GEOLOGICAL SURVEY OF CANADA
OPEN FILE 5990

SEDIMENTOLOGY OF AGGREGATE PITS BETWEEN WATERLOO AND LONDON, SOUTHERN ONTARIO: A RECONNAISSANCE SURVEY FOR GROUNDWATER APPLICATIONS

H. A.J. Russell, D. I. Cummings, D. R. Sharpe, and A. Bajc[2]

[2] Ontario Geological Survey

2009

Natural Resources Canada Ressources naturelles Canada

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 5990

SEDIMENTOLOGY OF AGGREGATE PITS BETWEEN WATERLOO AND LONDON, SOUTHERN ONTARIO: A RECONNAISSANCE SURVEY FOR GROUNDWATER APPLICATIONS

H. A.J. Russell[1], D. I. Cummings[1], D. R. Sharpe[1], and A. Bajc[2]

2009

Available from
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

Russell, H. A.J., Cummings, D.I., Sharpe, D.R., and Bajc, A..
2009: Sedimentology Of Aggregate Pits Between Waterloo And London, Southern Ontario: A Reconnaissance Survey For Groundwater Applications; Geological Survey of Canada, Open File 5990, 70 p.

Open files are products that have not gone through the GSC formal publication process.

ABSTRACT

Thirty-three aggregate pits between Cambridge and London are documented. The pits are situated in a variety of landforms (moraines, drumlinized uplands, hummocky terrain, outwash plains), geological map units, and stratigraphic positions. Many have not been documented previously. The objective was to capture a snapshot of the general sedimentary character of as many pits as possible in a four day timeframe.

For each pit, a point form summary is provided followed by a general description and photographs that document the facies architecture of the deposits. A summary section provides a brief synthesis of the observations and highlights three key hydrogeological points that can be further understood by study of these deposits.

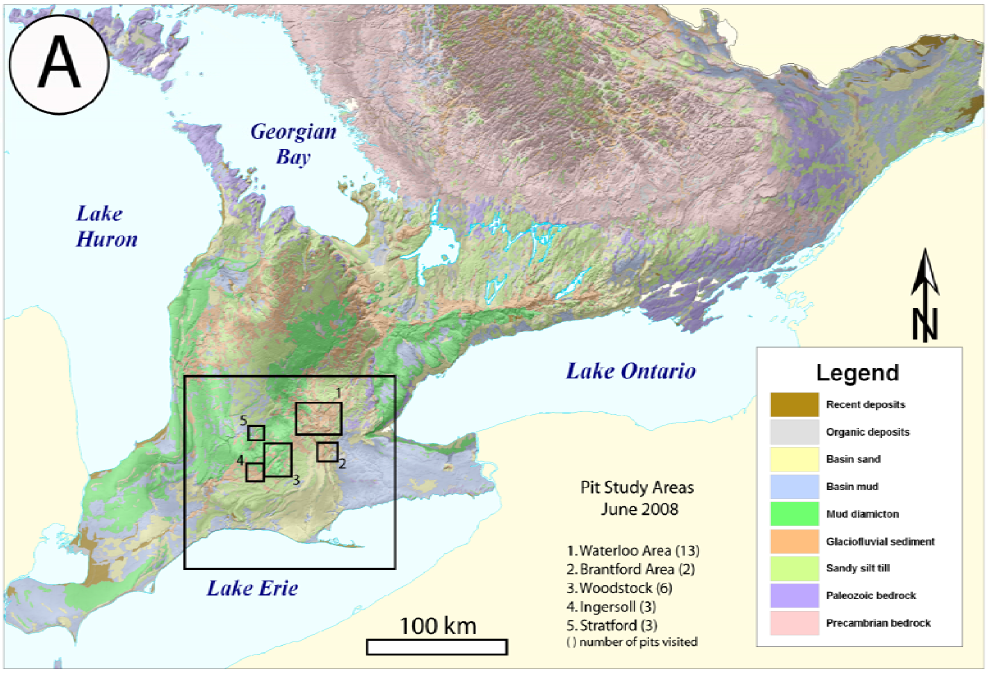
Detailed sedimentological observation in this integrated regional framework provides the opportunity to begin a re-assessment of the underlying conceptual geological models for parts of southern Ontario.

1. INTRODUCTION

The surficial sediment cover of Southern Ontario (Fig. 1) provides an important basis for socio-economic development in the area (Bocking, 2005). The heterogeneity of the sediment cover exerts a first order control on groundwater recharge, aquifer location and extent, and groundwater discharge (e.g. Sharpe et al., 2002). The deposits influence agricultural practices in the area (e.g. Holland Marsh) and are highly sought after for aggregate extraction. As the population expands, agriculture evolves toward higher intensity practices, and the demand for aggregate increases, there is a need to better understand the geology of the surficial sediment cover in three-dimensions (e.g. Hunter, 1996). Since the Walkerton drinking-water tragedy in 2000 (O'Conner, 2002), the Ontario Geological Survey has started to collect data to develop such an understanding (Bajc and Shirota 2007; Russell et al., 2007; Burt, 2007). Detailed stratigraphic studies achieved by continuous coring of the Quaternary cover followed by the construction of a fully attributed 3-dimensional block model are the main components of this work. Drill cores provide exceptional detail of the subsurface sediment column, but only in one dimension (e.g., Burt, 2007). Outcrop studies provide an improved understanding of the architecture of deposits intercepted in drillcore. Furthermore, outcrop studies provide high resolution data on strata that are commonly analogous, and often correlative with, aquifers and aquitards in the subsurface.

Objectives

This outcrop study documents the character and context of sand and gravel deposits in 33 aggregate pits located between Cambridge and London and visited between 2004-2008 (Fig. 1). These data are integrated into the regional stratigraphic, landform, and surficial geology framework. Detailed sedimentological observation in this regional framework contributes to a re-assessment of the underlying conceptual geological models for this part of southern Ontario.



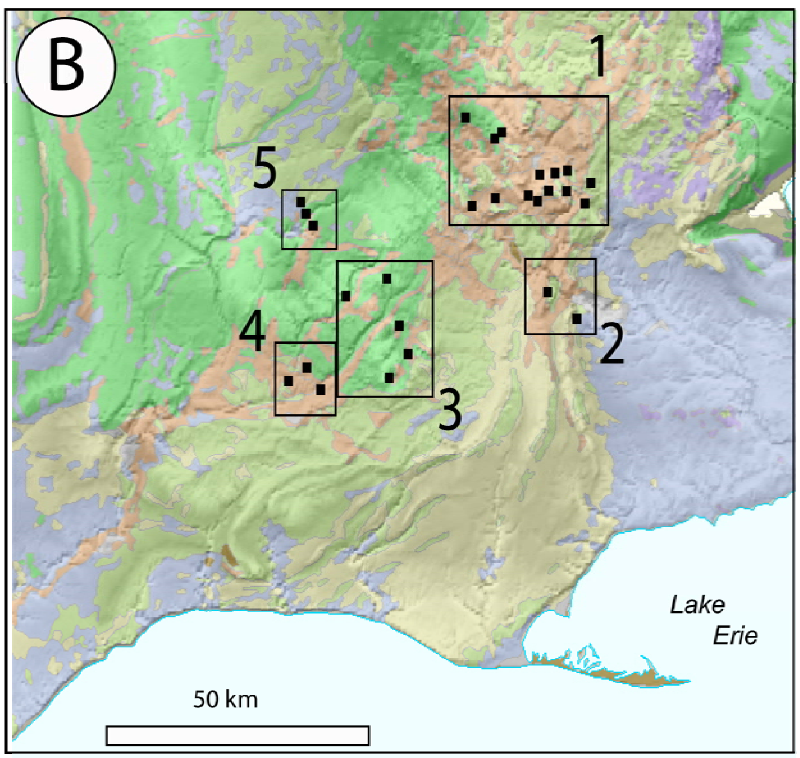


Figure **1**. Simplified geology draped on a DEM of Southern Ontario (modified from Barnett et al 1991) and location of five general study areas. B) Location of pits within respective areas. Geological legend for B) is the same as in A).

1.1. Geological Setting

Southern Ontario is covered, almost completely, by surficial sediment (e.g. Barnett, 1992). Bedrock crops out along escarpments, the largest being the Niagara Escarpment, and in river valleys. Surficial deposits extend back to lllinoian age (perhaps older), with Lake Ontario bluffs forming the type section for much of the pre-Nissouri Phase (formerly Late-Wisconsinan) stratigraphy (Coleman, 1932; Karrow, 1974). Older deposits are also exposed in the Lake Erie Bluffs and at isolated locations elsewhere (e.g. Innerkip, Cowan, 1975; Zorra Quarry, Bajc 2007). Most of the surficial deposits are attributed to the Port Bruce Phase and consist of till and lacustrine units. These deposits have been the focus of most previous studies (Karrow, 1974; Piotrowski, 1987; Barnett, 1985). Glacifluvial deposits are aerially less extensive, occurring in corridors dominated by sand and gravel and in stratified moraines, which form a subparallel network of ridges around the margin of the Niagara cuesta (Fig. 1b). Moraines in the Cambridge area are commonly fronted by expansive glacifluvial spillway deposits and diamicton units within the moraines are commonly underlain by meltwater gravel (Table 1). A summary of the Quaternary stratigraphy in the Woodstock area highlights the problems involved in correlating glacifluvial and till deposits in the area (Table 1).

1.1.1. Till Units

Four till units have been mapped (Table 2) between Cambridge and London (oldest to youngest), Catfish Creek, Port Stanley, Tavistock, and Wentworth tills (Karrow, 1973; Ontario Geological Survey, 2003). Inliers of Catfish Creek Till occur in the south west part of the area, west and north of Ingersoll. Port Stanley Till occurs south and east of the Highway 401 between London and Ayr in a westward facing crescent. Tavistock Till (formerly Zorra Till, Cowan, 1975) occurs north and west of the Highway 401 and onlaps onto the flanks of the Waterloo Moraine to the north. Cowan (1975) noted the difficulty of distinguishing the Tavistock Till from underlying Catfish Creek Till in the Woodstock area and suggested that, substantial inliers of Catfish Creek Till may be present in areas previously mapped as Tavistock Till. Bajc (2008) also noted similar widespread occurrences of Catfish Creek Till within areas previously mapped as Tavistock Till. This stratigraphic confusion means that it is difficult to correlate gravels observed beneath tills in this area. In the area of aggregate pits visited for this study, Wentworth Till is restricted to areas of the Paris and Galt moraines.

1.1.2. Moraines

Moraines were first mapped in the area by Taylor (1913) and then classified as either till moraines or kame moraines (Chapman and Putnam, 1943). Taylor identified the moraines based on the inferred ice lobes related to the respective Great Lake: Huron, Erie, and Ontario, and adjacent water bodies Georgian Bay–Lake Simcoe. Geological knowledge of many of these moraines is limited to surficial geological mapping at a 1:50,000 scale (e.g. Karrow, 1993; Cowan, 1975; Ontario Geological Survey, 2003) and observations made as part of 3-dimensional mapping studies within the region (Bajc and Shirota 2007 and Bajc 2008).

Table 1. Stratigraphy of the Brantford-Woodstock area. Stratigraphic equivalence between Erie and Huron lobes is not inferred by the parallel arrangement of the table (Age terminology from Karrow et al., 2000).

Age	**Erie Lobe**		**Huron Lobe**	
	Deposit	**Texture**	**Deposit**	**Texture**
	Older alluvium	Sand and gravel	Older alluvium	Sand and gravel
Michigan Subepisode (Late Wisconsin)	Lake Whittlesey	Sand and mud	Lake Whittlesey	Sand and mud
	Glacial ponds	Silt and fine sand	Glacial ponds	Silt and fine sand
	Glacifluvial sediment	Gravel and sand	Glacifluvial sediment	Gravel and sand
	Port Stanley Till	Clayey silt to sandy silttill	**Tavistock Till**	Clayey silt to sandy silt till
	Glacilacustrine sediment	Sand and mud	Glacilacustrine sediment	Sand and mud
	Glacifluvial sediment	Gravel and sand	Glacifluvial sediment	Gravel and sand
	Erie/Huron -Northern Source-Erie/Huron			
	Catfish Creek Till	Silty sand to clayey silt till	**Catfish Creek Till**	Silty sand to clayey silt till
	Glacifluvial sediment	Gravel and sand	Glacifluvial sediment	Gravel and sand
	Glacilacustrine sediment	Sand, silt, clay	Glacilacustrine sediment	Sand, silt, clay
Elgin Subepisode/ Ontario Subepisode/ Sangamon Episode	Alluvial and pond deposit	Sand, gravel, organic mud	Alluvial and pond deposit	Sand, gravel, organic mud
Ontario Subepisode/ Illinois Episode	**Canning Till**	Silty clay to sandy silt till		

Waterloo Moraine: The Waterloo Moraine is a prominent topographic feature with an elevation range from 330 to 420 m asl., and relief of ~ 50 m (Fig. 2). Deposits of the moraine overlie Catfish Creek Till (Fig. 3, Bajc and Karrow, 2004) and consist of a main southeast–northwest trending ridge with a number of associated ridges that are radial to the main moraine (e.g. Crosshill, Hawkesville; Karrow, 1993). The moraine consists of sand with lesser gravel, and minor amounts of muddy diamicton and associated fine-textured glacilacustrine deposits (Bajc and Karrow, 2004). The diamicton has been correlated on the basis of matrix texture, clast lithology and matrix chemistry with the upper, middle and lower Maryhill, Tavistock, Mornington and Port Stanley tills

(Karrow, 1993). Bajc and Karrow (2004) suggest that the Tavistock and Mornington tills are correlative and be referred to as the Tavistock Till, and similarly that the Maryhill and Port Stanley tills are correlative and should be referred to as the Port Stanley Till.

Table 2. Key till units in the study area (modified from Karrow, 1974; Cowan, 1975; Barnett, 1991).

Till Name	Texture	Thick-ness	Landform associations	Depositional lobe (Karrow (1973)
Wentworth	Sandy; $CaCO_3$ 30-40%; 7-10%?		Paris and Galt moraines	Ontario
Tavistock	Clayey silt to Sandy silt; $CaCO_3$ ~40 %; clast content 5-10%	< 12 m	Woodstock drumlins?	Huron
Port Stanley	Sandy silt to silty clay; $CaCO_3$ 30-40 %; clast content < 2%	< 25 m usually 2-10 m	Guelph drumlins and Ingersoll, St. Thomas, Norwich and Tillsonburg moraines	Erie / Ontario
Catfish Creek	Stoney, sandy silt to clayey silt; $CaCO_3$ 35-60 %; clast content 10-25%	up to 30-40 m	Generally not exposed (Woodstock drumlin field?)	Huron, Georgian Bay, Erie

On the basis of terrain mapping and till stratigraphy, the Waterloo Moraine has been interpreted as an interlobate moraine deposited between converging flow of the Georgian Bay–Lake Huron ice lobes from the north and west, Lake Ontario lobe from the east, and the Lake Erie lobe from the south (Karrow, 1973; Chapman and Putnam, 1984). In this deglacial model a proposed interlobate re-entrant is attributed to climatic warming (Karrow, 1974; Karrow. and Paloschi, 1996). On the basis of surficial geological mapping and sedimentary facies analysis, the moraine has been interpreted to consist of esker, subaqueous fan and deltaic deposits, of episodic high-energy meltwater events (see references in Russell et al., 2007).

Paris and Galt moraines: The Paris and Galt moraines were first identified by Taylor (1913), who described the Paris Moraine as

"…one of the best known moraines in Ontario, having been traced with substantial continuity from the shore of Lake Erie southwest of Port Rowan to the brow of the (Niagara) escarpment south of Collingwood, where it is found to be the same as the Seaforth moraine of the Lake Huron slope".

Subsequently, Chapman and Putnam (1985) suggested that the Paris Moraine terminates at Caledon Village. South of Paris, the moraine has a subdued topography within a large paleolake basin (Taylor, 1913). North of Paris, it is well defined and clearly identified on digital elevation models of the area (Fig. 2). The Galt moraine is located just east of the Paris Moraine and generally trends parallel to it. Locally, the two are virtually indistinguishable (Taylor, 1913). In the Guelph–Cambridge area, the two moraines are amalgamated, forming an irregular tract of hummocky terrain ~ 10 km in width and with local relief of ~ 30 m (Bajc and Karrow, 2004; Sadura et al., 2006) whereas south of Brantford, in the Erie Basin, the two moraines diverge and become separated by up to 15 kms. Unlike the Paris Moraine, the southern section of the Galt Moraine extends to the Lake Erie bluffs with a strong topographic expression. The northern section of the moraine consists of a mixture of diamicton and stratified deposits; whereas the southern section of the moraine consists primarily of stratified deposits with a thin diamicton cap. Detrital plant remains transported along the Galt ice margin into a high level Erie basin lake have been radiocarbon dated at 13.4 ka BP and provide a maximum age for the feature (Barnett, 1985). The moraines have been interpreted as recessional moraines prior to ice retreat into the respective basins (Chapman and Putnam, 1985).

1.1.3. Glacifluvial Outwash

Glacifluvial sand and gravel forms large mounds, thin, aerially extensive deposits, valley terraces, and elevated flat-topped sediment bodies (Taylor, 1913; Chapman and Putnam 1985; Cowan, 1975). Beyond the Paris ice margin at Cambridge, is a ~ 100 km^2 dissected area mapped as a complex of outwash gravel, ice-contact stratified sediment, and till (Karrow 1987). Thick gravel deposits occur beneath Tavistock or Catfish Creek till uplands in the vicinity of Woodstock, identified as the Woodstock Moraine (Piotrowski 1987, Krzyszkowski and Karrow, 2001, Bajc 2008). In the vicinity of Washington, a lower relief area appears to have a common connection with outwash gravels to the south near Stratford and Woodstock (Ontario Geological Survey, 2003). In the vicinity of meltwater channels, two distinctly different gravel deposits occur. Along the margins of steep-walled, linear channels north of Woodstock, extensive marginal gravel deposits are mapped by Cowan (1975) as outwash gravel. Older deposits of sand and gravel may extend beneath surface tills as well (Krzyszkowski. and Karrow, 2001). In the vicinity of the Grand River between Cambridge and Paris, higher gravel deposits are mapped beyond the modern valley and other gravel is mapped as valley terraces (Ontario Geological Survey, 2002). Elsewhere in the area, gravel is mapped below Catfish CreekTill, which means the deposits predate the last glacial maximum (Bajc and Karrow, 2004; see stops 1.5, 2.3)

2. PITS

Thirty-three pits are presented in this report with summary comments and illustrative photograph documentation (Fig. 1). Nineteen are in areas mapped as ice-contact stratified drift, eleven are in areas mapped as subaerial outwash, and three are areas mapped as till.

Information for each site is presented with the following format.
Location:
OGS map reference:
Landform:
Map unit:
Stratigraphic position:
Sediment exposed:
Paleoflows:
Horizontal grain-size trend:
Vertical grain-size trend:
Depositional environment:
Aquifer potential:

This overview is followed by a general comment on the site. Stratigraphic architecture and sediment facies are illustrated with a few photographs. General paleoflow measurements are provided for each site without correction for declination. Each of the sites also has a site map indicating the location of the observed faces (Appendix A) The table in Appendix B contains location and elevation information in NAD 83, UTM zone 17..

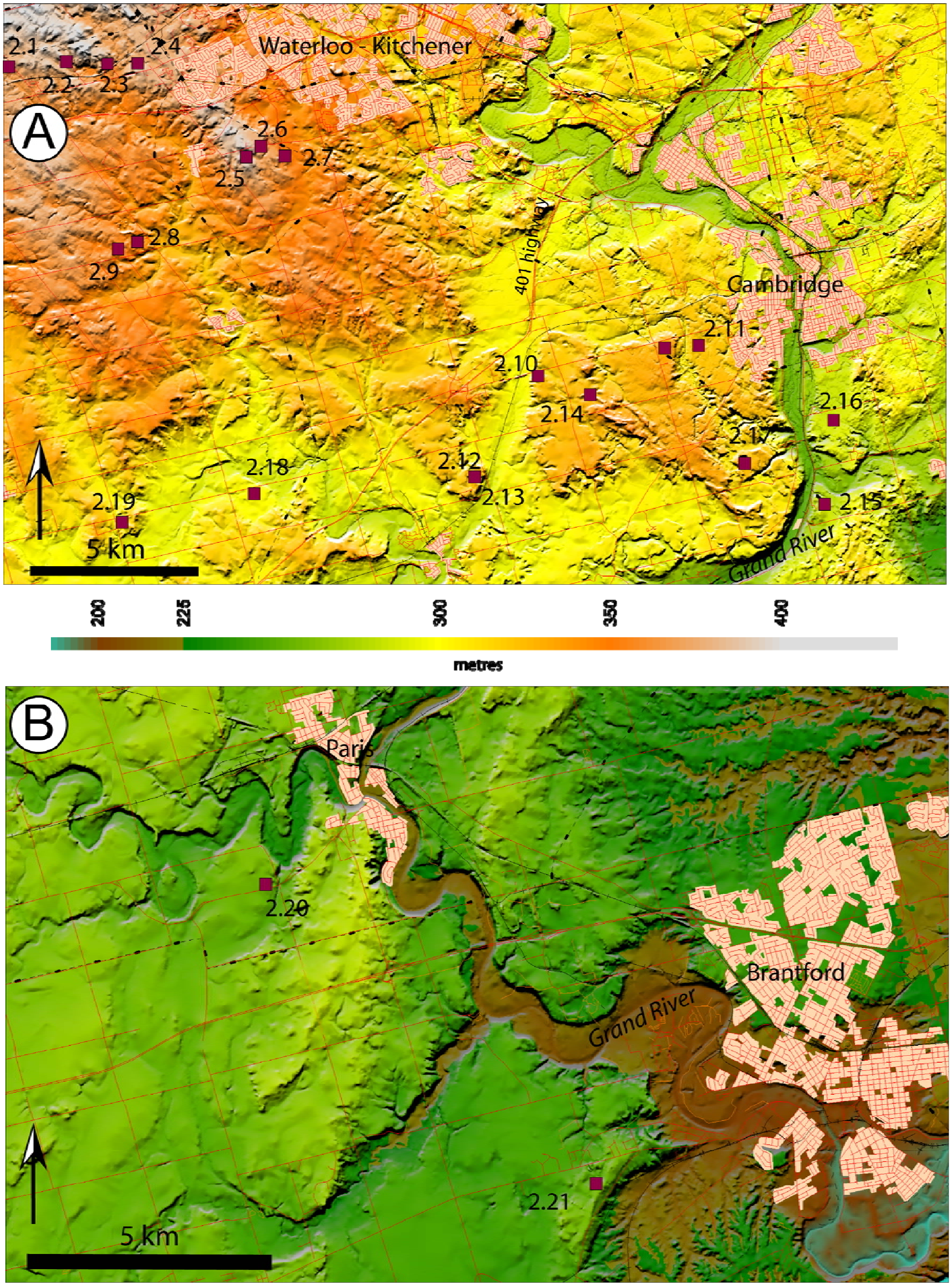


Figure 2. Close-up DEM and site locations. A) Pits in the Waterloo–Cambridge area. B) Pits in subaerial outwash and Paris–Galt moraines near Brantford. Red lines are roads. Elevation scale is in metres above sea level.

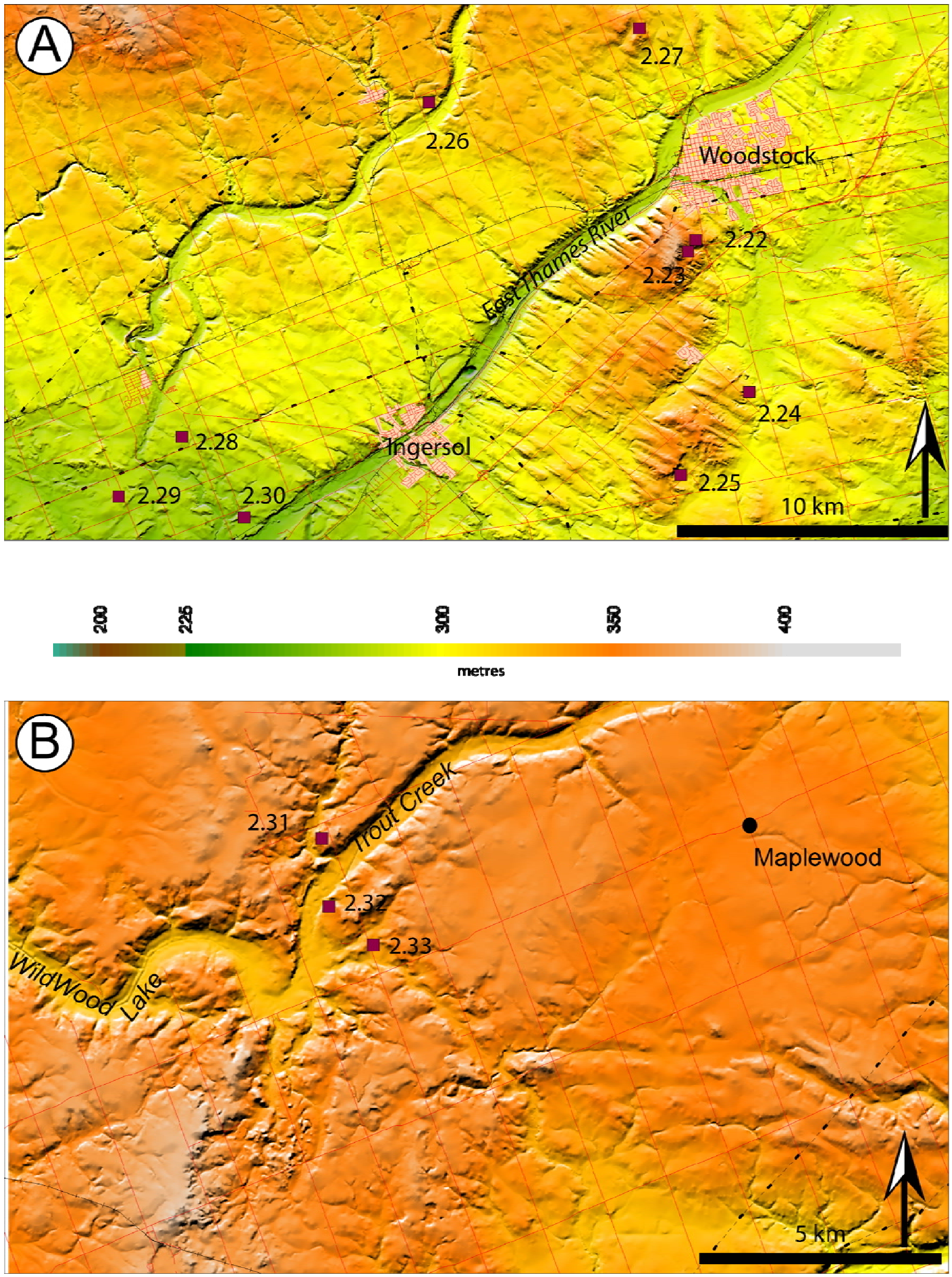


Figure 3. Close-up DEM and site locations. A) Pits in the area of Woodstock–Ingersoll. Note the linear meltwater channels occupied by modern underfit streams (Cowan, 1975). B) Pits near Trout Creek. Red lines are roads. Elevation scale is in metres above sea level.

2.1. NOTRE DAME ROAD PIT

Location: Waterloo – Kitchener
OGS map reference: Karrow (1993)
Landform: Waterloo Moraine, hummocky to rolling terrain
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Dune-scale cross stratified medium sand
Paleoflows: Generally westward
Horizontal grain-size trend: None observed locally capped by fine-grained diamicton and glaciolacustrine muds
Vertical grain-size trend: Upward fining
Depositional environment: Subaqueous fan environment ?
Aquifer potential: Moderate to good

General comments: Exposed strata consist of horizontal stratified and dune cross-stratified pebble-cobble gravel and coarse sand (Fig. 4). During a 2006 visit working sections were restricted to the north end of the pit. Of particular note are large foresets exposed in the most northern wall of the pit with a general westward dip direction (Fig. 5).

Figure 4. Succession of cross-stratified coarse sand overlain by cross-stratified gravel.

Figure 5. Photograph mosaic of large westward dipping foresets at the north end of the Notre Dame Road pit. Note one metre scale stick in lower right.

2.2. *TOP OF THE HILL PIT*

Location: Waterloo – Kitchener
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Waterloo Moraine, hummocky to rolling terrain
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Dune-scale cross stratified medium sand; ripple-scale cross-laminated fine sand; coarse sand; pebble gravel; mud.
Paleoflows: 270° to 320° (no declination correction)
Horizontal grain-size trend: Downflow fining over hundreds of metres
Vertical grain-size trend: Upward fining, overlain by mud
Depositional environment: Subaqueous environment; unidirectional flows
Aquifer potential: Moderate to good

General comments: Top-of-the-Hill pit is a spectacular 600 by 200 m southeast–northwest orientated oblong excavation into an area of hummocky terrain within the Waterloo Moraine. The pit stratigraphy has been described by Russell et al. (2007) and by Bajc and Karrow (2004). The site is interpreted to be an outstanding example of the depositional transitions in a region of flow expansion. There is a very pronounced downflow fining accompanied by an upward fining trend. A range of architectural elements are observed, including transverse bar forms (possibly a conduit mouth feature) and steep-walled scours (Russell et al., 2007). Evidence of subcritical flow include ripples and dune-scale cross-stratification, whereas low-angle, wavy stratification and diffusely graded scour fills suggest supercritical flow. Large (metre scale) ball and pillow and flame structures are present locally.

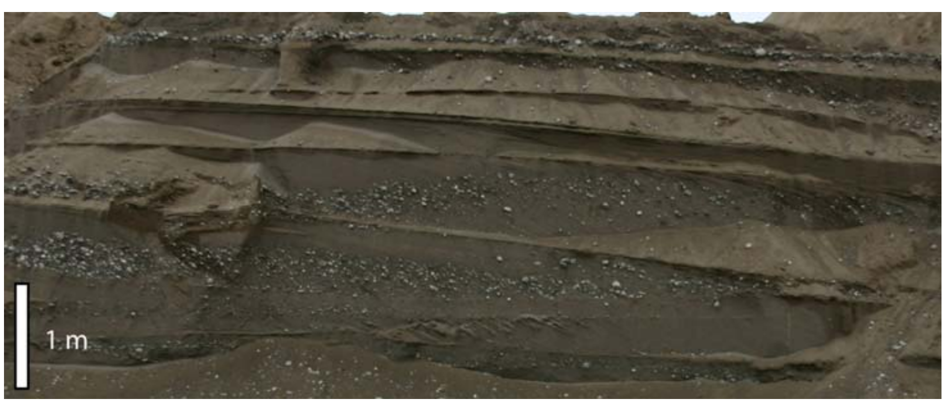


Figure 6. Succession of climbing pebbly sand dunes. The upward fining beds suggest diminishing flow strength, position of gravel on foreset, and variable truncation of preserved topset beds suggest variable flow strength and suspended sediment flux. Also of note is the variable dip angle of the foreset bed.

2.3. HIGHLAND AGGREGATES PIT

Location: Waterloo–Kitchener
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Waterloo Moraine, hummocky to rolling terrain
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Dune-scale cross stratified medium sand; ripple-scale cross-laminated fine sand, coarse sand; pebble gravel; mud.
Paleoflows: Generally westward
Horizontal grain-size trend: None observed
Vertical grain-size trend: Upward fining, overlain by up to 8 m of mud and fine-textured diamicton
Depositional environment: subglacial conduit
Aquifer potential: Good to excellent

General comments: The Highland Aggregates site consists of two separate pits that have completely different grain-size character. The main pit at the northwest end of the property consists of gravel buried beneath an upward fining succession of sand and mud (Fig. 7). The second pit on the southwest side of the property consists entirely of fine to coarse sand.

Gravel in the main pit exhibits several different types of cross-stratification (Fig. 7). Thin, simple cross-bed sets (10s of cm thick) are interpreted to have been deposited by dunes. Thick, composite cross-bed sets (several meters thick) that locally contain smaller dune-scale cross-stratified beds with a similar paleoflow are interpreted to be barform deposits. Pebbles and small cobbles are predominant, although boulders are also present locally.

Sediment in the sand-dominated pit is generally poorly exposed. It consists of ripple- to dune-scale cross-stratified fine to coarse sand with minor amounts of pebbles, often concentrated along scour contacts. The largest cross-strata observed in the pit are 2–3 m high and have reverse-flow, ripple-scale, cross-sets in their toeset (Fig. 8).

Figure 7. Large, relatively low-angle cross-stratified gravel with a generally westward dip direction (interpretation: barform deposit c.f. Todd, 1996).

Figure 8. Thick cross-stratified bed with reverse-flow ripples in the toeset. Note the increased concentration of gravel in the lower part of the cross-set.

2.4. A-1 AGGREGATES PIT

Location: Waterloo–Kitchener
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Waterloo Moraine, hummocky to rolling terrain
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Dune-scale cross stratified medium sand; ripple-scale cross-laminated fine sand; coarse sand; pebble gravel; mud.
Paleoflows: Generally northwest
Horizontal grain-size trend: None observed
Vertical grain-size trend: Upward fining, overlain by mud
Depositional environment: Subglacial
Aquifer potential: Good to excellent

General comments: The A-1 pit has a stratigraphy similar to the Highland pit (2.3), but with slightly more sand near the surface. The exposed pit stratigraphy from 2004 is described in Russell et al (2006, 2007). Gravel facies include openwork pebble gravel, bimodal medium sand and cobbles, and poorly sorted pebble and cobble gravel (Figs. 9, 10). Gravel is organized into cross-sets attributed to dunes and barforms (see Russell et al., 2007). Sand overlying the gravel contains high-angle and low-angle cross-stratification interpreted to have been deposited by subcritical and supercritical flows, respectively.

Figure 9. Transverse-to-flow section ~ 200 m long and 6 m high. Gravel coarsens upward from thin beds of horizontal openwork gravel and poorly sorted gravel to thicker beds of cross-stratified openwork gravel, bimodal gravel, and poorly sorted gravel. Note the remnant of sand that remains from benching of the pit face.

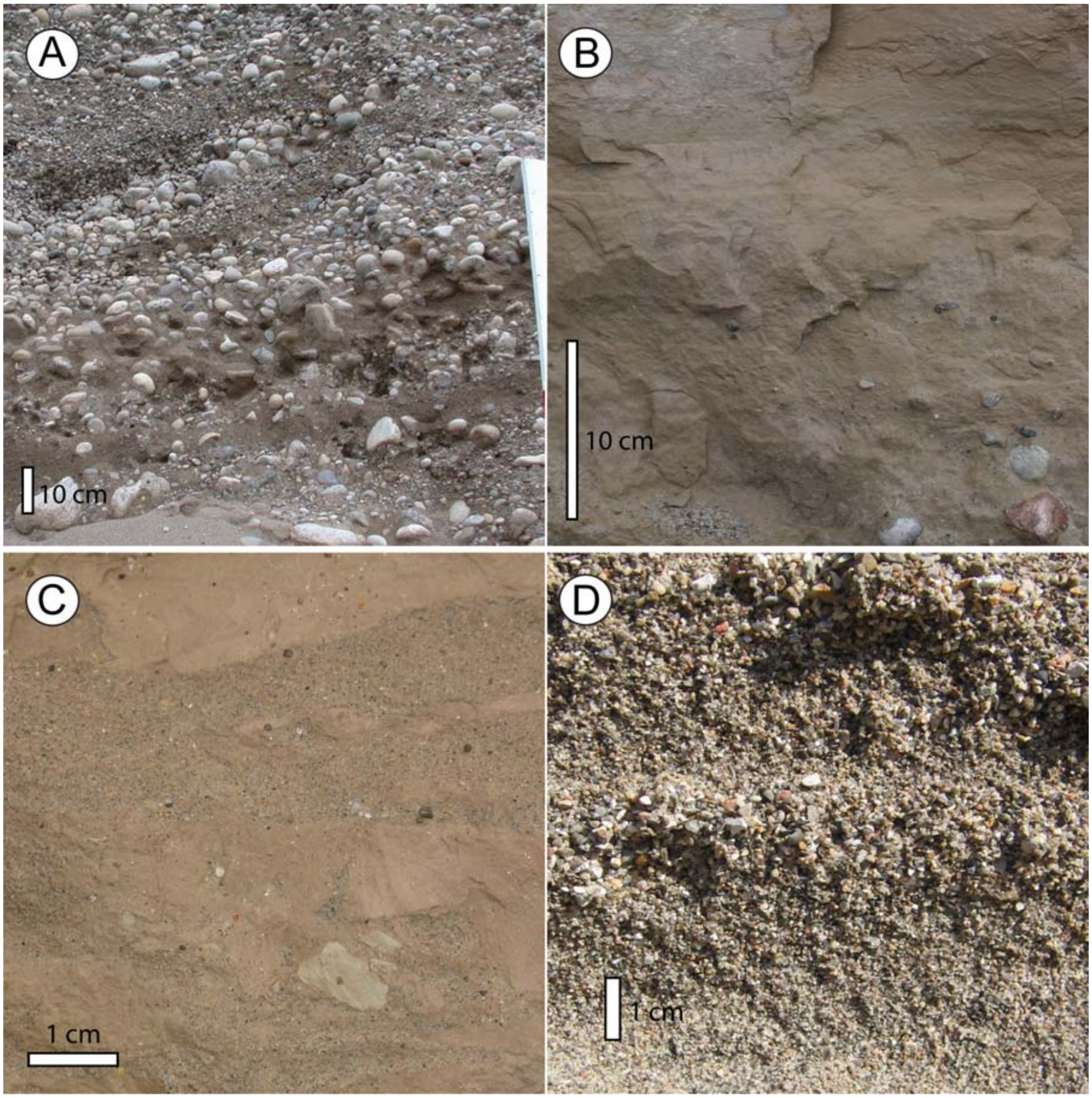


Figure 10. Characteristic images of sediment exposed in A-1 pit. A) Bimodal matrix-supported cobble gravel fining upward to bimodal framework-supported gravel in gravel foresets. B) Massive, faintly laminated mud with pebbles that grade upward to laminated mud. C) Mud and sand facies with intraclasts of mud. D) Dune –scale cross-stratified coarse sand. Note inclined laminae coarsen up-dip. Paleoflow direction is from right to left.

.

2.5. ADAMS AGGREGATE PIT

Location: Manheim**,** Waterloo–Kitchener
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Waterloo Moraine
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Cross stratified medium sand; ripple scale cross-laminated fine sand; coarse sand; pebble gravel; mud.
Paleoflows: Northwest
Horizontal grain-size trend: Downflow fining over hundreds of metres
Vertical grain-size trend: Upward fining, overlain by mud and silty to sandy diamicton
Depositional environment: Subaqueous environment
Aquifer potential: Moderate to good

General comments: The Adams pit is a relatively large pit that is for the most part worked out. Intermittent, small scale excavation continues, however, and provides local insight into the sedimentology of the moraine (Figs. 11, 12). The deposit appears to coarsen upward and it also fines westward toward Trussler Road. This westward fining corresponds with the downward slope of the ridge that Keiswetter and Adams pits are excavated into, which also hosts the Manheim water treatment facility approximately 500 metres to the north. The lowest flanking parts of the deposit are also the finest, and consist of mud and muddy diamicton near the surface and medium sand at depth (Fig. 12). The sand is commonly ripple- and dune-scale cross-stratified and is locally diffusely graded. Overlying this where the terrain is higher is a pebble to cobble gravel that fines upward (Fig. 11).

Figure 11. Gravel-rich face from top of succession exposed in the Adams pit showing various styles of cross-stratification, basal scouring, and channel fills. Pit face is 5–6 m high.

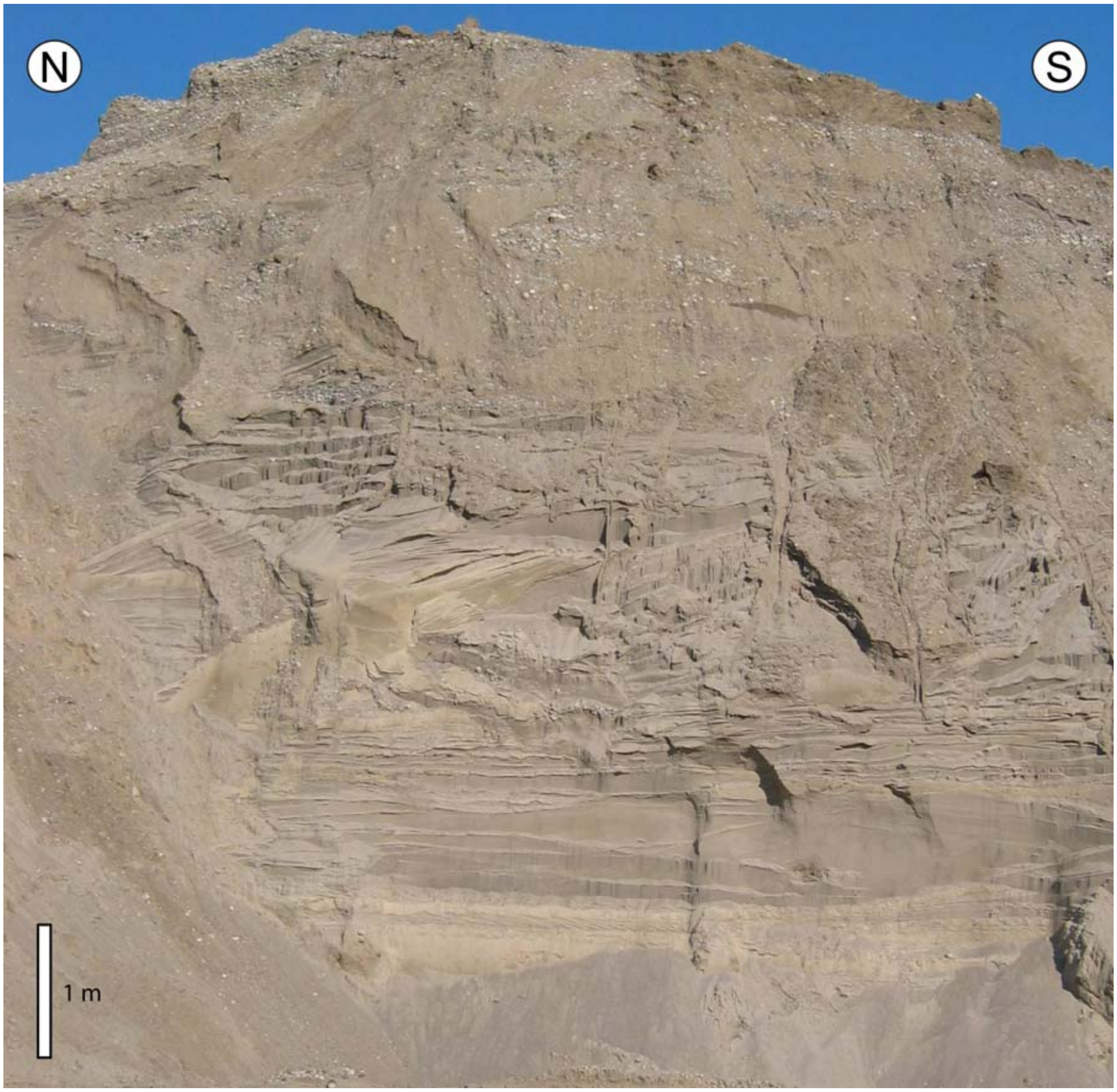


Figure 12. Section from low in the Adams aggregate pit showing underlying dune-scale cross-stratified sand and diffusely graded sand overlain by partially obscured gravel.

2.6. KEISWETTER PIT

Location:, Manheim**,** Waterloo–Kitchener
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Waterloo Moraine
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Dune-scale cross stratified medium sand; ripple scale cross-laminated fine sand; coarse sand; pebble gravel; mud.
Paleoflows: ~northwestward
Horizontal grain-size trend: Downflow fining over hundreds of metres
Vertical grain-size trend: Upward coarsening, but overlain by mud
Depositional environment: Subaqueous environment
Aquifer potential: Moderate to good

General comments: From the front gate this pit extends 750 metres to the southwest and consists of a series of inactive and active amphitheatre-shaped smaller pits. The southwestern part of the pit, predominantly sand in 2008, is the focus of MSc thesis at the University of Waterloo. The front part of the pit northwest of the entrance and close to the road is now worked out, but was photographed and examined briefly in 2004. It consisted of interbedded sand and gravel with a number of dewatering features and faults. The sand and gravel was horizontally laminated and dune-scale cross stratified (Fig. 13).

A lower bench cut into the southern part of the site exposed approximately 3 m of channelized pebbly sands and fine to medium sand with broad, shallow scours trending to the northwest. This unit erosively overlies approximately 3 m of planar and ripple laminated silty fine to very fine sand units, each 1.5 m thick and capped by 10 cm thick units of clay. The clay layers are continuous and extend laterally for at least 100 m.

Figure 13. Photographic mosaic of the northwest corner of the Keiswetter pit adjacent to Bleams Road. Photos taken in 2004.

2.7. PRESTON PIT

Location: Manheim**,** Waterloo–Kitchener
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Waterloo Moraine
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Sequence of fine–medium sand and - gravel -.
Paleoflows: west and northwest
Horizontal grain-size trend: Northward fining trend
Vertical grain-size trend: Upward coarsening, abruptly overlain locally by mud at surface
Depositional environment: Glacifluvial
Aquifer potential: Moderate to good

General comments: The Preston pit is excavated into the eastern flank of the Manheim ridge and is ~ 350 m wide by 500 m long. The western wall of the pit is the highest (> 6 m) and tapers eastward to a height of 1–2 metres. The pit is locally overlain by muddy sediment. A general south to north fining trend is observed. Beneath the mud surface cover strata locally coarsen upward (Fig. 14, 15). Since 2004 the pit has been relatively inactive and fresh exposure has been intermittent and difficult to map out. Data from 2004 and 2006 suggest that a switch in depositional setting occurred over the course of deposition of the pit strata. Lower deposits are sand dominated (Fig. 14, 15) overlain by gravel. In places the gravel sharply overlies the sand, whereas in others the contact is gradational.

In 2002, up to 2 m of fine-textured diamicton and glaciolacustrine deposits were observed to overlie 7 m of cobble to small boulder gravel containing broad, shallow channel scours trending towards the west and northwest. These gravels are cut into planar and trough cross-bedded sands indicating flow to the northwest as well. Exposures on the southeast corner of the license contain a similar sequence although the lower sands were finer-textured, ripple-laminated and contained faulting, contorted beds and dewatering structures reminiscent of subaquatic fan deposition.

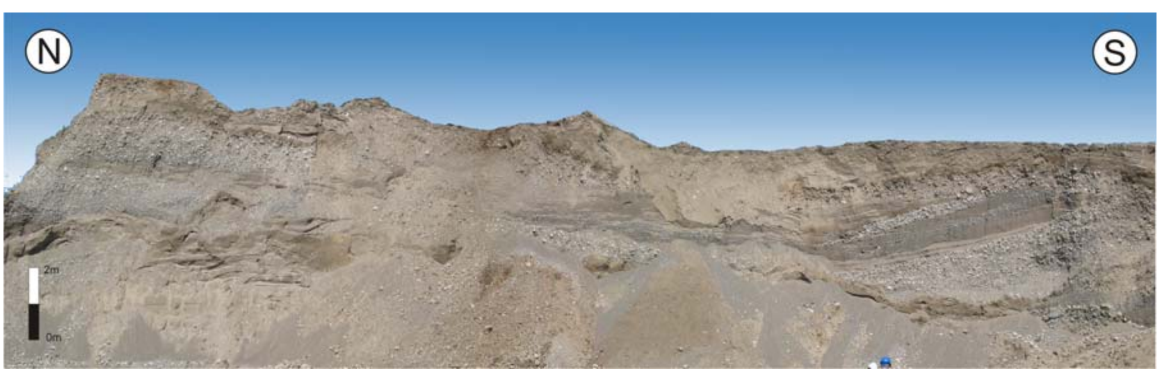


Figure 14. Face exposed in summer of 2004 in southeastern corner of the Preston pit.

Figure 15. A sand-dominated face sharply overlain by gravel in the Preston pit. Viewer is facing north-northwest. Face is located at northwestern corner of the property.

2.8. *WILMOT TOWNSHIP PIT*

Location: New Dundee, Waterloo–Kitchener
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Waterloo Moraine
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Fine–medium sand overlying pebble gravel.
Paleoflows: 250^{o} (not corrected for declination)
Horizontal grain-size trend: None observed
Vertical grain-size trend: Net upward fining
Depositional environment: Glacifluvial
Aquifer potential: Moderate to good

General comments: In 2004, this relatively shallow pit (< 4 m deep) consisted of a fine–medium sand unit overlain abruptly by planar and trough cross-bedded pebble gravel. Beds dip towards 250° at west end of face. A number of depressions were infilled with up to 3 m of horizontally laminated silty very fine sand and silt. There were few active faces.

Figure 16. Cross-stratified gravel overlain abruptly by sand, Wilmot Township pit. Note back filled depression at location of person.

2.9. SECURITY PIT

Location: New Dundee, Waterloo–Kitchener
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Waterloo Moraine
Map unit: Ice-contact sand
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Sequence of fine–medium sand – gravel – sand .
Paleoflows: 250^{o} (not corrected for declination)
Horizontal grain-size trend: None observed
Vertical grain-size trend: Net upward coarsening
Depositional environment: Glacifluvial
Aquifer potential: Moderate to good

General comments: This pit extends ~ 700 metres north from the road. The back of the pit is ~400 metres wide. In 2002, up to 10 m of cross-stratified pebble to small cobble gravel was abruptly overlain by 4 m of trough cross-stratified pebbly sands and sands indicating flow towards the west and southwest. High-angle normal faults were observed in the sands. There was only limited exposure in 2004. Overlying deposits had been scraped back leaving a face of sand overlain by cross-stratified gravel. Deposit exhibits well developed, dune-scale, cross-strata (Fig. 17).

Figure 17. Characteristic face of dune-scale cross-bedded gravelly sand overlying cross-bedded sand in the Security pit. Fine muddy sediment at top of face are pit spoils.

2.10. DAVID PIT (CBM Aggregates)

Location: Cambridge
OGS map reference: Map 2508, report 255, Karrow (1987)
Landform: Outwash plain
Map unit: Outwash gravel
Stratigraphic position: Above Port Stanley Till
Sediment exposed: Pebble-cobble gravel and coarse sand. Rare fine sand lenses.
Paleoflows: 245° to 320° (dune-foreset dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: Upward coarsening
Depositional environment: Glacifluvial
Aquifer potential: Good to very good

General comments: Exposed strata consist of crudely horizontally stratified and dune cross-stratified pebble–cobble gravel and coarse sand (Fig. 18). Lens-shaped fine sand units, some several meters thick, are also present. A few large angular boulders have been extracted from the pit. These are common in the sandy units, and have not been observed in the gravely units (pit owner, personal communication). There are no obvious horizontal trends within pit itself. A possible net upward-coarsening trend exists, at least above water table. In 2002, the lower ripple and planar laminated fine to medium sands were well exposed and contained thin horizontal layers of silt and clay. A borrow pit lateral to the face in Figure 18 has large cross-strata and abrupt horizontal juxtaposition of strata suggestive of faulting.

Figure 18. Illustrative photograph of strata exposed in David pit. Dune cross-stratified pebbly sand overlies dune cross-stratified coarse sand. Cross-sets tend to be 10–50 cm thick. Paleoflows are northwest.

2.11. DANCE PIT (CBM Aggregates)

Location: Cambridge
OGS map reference: Map 2508, report 255, Karrow (1987)
Landform: Outwash plain
Map unit: Wentworth Till
Stratigraphic position: Above Port Stanley Till
Sediment exposed in pit: Pebble–cobble gravel
Paleoflows: 280° to 345° (dune-foreset dip direction)
Horizontal grain-size trend: None
Vertical grain-size trend: None
Depositional environment: Glacifluvial, higher energy; flow width at least 30 m perpendicular to paleoflow; silt at top may be loess.
Aquifer potential: Excellent

General comments: The Dance pit is gravel rich (Fig. 19). Exposed strata are crudely horizontally stratified, dune-scale cross-stratified or large-scale, low-angle cross-stratified. There are no obvious horizontal or vertical grain size trends. Gravel is commonly partially cemented. A thin silty unit caps the succession. The association of cemented gravels with an overlying mud unit is a common theme in the aggregate pits visited. In the Dance pit, the capping silt is stripped and stockpiled in the middle of the pit. Beds are at least 30 m wide perpendicular to paleoflow. Rare fine sand lenses are present (see photograph). Attempts by the pit operator to draw down the water table using a 6-inch pump have not been successful. Rather, a 12-inch pump is required, and even then it only works where the pit floor is underlain by silty sand unit. Following pumping, draw down recovers within 24 hours. A cored borehole located a few hundred meters south of the license recorded approximately 9 m of pebble-cobble gravel over 40 m of sand with lesser silt. The sands, which are likely of glaciolacustrine origin contain two 20 m thick coarsening upward cycles of silt grading to sand.

Figure 19. Illustrative photo of strata exposed in the Dance pit (dune-scale cross-stratified pebbly gravel). Paleoflow is from left to right.

2.12. AYR PIT (CBM Aggregates)

Location: Ayr
OGS map reference: Map 2508, report 255, Karrow (1987)
Landform: Hummocky terrain
Map unit: Outwash gravel
Stratigraphic position: Above Port Stanley Till
Landform association: Hummocky terrain
Sediment exposed: Pebble gravel to silty sand
Paleoflows: 270° to 345° (westward fining trend and direction of current-ripple climb)
Horizontal grain-size trend: Westward fining
Vertical grain-size trend: Upward fining?
Depositional setting: Subaqueous fan (stacked, small and relatively low energy depositional lobes)
Aquifer potential: Moderate to low

General comments: Sediment exposed in this pit is organized into several thick (2–3 m), stacked cross-sets that fine towards the west over several tens of meters (Fig. 20). In the best exposed cross-set, a distinct westward-fining trend is observed: pebbly coarse sand is exposed in the east and wavy horizontally bedded fine sand is exposed in the west (see photograph). The pebbly sand, when viewed perpendicular to paleoflow, has a distinct outward-building mound shape. Climbing current ripples are abundant and several climbing dunes are observed at the western end of the exposed cross-set. Climbing bedforms suggests rapid deposition from westward moving unidirectional flows. Horizontal fining in the cross-set suggests depositional energy decreased during its deposition. The net vertical fining trend (there is mud near (or possibly at?) the top of the outcrop) suggests a net decrease in energy over time.

In 2002, approximately 6 m of horizontally bedded fine to medium sands containing ripple laminae and planar cross-beds indicating flow towards the southwest were abruptly overlain by approximately 6 m of cross-stratified cobble to pebble outwash gravel.

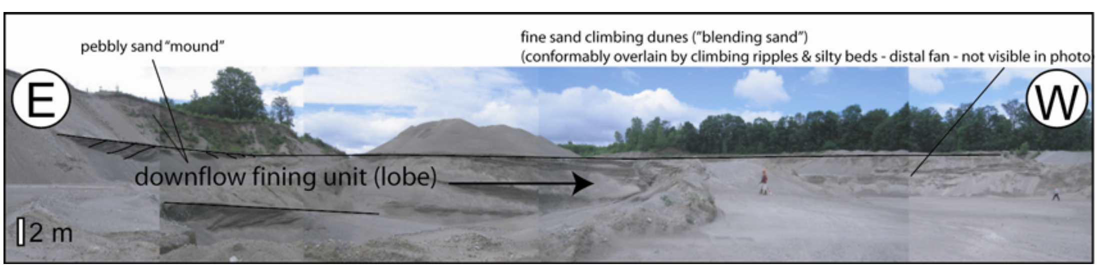


Figure 20. Large, westward fining cross-set (interpreted to be a subaqueous-fan lobe) exposed in the Ayr pit. Note the mound-like architecture of gravely proximal part of the lobe in the left side of the photograph, where the exposure is nearly perpendicular to paleoflow.

2.13. AYR PIT (Greenfield Aggregates)

Location: Ayr
OGS map reference: Map 2508, report 255, Karrow (1987)
Landform: Hummocky terrain
Map unit: Outwash gravel
Stratigraphic position: Above Port StanleyTill
Landform association: Hummocky terrain
Sediment exposed: Pebble-cobble gravel to silty sand; lots of stockpiled boulders
Paleoflows: 235° (Lobe 1) to 270° to 90° (Lobe 2)
Horizontal grain-size trend: None observed
Vertical grain-size trend: None observed
Depositional setting: Subaqueous fan (stacked, smaller, moderate to low energy lobes). Were boulders potentially part of a feeder deposit?
Aquifer potential: Excellent to good; local mud units

General comments: In general, exposed strata consist of pebbly gravel to fine sand. Gravel is locally overlain by mud and (note the correlation) there are cemented gravel pods locally. In the past, abundant coarse gravel has apparently been extracted from the pit because a large mound of cobbles and small boulders is stockpiled in the middle of the pit.

Figure 21. Two distinct units ("lobes") with contrasting paleoflow indicators, Ayr pit.

In the northwest corner of the pit, two distinct lobes were well exposed. The lower unit (Fig. 21. "Lobe 1") fines and thins westward from diffusely laminated sand to climbing ripples that climb westward. By contrast, unit 2 ("Lobe 2") consists of interstratified pebble gravel and climbing rippled fine sand. Unit 2 appears to fine eastward, and climbing ripples were deposited by eastward-moving flows. Are we looking at two stacked subaqueous fan lobes? If so, there were either multiple feeders, or avulsion of the jet-plume depocenter.

2.14. CAMBRIDGE PIT (Lafarge)

Location: Cambridge
OGS map reference: Map 2508, report 255, Karrow (1987)
Landform: Outwash plain
Map unit: Ice-contact gravel
Stratigraphic position: Above Port Stanley Till
Sediment exposed: Pebble-cobble gravel
Paleoflows: 280°
Horizontal grain-size trend: Westward fining
Vertical grain-size trend: None observed
Depositional setting: Glacifluvial
Aquifer potential: Very good

General comments: The pit is gravel rich and relatively coarse grained (small boulders are common; Fig. 22). More sand is present in the west than in the east of the pit. Gravel and sand facies interfinger. At the top of the pit, an esker containing faulted and chaotically-bedded cobble and small boulder gravel with minor sand is superimposed on horizontally bedded and cross-stratified pebble to cobble gravels indicating flow to the west-northwest. Up to 5 m of silty to sandy diamicton and/or well laminated muds locally overlie the glaciofluvial deposits on either side of the esker ridge. A cored borehole on Alps Road just southeast of the licence intersected approximately 22 m of interbedded sandy diamicton, sand and gravel over 32 m of gravel with lesser sand then 21 m of sand (Bajc and Shirota, 2007). These sediments rested directly on Port Stanley drift and older deposits

Figure 22. Mosaic of strata exposed in Cambridge pit. Note westward fining trend and esker at top of pit face.

2.15. STUEHLER PIT (Waynco)

Location: Cambridge
OGS map reference: Map 2508, report 255, Karrow (1987)
Landform: Paris Moraine
Map unit: Outwash gravel
Stratigraphic position: Above Port Stanley Till
Sediment exposed: Boulder–cobble gravel; minor coarse sand
Paleoflows: 220° to 335° (cross-strata dip direction)
Horizontal grain-size trend: Westward fining
Vertical grain-size trend: None observed
Depositional setting: Proximal glacifluvial
Aquifer potential: Excellent; local cementation

General comments: Very coarse grained pit. Maximum clast size was around 1 meter. Boulders between 30 and 40 cm in diameter are common. Paleoflow is westward, perpendicular to the Paris Moraine. No obvious overlying diamicton is exposed although it is suspected that diamicton was either removed by subsequent glaciofluvial activity or by the pit operator. Near the pit entrance, cemented gravel may suggest that the deposit, was at least locally, overlain by mud.

Figure 23. Illustrative photograph of strata exposed in the Waynco, Stuehler Pit, which is excavated into deposits laid down either directly in front of or in the Paris Moraine. Pit face is approximately 4 m high. Note that grain size is relatively coarse—generally cobble gravel with coarse sand matrix—and that fine-sand lenses occur locally (as in the north side of this photograph). Paleoflows are westward. No muddy unit was observed at the top of the pit, but local gravel cementation may suggest one was present and has been removed.

2.16. WAYNCO-2 PIT

Location: Cambridge
OGS map reference: Map 2508, report 255, Karrow (1987)
Landform: Paris Moraine
Map unit: Outwash gravel
Stratigraphic position: Above Port Stanley Till
Sediment exposed: Cross-stratified pebble-cobble gravel with coarse sand matrix, diamicton intercalated with gravel near top.
Paleoflows: 180° to 270° (cross-set dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: Upward fining
Depositional setting: Ice-marginal glacifluvial
Aquifer potential: Very good

General comments: This pit is documented in Bajc and Karrow (2004, stop 1.2). It extends ~ 500 m in a north–south direction and over 400 m in an east–west direction, faces are ~ 10 m high and exposed for several hundred metres oblique to paleoflow.

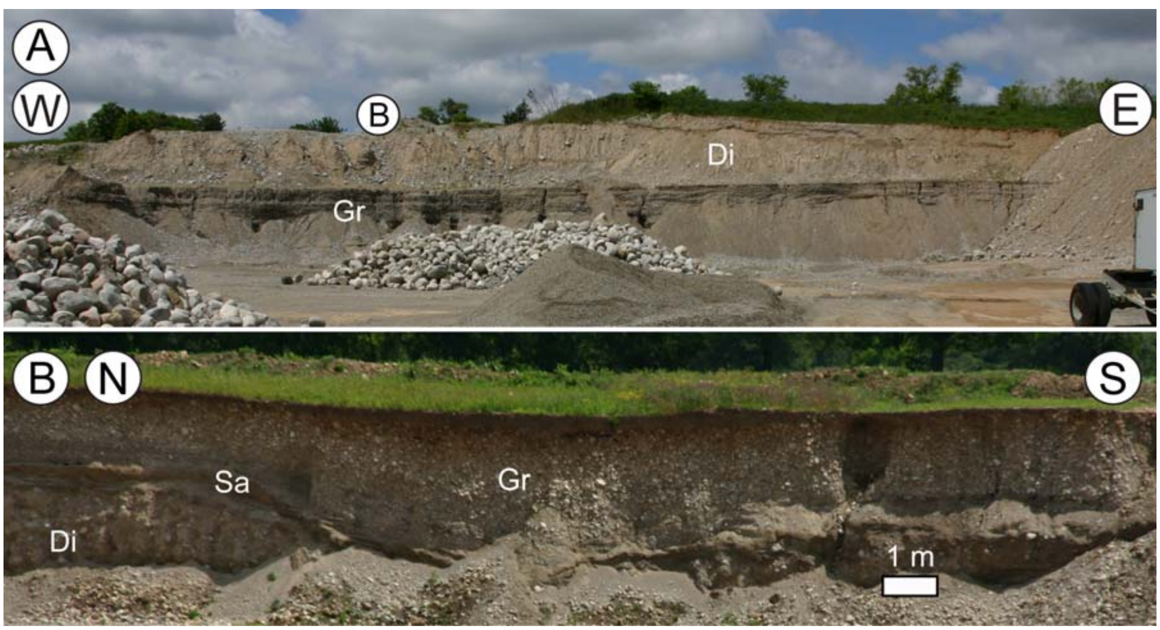


Figure 24. Illustrative photograph of strata exposed in the Waynco-2 pit on Wayco Road. A) Overview of northern pit face with multiple benches with > 10 m height. Face consists of a succession of gravel, diamicton, gravel. Note relatively large piles of unprocessed boulders. B) North – south face at top of A illustrating complex relationship of diamicton and gravel and local channelization. Face is ~ 3 m high.

Sediment is relatively well sorted; small stockpiles of small boulders are present in centre of pit. Gravel is dune-scale cross-stratified. However, moderately continuous dune cross-stratified sand layers are locally interstratified with the gravel. The stratigraphy consists of interbedded sand, gravel and diamicton with considerable variations in diamicton thickness. The succession is, at least locally, capped by Grand River spillway gravel (Fig. 25).

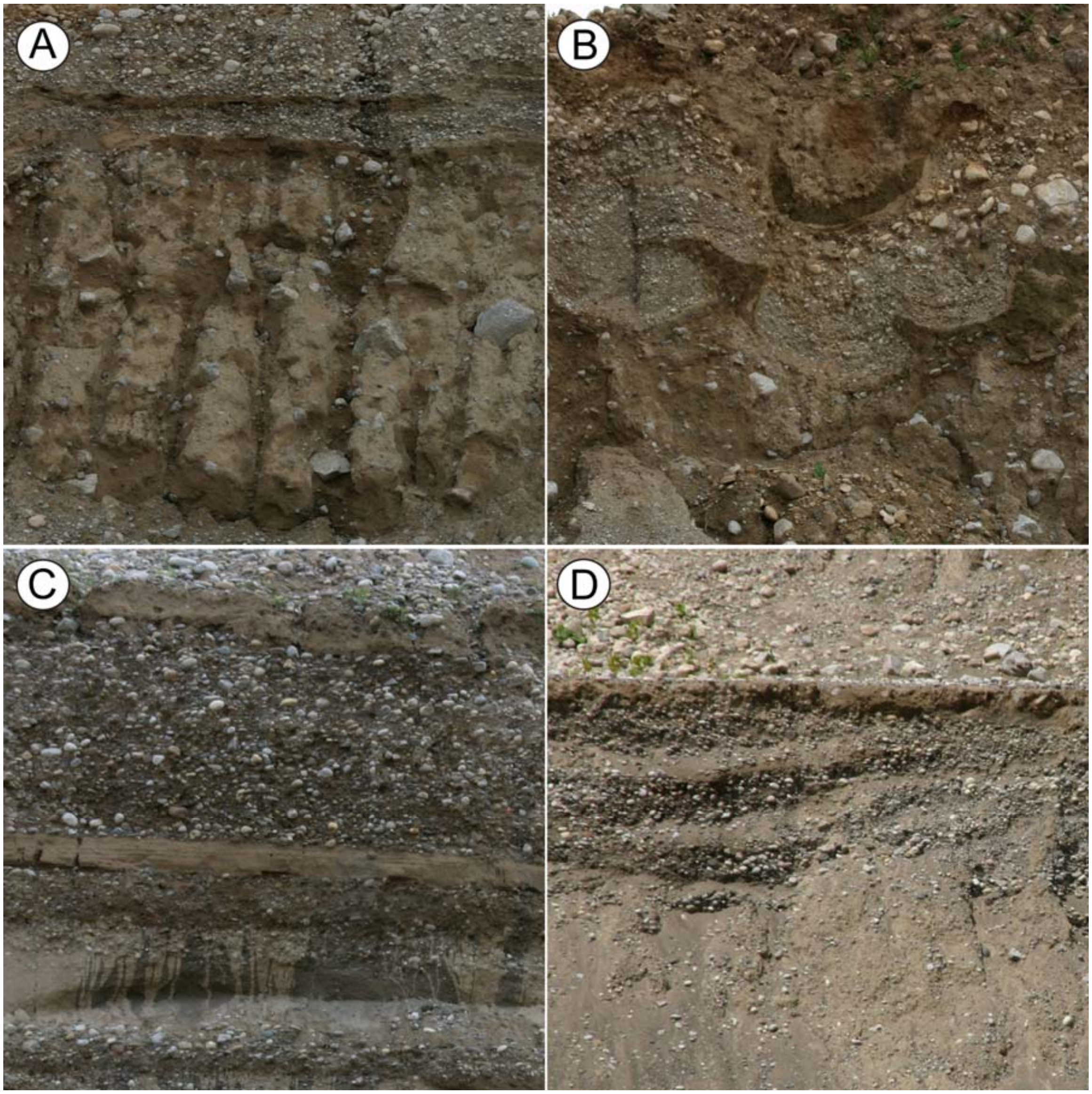


Figure 25. Illustrative photos of sediment textures and structures from the Waynco-2 pit. A) Diamicton with small boulder clasts with overlying crudely stratified gravel. B) Load structures of gravel into diamicton. C) Cross-stratified pebble gravel with underlying sand horizon. D) Stacked cross sets of pebble gravel.

2.17. LAKEVIEW PIT

Location: Cambridge
OGS map reference: Map 2508, report 255, Karrow (1987)
Landform: Outwash plain
Map unit: Outwash gravel
Stratigraphic position: Above Port Stanley Till
Sediment exposed: Pebble gravel to silty sand
Paleoflows: 290° to 340° (cross-strata dip direction)
Aquifer potential: Very good to good
Horizontal grain-size trend: Westward fining in one element
Vertical grain-size trend: Locally capped by silty diamicton
Depositional setting: Glacifluvial – subaqueous fan?
Aquifer potential: Good

General comments: The Lakeside aggregate operation consists of two pits in close proximity that had relatively little fresh exposure. The main pit has a single well exposed face (Fig. 26) of pebble gravel and sand. Fine silty sand is exposed in a smaller adjacent pit that from a distance appears to be subaqueous fan material (the pit faces were not observed from up close).

Figure 26. Illustrative photograph of strata exposed in Lakeside Pit. All units are cross-stratified.

2.18. WASHINGTON PIT

Location: Perry's Corner, Waterloo area
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Flat low-lying area. Low relief plain with hummocky upland to south.
Map unit: Outwash gravel and ice-contact stratified sediment
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Small-scale dune cross-stratified pebbly gravel and pebbly sand
Paleoflows: 180° to 280° (dune cross-strata dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: None obvious
Depositional setting: Likely subaerial outwash flanking Waterloo Moraine sediments to south
Aquifer potential: Good to very good

General comments: Moderate sized pit of coarse sand and pebble gravel. Dune cross-stratified beds are thin (10–40 cm) and have substantial lateral continuity (tens to hundreds of meters oblique to paleoflow). Bed surfaces dip very gently southward (apparent dip) at around 3–5°. (Are these lateral accretion barform surfaces? If so, the channel would have been at least 3 m deep (the relief on the surfaces), and at least several hundred meters wide.) The deposit consists of fine pebbly gravel with medium to coarse sand interbeds. There is also almost a complete absence of larger "outsized" clasts (none are stockpiled, and none are observed in situ), and there are no subaqueous-fan looking fine sand beds interstratified in the succession. Almost all extracted aggregate is used for "ready mix" (pit operator, personal communication). Water table corresponds approximately with pit floor. These observations, along with association with flat lowland, suggest that sediment was deposited in a relatively shallow setting by unidirectional flows.

An exposure at the southeast corner of the site, in an area of hummocky terrain, was observed in 2006. It consisted of approximately 5 m of well bedded silt, silty very fine sand and clay with lesser pebbly sand and fine to medium sand. A number of boulders up to 0.75 m diameter were noted on the pit floor. This sediment was likely deposited in a distal subaquatic fan setting and is considered part of the Waterloo Moraine. The subaerial outwash gravels described above onlap this deposit.

Figure 27. Illustrative photograph of sediment exposed in the Washington pit showing laterally continuous face (~250 m) and thin cross-stratified beds

2.19. MAR-CO PIT

Location: Washington, Waterloo Area
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Hummocky terrain
Map unit: Ice-contact stratified sediment
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Upward fining succession (gravel to sand to mud)
Paleoflows: 320° to 120° (gravel); 020° to 280° (sand) (cross-strata dip direction)
Horizontal grain-size trend: None obvious in exposure
Vertical grain-size trend: Upward fining
Depositional setting: Subaqueous fan
Aquifer potential: Good (gravel unit, below pit floor)

General comments: As is common in pits in areas mapped as ice-contact stratified sediment, strata exposed in the Mar-co pit exhibit a net upward fining trend. Gravel at the base of the pit is overlain by laminated mud at the top of the succession. The mud unit grades up-flow into silty fine sand with abundant climbing ripples. Cemented layers occur locally in the mud unit, and also in the sand immediately below the mud. Exposure was relatively limited; the pit was largely worked out. Mud layers at top of pit likely provide some protection from surface contamination, but at the same time may inhibit recharge. Owner has two commercial water wells that are licensed to take water. At present, pit is being used to store clay bricks, which are pulverized on premises into a fine reddish powder used by baseball diamonds. In 2006, a succession of 3-4 m of planar bedded and trough cross-stratified pebble gravel and gravelly sand was overlain by 7-8 m of diffusely bedded and ripple-laminated silty very fine and fine sands with steep-walled channels, ball and pillow structures and minor faulting. This was capped by 6 m of glaciolacustrine muds with abundant ice-rafted debris and load structures. Paleoflow indicators in the lower unit indicated flow to the northwest.

Figure 28. Gravel overlain by laminated mud in the Mar-co pit. The mud unit grades to sand up-paleoflow,.

Figure 29. (next page) Illustrative sediment facies from the Mar-Co pit. A) Gravel with fine sand interbeds that likely function as baffles to groundwater flow. B) Open-work pebble gravel within the sandy baffles. C) Dewatered sand and gravel forming a matrix supported sandy gravel. D) Dune-scale cross bedded medium to coarse sand with pebble lags along scours. E) Ball and pillow structures (Bajc, 2006). Darker sediment is mud, lighter sediment is silt. D) Concretions within mud unit along bedding plane. F) Concretions in the near surface laminated mud.

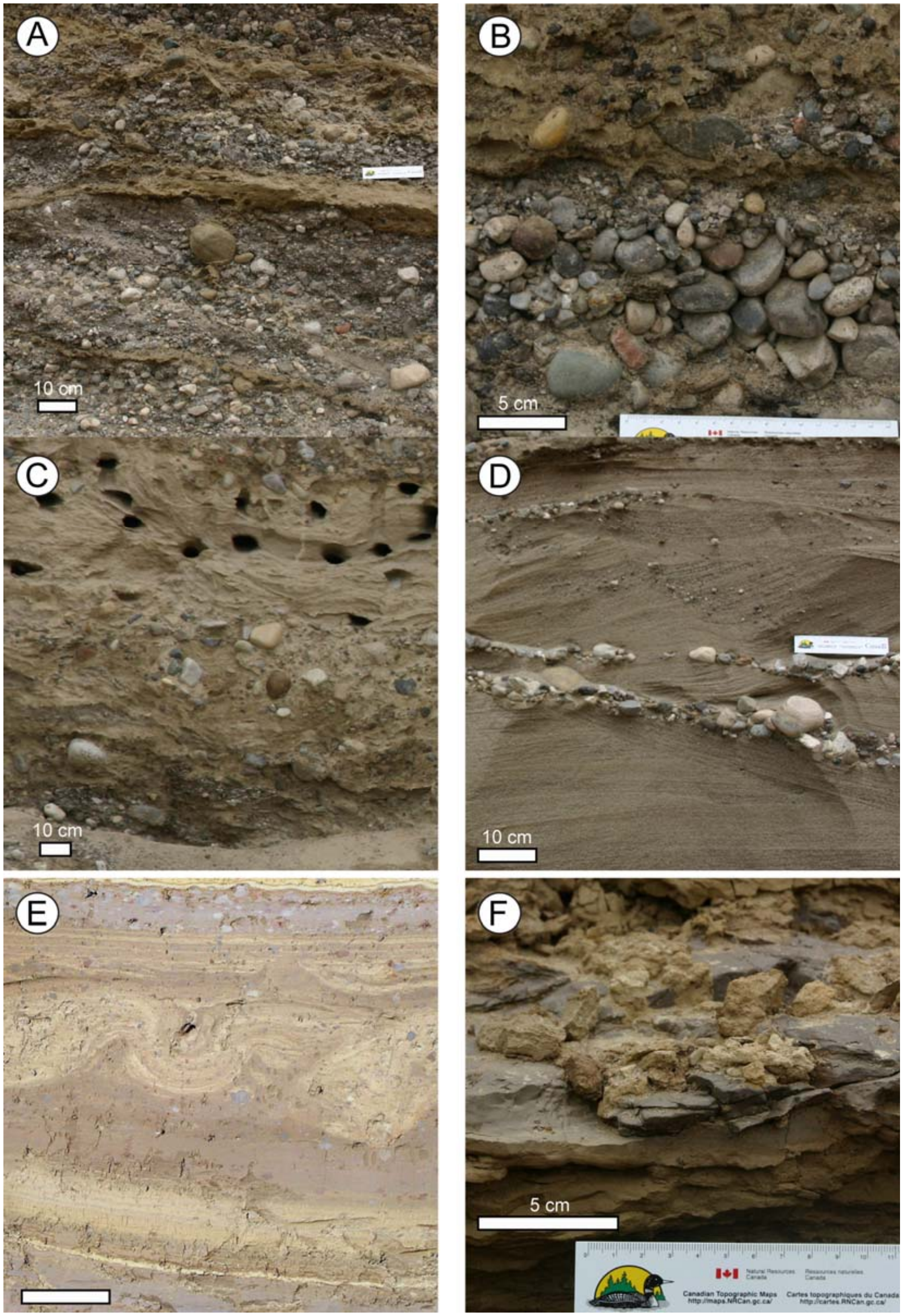


Figure 29. See previous page.

2.20. WEST PARIS PIT (Lafarge)

Location: Paris
OGS map reference: M2240, Cowan (1971)
Landform: Outwash plain / terrace, Low-relief area in front of Paris Moraine
Location: Washington, Waterloo Area
Map unit: Subaerial outwash
Stratigraphic position: Above Catfish Creek and Port Stanley
Sediment exposed: Dune cross-stratified pebble gravel with coarse sand matrix
Paleoflows: 205-235° (gravel); 140° in rare coarse sand beds (cross-set dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: None obvious
Depositional setting: Glacifluvial outwash
Aquifer potential: Excellent

General comments: The pit is very large. Faces are ~ 15 m high and extend for at least ~ 500 m oblique to paleoflow. Like other pits in areas mapped as glacifluvial outwash, grain size is very consistent: there are very few "outsized" clasts and few fine sand beds. Unlike the Thornton and Oxford pits, there are very few if any silty sand "pause planes" in between cross-sets. Also, the exposed strata are distinct from Waynco Pit 1 (Paris Moraine) because no boulder gravel is observed and facies are very laterally continuous. Probably > 95% of the exposed sediment is sandy pebble–cobble gravel. Dune-scale cross-strata are ubiquitous. Cross-sets are typically medium-scale, ranging from a few 10s of centimeters to two meters thick. One large, 2.5 m thick cross-set may possibly be a macroform. Pit operator suggests that very little overburden needs to be stripped before excavation.

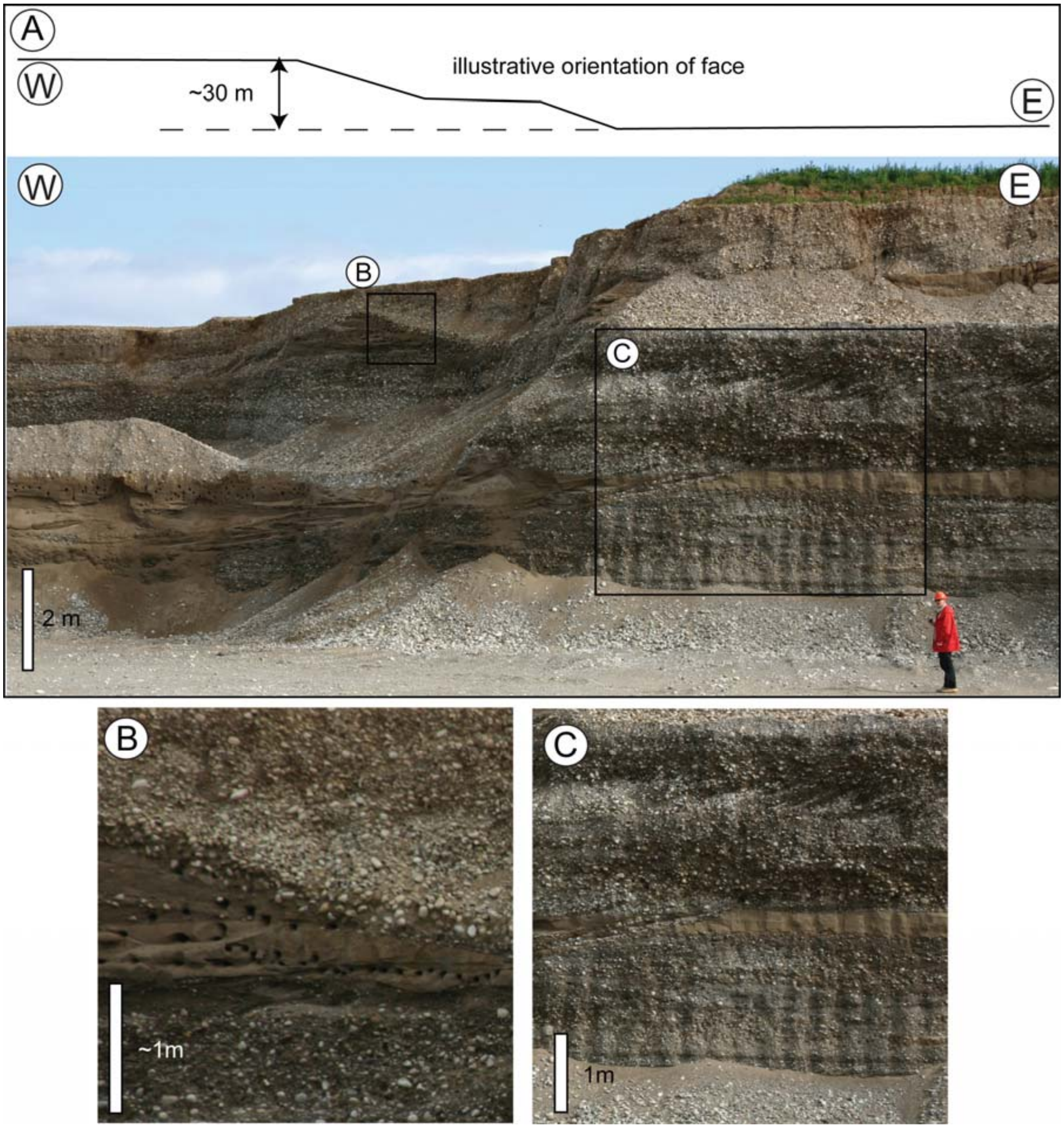


Figure 30. Illustrative image of exposures in the West Paris pit. The sediment exposed consists largely of stacked cross-stratified pebble to cobble gravel with sand interbeds and sand channel fills. A) Large channel near top of section between letters B and C. Line at top indicates plan view orientation of face. B) Channel margin with bimodal sand cobbles at contact. C) Gravel cross-strata with sand interbed.

2.21. BRANTFORD PIT (Telephone City Aggregates)

Location: Brantford
OGS map reference: M2240, Cowan (1971)
Landform: Galt Moraine
Map unit: Wentworth Till
Stratigraphic position: Above Port Stanley Till
Sediment exposed: Highly variable, from small-boulder gravel to fine sand to diamicton
Paleoflows: NW (large-scale “macroform” cross-sets)
Horizontal grain-size trend: Northwestward fining
Vertical grain-size trend: Vague upward fining?
Depositional setting: Ice-marginal to subaqueous fan
Aquifer potential: Excellent

General comments: Very big pit. Faces are ~ 15 m high locally and extend for at least ~ 500 m oblique to paleoflow. Like other pits in areas mapped as Paris Moraine, grain size is highly variable, ranging from bouldery gravel to lateral extensive fine sand beds to lensoid diamicton units. Gravel units interfinger, form lenses, and overlie diamicton.

Gravel is most common near the base of the pit. Pebbles and cobbles are abundant. Boulders (20–50 cm) are less common but present locally in high concentrations. Gravel typically has a coarse sand matrix. It is locally cemented. In several places, it is organized into large scale (5–10 m thick) cross-sets that dip westward to northwestward. Individual large scale cross-strata are commonly crudely stratified open-work to closed-work pebble gravel units; some sandier ones consist of thin (10–20 cm) cross-sets interpreted to have been deposited by dunes that migrated back up the foreset (i.e., they were generated by recirculation in a zone of flow separation). Unlike subaerial outwash pits, gravel units are not necessarily laterally continuous for more than several tens of meters. In one face, gravel clearly pinches out into fine sand moving northwestward.

Laterally extensive fine sand beds are intercalated locally with gravel and, less commonly, diamicton units. Beds are commonly climbing ripple cross-stratified. Fine sand beds appear to be more common near the top of succession; however, they are also observed intercalated with gravel near base of succession. Minor soft sediment deformation structures are present locally.

Diamicton overlies stratified deposits and also is intercalated with gravel and sand. Diamicton contains lenses of gravel. In one location, in the east end of the pit, a 2 m thick lens-like unit of diamicton is interstratified with laterally extensive fine sand beds and cobble gravel. The diamicton may be massive or weakly stratified, and exhibits local clast imbrication. Larger clasts (i.e., boulders) rarely may have a vertical fabric. At least in this one location, diamicton does not form the surface material; rather, it is overlain by laterally extensive gently-dipping fine sand beds, which are in turn overlain by cobble gravel, then the modern soil at ground surface.

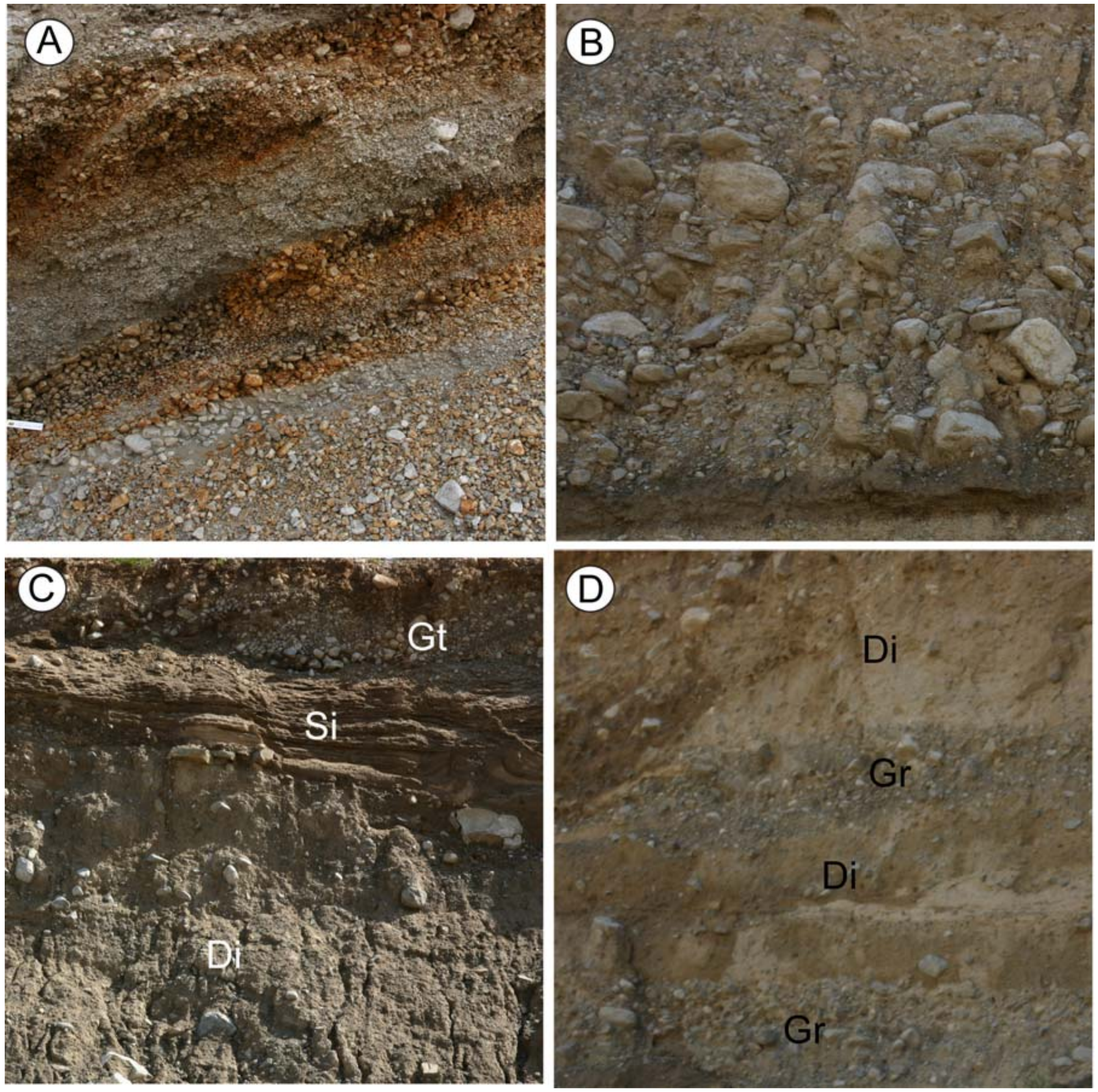


Figure 31. Illustrative sediment facies of the Brantford Telephone City Aggregates pit. A) Large-scale cross-stratified gravel. Note iron staining and cementation. B) Boulder gravel with chaotic clast fabric. C) Interstratified diamicton (Di), silt (Si), and cross-bedded gravel (Gt). Locally the diamicton has a gradational lower contact. D) Interstratified (Gr) gravel and diamicton (Di).

2.22. THORNTON PIT

Location: Woodstock
OGS map reference: M2281, report GR119, Cowan (1975)
Landform: Drumlinized till upland
Map unit: Tavistock (Zorra) Till
Stratigraphic position: Beneath sharp-based diamicton (Tavistock or Catfish Creek Till)
Sediment exposed: Pebble-cobble gravel
Paleoflows: 150° to 180° (cross-strata dip direction)
Horizontal grain-size trend: None
Vertical grain-size trend: None
Depositional setting: possibly subglacial
Aquifer potential: Excellent

General comments: The Thornton pit is a large pit, nearly 1 km in a N–S direction by 500 m in an E–W direction. This site has been partially documented by Sharpe, (1987, stop 19). There are no obvious horizontal or vertical grain size trends: grain size is very consistent. The exposed sediment consists predominantly of pebble–cobble gravel with coarse sand matrix. Coarse sand lenses and small boulders are present but rare. Gravel strata typically are crudely horizontally stratified and imbricated or dune-scale cross-stratified. Cross-sets are commonly 1–2 m thick. Paleoflows from dune-scale cross-strata and imbrication are southward to eastward. Gravel is cemented locally. Diamicton is present locally at top of outcrop. It truncates underlying gravel

Gravel is interpreted to have been deposited from relatively steady unidirectional flows. Flow depths were at least several meters, and possibly deeper given thickness of dune-scale cross-sets. This would have been very deep for coarse-grained subaerial fluvial channels. The high position of the pit in the landscape suggests deposition in an ice-contact setting, and the 50 m of aggradation suggests that there was abundant space to accommodate sediment deposition.

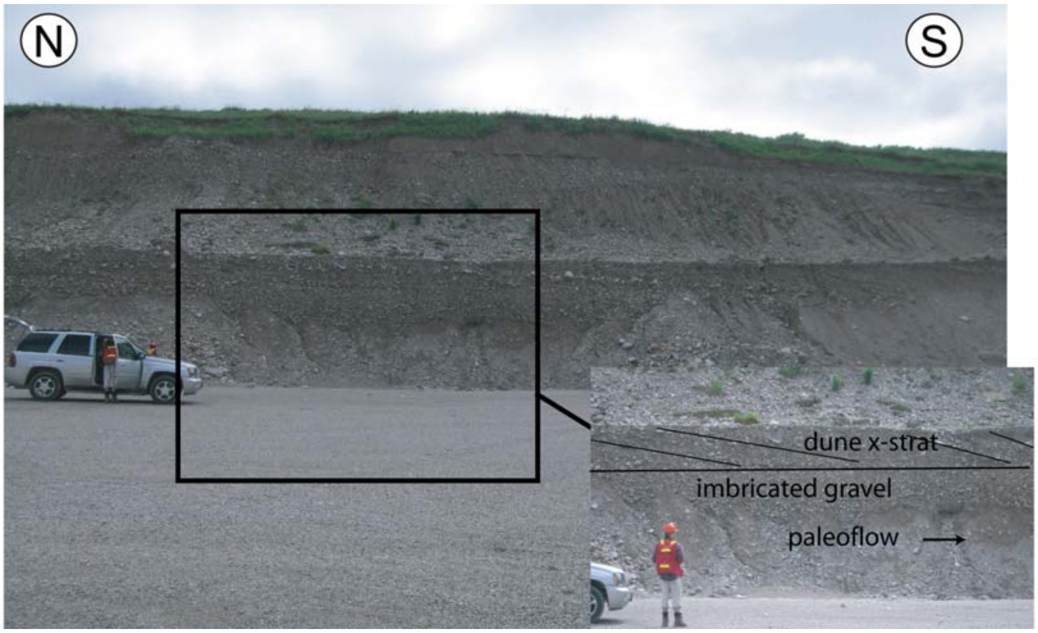


Figure 32. Illustrative photograph of strata exposed in the Thornton pit. The pit is very large. Grain-size is very consistent (pebble–cobble gravel), and vertical and horizontal grain-size trends are not observed. Paleoflows are southward to southeastward.

2.23. OXFORD PIT

Location: Woodstock
OGS map reference: M2281, Report GR119, Cowan (1975)
Landform: Drumlinized till upland
Map unit: Tavistock (Zorra) Till
Stratigraphic position: Beneath Tavistock or Catfish Creek Till
Sediment exposed: Pebble-cobble gravel; rare boulder-rich units and laterally continuous fine sand beds near top of outcrop
Paleoflows: 170° to 230° (cross-strata dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: Slight fining upward trend; grades up into sandier strata
Depositional setting: High energy subaqueous setting; unidirectional flows; Possibly in an ice-walled canyon
Aquifer potential: Excellent

General comments: Like the adjacent Thornton pit, the Oxford pit is very big and contains a similar gravel succession. Toward the top of the succession however, laterally continuous sand beds are present. They have the appearance of subaqueous fan strata. Bar forms migrating to the west, southwest and northwest were observed. Like Thornton pit, lower strata consist almost entirely of pebble–cobble gravel with coarse sand matrix. Outsized clasts are more common in the western part of the pit and reach diameters of 1.5 m. Gravel is typically either crudely horizontally stratified and imbricated or large-scale dune cross-stratified (up to 5-6 m high). Dune-scale cross-strata are organized in several places into large-scale "macroform" cross-sets. Laterally continuous silty layers, several tens of centimeters thick, locally underlies the base of the macroform cross-sets. The dunes appear to have migrated down the larger-scale clinoform surfaces; the large-scale forms that generated these structures therefore accreted downflow, not lateral to flow (although several possible lateral accretion cross-sets may be present as well). Dune-scale cross-sets are commonly 0.5–2 m thick, and the composite "macroform" cross-sets are 2–4 m thick. Paleoflows from dune cross-strata, macroform cross-strata and clast imbrication are southwestward to southeastward.

The coarsest boulder gravel occurs in the western pit face. Two distinct sedimentary units are observed. The largest, highest concentration of boulders occur in a massive, sharp-based unit of 2–3 m thickness that fines upward. The unit appears to be laterally discontinuous and fills shallow concave structures incised into cross-stratifed cobble gravel. A second overlying unit has much better organization, better sorting, and smaller, lower concentration of boulders. Cross stratification is commonly present and gravel facies range from openwork to poorly sorted pebble gravel

The top of the succession is characterized by an increase in sand content and alternating sequence of gravel sand units. The sand is predominately fine to medium caliber and is dominated by ripple- and dune-scale cross-lamination, with minor diffusely graded sand. The transition from underlying gravel is abrupt; however gravel clasts are locally enclosed in a sand matrix along the contact. In some cases the gravel unit appears to fine upward from cross-stratified gravel to pebble gravel and then coarse sand. Nevertheless, the transition to the sand unit is still abrupt. Locally, rare sand intraclasts appear to be incorporated into the gravel unit.

Deposition at the site is interpreted to have been from unidirectional flows, and the depositional environment was likely similar, if not the same, as the gravel in the Thornton pit. Laterally continuous fine sand beds near the top of the succession look very similar to laterally continuous sand beds in subaqueous fan complexes. The down-flow accreting macroforms are also perhaps indicative of deposition in a deeper flow (at least 5 m deep).

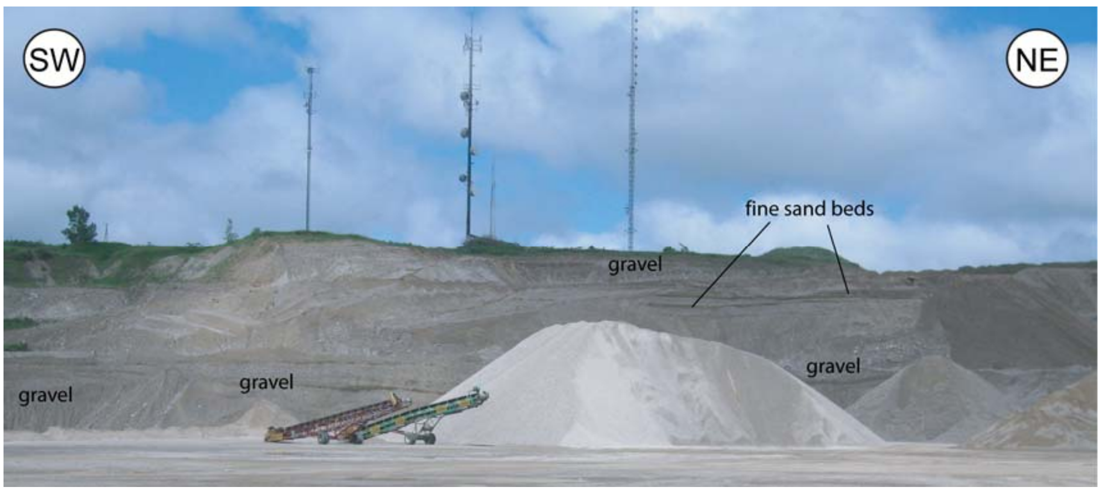


Figure 33. Illustrative photograph of strata exposed in Oxford pit. Note laterally continuous fine sand layers near top of outcrop.

Figure 34. Features common to large-scale ("macroform") gravelly cross-stratification in the Oxford pit.

2.24. VIEWCON PIT

Location: Sweaburg, south of Woodstock
OGS map reference: M2281, report GR119, Cowan (1975)
Landform: Flank of drumlinized till upland
Map unit: Glacifluvial outwash
Stratigraphic position: Beneath sharp-based diamicton (Tavistock or Catfish CreekTill)
Sediment exposed: Pebbly sand to fine sand organized into composite, downflow accreting macroform cross-sets (like at Oxford pit). Capped by massive diamicton which appears to be interbedded with gravel.
Paleoflows: 130° to 200° (cross-strata dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: None obvious
Depositional setting: Subaqueous setting; deposition from unidirectional flows that were at least 3 m deep (thickness of macroforms)
Aquifer potential: Good to moderate

General comments: The exposure in this pit is < 4 m high and is oriented subparallel to paleoflow. As observed in the Oxford pit, strata tend to be organized into 2–3 m thick "macroform" cross-sets. These consist of master southward-dipping clinothems. Each clinothem is a dune-scale cross-set. Dunes migrated down clinoforms, not across them, suggesting each clinothem package is a downflow accretary feature; they were not generated by pure lateral accretion. Silty sand "pause plane" layers are commonly present beneath base of clinothem package, effectively separating it from the underlying clinothem package. The base of the clinothem erosionally overlies the silty pause plane layer. Each macroform cross-set package is interpreted to have been deposited by a steady unidirectional flow. However, pause planes separating macroforms suggest that flow was not steady throughout deposition of entire succession. The down-flow accreting macroforms are indicative of deposition into deep water (at least 3 m deep at this location). The deposit is capped by 2.5-3.0 m of a fissile, silty to sandy subglacial diamicton that displays a sharp, erosive contact with the underlying strata.

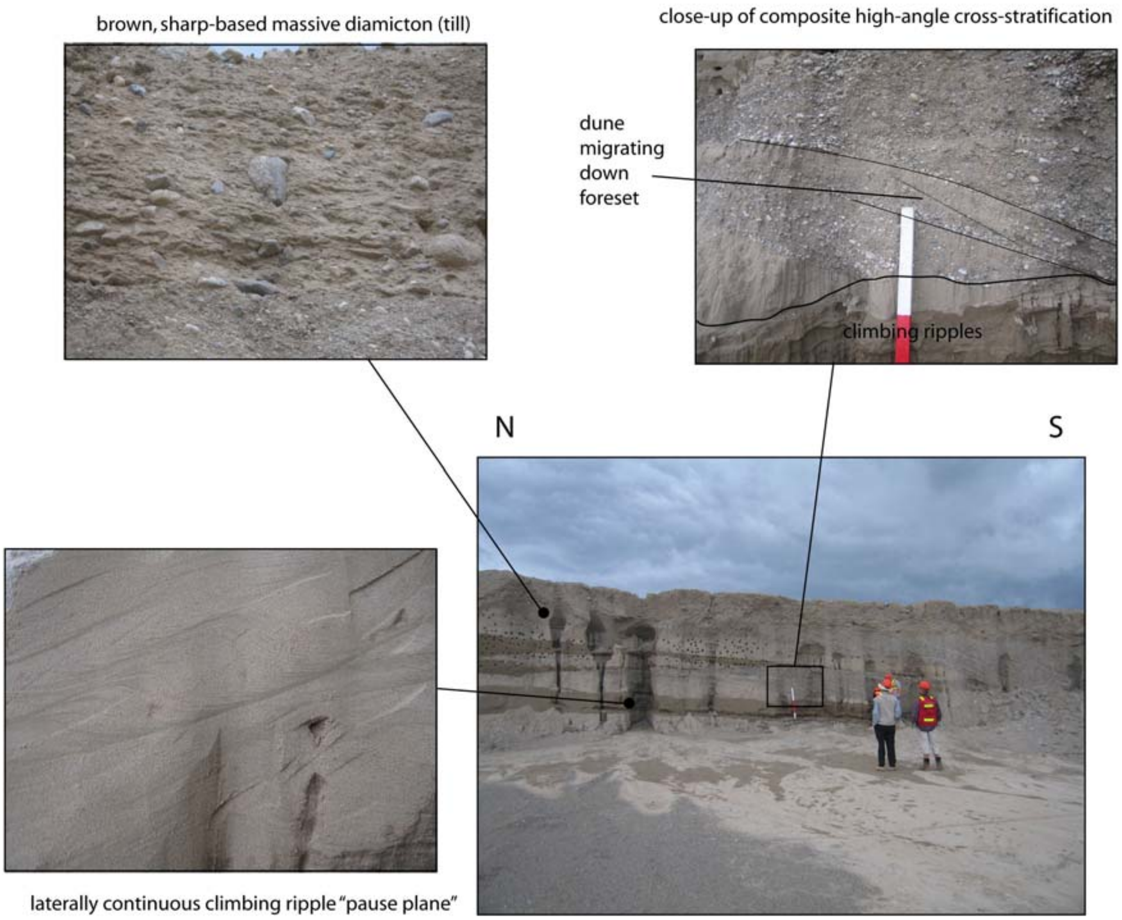


Figure 35. Illustrative photos of strata exposed in Viewcon pit showing overlying diamicton, high-angle cross-strata, climbing ripple-scale cross-lamination

2.25. HUMMOCK FARMER'S FIELD

Location: near Foldens, south of Woodstock
OGS map reference: M2281, report GR119, Cowan (1975)
Landform: Flank of drumlinized till upland
Map unit: Ice-contact stratified sediment
Stratigraphic position: Uncertain, below Tavistock or Catfish Creek Till?
Landform association: Flank of drumlinized till upland
Sediment exposed: Dune-scale cross stratified fine–medium sand; silty fine sand; shallow scours; ball and pillow structures
Paleoflows: Not measured
Horizontal grain-size trend: None obvious
Vertical grain-size trend: Cyclic bedding of dune-scale cross strata with silty fine sand
Depositional setting: Subaqueous setting; deposition from unidirectional flows
Aquifer potential: Moderate

General comments: A small borrow pit at the back of a farmers field. Face is a few tens of metres long and ~ 6 m high. Sedimentary structures are predominantly ripple-scale cross-stratification in fine to medium sand. Land surface appears to truncate bedding.

Figure 36. Ripple-scale cross laminated fine sand and minor dune-scale cross-stratification exposed in hummock in farmer's field.

2.26. THREE GUYS PIT

Location: near Embro, Zorra, north of Ingersoll
Landform: Flank of meltwater channel
Map unit: Glacifluvial outwash
Stratigraphic position: between Catfish Creek and Tavistock Till and above Tavistock Till
Landform association: Flank of steep-walled incised channel
Sediment exposed: Cobble gravel, local boulder present
Paleoflows: Generally westward
Horizontal grain-size trend: None observed
Vertical grain-size trend: None observed
Depositional setting: Glacifluvial
Aquifer potential: Good

General comments: A shallow (< 3 m deep) excavation. Little information was collected as we were only permitted a five minute drive around. The pit has one or two clean faces as illustrated in Figure 37. Boulders (Fig. 37A) were being stock piled. The largest boulders were ~ 1 m in diameter.

A visit to the pit during the summer of 2006 suggests that there are 2 distinct packages of glaciofluvial sediment in the pit. A 2 m thick massive, matrix-supported cobble to small boulder gravel graded upward into well bedded fine to medium sand occurred between an upper 2 m thick layer of diamicton (possibly Tavistock Till) and a lower gritty, pebbly sandy silt diamicton with diffuse silt and clay laminae (possibly Catfish Creek Till). The stratified sands are planar cross-bedded and indicate flow towards the southwest to northwest.

Up to 4 m of younger spillway gravels are exposed at the southern edge of the pit. The gravels are crudely bedded although well imbricated indicating flow to the west. These gravels rest sharply on dense, gritty, pebbly sandy silt to clayey sandy silt diamicton presumed to be Catfish Creek Till. Numerous Gowganda Formation tillites were observed in the till further supporting a northern provenance for the unit.

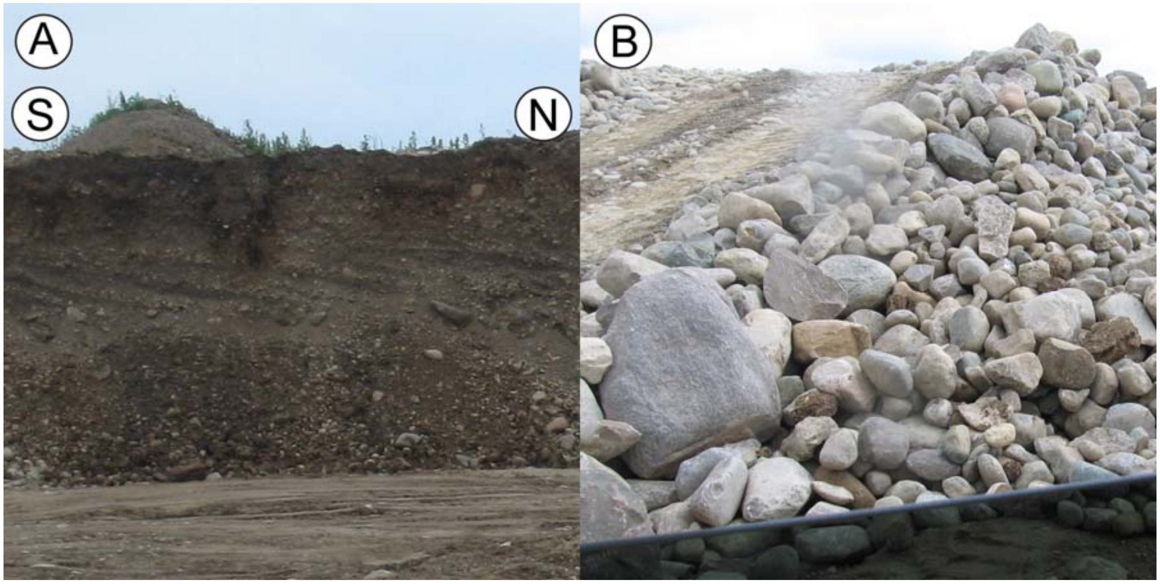


Figure 37. Illustrative images from Three Guys pit on the northwest side of the Thames River valley. A) Large, low-angle foresets in a ~4 metre high pit face. Note boulder in lower part of foreset. B) Pile of unprocessed oversized clasts in pit. The largest subrounded boulder in this photograph has a diameter of ~ 1 m.

2.27. ALAN HART PIT (Dufferin Aggregates)

Location: near Havelock Corners, north of Woodstock
OGS map reference: M2281, report GR119, Cowan (1975)
Landform: Hummocky terrain
Map unit: Ice-contact stratified drift
Stratigraphic position: Either between Catfish Creek and Tavistock Till or below Catfish Creek Till
Sediment exposed: Pebble to cobble gravel
Paleoflows: Towards the east
Horizontal grain-size trend: None obvious
Vertical grain-size trend: Several cycles of gravel separated by finer-grained units
Depositional setting: .Glacifluvial
Aquifer potential: Very good (gravel)

General comments: Access to this pit was granted on the condition that all individuals remained in the vehicle. Consequently, observations were made from the vehicle. In 2006, approximately 20 m of cobble to pebble gravel with some small boulder gravel was observed on the west face. Large bar forms containing open framework and bimodal sandy gravels indicate paleoflow towards the east. One broad, shallow channel at the north edge of the pit measured 50 m wide and 2 m deep. Boulders up to 1.5 m diameter were observed on the pit floor.

Figure 38. Overview photograph of cobble gravel strata, Alan Hart pit. Interbeds of fine-grained sand rich beds are highlighted as dark bands.

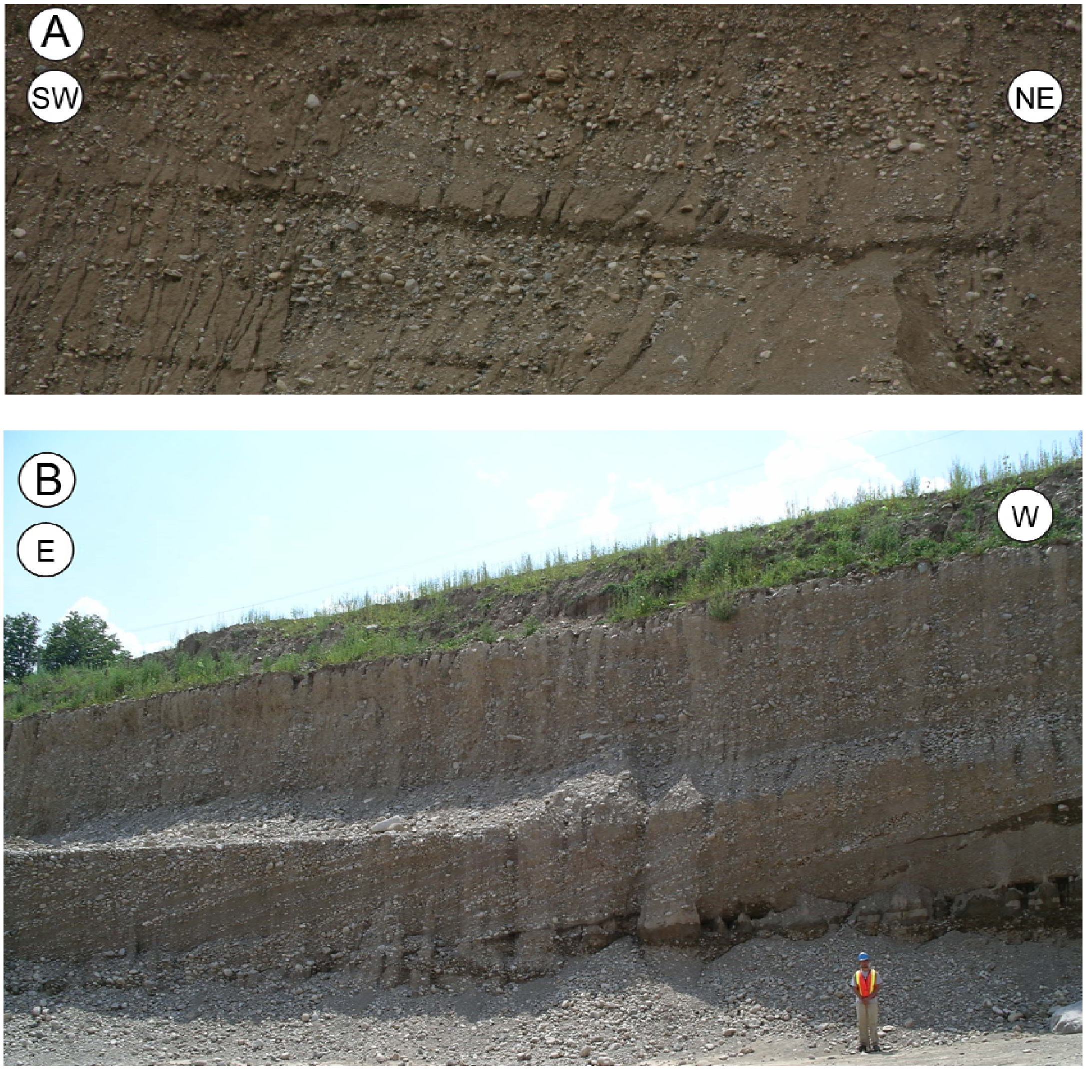


Figure 39. A) Illustrative photograph of cobble gravel in Alan Hart pit showing stacked nature of gravel succession, upward coarsening character of units, and low-angle cross-stratification. B) Large scale foresets exposed in 2006. Person for scale is ~2m.

2.28. THAMES VALLEY PIT

Location: West of Ingersoll
OGS map reference: M2281, report GR119, Cowan (1975)
Landform: Low-relief terrain
Map unit: Glacifluvial outwash
Stratigraphic position: Above Port Stanley Till
Sediment exposed: Pebble gravel; coarse sand matrix
Paleoflows: 145° to 220° (cross-strata dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: None obvious
Depositional setting: Glacifluvial outwash
Aquifer potential: Very good

General comments: Moderate–large pit. Pit faces are 2–3 m high. This site is similar to the Washington pit in that sediment is uniformly pebbly gravel and beds are laterally continuous and dune cross-stratified. However, dune cross-sets are thicker, on the order of 0.5–2 meters. The landscape is relatively flat with very little undulation. Depth of excavation at the site is limited by a high water table.

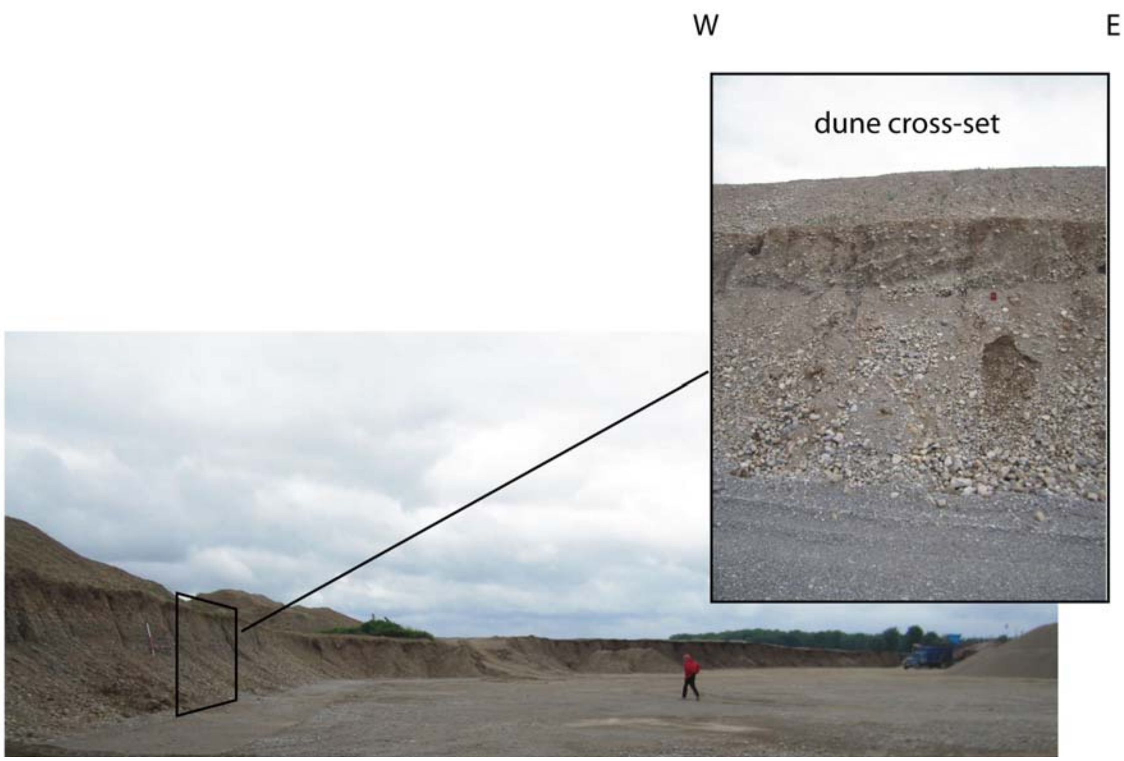


Figure 40. Illustrative photograph of extensive 3-4 m high pit face and close-up of dune-scale cross-strata, Thames Valley pit.

2.29. BAIGENT PIT (Nicli Aggregates)

Location: West of Ingersoll
OGS map reference: M2281, report GR119, Cowan (1975)
Landform: Hummocky terrain associated with Dorchester Moraine
Map unit: Ice-contact stratified sediment
Stratigraphic position: Above Catfish Creek Till
Sediment exposed: Pebble gravel; coarse sand matrix
Paleoflows: 195° to 310° (cross-strata dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: None obvious
Depositional setting: Subaerial outwash
Aquifer potential: Very good

General comments. The pit is moderately large and is mostly worked out. Pit faces are 4–5 m high. The additional depth of this pit, as compared to Thames Valley illustrates the generally deeper nature of ice-contact stratified sediment compared to outwash. The top of the pit faces is the modern soil, and large rusty root casts extend down into the sediment. Sediment consists of well sorted pebble gravel with a coarse sand matrix. Beds are commonly 10–75 cm thick and are typically dune cross-stratified. Locally dune-scale cross stratified sand is observed (Fig. 41). One- to two-meter thick sand beds with concave-up lower contacts and lateral extents greater than 10 m are inferred to be channel structures. Paleoflows are westward. No outsized clasts are stockpiled or observed *in situ*.

Figure 41. Illustrative photograph of cross-stratified gravel and sand, Baigent pit.

2.30. SPIVAK PIT (Aaroc)

Location: West of Ingersoll
OGS map reference: M2281, report GR119, Cowan (1975)
Landform: Hummocky terrain
Map unit: Glacifluvial outwash
Stratigraphic position: Above Port Stanley Till
Sediment exposed: Dune cross-stratified pebble gravel with coarse sand matrix
Paleoflows: 235° (gravel); 140° in rare coarse sand beds (cross-set dip direction)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: None obvious
Depositional setting: Glacifluvial outwash
Aquifer potential: Excellent

General comments. The pit is very large and shallow. It has largely been worked out and has very few fresh sediment faces. Large boulders are observed on the floor of the the pit. The pit is being used as a landscaping staging area. In 2006, approximately 3 m of outwash cobble gravel overlying greater than 0.5 m of grey clayey silt diamicton was observed. The diamicton is interpreted to be Port Stanley Till.

Figure 42. Illustrative photograph of largely worked out and partially rehabilitated shallow (< 3 m deep) Spivak pit with isolated piles of oversized unprocessed boulders and cobbles

2.31. STEVE SMITH PIT

Location: Northeast of Harrington, South of Stratford
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Hummocky terrain (next to incised channel) in Lakeside Moraine
Map unit: Ice-contact gravel
Stratigraphic position: Between Tavistock and Catfish Creek Till
Sediment exposed: Pebble gravel overlain by well-sorted sand overlain by mud overlain by diamicton
Paleoflows: 180–240° (gravel); 150–330° (sand dunes); 070–190° (climbing ripples)
Horizontal grain-size trend: None obvious
Vertical grain-size trend: Net upward fining
Depositional setting: Subaqueous fan. Gravel possibly a conduit deposit.
Aquifer potential: Very good (gravel)

General comments. Moderate sized pit. Exposed succession fines upward from 1) dune cross-stratified pebble gravel (locally cemented) to 2) well sorted fine sand with abundant dune cross-sets and climbing ripples to 3) laminated mud with dropstones and large lens of sandy boulder gravel (big dropstone) (sharp based) to 4) mud-rich diamicton (Tavistock Till). The diamicton has a sharp lower contact, but bedding is conformable (contact may be gradational). Minor high-angle faults are observed in sand. The mud unit thickens toward the north. The sand and gravel units are interpreted to have been deposited in a subaqueous fan setting. The gravel may possibly be a conduit (R-channel) deposit.

Figure 43. Remnant cemented dune-scale cross-stratified pebble gravel at base of Steve Smith pit near the entrance.

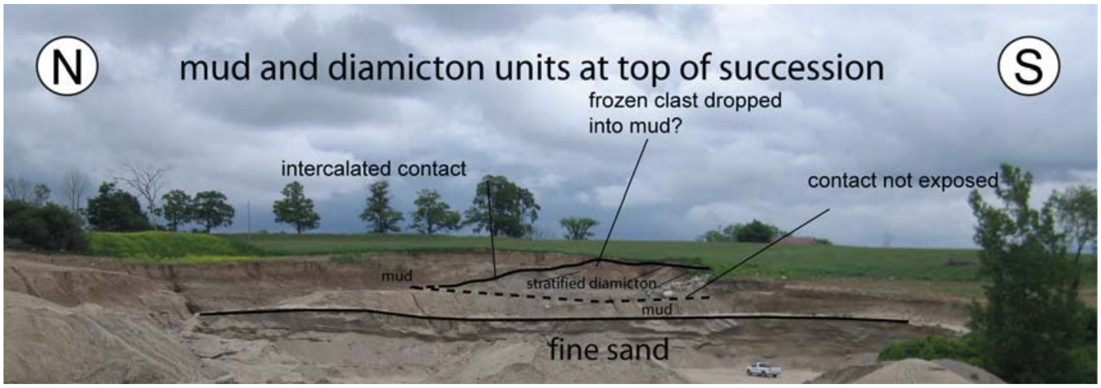


Figure 44. Overview photograph from the Steve Smith pit. The pit face is composed predominantly of ripple- and dune-scale cross-stratified sand overlain by diamicton and mud units.

2.32. TROUT CREEK PIT (Lafarge)

Location: Northeast of Harrington, South of Stratford
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Hummocky terrain in Lakeside Moraine
Map unit: Ice-contact gravel
Stratigraphic position: Above Catfish Creek Till, below Tavistock Till
Sediment exposed: Pebble–cobble gravel in back of pit (local boulder horizons). Fine sand in front of pit (Fig. 45).
Paleoflows: 180° to 235° (gravel) (dune cross-strata dip direction)
Horizontal grain-size trend: No sand over gravel at back of pit.
Vertical grain-size trend: Upward fining
Depositional setting: Subaqueous fan
Aquifer potential: Very good

General comments: This relatively large pit had few freshly exposed pit faces when visited in 2008. There was fresh gravel exposed at the back of pit, whereas at the front of the pit, gravel was overlain by sand. The gravel is locally high-angle cross-stratified. Cross-sets are 50–70 cm thick..

In 2006, up to 10 m of planar bedded and trough and planar cross-bedded pebble gravel to pebbly sand was observed. Cross-beds indicate flow towards the southeast, south and southwest. The west and southwest side of the pit displayed a higher proportion of ripple-drift, cross-laminated and planar laminated fine to medium sand. Nested channels containing ball and pillow and flame structures were observed. A 2-3 m thick layer of clayey silt diamicton, interpreted to be Tavistock Till, was observed midway through a 15 m section in the southwest corner of the pit. The base of the pit was floored by grey, stony, sandy silt diamicton interpreted to be Catfish Creek Till. The pit operator indicated that the depth of excavation at the site was limited by this unit.

At the extreme northwest corner of the pit, up to 10 m of well bedded cobble to boulder gravels containing lenses of grey-brown clayey silt diamicton reaching thicknesses of 5 m were observed. Boulders up to 1.5 m diameter and of Huron lobe provenance were commonly seen on the pit floor. Imbricate clasts indicate flow towards the south.

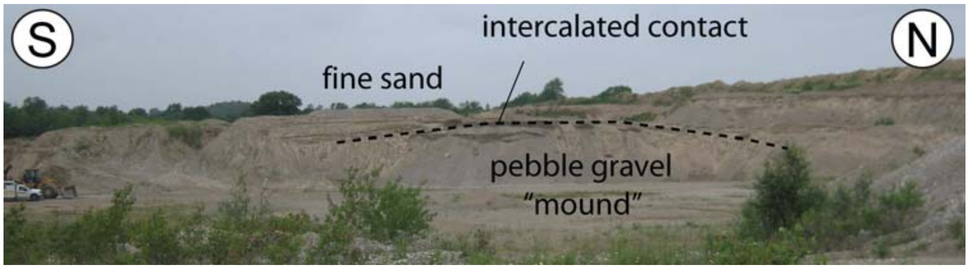


Figure 45. Illustrative photograph of sediment exposed in front half of the Lafarge Trout Creek pit. Capping fine sand unit is absent in back half of pit.

2.33. BLYTH DALE PIT # 2

Location: Northeast of Harrington, South of Stratford
OGS map reference: Map 2559, report 283, Karrow (1993)
Landform: Hummocky terrain in Lakeside Moraine
Map unit: Ice-contact gravel
Stratigraphic position: Above Catfish Creek Till, below Tavistock Till
Sediment exposed: Cross-stratified fine to medium sand with minor pebbly sand near top
Paleoflows: None recorded – observed pit from road
Horizontal grain-size trend: None apparent.
Vertical grain-size trend: Not apparent
Depositional setting: Subaqueous fan
Aquifer potential: Moderate

General comments: Small roadside pit with one small partially slumped face. The pit faces were photographed from the road as the pit was closed . In 2006, approximately 7 m of trough cross-bedded and planar bedded pebbly sand and fine to medium sand were observed. Paleoflows towards the southwest, south and southeast were noted.

Figure 46. Blyth Dale pit adjacent to Lafarge (pit 2.32). Exposed sediment consists predominantly of cross-stratified sand. Photograph taken from roadside.

3. SUMMARY

The classical deglacial hypothesis for southern Ontario was developed by Taylor (1913) and Chapman and Putnam (1943) based on landform mapping. Surficial geological mapping by the Ontario Geological Survey in the second half of the century, along with academic studies, led to the refinement of this hypothesis (Karrow, 1974; Barnett, 1992). In this hypothesis, direct deposition from glacier ice is emphasized and meltwater processes are downplayed. Increasing knowledge from modern glaciers and improved understanding of landform–process relationships has led to a controversial, modified version of the classic hypothesis that brings to the fore the role of regional meltwater floods (Shaw and Gilbert, 1990; Kor et al., 1991; Kor and Cowell, 1998; Brennand and Shaw, 1994; Sharpe et al, 2004). Some of these hypotheses lack a broad basis of support across the region, as they rely on individual studies or extensive work in any one part of the region. The work presented in this document is an initial attempt to collect observations from stratified deposits in the area that may yield valuable information deglaciation of the area and Laurentide ice sheet dynamics following the Michigan Subepisode. The depth and breadth of commentary is limited by the data collected and is consequently focused on three aspects of the glacial deposits i) glacifluvial gravels, ii) moraines, and iii) subaqueous fan deposits.

3.1. Glacifluvial Gravels

Three distinct gravel-rich facies associations are identified in moraines, outwash, ice-contact deposits, and in deposits beneath till uplands.

I Coarse boulder gravel deposit. Coarse boulder gravel occurs in the Brantford, Stuehler, and Oxford pits. The Brantford and Stueler pits are in the Paris and Galt moraines, and the Oxford pit is excavated into the side of a till upland at Woodstock. The deposits consist of framework boulder gravel that occurs in sharp based, concave upward or tabular units. Clast imbrication is poor to well developed, with subangular to subrounded clasts. Maximum clast axis length is approximately 1 m. Local clast clusters, massive texture, and cross-stratification are present.

At the Brantford and Stueler sites, the coarse boulder units appear to be more proximal deposits of the moraine sediment facies. At the Brantford site, these deposits are intimately associated with diamicton, in that an interbedded relationship is evident. This suggests that the diamicton may well be evidence of debris flow activity rather than subglacial till deposition. At the Oxford site, the coarse gravels occur high in the landscape near the top of a gravel succession and suggest a dramatic change in flow energy, possibly related to an episodic event such as an outburst storage release.

II Thick bedded gravel deposits. Thick cross-stratified gravel deposits are the more commonly observed bedding style, occurring at Highland, A-1, Dance, Lafarge Cambridge, Oxford, and Thorton pits. At all of these sites, it is not uncommon to observe cross-stratified beds >1 m thick that contain cobbles and boulders. Dune-scale cross-strata within these larger foreset packages are common. Gravel cross-sets contain a variety of facies, including bimodal, matrix-supported, cobble gravel, openwork gravel, bi-modal framework cobble gravel, and poorly sorted gravel. Massive gravel units are generally poorly sorted cobble caliber. The scale of the bedsets, style of stratification and location all indicate that these deposits are slightly lower energy deposits that in some cases may be more distal equivalents of the coarse boulder gravel deposits.

III Thin bedded gravel deposits. These deposits are recognized at a single site, the Washington pit, and consist of low-angle–dipping master bedding planes with relatively extensive lateral continuity and dune-scale cross-sets of less than 50 cm thickness. The strata have a uniformity of bedding thickness along hundreds of metres of section. Grain size at this site is remarkably consistent and varies very little from fine to medium pebble gravel with intervening units of medium to coarse sand. The deposits occur in areas mapped as glacifluvial outwash and have relatively little topographic relief. These deposits are most likely the deposits of relatively shallow braided fluvial streams in a proglacial setting. These deposits are very distinct from those described above.

3.2. Moraines – Composition and relationship of gravels and overlying tills

Three of the five Great Lakes surround Southern Ontario. They are thought to have functioned as conduits for late glacial ice lobes that converged on Southern Ontario and left a radial arrangement of moraines (Taylor, 1913). Most work on these moraines has focused on the age and provenance of tills that commonly overlie or occur within them. There continues to be a dearth of information, however, on the nature of the sediments within them and their stratigraphic position. Work in the 1990's has significantly revised early concepts on the origin and stratigraphic position for the Oak Ridges Moraine north of Lake Ontario (e.g. Sharpe et al., 2002). Similarly, work is on going to improve understanding of the depositional controls and depositional setting of the Waterloo Moraine (e.g. Bajc and Karrow, 2004; Russell et al., 2007). There continues to be a lack of similar studies of other moraines. This study visited 10 pits in the Waterloo Moraine (2.1 to 2.9, and 2.19) and 3 pits in the Paris – Galt moraines (sites 2.15,16, 21), 3 pits in the Lakeside Moraine and a single pit in the Dorchester Moraine.

Waterloo Moraine. The Waterloo Moraine consists of a diverse suite of sedimentary units attributed to deposition in a number of different environments, including subglacial meltwater conduits. subaqueous fans, and deltas. Sites presented in this study are inferred to have been deposited in subglacial and subaqueous fan settings. For example, the gravel deposits of the Highland and A-1 pits of the Waterloo Moraine are interpreted to be the proximal glacifluvial conduit deposits of downflow and lateral subaqueous fan deposits. Finer, sand-dominated deposits of the Top-of-the-Hill and Adams sites are interpreted to be subaqueous fan deposits lateral to and downflow of conduit deposits. Gravel deposits near the surface (Adam, Keiswetter, Security) have a more ambiguous depositional setting and may have been deposited in a conduit or open channel glacifluvial setting.

The accumulating data set from the Top-of-the-Hill site provides a well constrained case that large low-angle clinoforms in these settings are likely subaqueous barform deposits rather than being deltaic in origin. A similar interpretation is adopted for clinoforms in the Notre-Dame Road pit, which is located downflow of the Top-of-the-Hill site.

The Maryhill Till has been mapped beneath, within, and over top of the Waterloo Moraine (Karrow, 1996). At sites documented in this study (notably Top-of-the-Hill, Highland, A-1, MAR-CO) pebbly mud is indeed present locally at the top of the succession. However, the pebbly mud has a definite lamination and contains rare, thin sand beds. Consequently it is interpreted to be a glacilacustine deposit formed by density underflows, suspension sedimentation, and ice rafting of debris. Mud units at the A-1 site, which overlie gravel deposits and are in turn, overlain by sand, are well laminated, likewise contain graded silt and sand horizons, and are consequently interpreted to have formed in a similar fashion. These observations question the idea that the Maryhill Till units in and over the Waterloo Moraine are subglacial tills generated during ice advances. Rather, it seems possible that they record glacilacustrine phases related to reduced meltwater discharge (Bajc and Karrow, 2004).

Paris–Galt moraines. The Paris and Galt moraines have long been referred to as "till" moraines (e.g. Chapman and Putnam, 1943). Observations made in this study, however, suggest that there are significant quantities of stratified sediment within these moraines and that the till is largely a surficial element. The relative proportion, stratigraphic relationship, and lateral continuity of the gravel/sand and diamicton units may vary considerably. In the Brantford pit, the moraine consists of a thick succession of gravel organized into large clinoforms that fine downflow to sand rich deposits interpreted to be deposited in a subaquatic fan environment. The overlying diamicton is interstratified with the gravel and is locally stratified. Based on this relationship the diamicton is interpreted to be of debris flow origin consistent with deposition in a moraine setting. At the two Waynco pits in the Cambridge area, diamicton at the top of the succession is also interstratified with underlying gravel. The aspect of the gravel differs considerably from pit to pit, ranging from poorly sorted boulder gravel in the Stuehler pit to relatively well sorted, thinly bedded dune-cross-stratified gravel at the Waynco II pit. Consequently, it is likely that the moraines were deposited under a highly variable hydraulic regime that may contribute to rapid lateral facies transitions and potentially in considerable depths of water.

3.3. Subaqueous Fan Deposits

Deposits at the Top-of-the-Hill appear to record deposition from relatively strong, sustained ice-marginal discharges that can be modeled by a jet-efflux model (Russell and Arnott, 2003). Elsewhere, for example the Mar-Co pit (2.19), the later stage of smaller, less sustained flow discharges is recorded. In this setting, the interstratified character of pebble gravel and fine sand has produced a complex, compartmentalized aquifer geometry. The pebble gravel can consist of openwork pebble to heterogeneous sandy gravel. The interbeds of fine sand can be predominantly fine sand or contain a significant proportion of pebble material providing a bimodal character to the bed. This baffled gravel complex has locally, highly conductive pathways within the open work gravel, however, lateral continuity of the pathways is probably poor. In drill core, this baffled complex would be difficult to recognize. Failure to recognize this relationship could be significant, as within an aquifer setting this baffled complex would have relatively limited production capacity.

3.4. Hydrogeological Implications

Four main points regarding the hydrogeology of Southern Ontario can be drawn from the observations presented in this report.

i) **Recharge Areas on Moraines:** The till cover of moraines is a surficial element that has considerable spatial variability in both thickness and texture. Given its fine texture, it likely limits recharge into the ground. By contrast, the underlying coarse grained deposits of the five moraines visited are highly conductive and where saturated would form high-yield aquifers. Beyond this simplistic view, however, exactly how these moraines function as recharge zones continues to be poorly understood due to limited study. In an environment of increasing land use pressure and expanding urban development into these recharge areas, there is a need for increased study of these settings.

ii) **Preferential Flow paths:** Buried gravel deposits occur throughout Southern Ontario, not only in the mapped outwash deposits but also the stratified moraines, beneath till uplands, and within till covered moraines. Consequently, gravel deposits are more widespread than anticipated from review of surficial maps. Furthermore, within gravel units, it is apparent that there is considerable spatial variability and that locally, understanding of high yield zones, or preferential flow paths, is complicated and will require detailed sedimentological studies and application of well researched understanding.

iii) **Aquifer geometry and heterogeneity:** Acquisition of detailed sedimentological information on the architecture and sediment facies can contribute to development of improved depositional models. Such qualitative models can provide valuable conceptual knowledge on the likely distribution and scale of aquifer units.

iv) All deposits, except the Woodstck pits 2.22 – 2.25 occur above the regional unconformity. This relationship is an example of ongoing assessment that is needed related to regional event-sequence stratigraphic concepts.

4. CONCLUSION

The 33 sites visited for this study are distributed across a broad (75 x 50 km) area within Southwestern Ontario. The sites are situated in a variety of landforms (moraines, drumlinized uplands, hummocky terrain, outwash plains) geological map units, and stratigraphic positions. This reconnaissance survey did not collect detailed measurements but was focused on capture of a snapshot of the sedimentary character of as many pits as possible to assess the need for more focused study.

In light of the considerable advances in understanding of glacial dynamics in the past decade, new data collection and interpretation in Southern Ontario is warranted and timely. Recognition of depositional environments based on strict sedimentological criteria is difficult. Consequently, elucidation of questions related to deposition in subglacial or proglacial settings will require careful sedimentological, stratigraphic, and landform analysis within the framework of the complexity of knowledge of modern glacial settings. This report illustrates the wealth of field evidence available in Southern Ontario that future studies can access to help elucidate the geological history of the area and consequently can contribute to improved aquifer and hydraulic understanding and land use planning..

5. REFERENCES

Barnett, P.J. 1985. Glacial retreat and lake levels, north central Lake Erie Basin, Ontario. In: Quaternary Evolution of the Great Lakes (Eds P.F. Karrow and P.E. Calkin), pp. 185-194. Geological Association of Canada, Special paper 30.

Barrnett, P.J. 1992. Quaternary geology of Ontario. In: Geology of Ontario (Eds P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G.M. Stott), pp. 1011-1088. Ontario Geological Survey, Special Volume 4, Part 2, Toronto.

Barnett, P.J., Cowan, W.R. and Henry, A.P. 1991. Quaternary Geology of Ontario, southern sheet. Ontario Geological Survey, map 2556, 1: 1,000,000.

Bajc, A. F. 2007. Three-dimensional mapping of Quaternary deposits in the Brantford-Woodstock area, southwestern Ontario: a progress report; *in* Summary of Field Work and Other Activities 2007, Ontario Geological Survey, Open File Report 6213, p.22-1 to 22-9.

Bajc, A. F. 2008. An update on 3-dimensional mapping of aquifers in the Brantford-Woodstock area, southwestern Ontario; *in* Summary of Field Work and Other Activities 2008, Ontario Geological Survey, Open File Report 6226, p.29-1 to 29-8.

Bajc, A.F. and Karrow, P.F. 2004 3-dimensional mapping of Quaternary deposits in the Regional Municipality of Waterloo, southwestern Ontario. Geological Association of Canada and Mineralogical Association of Canada, Joint Annual Meeting, 2004, Fieldtrip FT-7, St Catharines, Ontario, 72 pp.

Bajc, A.F. and Shirota, J. 2007. Three-dimensional mapping of surficial deposits in the Regional Municipality of Waterloo, Southwestern Ontario; Ontario Geological Survey, Groundwater Resources Study 3, 41p.

Bocking, S. 2005. Protecting the rain barrel: Discourses and the roles of science in a suburban environmental controversy. Environmental Politics, 14, 611-628.

Brennand, T. A. and J. Shaw (1994). Tunnel channels and associated landforms, south-central Ontario: their implications for ice-sheet hydrology. Canadian Journal of Earth Sciences 31(3): 505-522.

Burt, A.K. 2007. Results of 2005 and 2006 Oro Moraine drilling program in the Barrie area, central Ontario. Ontario Geological Survey, Miscellaneous Release—Data 227.

Chapman, L.J. and Putnam, D.F. 1943. The moraines of southern Ontario. Transactions of the Royal Society of Canada, 37, 33-41.

Chapman, L.J. and Putnam, D.F. 1984. The Physiography of Southern Ontario. Special Volume 2. Ontario Geological Survey, 270 pp.

Coleman, A.P. 1932 The Pleistocene of the Toronto region. Ontario Department of Mines, Map no. 42g, scale 1:63,360, Toronto.

Cowan, W.R. 1973. Quaternary geology of the Woodstock area, southern Ontario. Ontario Geological Survey, Map 2281, scale 1:63 360.

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

Cummings, D.I. and Russell, H.A.J. 2008. Sedimentology of aggregate pits in the Alliston - Orangeville area, Southern Ontario: A reconnaissance survey for groundwater applications. Geological Survey of Canada,, Open File 5693, 77 p.

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

Dreimanis, A., Reavely, G.H., Cook, R.J.B., Knox, K.S. and Moretti, F.J. 1957. Heavy mineral studies of tills of Ontario and adjacent areas. Journal of Sedimentary Petrology, 27, 148-161.

Dreimanis, A. and Vagners, U. (Eds) 1971. The bimodal distribution of rock and mineral fragments in basal tills. (Ed R.P. Golthwait), Till-a symposium. Ohio State University Press., 237-250 pp.

Eyles, C.H. and Eyles, N. 1983. Sedimentation in a large lake: a reinterpretation of the late Pleistocene stratigraphy at Scarborough Bluffs, Ontario, Canada. Geology, 11, 146-152.

Hein, F. J. (1984). Deep-sea and fluvial braided channel conglomerates: a comparison of two case studies. Sedimentology of Gravels and Conglomerates. E. H. Koster and R. J. Steel. Calgary, Canadian Society of Petroleum Geologists. Memoir 10: 33-50.

Hunter, G.T. 1996. Executive summary: hydrogeological evaluation of the Oak Ridges Moraine Area (part of background report no. 3 for the Oak Ridges Moraine planning study). prepared by Hunter and Associates with Raven Beck Environmental Ltd.

Karrow, P.F. 1973. The Waterloo kame-moraine, a discussion. Zeitschrift fur Geomorphologie, 17, 126-133.

Karrow, P.F. 1974. Till stratigraphy in parts of southwestern Ontario. Geological Society of America Bulletin, 85, 761-768.

Karrow, P.F. 1987. Quaternary geology of the Hamilton-Cambridge area, southern Ontario; Ontario Geological Survey Report 255, 94p.

Karrow, P.F. 1993. Quaternary geology Stratford - Conestogo area. Ontario Geological Survey, Report 283, 104 p.

Karrow, P.F., Dreimanis, A. and Barnett, P.J., 2000. A proposed diachronic revision of late Quaternary time-stratigraphic classification in the eastern and northern Great Lakes area. Quaternary Research, 54(1): 1-12.

Karrow, P.F. and Paloschi, G.V.R. 1996. The Waterloo kame moraine revisited: new light on the origin of some Great Lake region interlobate moraines. Z. Geomorph. N F, 40, 305-315.

Karrow, P.F. and Terasmae, J. 1970. Pollen-bearing sediments of the Saint Davids buried valley fill at the Whirlpool, Niagara River gorge, Ontario. Canadian Journal of Earth Science, 7, 539-542.

Kor, P. S. G. and D. W. Cowell (1998). Evidence for catastrophic subglacial meltwater sheetflood events on the Bruce Peninsula, Ontario. Canadian Journal of Earth Sciences 35: 1180-1202.

Kor, P. S. G., J. Shaw, et al. (1991). Erosion of bedrock by subglacial meltwater, Georgian Bay, Ontario; a regional view. Canadian Journal of Earth Sciences 28(4): 623-642.

Krzyszkowskia, D. and Karrow, P.F. 2001. Wisconsinan inter-lobal stratigraphy in three quarries near Woodstock, Ontario. Géographie physique et Quaternaire, 55, 3-22.

Martini, I.P. 1990. Pleistocene glacial fan deltas in southern Ontario, Canada. In: Coarse-grained Deltas (Eds A. Colella and D.B. Prior), 10, pp. 281-295. Special Publication of the International Association of Sedimentologists.

O'Connor, D.R. 2002. Report of the Walkerton Inquiry The Events of May 2000 and Related Issues. Ontario Ministry of the Attorney General. URL: http://www.attorneygeneral.jus.gov.on.ca/english/about/pubs/walkerton/part1/

Ontario Geological Survey 2003. Surficial geology of southern Ontario. Ontario Geological Survey, Miscellanoeus Release - Data 128, 2 CD-ROMSp.

Piotrowski, J.A. 1987. Genesis of the Woodstock drumlin field, southern Ontario, Canada. Boreas, 16, 249-265.

Russell, H.A.J. and Arnott, R.W.C., 2003. Hydraulic Jump and Hyperconcentrated Flow Deposits of a Glacigenic Subaqueous Fan: Oak Ridges Moraine, Southern Ontario. Journal of Sedimentary Research, 73(6): 887-905.

Russell, H.A.J., Sharpe, D.R. and Bajc, A.F. 2005. Sedimentological Models Of The Waterloo Moraine For Groundwater Applications, Southern Ontario. In: Vol. 37, pp. 144. Geological Society of America Abstracts with Programs,, Salt Lake City Annual Meeting, October 16–19, 2005.

Russell, H.A.J., Sharpe, D.R. and Bajc, A.F. 2007. Sedimentary Signatures of the Waterloo Moraine: Emerging Insights. In: Glacial Sedimentology (Ed N. Glasser), International Association of Sedimentology, Special Publication 39, pp. 85-108..

Russell, H.A.J., Cummings., D I; Sharpe, D R; Slattery, S. 2007. Toward improved understanding of aquifer heterogeneity: a case study from the Lake Simcoe Regional Conservation Authority, Southern Ontario. In: Geological Society of America, Abstracts With Programs, vol. 39, pp. 162.

Sado, E.V. and Vagners, U.J. 1975. Quaternary geology of the Lucan area, southern Ontario. Ontario Geological Survey, Preliminary Map P. 1048, scale 1:50 000.

Sadura, S., Martini, I.P., Endres, A.L. and Wolf, K. 2006. Morphology and GPR stratigraphy of a frontal part of an end moraine of the Laurentide Ice Sheet: Paris Moraine near Guelph, ON, Canada. Geomorphology, 75, 212-225.

Sharpe, D.R., 1987. Stop 19 Woodstock Drumlin; in Barnett, P.J. and Kelly, R.I., XII INQUA Congress Field Excursion A-11: Quaternary History of Southern Ontairo, International Union For Quaternary Research.

Sharpe, D.R. and Barnett, P.J. 1985. Significance of Sedimentological studies on the Wisconsinan stratigraphy of southern Ontario. Geographie physique et Quaternaire, 39, 255-273.

Shaw, J. and R. Gilbert (1990). Evidence for large-scale subglacial meltwater flood events in southern Ontario and northern New York State. Geology 18: 1169-1172.

Sharpe, D.R., Hinton, M.J., Russell, H.A.J. and Desbarats, A.J. 2002. The need for basin analysis in regional hydrogeological studies: Oak Ridges Moraine, Southern Ontario. Geoscience Canada, 29, 3-20.

Sharpe, D.R., Pugin, A., Pullan, S.E. and Shaw, J., 2004. Regional unconformities and the sedimentary architecture of the Oak Ridges Moraine area, southern Ontario. Canadian Journal of Earth Sciences, 41(2): 183-198.

Spencer, A. 1890. Origins of the basins of the Great Lakes of America. American Geologist, 7, 86-97.

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

Todd, S.P., 1996. Process deduction from fluvial sedimentary structures. In: P.A. Carling and M.R. Dawson (Editors), Advances in Fluvial Dynamics and Stratigraphy. Wiley, pp. 299-350.

5.1. APPENDIX A (Individual Pit Outline Maps)

Legend

Symbols

	pit outline
	roads
	rail line
	~location of face
??	uncertain
	North arrow
100m	scale

Paleoflow

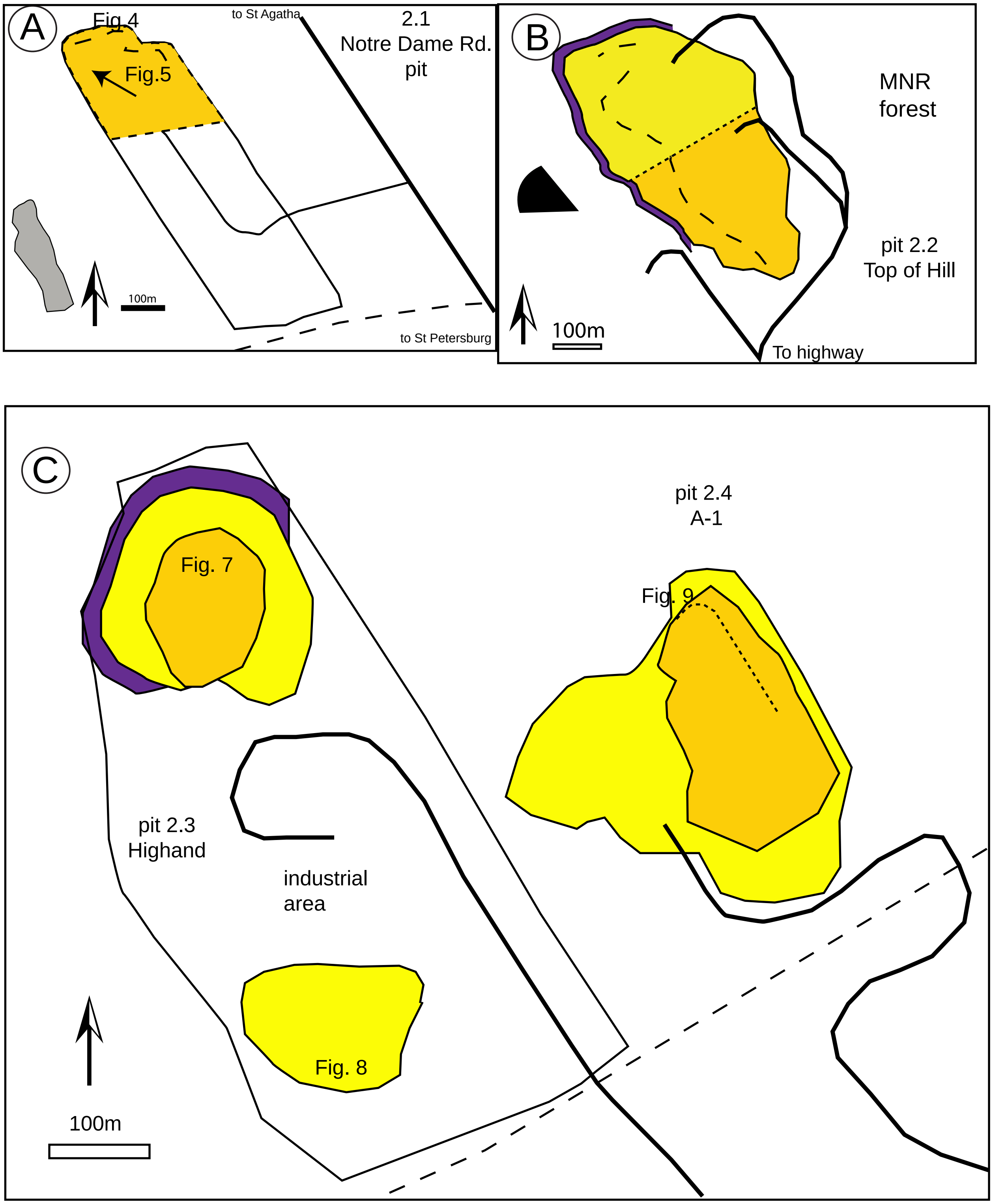
	range		solitary

Polygon Fill

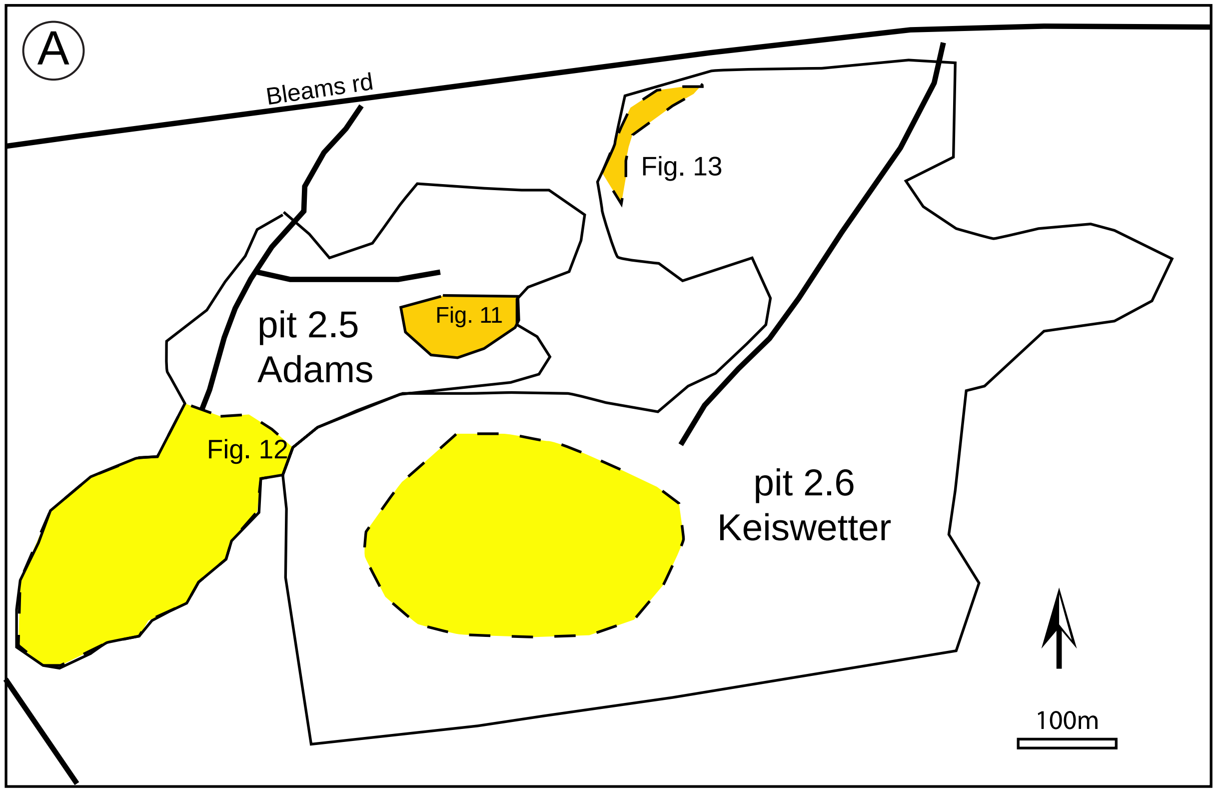
	gravel		water
	sand		not specified
	mud		not visited

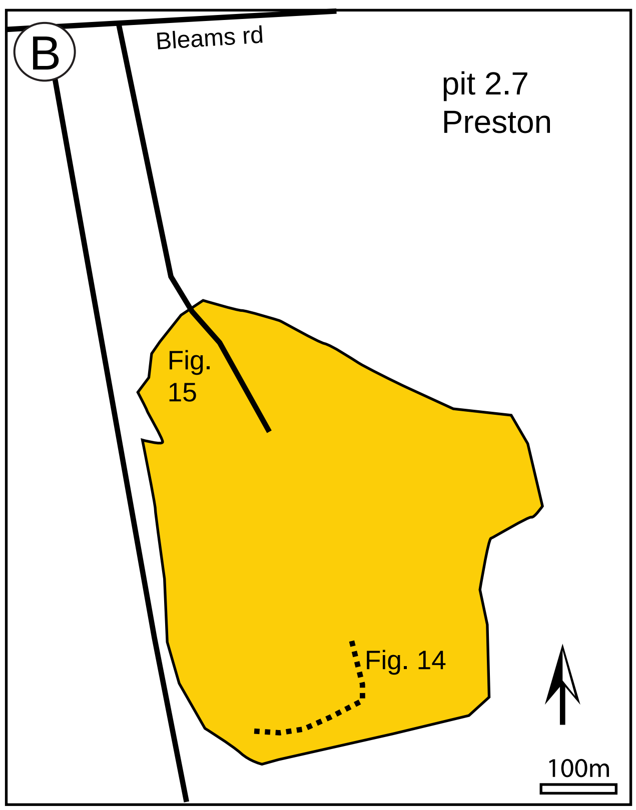
Sediment Codes

Di	diamicton	M	mud
Gr	gravel	Si	silt
Sa	sand	Cl	clay
Sr	ripple-scale cross laminated sand		

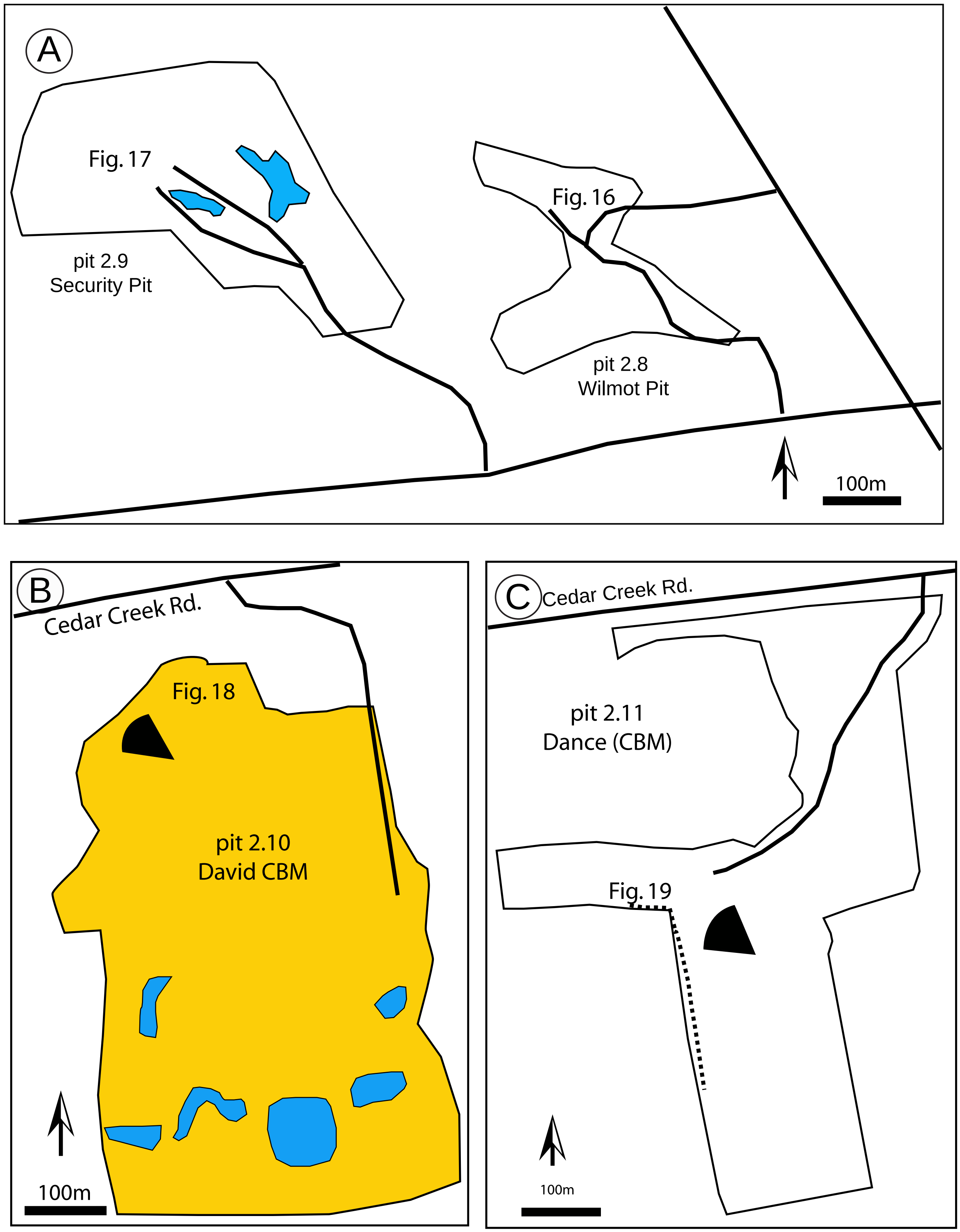


Appendix A. Figure 1. Pit location maps. A) pit 2.1 Notre Dame Road, B) pit 2.2 Top of the Hill, C) pits 2.3 Highland and pit 2.4 A-1

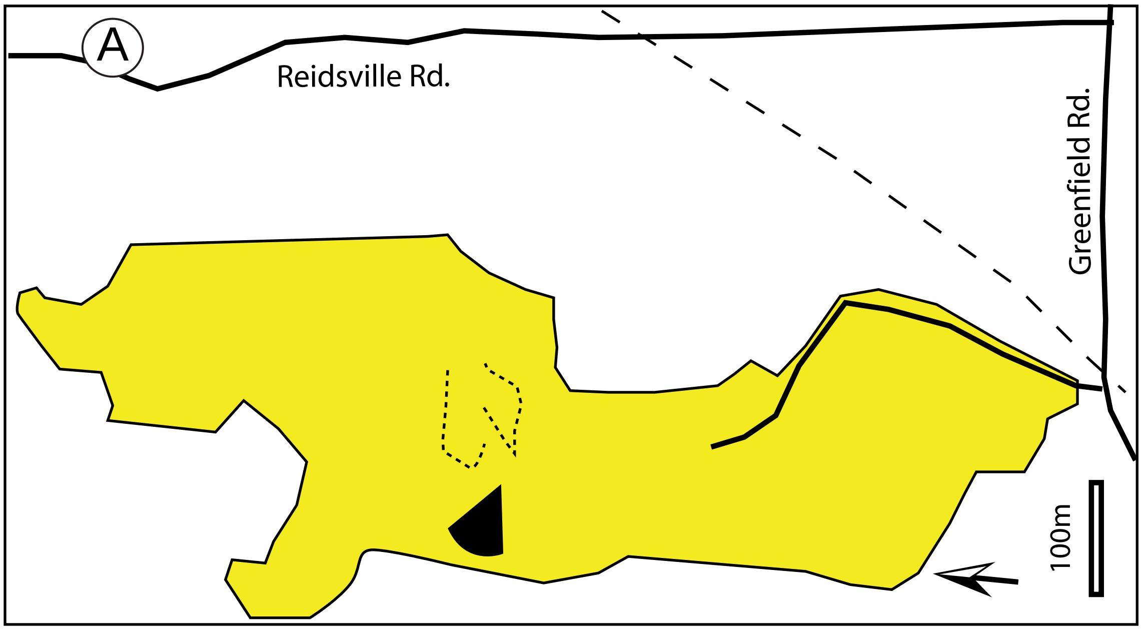


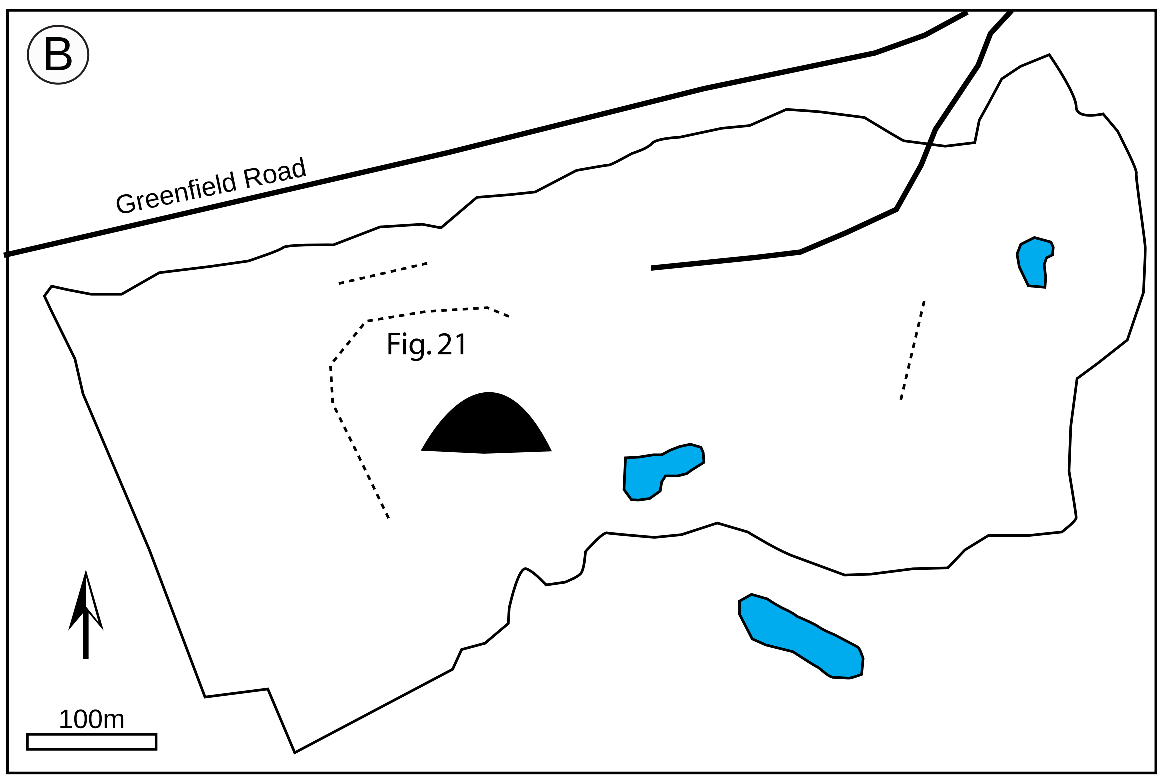


Appendix A. Figure 2. Pit plans, A) pit 2.5 Adams and pit 2.6 Keiswetter, B) pit 2.7 Preston

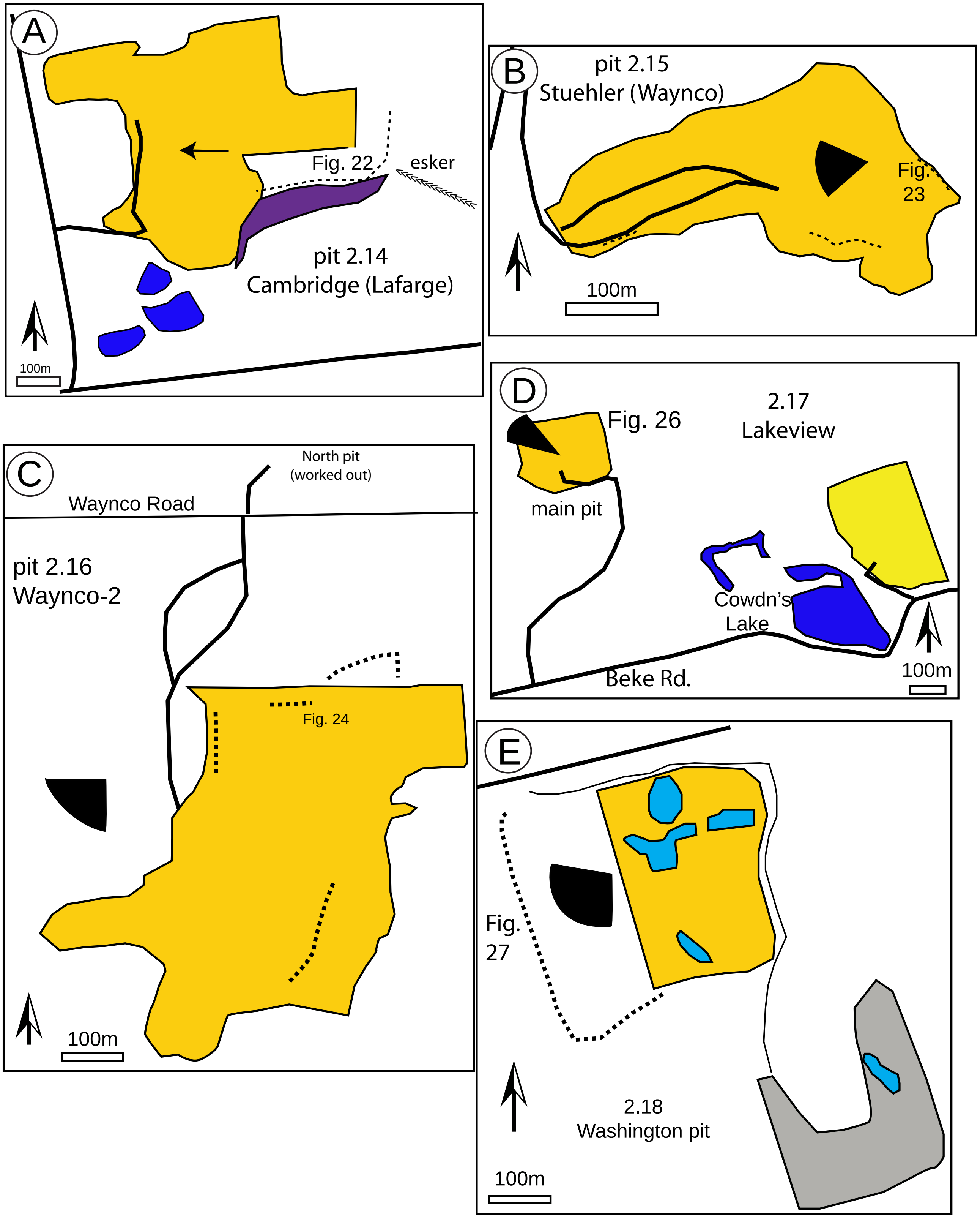


Appendix A. Figure 3. Pit plan maps. A) pit 2.9 Security, and pit 2.8 Wilmont, B) pit 2.9 David, C) pit 2.10 Dance

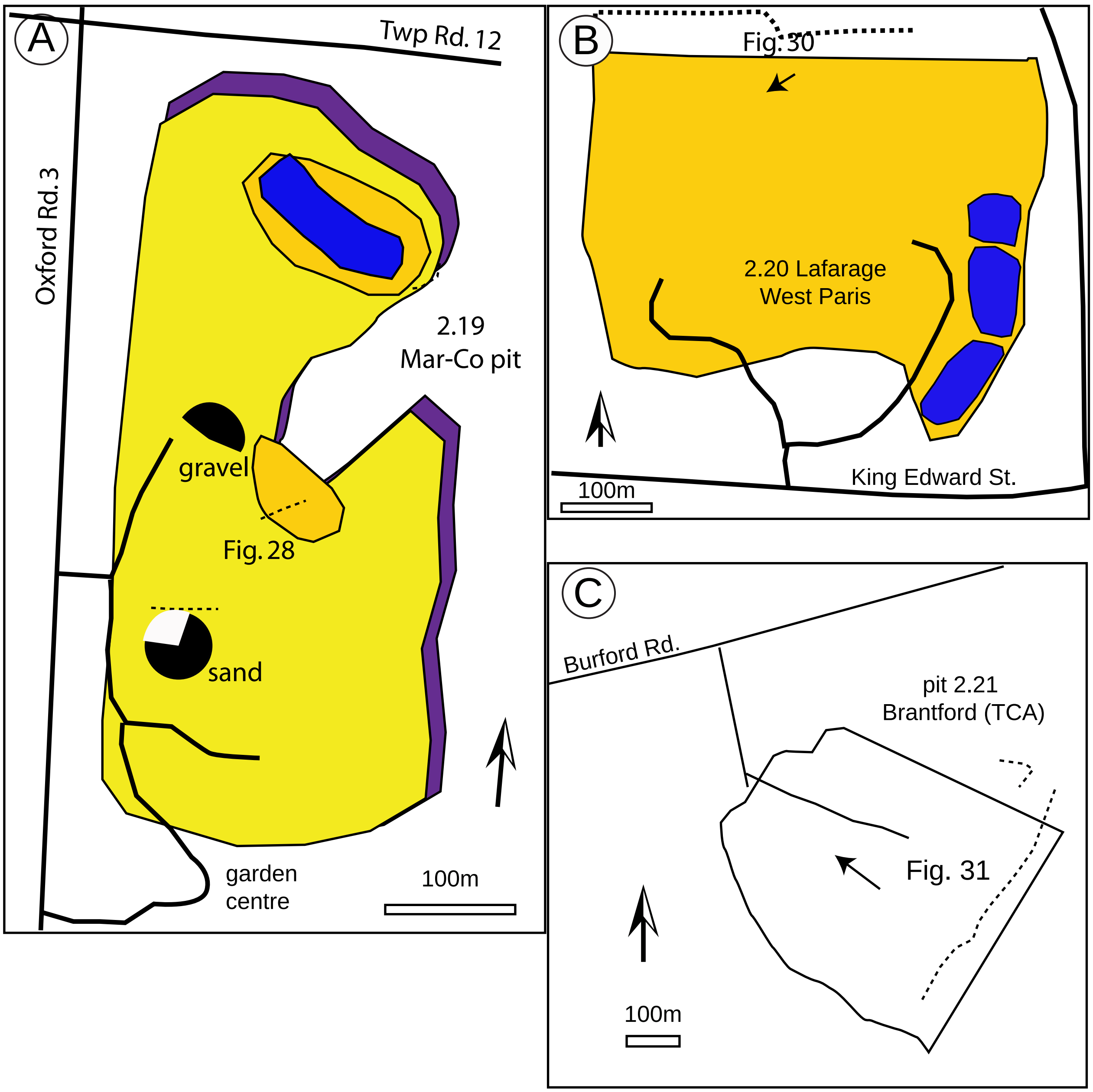




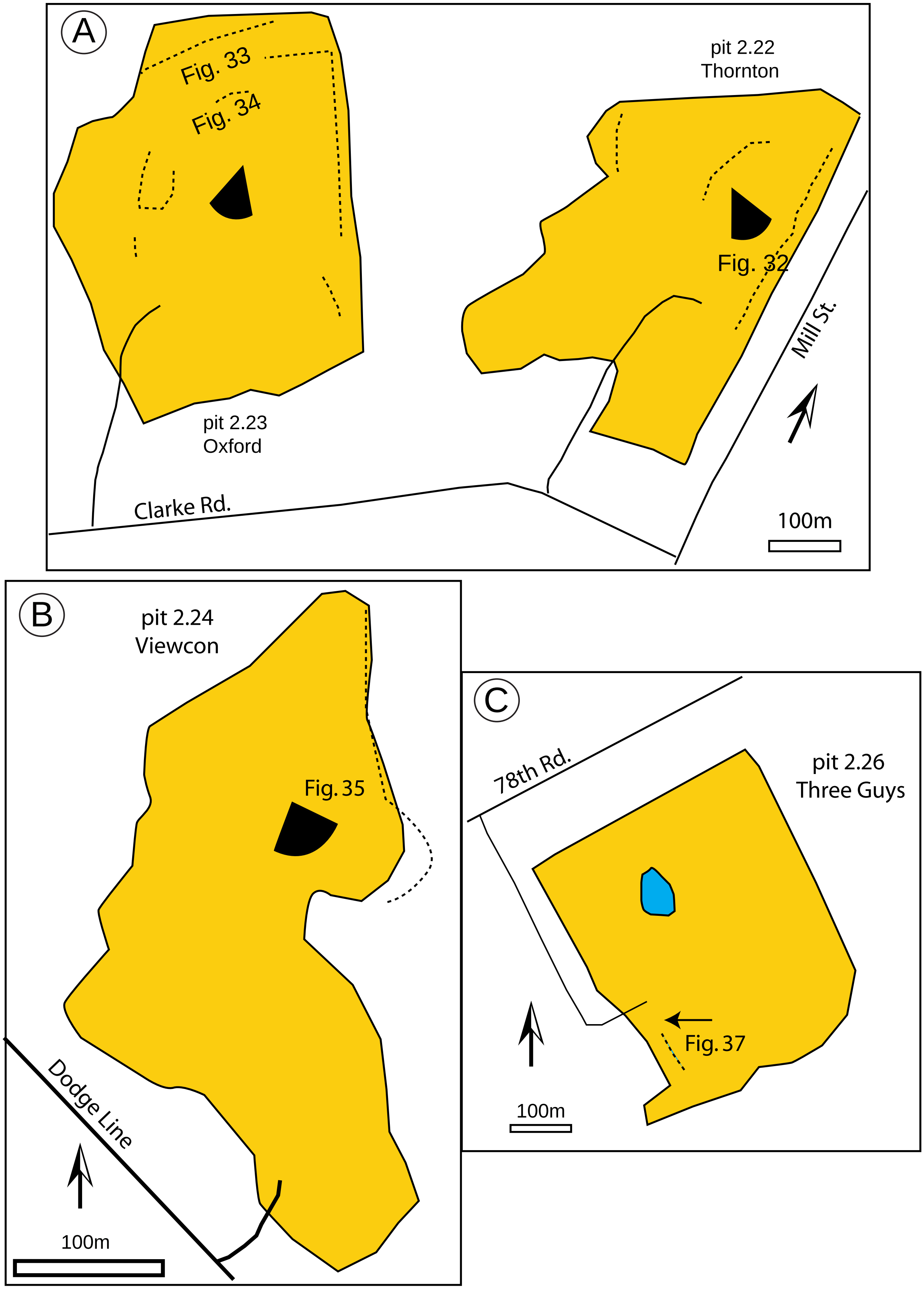
Appendix A. Figure 4. Pit plan maps, A) pit 2.12 Ayr pit (CBM Aggregates), B) pit 2.13 Ayr pit (Greenfield Aggregates)



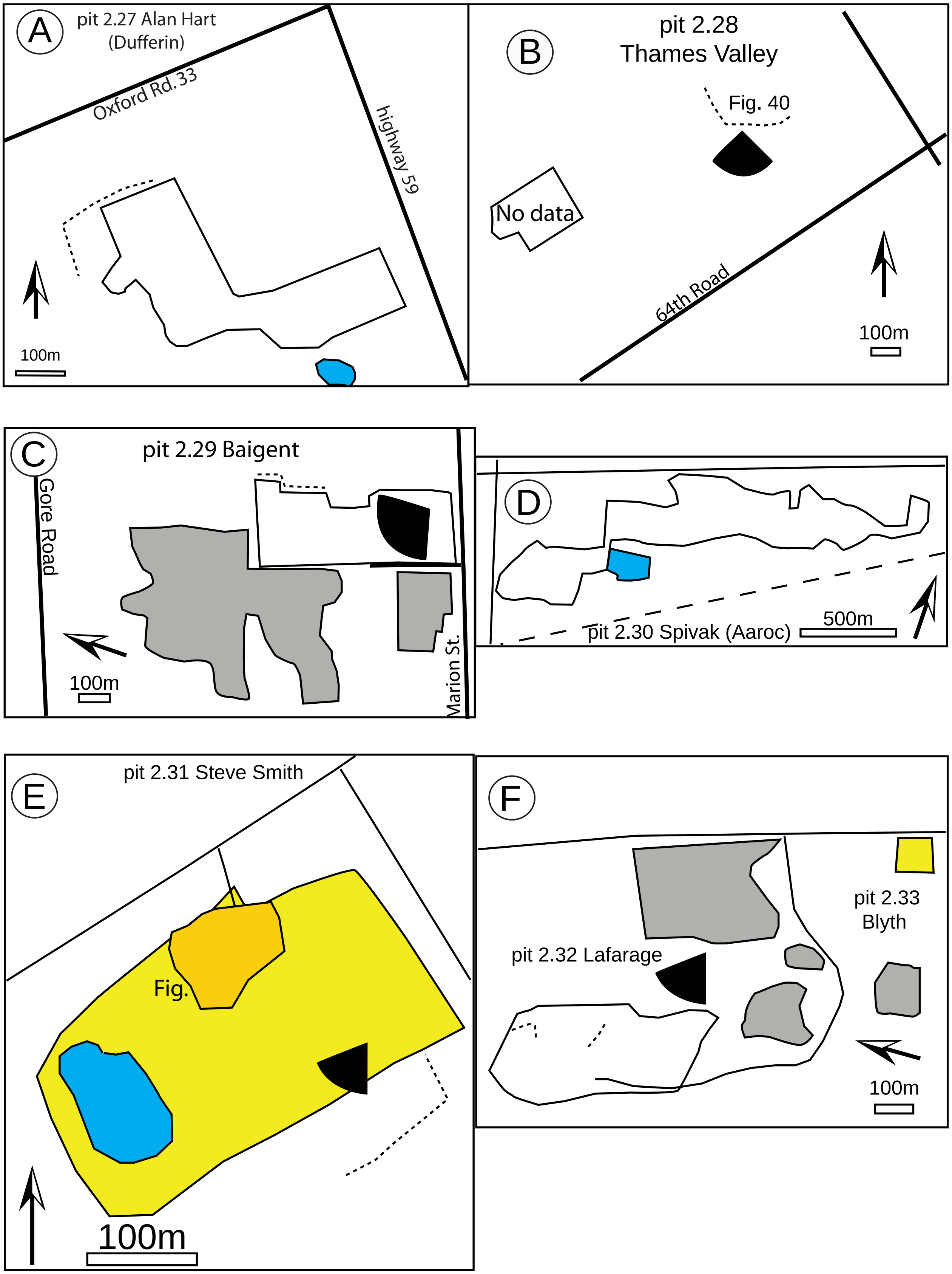
Appendix A. Figure 5. Pit plan maps, A) pit 2.14 Cambridge (Lafarage), B) pit 2.15 Stuehler (Waynco), C) pit 2.16 Waynco-2, D) pit 2.17 Lakeview, E) pit 2.18 Washington



Appendix A. Figure 6. Pit plan maps A) pit 2.19 Mar-Co, B) 2.20 Lafarge West Paris, C) pit 2.21 Brantford pit (Telegraph City)



Appendix A. Figure 7. Pit plan maps, A) 2.22 Thornton and 2.23 Oxford Sand and Gravel, B) pit 2.24 Viewcon, C) 2.26 Three Guys



Appendix A. Figure 8. Pit plan maps, A) pit 2.27 Alan Hart (Dufferin), B) pit 2.28 Thames valley, C) pit 2.29 Baigent, D) pit 2.30 Spivak (Aaroc), E) pit 3.31 Steve Smith, F) pit 3.32 Lafarage and pit 2.33 Blyth.

5.2. APPENDIX B (Table of sites visited)

2008 number	Pit Name	Pit Operator	Easting	Northing
2.10	Notre Dame	not identified	532908.00	4807840.00
2.20	Top of the Hill	not identified	532906.33	4807839.67
2.30	Highland	not identified	533824	4808002
2.40	A-1	not identified	534434	4807848
2.50	Adam	not identified	538458	4804886
2.60	Keiswetter	not identified	538628	4805087
2.70	Preston	Preston	539648.78	4804966.14
2.80	Wilmot Pit	Wilmot County pit	534988	4802459
2.90	Security	not identified	534298	4802359
2.10	David	CBM	547470.62	4798268.74
2.11	Dance	CBM	552439.61	4799197.58
2.12	Ayr	CBM	545513.23	4795195.59
2.13	GreenField	Fermar Crushing & Recycling	545513.23	4795195.59
2.14	Cambridge	Lafarge	549087.91	4797710.09
2.15	Stuehler	Waynco, Nelson Aggregates	556344.93	4794373.64
2.16	Main	Waynco, Waynco, Nelson Aggregates	556608.00	4796933.00
2.17	LakeView	LakeView	553863.66	4795618.46
2.18	Washington	not identified	538705.00	4794687.00
2.19	Marco-clay	Marc-Clay	534621.00	4793810.00
2.20	West Paris	Lafarge	548150.00	4780654.00
2.21	East Bradford	Telephone Corporation Aggregate	554888.00	4774794.00
2.22	Woodstock	Thornton	519308.00	4772662.00
2.23	Oxford Sand and Gravel	Oxford Sand and Gravel	519055.00	4772235.00
2.24	viewcon	Viewcon	521177.00	4766986.00
2.25	farmers hummock	Farmers hummock	518860.00	476370.00
2.26	three guys	Three guys	510012.12	4777783.46
2.27	Alan Hart Pit	Dufferin Sand and Gravel	517343.22	4780526.29
2.28	Thames Valley	Thames Valley	501421.00	4765323.00
2.29	Baigent Pit	Nicli	499218.00	4763101.00
2.3	Spivak Pit	Aaroc		
2.31	Steve Smith	Steve Smith	501606.00	4791311.00
2.32	Lafarge	Lafarge	501748.00	4789902.00
2.33	pit # 2	Blyth Dale	502672.00	4789103.00