tills at Zorra and Beachville quarries near Woodstock, southern Ontario

Till bed	Number of samples	Grain size % clay	Grain size % silt	Grain size % sand	Carbonate content % calcite	Carbonate content % dolomite	Carbonate content % total
Tavistock Till C	5	9 3-14	40 30-52	52 36-67	14 13-16	18 17-19	32 30-34
Tavistock Till B	5	5 2-10	43 36-57	50 40-54	14 6-17	16 11-20	30 18-35
Tavistock Till A	9	13 5-17	49 42-58	38 25-53	19 15-21	16 14-24	35 32-41
Port Stanley Till (brown till)	5	11 6-19	59 45-82	30 11-42	19 17-23	16 13-19	35 33-37
Port Stanley Till (black till)	11	24 12-51	62 44-87	14 1-32	23 19-26	14 10-18	37 35-39
Port Stanley Till (grey till)	3	14 8-23	58 51-69	28 23-36	20 18-21	16 14-18	36 34-38
Catfish Creek Till 2	13	15 2-36	52 24-70	33 16-74	21 14-31	18 10-28	39 33-53
Catfish Creek Till 1	10	15 6-23	42 31-52	43 33-63	23 17-33	19 15-25	42 36-54
Canning Till 3	1	22	42	36	15	9	24
Canning Till 2	3	16 12-18	38 35-41	47 44-48	25 24-26	12 8-14	37 35-40
Canning Till 1	2	22 21-23	53 51-54	26 23-28	24 22-25	10 8-11	34 31-36
Till “A”	2	7 6-8	39 26-46	57 46-68	39 38-40	19	58 56-60

TABLE II

Mean percentage petrographic composition of tills and gravel series at Zorra, Beachville West and Beachville East quarries near Woodstock, southern Ontario (fraction 4-12 mm)

Stratigraphy	Number of samples	Black limestones	White limestones	Other limestones	Dolostone	Chert	Shale	Siltstone	Sandstone	Quartzite	Queenston sandstone	Quartz	Crystalline rocks	Gowganda tillite
Dunn’s Corner Gravels	2	0	0	44	25.2	3	1.7	0.5	3	1.2	4.8	3	12.4	1.2
Tavistock Till C	1	0	0	34	30	8	5	1	7	2	4	2	6.5	0.5
Tavistock Till B	3	0	0	43	16	4.7	2.4	3.4	8	4.4	0	3.4	15	0
Tavistock Till A	6	0	0	46.3	23.7	3.3	2	0.3	7.2	1.8	4.7	1.7	8.7	0.3
Zorra Gravels	3	0	0	52.8	23	3	1.8	0.9	4	0.9	0.7	2.4	10.4	0.3
Port Stanley Till (brown till)	5	0	0	42.8	30	4	1.2	0.4	4.4	1.1	4.3	1.5	10.3	0
Port Stanley Till (black till)	9	0	0	47.4	17.9	2.8	1	0.3	6.5	4.8	2.3	1.6	15.4	0
Port Stanley Till (grey till)	3	0	0	44.8	28.8	5	1	0.2	3.2	2.2	4.2	1	9.6	0
Rayside Gravels	2	0	0	41.4	28.4	4.4	0.5	0	6.4	2.5	1.5	3	11.2	0.7
Catfish Creek Till 2	7	0	0	46.5	26.8	4	1.6	0.1	4.3	2	3.4	0.7	10.5	0.1
Centreville Member	12	0	0	44.3	26.8	6.2	0.7	0.2	3.5	2.5	3.5	1.7	10	0.6
Catfish Creek Till 1	8	0	0	45.5	28	4	1	0.2	3	1.8	5.8	1.7	8.6	0.4
Beachville Gravels	1	0	0	45	27	6	0	1	1	2	9	1	8	0
C3/CC1 gravels	1	13	10	17	36	6.5	1	0	6	2	4	0.5	4	0
Canning Till 3	1	22	9	2	34	7	1	1	8	5	0	2	9	0
C2/C3 gravels	1	33	4	4	33	2	0.2	0	7	0.8	0	2	14	0
Canning Till 2	2	41	28	0.5	10	2	0.5	0.5	3	4	0	1.5	9	0
C1/C2 gravels	1	23	40	5	14	2	1	0.5	5	1	0	0.5	8	0
Canning Till 1	2	8	75	0.5	2	1	0.5	0	3	3	0	1	6	0
Till “A”	2	0	92	0	1	0.5	0.5	0	1	1.5	0	0.5	3	0

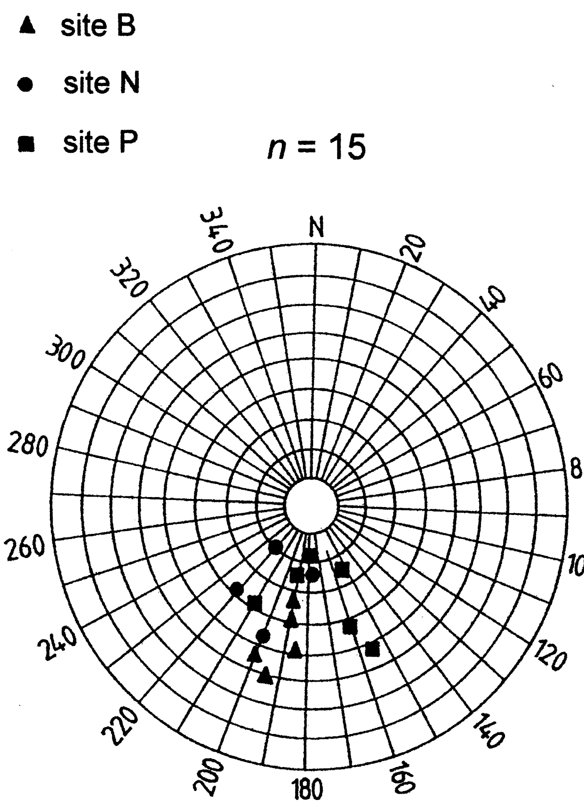

FIGURE 6. Orientation of thrust planes formed in Port Stanley tills at Beachville East quarry.

Orientation des plans de chevauchement qui se sont formés dans les tills de Port Stanley dans la carrière de Beachville East.

scattered single pebbles, sandy silts, rippled fine sands, and lenses of cross-bedded sand as well. Diamicton laminae occur at Beachville West and there the silts are sometimes interdigitated with gravel and sand.

Interpretation: As the gravels have a composition like underlying Catfish Creek Till 2, including a few Gowganda tillites (Table II), they are interpreted as outwash from the Catfish Creek ice retreat, and are also considered to be part of Catfish Creek Drift. Paleoflows were again from the southeast to northwest, perhaps marginal to northeasterly retreating Catfish Creek ice.

The silts are interpreted to represent a glaciolacustrine environment of the Erie Interstadial (Dreimanis and Karrow, 1972), an interval of substantial ice retreat during which extensive glacial lakes were formed. Rayside silts are correlated with similar deposits observed by Cowan (1975) and Sado (1980), with the Malahide Formation of Dreimanis (1987), and with the Wildwood Silts of the St. Mary's area (Sigleo and Karrow, 1977).

Zorra beds

Description: A sediment complex similar to the Rayside beds occurs between Port Stanley and Tavistock tills. Coarse facies up to 2 m thick include fine sand, medium to coarse trough cross-bedded and horizontally bedded sand, and massive, horizontally trough and planar-bedded gravel. They tend to occur in erosional channels in associated silts or in underlying till at Zorra (Fig. 3) and Beachville East (Fig. 5), but in more extensive sheets at Beachville West (Fig.4). They may be above, below, lateral to, or within the associated silts. Paleoflows were from the northeast (Fig. 8).

The silt facies are 0.5-1.5 m thick, brown to yellowish brown (10YR5/6 - 2.5YR5/4) with dark brown (10YR5/4 - 10YR4/4) clay laminae, up to 15 in number and ranging from a few millimetres to 10 cm thick. Rippled sandy silt and diamicton layers are sometimes present.

Interpretation: A complex of outwash and glacial lake environments with fluctuating water levels is envisioned for the deposition of the Zorra beds. Clast compositions (Table II) are like Rayside beds and Catfish Creek Drift and probably indicate meltwater erosional reworking. Since Catfish Creek deposits are at the surface northeast of Woodstock, forming terrain not subsequently overridden by Port Stanley and Tavistock ice advances, and also form surface inliers within the area of Tavistock Till (Cowan, 1975; Karrow, 1993) access to them for reworking by meltwaters was easily accomplished.

Dunn's Corner gravels

Description: The youngest coarse sediments, named from a nearby farm south of Zorra, occur between and overlying Tavistock tills. They occur only at Zorra (Fig. 3) and Beachville West (Fig. 4), but not at Beachville East (Fig. 5). They are spatially associated with a shallow surface valley trending from Zorra to Beachville mapped by Cowan (1975). Exposures in two gravel pits near Beachville West quarry supplement the quarry exposures.

At Zorra (Fig. 3), trough cross-bedded pebbly sand and gravel with planar and small-scale cross-bedding, horizontal lamination, and massive gravels fill two erosional channels 2-3 m deep and 50-70 m wide (Fig. 8A). At Beachville West (Fig. 4) they form a 1-3 m-thick surface sheet on the till and fill a 5-8 m-deep erosional channel in the northwestern corner of the quarry, corresponding to the shallow surface valley mapped by Cowan (1975). In the pits they form large-scale planar or cross-bedded gravel or pebbly sand; trough cross-bedding is only rarely present near the top. Planar sets are 0.3-2.0 m thick in pit 2 and at least 5 m thick at pit 1 (Fig. 8B).

Interpretation: These sediments probably represent braided river deposition with well developed transverse bars deposited during fluctuations of Tavistock ice and during its retreat. Gravel composition is like that of the Rayside and Zorra beds, *i.e.* like Catfish Creek Drift, with Gowganda tillite, and again may represent at least partly reworked material (Table II). The peripheral zone of Tavistock Till regionally shows strong evidence of alteration with reworked Catfish Creek Drift (Cowan, 1975; Karrow, 1993).

Postglacial sediments

In the northwest corner of the Zorra quarry (Fig. 3) about 5 m of laminated to massive fossiliferous silt and sand, probably

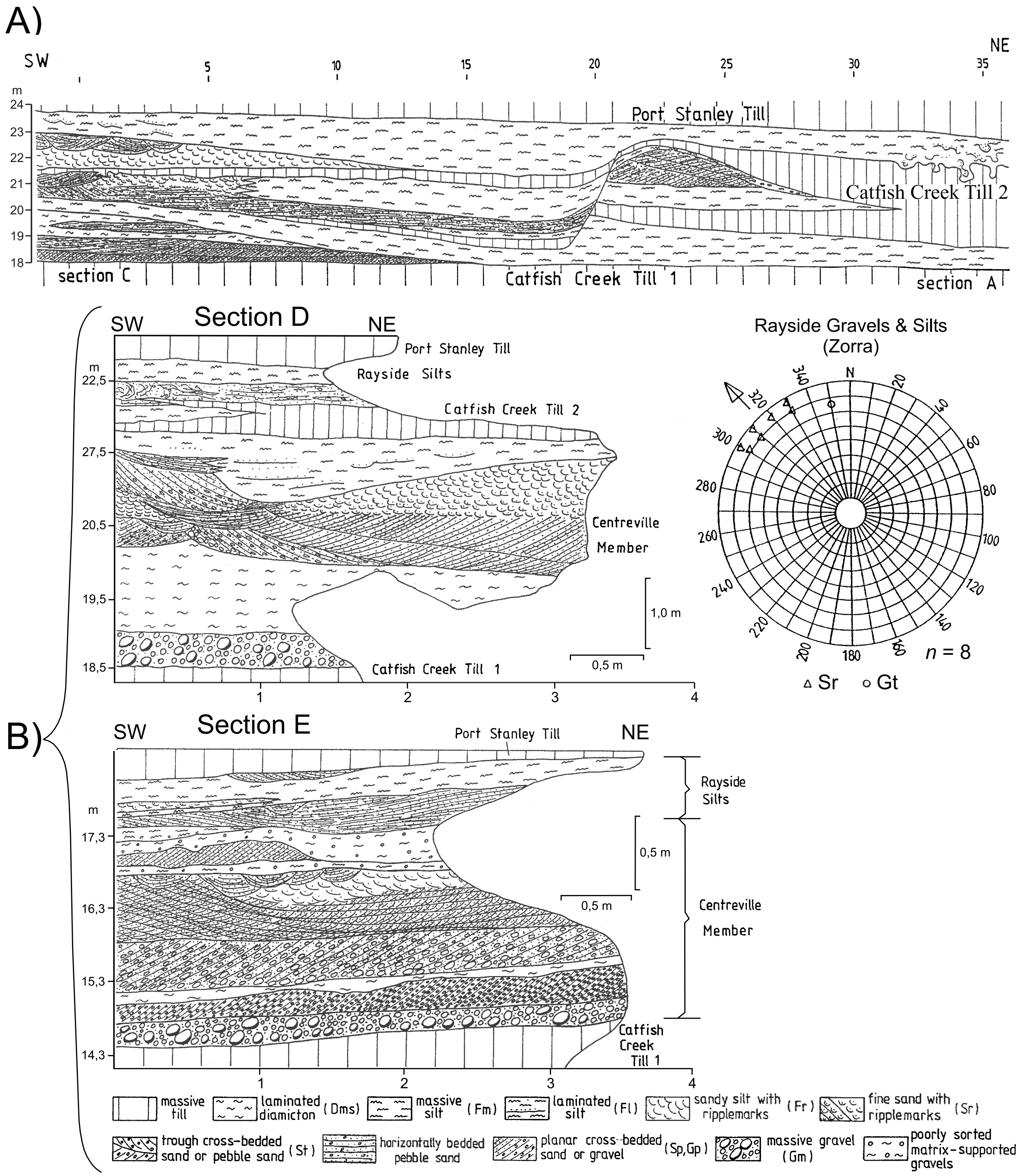

FIGURE 7. A) Sediment succession between Catfish Creek Till 1 and Port Stanley Till at Zorra sections A and C. Note that Catfish Creek Till 2 disappears to the west and that the Centreville Member becomes southwestward more complex. B) Sediment succession between Catfish Creek Till 1 and Port Stanley Till at Zorra sections D and E. Note that the boundary between the Centreville Member and the Rayside silts is unclear where Catfish Creek Till 2 disappears.

A) Succession sédimentaire entre le Till de Catfish Creek 1 et le Till de Port Stanley dans les coupes de Zorra A et C. À noter que le Till de Catfish Creek 2 disparaît vers l'ouest et que le Membre de Centreville devient plus complexe vers le sud-ouest. B) Succession sédimentaire entre le Till de Catfish 1 et le Till de Port Stanley dans les coupes de Zorra D et E. À noter la limite imprécise entre le Membre de Centreville et les silts de Rayside, là où disparaît le Till de Catfish 2.

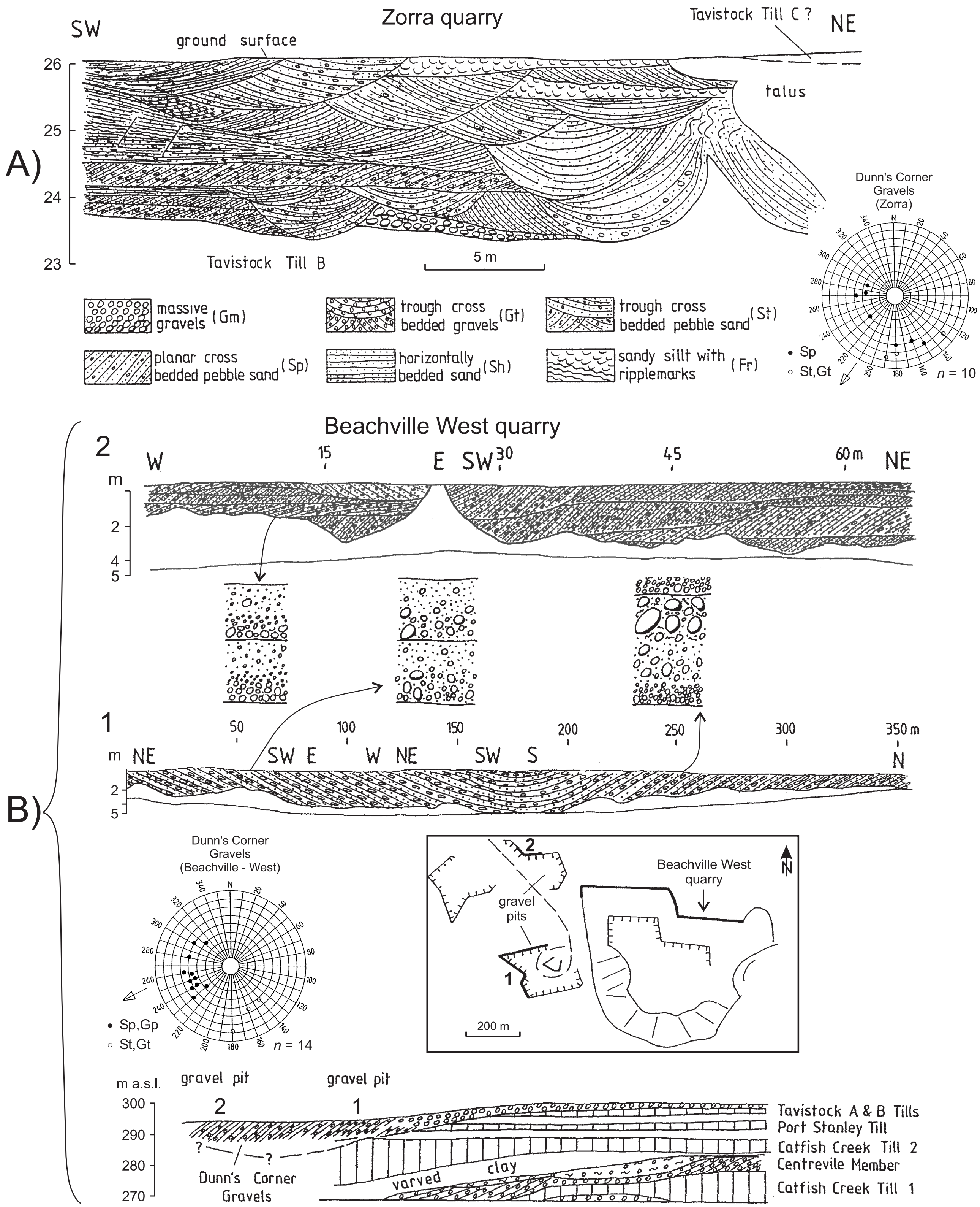

FIGURE 8. A) Sedimentological features of Dunn's Corner gravels at Zorra section M. B) Sedimentological features of Dunn's Corner gravels in two gravel pits near Beachville West quarry. The third and lowermost section shows the stratigraphic correlation between the quarry and gravel pits.

A) Caractéristiques sédimentologiques des graviers de Dunn's Corner dans la coupe de Zorra M. B) Caractéristiques sédimentologiques des graviers de Dunn's Corner dans deux gravières près de la carrière de Beachville West. La troisième coupe (inférieure) montre la corrélation stratigraphique entre la carrière et les deux gravières.

colluvial slope-wash, fill a depression in the surface till. Lenses and laminae of plant debris and molluscs are present. A radiocarbon date on woody debris of 12 150 ± 90 yrs (1σ: WAT-2917) provides a minimum age for the underlying Tavistock Till, estimated to have been deposited before 14 000 BP. This date can be compared with a date of 12 400 ± 180 (2σ: GSC-1156) on basal gyttja from Maplehurst Lake (Mott and Farley-Gill, 1978) situated in the window of Catfish Creek Drift northeast of Woodstock. Mott and Farley-Gill (1978) adjusted the age to 12 020 ± 180 BP because of possible old carbon error. Similar postglacial silts and peat also occur in the southeast part of Zorra quarry (Fig. 3) above Tavistock Till.

Thames River alluvium, containing abundant molluscs and plant debris, including logs, has been sporadically exposed by excavation during Beachville quarry operations over the years. These have had no systematic study and were little exposed at the time of the present project.

DISCUSSION

TILL A

Sediment at the Zorra quarry correlated with till A of Westgate and Dreimanis (1967) differs in several respects from their description, *viz*, high carbonate content and C/D ratio *vs.* their low values, pebbles mostly limestone *vs*. their equal limestone and dolostone, and minor chert *vs*. their 10 %. Color and stratigraphic position are similar. Material we encountered was clast-supported with angular clasts, and fabrics mostly random with a weak southeast trend; it may be local till, not representative of the sediment deposited by the related ice advance. A hypothesis that should be considered is that all sediments of this unit may have been emplaced finally during the Canning ice advance, rather than by a separate earlier event, all being local and/or immature with inclusions. Inasmuch as these sediments are restricted in distribution and few analyses are available, their true nature and origin remain uncertain.

CANNING TILL

Materials identified in this study as Canning Till at Zorra display a diminishing-upward effect of the underlying limestone bedrock. Fabrics indicate ice flow from the southeast and south, *i.e*. from the Erie basin. Till B of Westgate and Dreimanis (1967) most resembles Canning Till 3 of this study.

The regional correlation and age of the Canning Till is still unresolved. Karrow (1963) suggested it might be of Early Wisconsinan age. Sunnybrook Till of the Toronto area (Karrow, 1967) and the upper Bradtville Till of the Port Talbot sequence at Lake Erie (Dreimanis *et al.,* 1966) were considered correlative by Goldthwait *et al*., (1965). Dreimanis (1992) has suggested the alternative that Bradtville Till may be of Illinoian age. As the Canning Till has not been found in association with any dated organic remains or sediments of interglacial affinity, its age remains open; it is simply older than Catfish Creek Till. The quarry exposures at Zorra are the westernmost known occurrences of the Canning Till.

CATFISH CREEK TILL

Knowledge of the complexity of glacial history of Catfish Creek Drift has grown over the years as its widespread occurrence (Karrow, 1988) and existence of multiple units have been documented (Gibbard, 1980; Dreimanis, 1982). Westgate and Dreimanis (1967) correlated their Zorra quarry unit C with Dunwich Till of the Port Talbot sequence and unit D as a Middle Wisconsinan till of unknown affinity. Dreimanis (1987) subsequently grouped Dunwich and Southwold tills at Port Talbot with Catfish Creek Drift. Cowan (1975) preferred to include Zorra tills C and D with Catfish Creek Till and the present work supports that interpretation. Figure 9 presents our reinterpretation of the Zorra site Quaternary stratigraphy compared to the original interpretation of Westgate and Dreimanis (1967). Westgate and Dreimanis (1967) considered their Zorra tills E and F to be Catfish Creek; unit E and perhaps part of F correlate with Catfish Creek Till 2 of our study whereas C and D wedge out westward and equate to our Catfish Creek Till 1. This interpretation would indicate the presence of three beds of Catfish Creek Till with the uppermost (2) the most extensive and the lower two (1A, 1B) and the associated Centreville member having formed with ice fluctuations during the main advance.

The description and definition of the Centreville Member of the Catfish Creek Drift in this study have led to the recognition of an ice-marginal position oriented northwest-southeast through the Zorra and Beachville West quarries. Tills 1A and 1B record ice advance to this position accompanied by proglacial meltwater ponding to the southwest. Sporadic formation of debris flow diamictons into lacustrine silts was followed by lowered water levels with glaciofluvial erosion and deposition of gravels by ice-marginal drainage trending northwest. Restoration of lacustrine conditions led to deltaic sedimentation along the ice front with slope failures mobilizing rapidly deposited sediments. Quiet-water conditions later fostered deposition of more distal silt-clay rhythmites considered to be varves, which record up to 150 years of stability before the subsequent ice advance eliminated local glaciolacustrine conditions. A period of 200-300 years may be a reasonable estimate for the time this ice-marginal position existed in the area.

Catfish Creek ice of the Nissouri Stadial apparently occupied the area continuously for several thousand years while it expanded south before 20 000 BP and retreated northward to initiate deglaciation in the area after 17 000 BP (Karrow, 1984; Karrow and Occhietti, 1989; Barnett, 1992). Gravels of the Rayside beds were formed as deglacial outwash, part of the Catfish Creek Drift, followed by lacustrine silts of the Erie Interstade. Widespread lacustrine sedimentation contributed fine sediments to be reworked during subsequent Port Bruce Stadial advances by both the Erie and Huron lobes (Chapman and Putnam, 1951).

PORT STANLEY TILL

This till is present as a single thin unit in Zorra (Fig. 3) and Beachville West (Fig. 4) but is a complex multiple unit locally in Beachville East (Fig. 5). Its thinness may be related to a postulated limit not far north of Zorra near Embro (Cowan, 1975). Its lithologic character is particularly variable, as also noted by Cowan (1975) who observed it to be clayey toward the base and coarser upward, which would be consistent with the hypothesis that its fine texture reflects reworking of fine glaciolacustrine sediments; there is also evidence of immature homogenization of fine glaciolacustrine sediments. The local complexity of the till at Beachville East (Fig. 5) appears to be attributable to subglacial glaciotectonic thrusting, which also involves Catfish Creek Till 2. All deformation planes have similar orientations which suggest thrusting generally from the south (Fig. 6) consistent with some fabrics in the till. As indicated by mapped extent (Cowan, 1975) and pebble fabrics, Port Stanley Till was deposited by northward-moving Erie lobe ice in the Port Bruce Stadial, perhaps about 15 000 BP

During the probably short interval between southeasterly retreat of the Port Stanley ice (Erie lobe) to later form a succession of end moraines (Ingersoll, St. Thomas, Norwich, etc.), and the advance of Tavistock ice from the northwest (Huron lobe), the Zorra beds of silt and gravel were deposited over the Port Stanley Till. As with the Rayside beds, both lacustrine and fluvial environments are indicated for these sediments, probably to be interpreted as a dynamic and rapidly changing setting for sedimentation. In this case flow directions are southwestward (marginal to Port Stanley ice).

TAVISTOCK TILL

Three thin sheets of Tavistock Till have been recognized in the quarries, although generally only one or two are present at a site. If these represent the same three ice fluctuations identified in the district by Piotrowski (1985, 1987), greater ranges of ice fluctuations are indicated; he suggested a few kilometres, but they may instead be of 20-25 km, *i.e.* Embro (near Zorra) to the Ingersoll moraine. Variability in lithology is consistent with previous observations on Tavistock Till being altered by underlying overridden material (Cowan, 1975; Karrow, 1993). Near Woodstock, Tavistock Till overlies Port Stanley Till. In contrast, to the north and east Tavistock interdigitates with equivalent Erie lobe tills (Maryhill and Port Stanley tills). At Kitchener-Waterloo Tavistock Till overlies an upper and lower Maryhill Till (= lower Port Stanley) but is overlain near Elmira and Fergus by (upper) Port Stanley Till. In extreme southwestern Ontario (Essex and Kent counties) Port Stanley Till overlies Tavistock Till, but they are regarded as having been deposited "around the same time" (Morris and Kelly, 1997, p. 244). This leads to the conclusion that Tavistock and Port Stanley complexes are roughly equivalent in age in the 14 000 to 15 000 BP range.

The closing event of glacial activity in the area by the Tavistock (Huron lobe) ice was the formation of the Dunn's Corner gravels, a body of late-glacial outwash deposited in a shallow valley tributary to the Thames Valley. Meltwater flow was from the northwesterly retreating Huron ice to join ice-marginal flow along the Thames Valley.

CONCLUSIONS

Combined study of three extensive quarry exposures has enhanced appreciation of the three-dimensional relationship

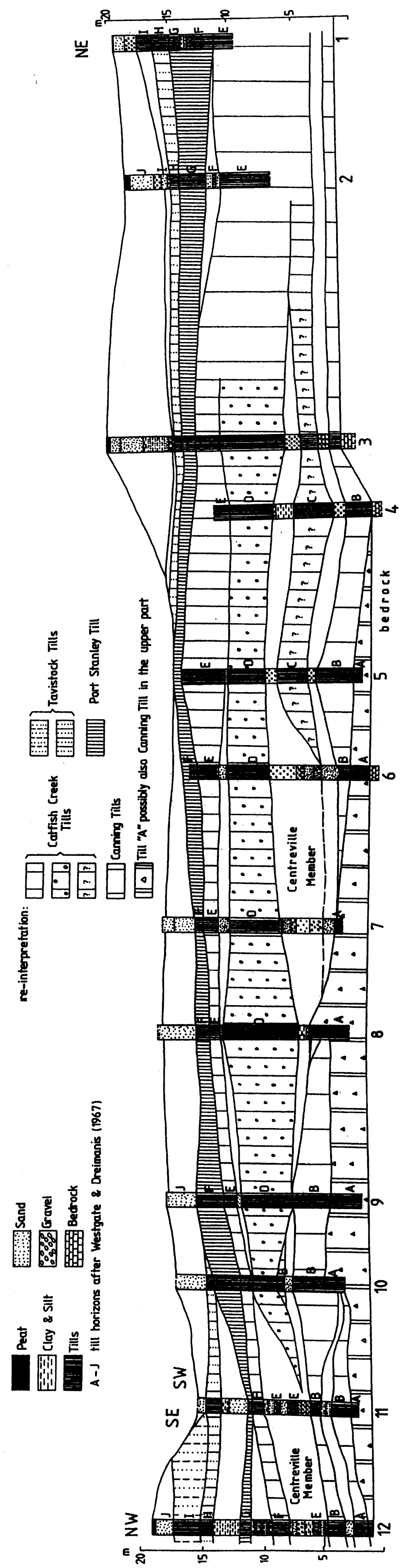

FIGURE 9. Reinterpretation of till stratigraphy from Westgate and Dreimanis (1967) in southeast part of Zorra quarry. Present interpretation infers the presence of three Catfish Creek tills: till C, till D, and till E plus part of till F of Westgate and Dreimanis (1967). Part of till E is believed to represent flow tills or debris flows of the Centreville Member. Canning Till is probably represented by till B and the upper part of till A of Westgate and Dreimanis (1967).

Réinterprétation de la stratigraphie du till à partir de Westgate et Dreimanis (1967) dans la partie sud-est de la carrière de Zorra. L'interprétation actuelle conclut à l'existence de trois tills de Catfish Creek : le till C, le till D et le till E plus une partie du till F de Westgate et Dreimanis (1967). On croit qu'une partie du till E équivaut aux tills d'écoulement ou aux coulées de débris du Membre de Centreville. Le Till de Canning équivaut probablement au till B et à la partie supérieure du till A de Westgate et Dreimanis (1967).

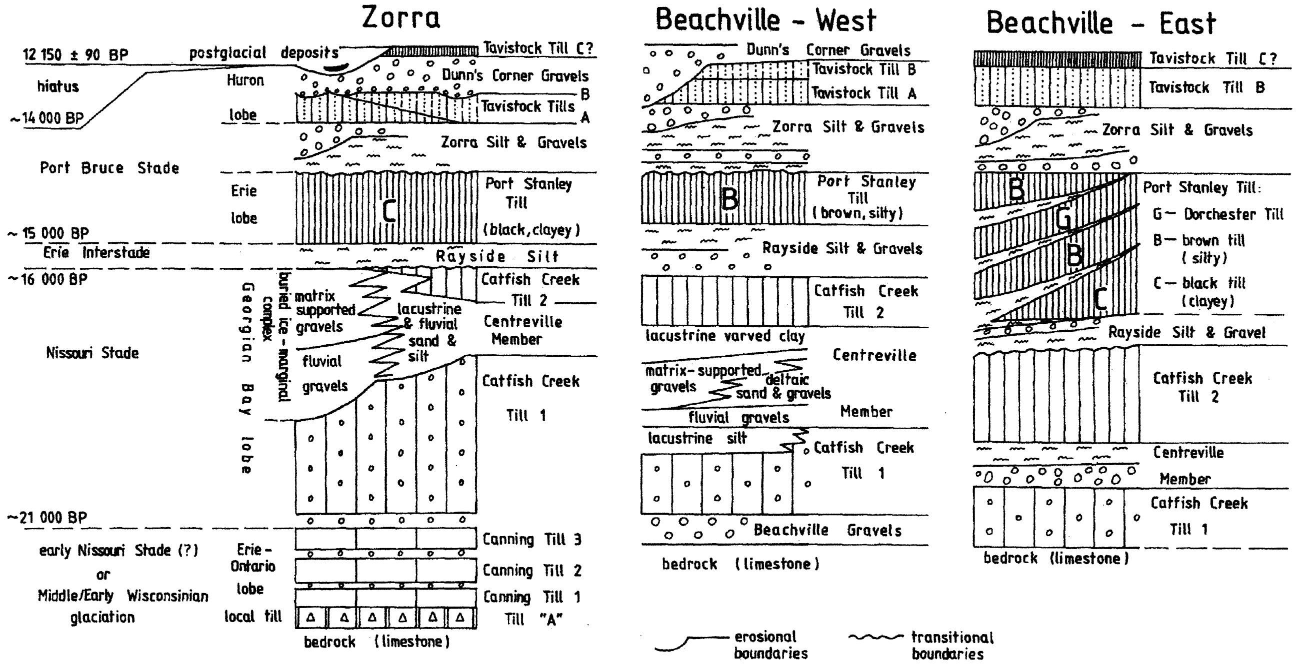

FIGURE 10. Correlation of units at Zorra and Beachville quarries with their chronostratigraphic positions and lobal origins.

Corrélation entre les unités, aux carrières de Zorra et Beachville, ainsi que leur position chronostratigraphique et leur origine glaciaire.

of tills and associated waterlaid sediments in the Woodstock-Ingersoll area. Ten till units have been described from the present work, representing at least four major glacial events, at least the latest three of which are of Late Wisconsinan age. Correlations between quarry sequences, lobal affinity, and age are shown in Figure 10.

The oldest deposits (till A and associated sediments) may be related to the Erie lobe ice advances of unknown age that deposited the Canning drift. Three Canning tills of reddish colour, but varying in other characteristics, are only present in the Zorra quarry (Fig. 3). Intercalated thin gravels between tills record local deposition of outwash during ice fluctuations. The main Late Wisconsinan glacial advance, with regional iceflow to the south and southwest, deposited complex Catfish Creek Drift, including two or three till beds and proglacial glaciofluvial and glaciolacustrine sediments (Centreville Member) along a northwest-southeast-trending ice front through Zorra and Beachville West quarries. Proglacial outwash gravels below (Beachville gravels) and above (Rayside beds) Catfish Creek tills formed during advance and retreat respectively. Glacial lakes of at least local extent formed repeatedly with ice advances and retreats, such as when the Centreville Member was deposited and during the major ice recession of the Erie Interstadial (Rayside beds) following deposition of Catfish Creek Till. Advance of the Erie lobe over lake sediments formed the Port Stanley Drift with one till bed of variable lithology, followed again by deposition of outwash and glaciolacustrine sediments (Zorra beds). A final glacial event brought Huron lobe ice from the northwest and three fluctuations of the ice margin deposited three thin Tavistock Tills, followed by proglacial outwash gravels (Dunn's Corner gravels).

Catfish Creek Drift comprises a large proportion of the deposits in the quarries. Although frequently encountered in southwestern Ontario as the lowest stratigraphic unit in valley wall sections, its base and older deposits are seldom revealed. Because it is usually buried by tens of metres of younger deposits and river bank exposures are usually very limited in extent, the extensive exposures in these quarries have provided a rare opportunity to study details of its stratigraphy. Subsequent lobal advances smeared thin veneers of younger tills on top of Catfish Creek Drift. Extensive exposures of Catfish Creek Drift occur along Lake Erie shorebluffs, but these quarry exposures provide unique access inland from the Great Lakes in what, later, became an interlobate setting. At the time of Catfish Creek deposition, when paleogeography may have been different, the only hint of interlobate conditions is the presence of high level glacial lakes, for which bordering ice lobe dams may be inferred to have existed.

The repeated presence of dammed meltwaters may be attributed to glacioisostatic downwarp in an interlobate setting. Cowan (1975) notes the present Thames River gradient is about 1.3 m/km, much of which would be cancelled out by restoring glacioisostatic downwarp at the time of glaciation. Otherwise, the Erie lobe advance (Port Stanley Drift) seems to have been an independent event unaffected by Huron lobe ice, just as the later Huron lobe advance (Tavistock tills) was unaffected by Erie lobe ice. The identification of the interlobate zone simply applies to the area of overlap. Other than the glaciolacustrine sediments, there is little to indicate the

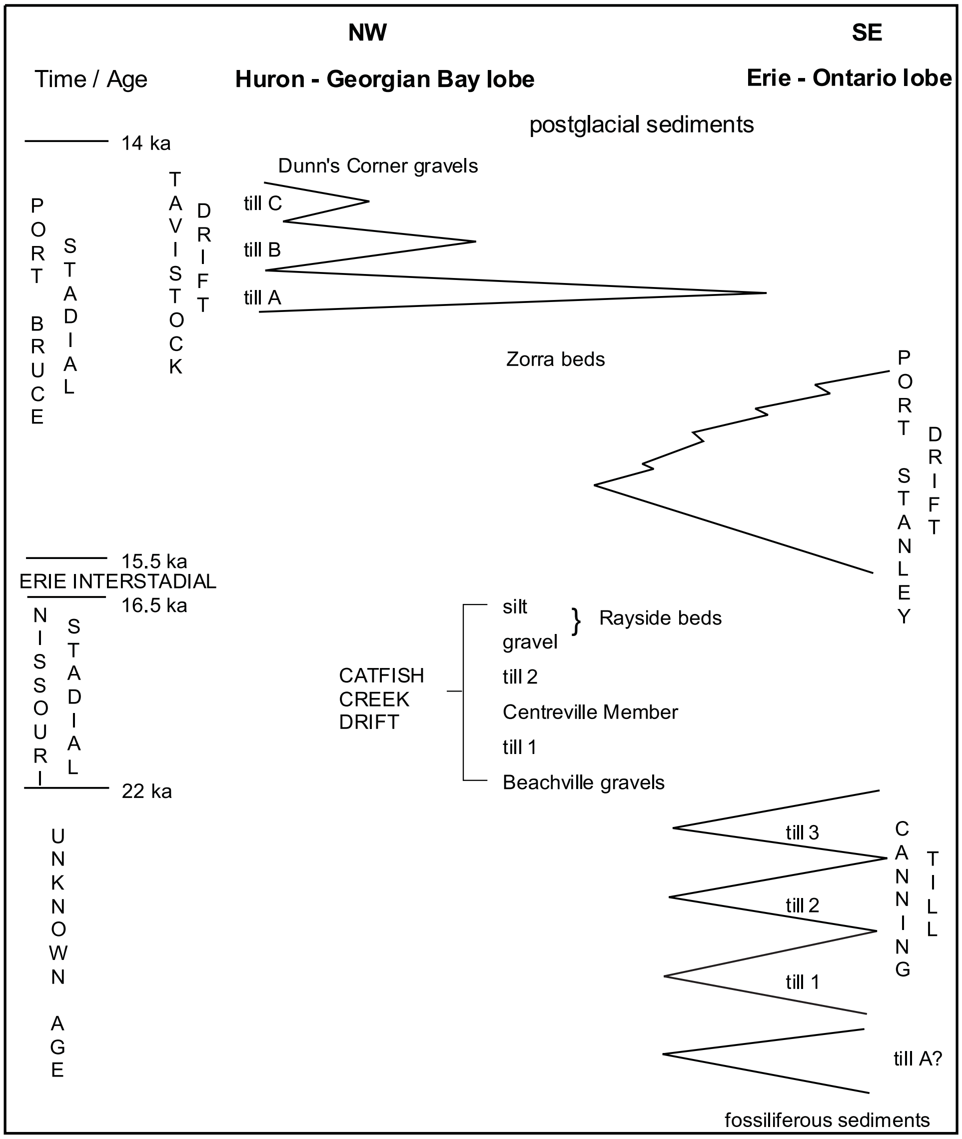

FIGURE 11. Time-distance diagram (NW-SE) showing interlobal relationships between stratigraphic units in the quarry exposures of the Woodstock interlobate area.

Diagramme spatio-temporel (NO-SE) montrant les relations interlobaires entre les unités stratigraphiques dans les affleurements des carrières de la région interlobaire de Woodstock.

contemporaneous proximity of both lobes with bulky sediment deposition between them. Figure 11 shows in a time-distance diagram the interlobal history in the Woodstock-Ingersoll area.

The Centreville Member and associated termination of thick Catfish Creek Till 1 may represent the formation of a Catfish Creek end moraine oriented northwest-southeast at the margin of southwesterly flowing ice. If so, the resulting landform was subsequently truncated and is not evident at the surface today. The younger Port Stanley and Tavistock tills did not form marginal moraines at their limits.

Which glacial style is the more common for interlobate zones? Is the passive overlap of the Woodstock area more typical, or is the Oak Ridges setting, with competing and interacting lobes more common? Perhaps the Waterloo moraine marks a major local glaciofluvial outflow along the trend of the Dundas buried valley from the Ontario basin and was interlobate between Ontario and Erie lobe ice.

As Westgate and Dreimanis (1967, p. 1135) remarked: "no vertical section at any one locality along the quarry face contains all the rock units described above. Lateral changes in the sedimentary sequence are abrupt and common. (...) This phenomenon ... shows how incomplete our understanding must be of the glacial history of areas with limited exposures". Our work further supports their comment, and further illuminates the generally unknown subsurface.

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REFERENCES

ASTM, 1996. Standard test method for particle-size analysis of soils, p. 10-16. *In* American Society for Testing Materials D422-63, 1996 Annual Book of Standards, 04-04, West Conshohochen PA, 962 p.

Barnett, P.J., 1992. Quaternary Geology of Ontario, p. 1011-1088. *In* Ontario Geological Survey Special Volume 4, 2 Parts, Toronto, 1525 p.

Barnett, P.J., Sharpe, D.R., Russell, H.A.J., Brennand, T.A., Gorrell, G., Kenny, E. and Pugin, A., 1998. On the origin of the Oak Ridges Moraine. Canadian Journal of Earth Sciences, 35: 1152-1167.

Chapman, L.J. and Putnam, D.F., 1951. The Physiography of Southern Ontario. University of Toronto Press, 284 p.

Cowan, W.R., 1975. Quaternary geology of the Woodstock area, southern Ontario. Ontario Division of Mines, Geological Report 119, Toronto, 91 p.

____ 1978. Trend surface analysis of major late Wisconsinan till sheets, Brantford-Woodstock area, southern Ontario. Canadian. Journal of Earth Sciences, 15: 1025-1036.

deVries, H. and Dreimanis, A., 1960. Finite radiocarbon dates of the Port Talbot interstadial deposits in southern Ontario. Science, 131: 1738-1739.

Dilabio, R.N.W., 1971. An Early(?) Wisconsin till from Beachville, southwestern Ontario. M.Sc. thesis, Carleton University, Ottawa, 49 p.

Dreimanis, A., 1958. Wisconsin stratigraphy at Port Talbot on the north shore of Lake Erie, Ontario. Ohio Journal of Science, 58: 65-84.

____ 1961. Tills of southern Ontario, p. 80-96. *In* R.F. Legget, ed., Soils in Canada. Royal Society of Canada Special Publications. 3, University of Toronto Press, 229 p.

____ 1962. Quantitative gasometric determination of calcite and dolomite using Chittick apparatus. Journal of Sedimentary Petrology, 32: 520-529.

____ 1982. Two origins of stratified Catfish Creek Till at Plum Point, Ontario, Canada. Boreas, 11: 173-180.

____ 1987. The Port Talbot interstadial site, southwestern Ontario, p. 345-348. *In* Geological Society of America Centennial Field Guide - Northeastern Section. Boulder, 481 p.

____ 1992. Early Wisconsinan in the north-central part of the Lake Erie basin: A new interpretation, p. 109-118. *In* P.U. Clark and P.D. Lea, eds., The Last Interglacial-Glacial Transition in North America. Geological Society of America, Special Paper 270, Boulder, 317 p.

Dreimanis, A. and Karrow, P.F., 1972. Glacial history of the Great Lakes-St. Lawrence region, the classification of the Wisconsin(an) Stage, and its correlatives, p. 5-15. *In* Section 12, 24th International Geological Congress, Geological Survey of Canada, Ottawa, 226 p.

Dreimanis, A., Terasmae, J. and McKenzie, G.D., 1966. The Port Talbot Interstade of the Wisconsin Glaciation. Canadian Journal of Earth Sciences, 3: 305-325.

Dreimanis, A., Winder, C.G. and Aaltonen, R.A., 1998. London, Ontario: Geology, geomorphology, geodata, p. 237-260. *In* P.F. Karrow and O.L. White, eds., Urban Geology of Canadian Cities. Geological Association of Canada, Special Paper 42, St. John's, Newfoundland, 500 p.

Gibbard, P., 1980. The origin of stratified Catfish Creek Till by basal melting. Boreas, 9: 71-85.

Goldthwait, R.P., Dreimanis, A., Forsyth, J.L., Karrow, P.F. and White, G.W., 1965. Pleistocene deposits of the Erie lobe, p. 85-97. *In* H.E. Wright, Jr., and D.G. Frey, eds., The Quaternary of the United States. Princeton University Press, 922 p.

Gwyn, Q.H.J. and Dreimanis, A., 1979. Heavy mineral assemblages in tills and their use in distinguishing glacial lobes in the Great Lakes region. Canadian Journal of Earth Sciences, 16: 2219-2235.

Karrow, P.F., 1963. Pleistocene geology of the Hamilton-Galt area. Ontario Department of Mines, Geological Report 16, Toronto, 68 p.

____ 1967. Pleistocene geology of the Scarborough area. Ontario Department of Mines, Geological Report 46, Toronto, 108 p.

____ 1974. Till stratigraphy in parts of southwestern Ontario. Geological Society of America Bulletin, 85: 761-768.

____ 1976. The texture, mineralogy, and petrography of North American tills, p. 83-98. *In* R.F. Legget, ed., Glacial Till. Royal Society of Canada, Special Publication. 12, Ottawa, 412 p.

____ 1984. Quaternary stratigraphy and history, Great Lakes-St. Lawrence region, p. 137-153. *In* R.J. Fulton, ed., Quaternary Stratigraphy of Canada – a Canadian contribution to IGCP Project 24. Geological Survey of Canada, Paper 84-10, Ottawa, 210 p.

____ 1988. Catfish Creek Till: An important glacial deposit in southwestern Ontario, p. 186-192. *In* 41st Canadian Geotechnical Conference Preprints, Kitchener, Ontario. Canadian Geotechnical Society, Waterloo, 405 p.

____1993. Quaternary geology of the Stratford-Conestogo area. Ontario Geological Survey, Report 283, Sudbury, 104 p.

Karrow, P.F. and Occhietti, S., 1989. Quaternary geology of the St. Lawrence Lowlands of Canada, p. 320-389. *In* R.J. Fulton, ed., Quaternary geology of Canada and Greenland. Geology of Canada No. 1, The Geology of North America, v. K-1, Geological Survey of Canada and Geological Society of America, Ottawa, 839 p.

Karrow, P.F. and Paloschi, G.V.R., 1996. The Waterloo kame-moraine revisited: New light on the origin of some Great Lakes region interlobate moraines. Zeitschrift für Geomorphologie, 40: 305-315.

Morris, T.F. and Kelly, R.I., 1997. Origin and physical and chemical characteristics of glacial overburden in Essex and Kent counties, southwestern Ontario. Canadian Journal of Earth Sciences, 34: 233-246.

Mott, R.J. and Farley-Gill, L.D., 1978. A late Quaternary pollen profile from Woodstock, Ontario. Canadian Journal of Earth Sciences, 15: 1101-1111.

Piotrowski, J.A., 1985. The Woodstock drumlin field, southern Ontario: Quaternary geology, paleogeomorphology and mechanism of formation. M.Sc. thesis, University of Waterloo, Waterloo, 165 p.

____ 1987. Genesis of the Woodstock drumlin field, southern Ontario, Canada. Boreas, 16: 249-265.

Sado, E.V., 1980. The Quaternary stratigraphy and history of the Lucan map-area, southwestern Ontario. M.Sc. thesis, University of Waterloo, Waterloo, 146 p.

Schwartz, F.W., 1968. Surficial deposits of the South Thames River valley southeast of London, Ontario. B.Sc. thesis, University of Western Ontario, London, 57 p.

Sharpe, D.R., Dyke, L.D., Hinton, M.J., Pullan, S.E., Russell, H.A.J., Brennand, T.A., Barnett, P.J. and Pugin, A., 1996. Groundwater prospects in the Oak Ridges Moraine area, southern Ontario: application of regional geological models, p. 181-190. *In* Current Research 1996-E, Geological Survey of Canada, Ottawa. 286 p.

Sigleo, W.R. and Karrow, P.F., 1977. Pollen-bearing Erie Interstadial sediments from near St. Mary's, Ontario. Canadian Journal of Earth Sciences, 14: 1888-1896.

Taylor, F.B., 1913. The moraine systems of southwestern Ontario. Transactions of the Canadian Institute, 10: 57-79.

Westgate, J.A. and Dreimanis, A., 1967. The Pleistocene sequence at Zorra, southwestern Ontario. Canadian Journal of Earth Sciences, 4: 1127-1143.