GEOLOGICAL SURVEY OF CANADA

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Sedimentology of aggregate pits in the Alliston – Orangeville area, Southern Ontario: A reconnaissance survey for groundwater applications

Cummings, D. I. and Russell, H. A. J.

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Sedimentology of aggregate pits in the Alliston – Orangeville area, Southern Ontario: A reconnaissance survey for groundwater applications

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INTRODUCTION

The heterogeneity of surficial sediments commonly exerts a first-order control on how water enters, exits and flows through the ground. Aggregate pits offer a cost-free, high-quality window of insight into this heterogeneity. Visiting aggregate pits is therefore a useful first step in developing effective groundwater management strategies.

The Lake Simcoe Conservation Authority has a mandate to better understand groundwater resources in watersheds that fall under its jurisdiction. In an effort to quantify the permeability of surficial sediment in the Nottawasaga River watershed, a necessary input variable for the numerical groundwater-flow model, several gravel pits were surveyed between November 6 and 10, 2006 (Fig. 1; Table 1). This report documents the results of the survey.

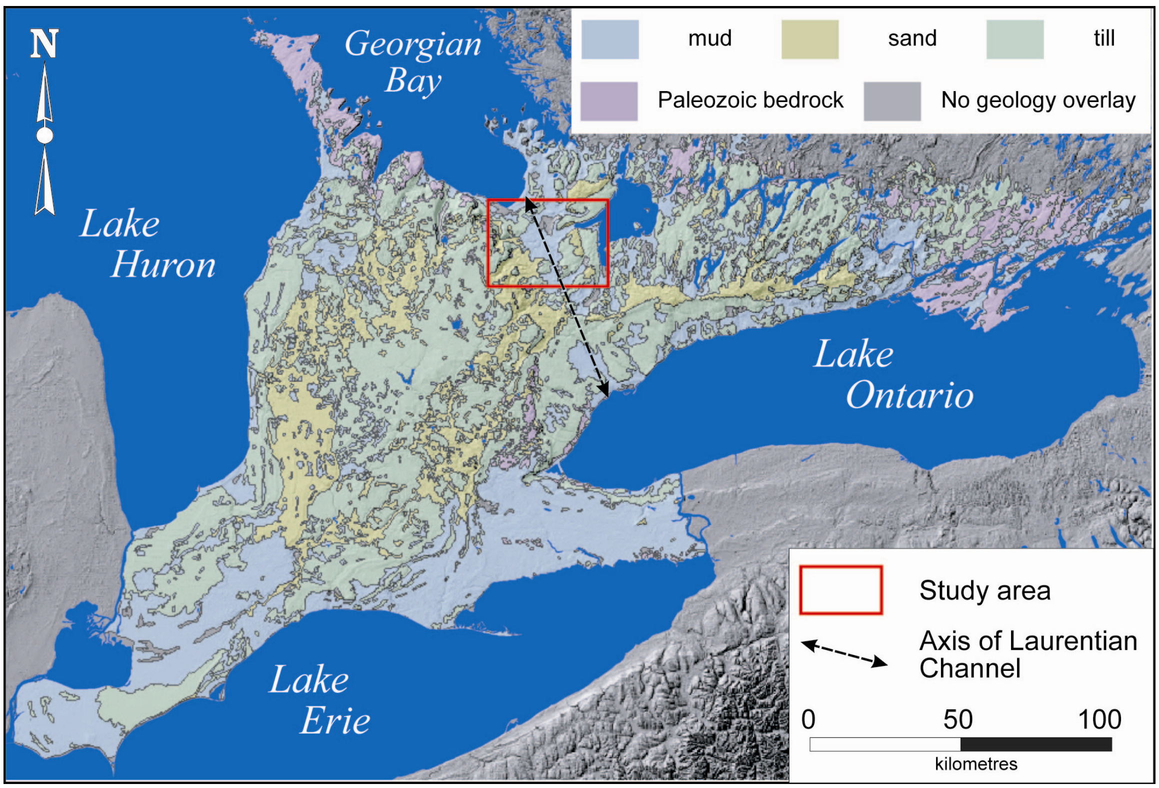

Figure 1. Location of study area, Lake Simcoe region, Southern Ontario (geology simplified from Barnett et al. 1991). Lake Simcoe is to the northeast of study area.

Study Area And Geological Setting

The Nottawasaga River watershed is roughly delimited by the Niagara Escarpment to the west, Lake Simcoe to the east, the Oak Ridges Moraine to the south and Georgian Bay to the north (Fig. 1, 2). Surficial sediment units in the watershed include till (~35%), ice-contact stratified sediment (~15%), glacifluvial deposits (~10%) and glacilacustrine sand and silt (~30%) (Fig. 2). All sediment in the western part of the watershed is interpreted to rest stratigraphically above the Newmarket Till, a sheet-like regional aquitard that was likely deposited subglacially during the last glacial-maximum (~18 ^{14}C ka BP) (Fig. 3).

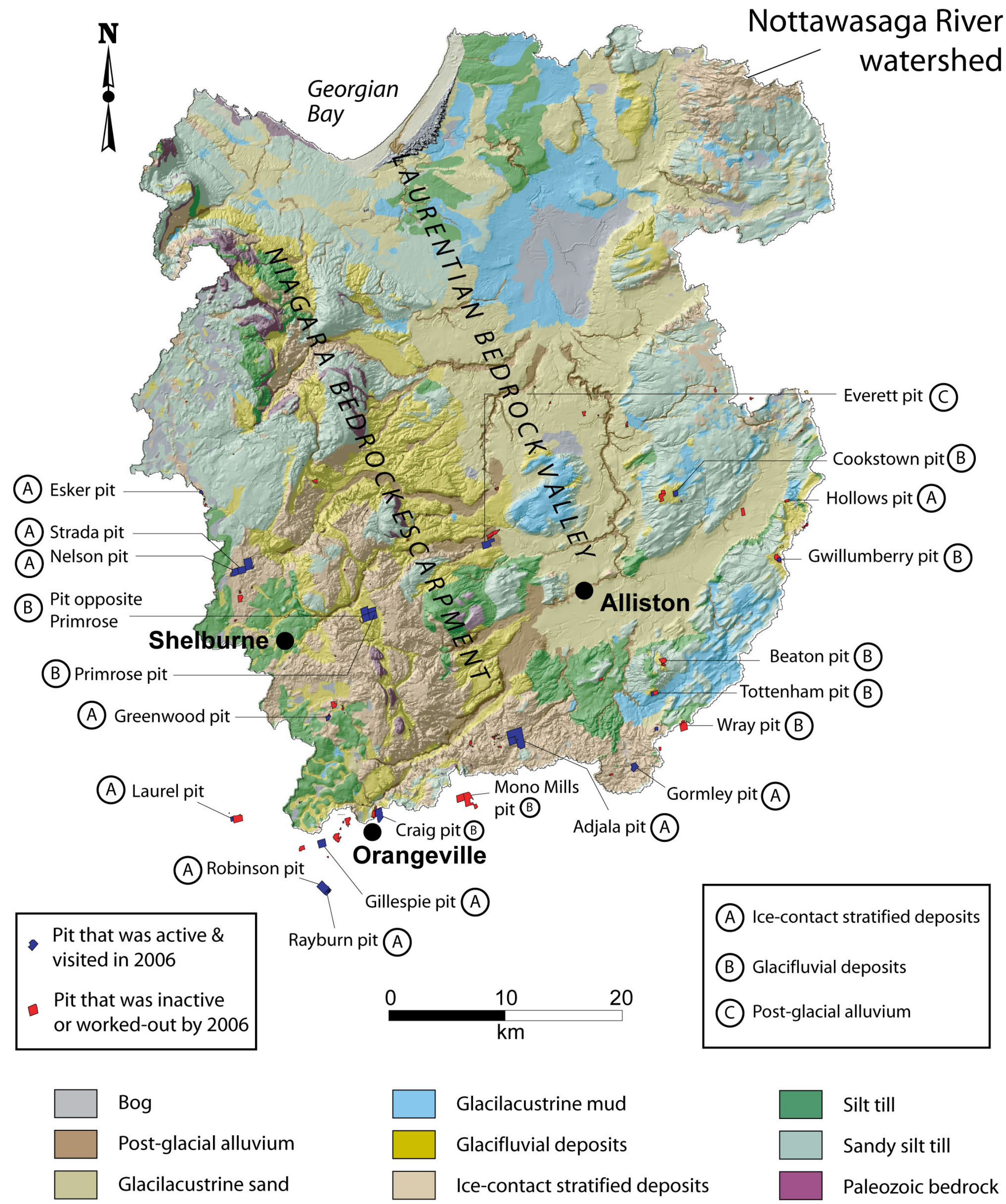

Figure 2. Surficial geology of the Nottawasaga River watershed draped on the Ontario Ministry of Natural Resources 10 m digital elevation model (DEM), showing the location of pits visited during November 2006. Surficial geology modified from Ontario Geological Survey (OGS) seamless map for Southern Ontario (1:50,000 coverage).

Five main landscape elements are identified in the watershed (oldest to youngest): 1) the Niagara Escarpment, 2) drumlinized Newmarket Till uplands (aquitard), 3) lowlands, 4) stratified moraines, and 5) proglacial glacifluvial channels. The Niagara Escarpment is a prominent bedrock-cored feature that trends north–south across the study area. East of the escarpment, and buried by the surficial sediment, is the Laurentian valley, a 100 m deep, 50 km wide valley extending from Georgian Bay to Lake Ontario (Sharpe et al., 2005). This buried feature is predominantly filled by lower sediment, which locally forms the Alliston aquifer. Lower sediment are overlain by drumlinized Newmarket Till which form uplands. Lowlands adjacent to till uplands are tunnel channels that are incised into lower sediment, and locally extend to bedrock (Fig. 3). Stratified moraines, in turn, overlie the Newmarket Till and tunnel channels locally. They are characterized by two distinct morphological signatures, hummocky terrain of the Orangeville and Oak Ridges Moraines and the more linear, ridge-like morphology of the Gibraltar and Singhampton moraines. These moraines are interpreted to have been deposited by westward-flowing meltwater that expanded into standing water bodies. They are commonly mapped as ice-contact stratified deposits. Following withdrawal of ice from the region, lowlands were inundated by Lake Algonquin and blanketed by a thin cover of glacilacustrine mud and sand (Sharpe et al., 1997).

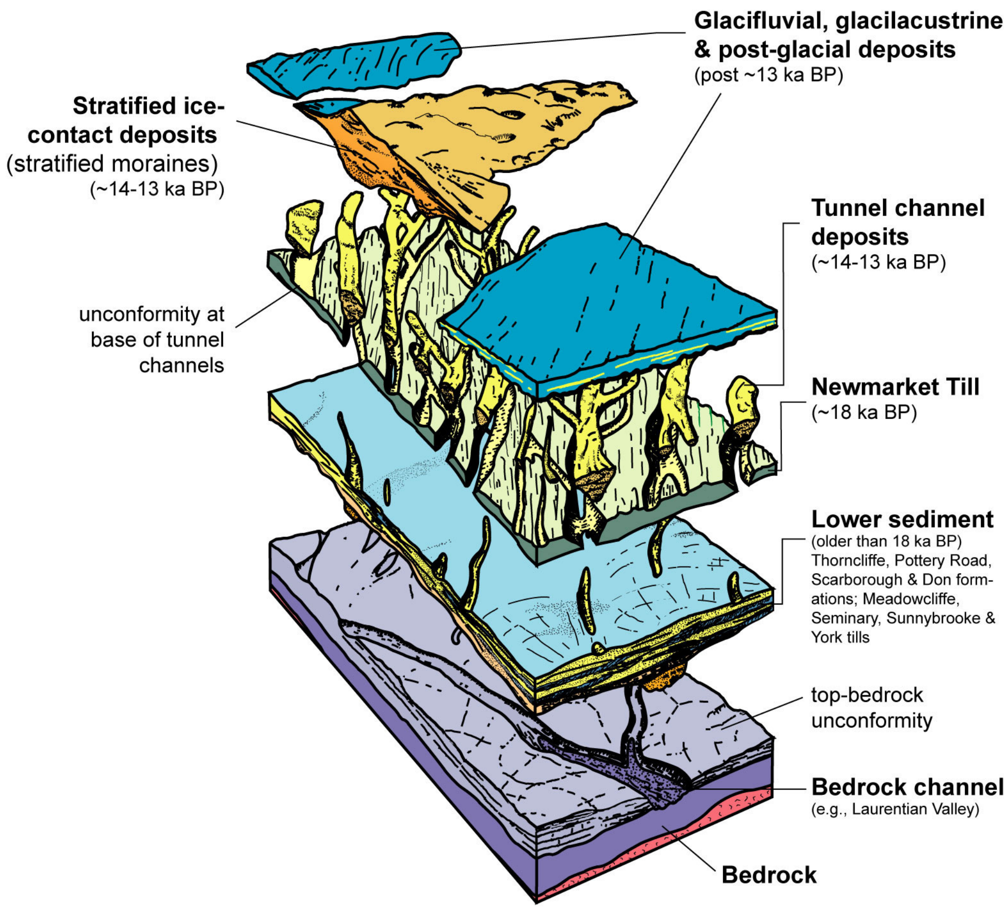

Figure 3. Stratigraphy of surficial deposits in the vicinity of the Nottawasaga River watershed, Southern Ontario (highly simplified and in part conceptual). Modified from Sharpe et al. (1997). Original drawing by John Glew.

METHODOLOGY

Prior to field work, pit locations were identified using Google Earth satellite images (Fig. 4). This reconnaissance mapping technique proved effective for most of the southern Nottawasaga watershed because high resolution DigitalGlobe data were available, which readily allowed aggregate pits to be identified as operational or inactive (Fig. 4A, C). Determining pit activity level in areas outside of the high-resolution DigitalGlobe coverage proved difficult (Figs. 4A,B). Pit locations were verified using the Ontario Ministry of Natural Resources (MNR) aggregate pit license cadastral layer (provided courtesy of Lake Simcoe Conservation Authority). Geological and topographic context for the study area was provided by the Ontario Geological Survey seamless 1:50000 geological map, the Ontario Ministry of Natural Resources 10 m DEM, and the

Figure 4. Selected Google Earth images from the Nottawasaga River watershed that were used to assess pit activity prior to field work. (A) Area around Shelbourne illustrating contrast between low resolution TM data and high resolution DigitalGlobe coverage. (B) image in vicinity of Nelson pit. Note old age of image (e.g., Strada pit is not present) and grainy quality of TM image. (C) Higher resolution DigitalGlobe image of Primrose pit.

respective 1:50,000 geological maps (e.g. Cowan, 1976). Efforts were made to visit all large pits, and all pits that appeared active (Fig. 5).

Sediment exposed in the pits was described using standard sedimentological and stratigraphic techniques and concepts (e.g., Walker and James, 1992; Benn and Evans, 1998; Posamentier and Allen, 1999). Pit faces were photographed and described in bed-scale detail. Major units were identified, noting sedimentary structures, textures, paleoflow directions (from dune and current-ripple cross-stratification), and the nature of contacts. This was a reconnaissance survey: time precluded the collection of extensive datasets. For example, in almost all cases, paleoflows are averages based on only several measurements. As such, they should only be considered accurate within +/- 45^{o}, unless otherwise noted. Data presented for three pits (Wray, Hollows, and Mono Mills) has been incorporated from visits in 1993 and 1994 by the second author. Assigned hydraulic conductivity (K) values in all figures are general book values from Domenico and Schwartz (1990).

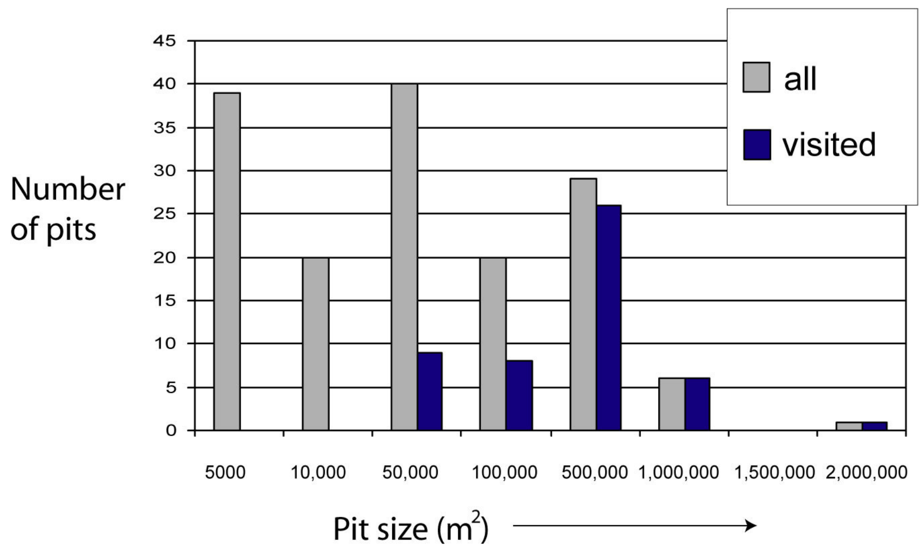

Figure 5. Size and number of pits in the watershed based on information from the Ontario Ministry of Natural Resources pit license cadastral file. Note that almost all large pits were visited.

SEDIMENTOLOGY OF AGGREGATE PITS

Of the 25 pits visited, 21 had active pit faces with some degree of fresh exposure (55 licenses), To provide ease of comparison the pits have been grouped according to the nature of the geological map units they occur within. Eleven pits were located in areas mapped as ice-contact stratified sediment, nine were located in areas mapped as glacifluvial deposits, and one was located in an area mapped as alluvial deposits (Fig. 2). Strata in all pits, with the possible exception of the Hollows and Beaton pits, are interpreted to stratigraphically overlie the Newmarket Till.

Ice-Contact Stratified Sediment Deposits

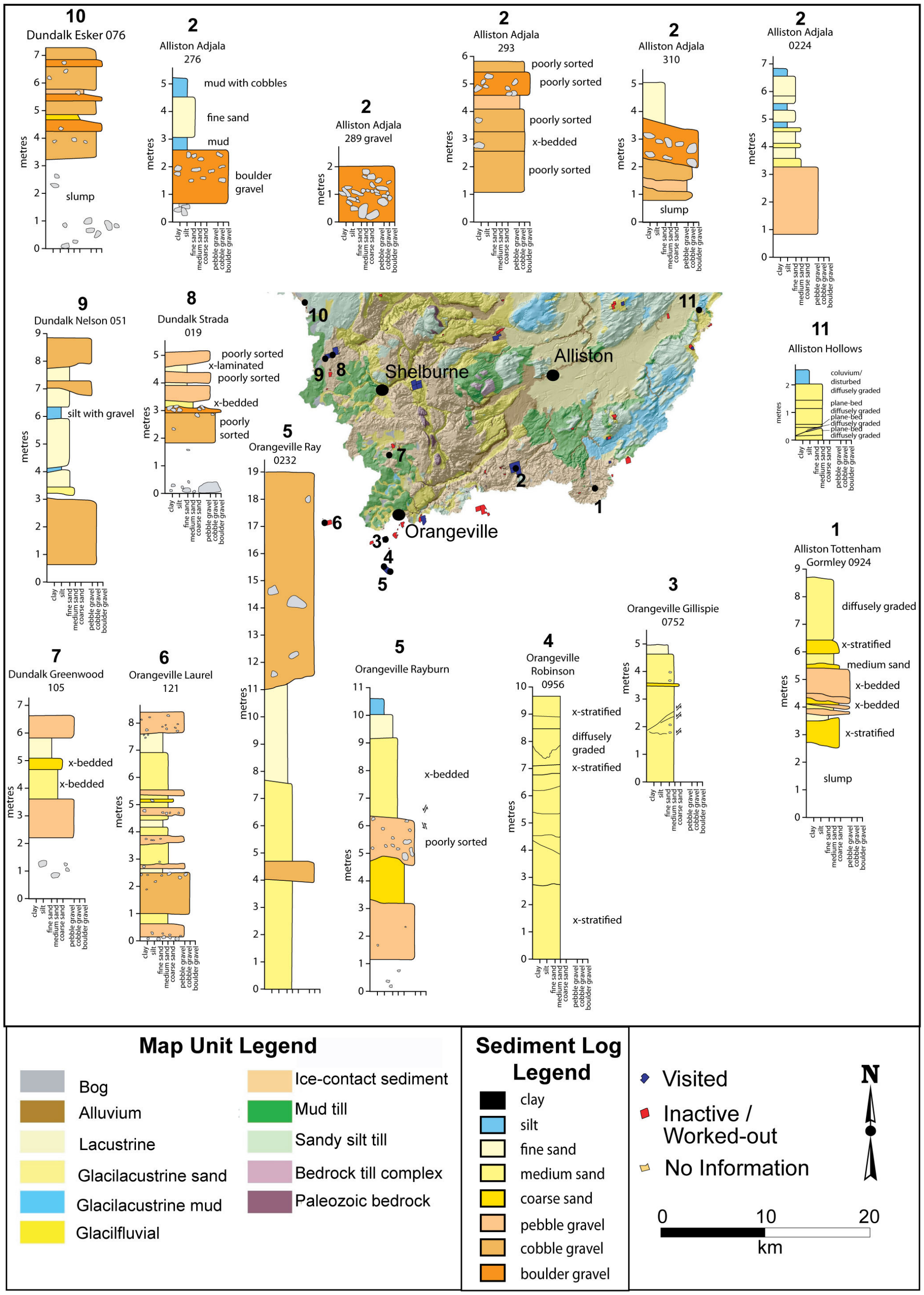

Figure 6. Summary display of graphic logs for sites visited in ice-contact stratified sediment deposits. Note variability in textures of deposits and depth of exposure. Numbers indicating sites correspond to heading numbers in text.

1. GORMLEY PIT

Map unit: Ice-contact stratified sediment (Oak Ridges Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Sand, pebble gravel, mud stripped from top?
Depositional environment: Subaqueous fan
Aquifer potential: Very good
Horizontal permeability: Very high
Vertical permeability: Moderate to low

The Gormley pit is located 14 km north–northwest of Bolton on Highway 9 at the Canadian Pacific railroad overpass in an area mapped as ice-contact stratified sediment of the Oak Ridges Moraine (Russell and White, 1997) (Figs. 2, 7). The landscape in the vicinity of the pit is undulatory to hummocky, with local relief of 3–5 metres. The pit was previously described by Russell and Arnott (2003) based on field observations made in 1993, 1994, 1996, and 1998. Since then, the pit faces have changed extensively.

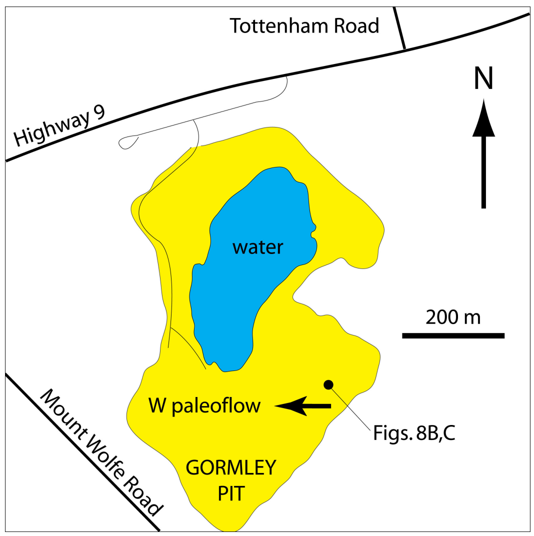

Figure 7. Overhead sketch of Gormley pit from Google Earth satellite images.

The active pit face is currently 7–12 m high and ~100 m in horizontal extent (Fig. 8A). A tripartite stratigraphy of sand, gravel, and sand is observed (Figs. 8B, 8C). An overlying muddy unit exposed in the 1990s is now absent, presumably because it has been stripped from the top of the outcrop by the pit operators. All units are traceable laterally over the extent of the exposed face, about 100 metres. The basal sand unit consists predominantly of dune cross-stratified medium sand. The overlying pebble gravel unit is 1–5 metres thick and dune cross-stratified. The upper sand unit consists of fine to medium sand with diffusely laminated intervals and dune cross-stratified beds. Cross-strata dip westward, and a westward fining trend is observed.

Based on the westward paleoflows, westward fining trend, and sediment facies, strata at the Gormley pit are interpreted to have been deposited in a subaqueous fan environment. See Russell and Arnott (2003) for further details.

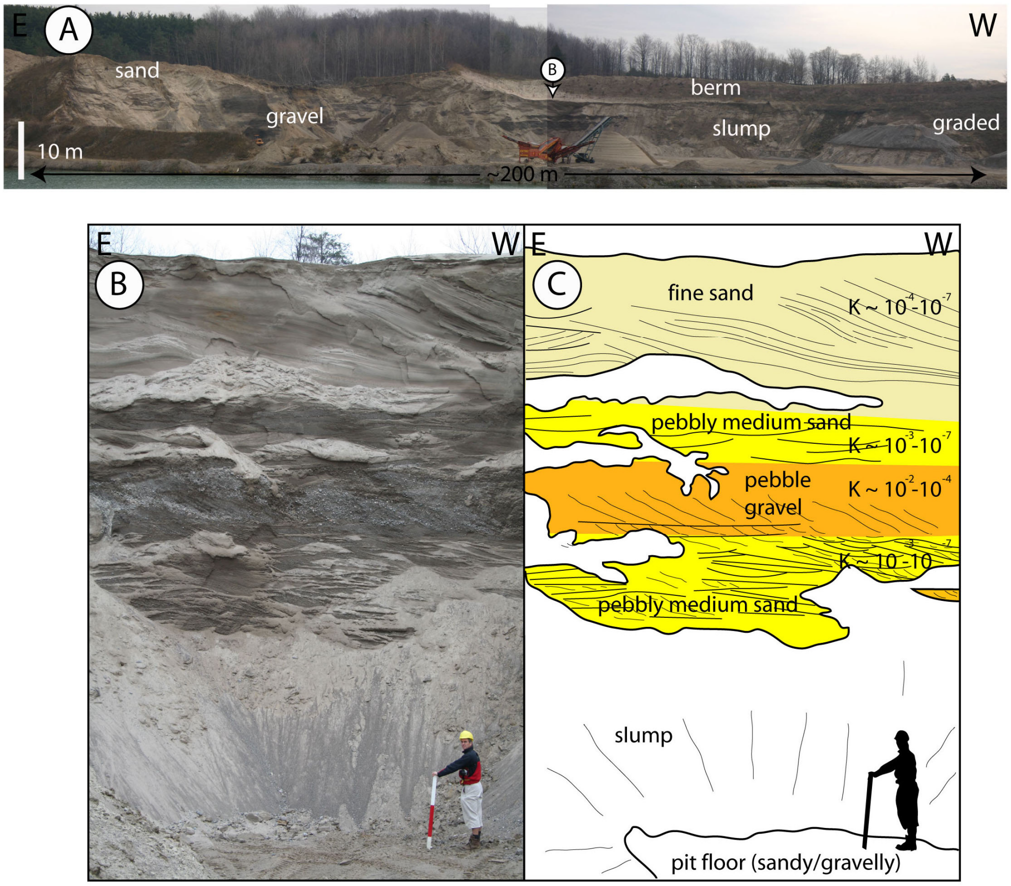

Figure 8. Photos from the Gormley pit, Oak Ridges Moraine. (A) Extent of active pit face at the Gormley pit in 2006. Note extensive tabular gravel unit overlain by sand. (B) Close-up photo of pit face at (B) in (A). Note the tripartite sand–gravel–sand succession and westward dip of dune cross-stratification (cross-stratified beds are 10–100 cm thick). Scale stick is 1.2 m long. (C) Line drawing and interpretation of (B). A muddy unit identified at top of succession in the 1990s has likely been stripped.

2. ADJALA PIT

Map unit: Ice-contact stratified sediment (Oak Ridges Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Cobble–pebble gravel, sand, mud
Depositional environment: Glaciofluvial gravel, subaqueous-fan sand & mud
Aquifer potential: Very good (reduced locally due to cementation)
Horizontal permeability: Very high
Vertical permeability: Moderate to low

The Adjala pit is located 10 km southwest of Tottenham in an area mapped as ice-contact stratified sediment of the Oak Ridges Moraine (Fig. 2). The Adjala operation currently consists of several pits in various states of exploitation (Fig. 9). Pits to the east of Concession Road 3 are generally inactive and have slumped pit faces, whereas pits west of Concession Road 3 are generally active and have clean pit faces. An upward-fining trend is observed in pits west of Concession Road 3, as described below.

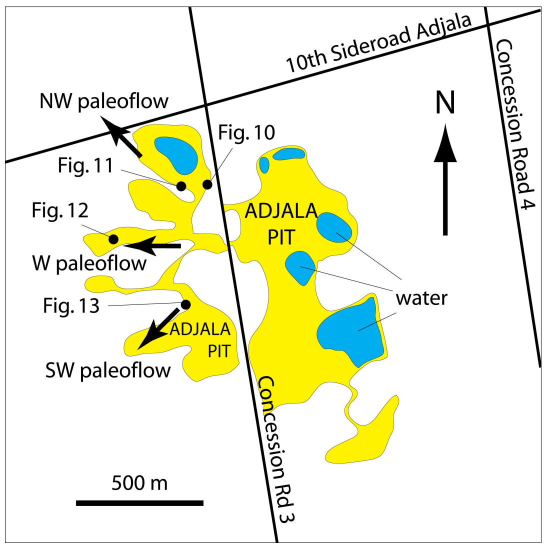

Figure 9. Overhead sketch of Adjala pit from Google Earth satellite images.

In the northernmost pit west of Concession Road 3, pebble gravel is sharply overlain by dune cross-stratified medium sand, which in turn is overlain by muddy fine sand (Fig. 10). Units are roughly planar and horizontal when viewed parallel to paleoflow (Fig. 11) but the gravel unit is distinctly mound-like perpendicular to paleoflow (Fig. 10). Dune cross-strata dip consistently northwest. The muddy fine sand unit contains large sigmoidal clinoforms (Fig. 11) and is locally soft-sediment deformed.

In the central pit west of Concession Road 3, the gravel unit is extensively exposed, and is overlain by muddy fine sand in the western wall of the pit (Fig. 12). Here, the gravel unit is 4–5 m thick, is commonly high-angle cross-stratified, and consists of well-rounded, well-sorted, clast-supported pebbles and cobbles, although rare beds of matrix supported boulder gravel are present locally. Clasts that were ultimately derived from Paleozoic bedrock predominate, with minor percentages of clasts derived from Precambrian bedrock. Precambrian boulders up to 1 m in diameter are rarely observed. Locally the gravel has been cemented with calcium carbonate and is fully consolidated and likely impermeable (Fig. 12).

In the southernmost pit west of Concession Road 3, the gravel unit is 3–4 m thick, consists of well-rounded cobbles (Fig. 13), and is sharply overlain by a poorly exposed muddy sand unit. Southwestward-dipping (dune-scale) cross-strata occur locally in the gravel.

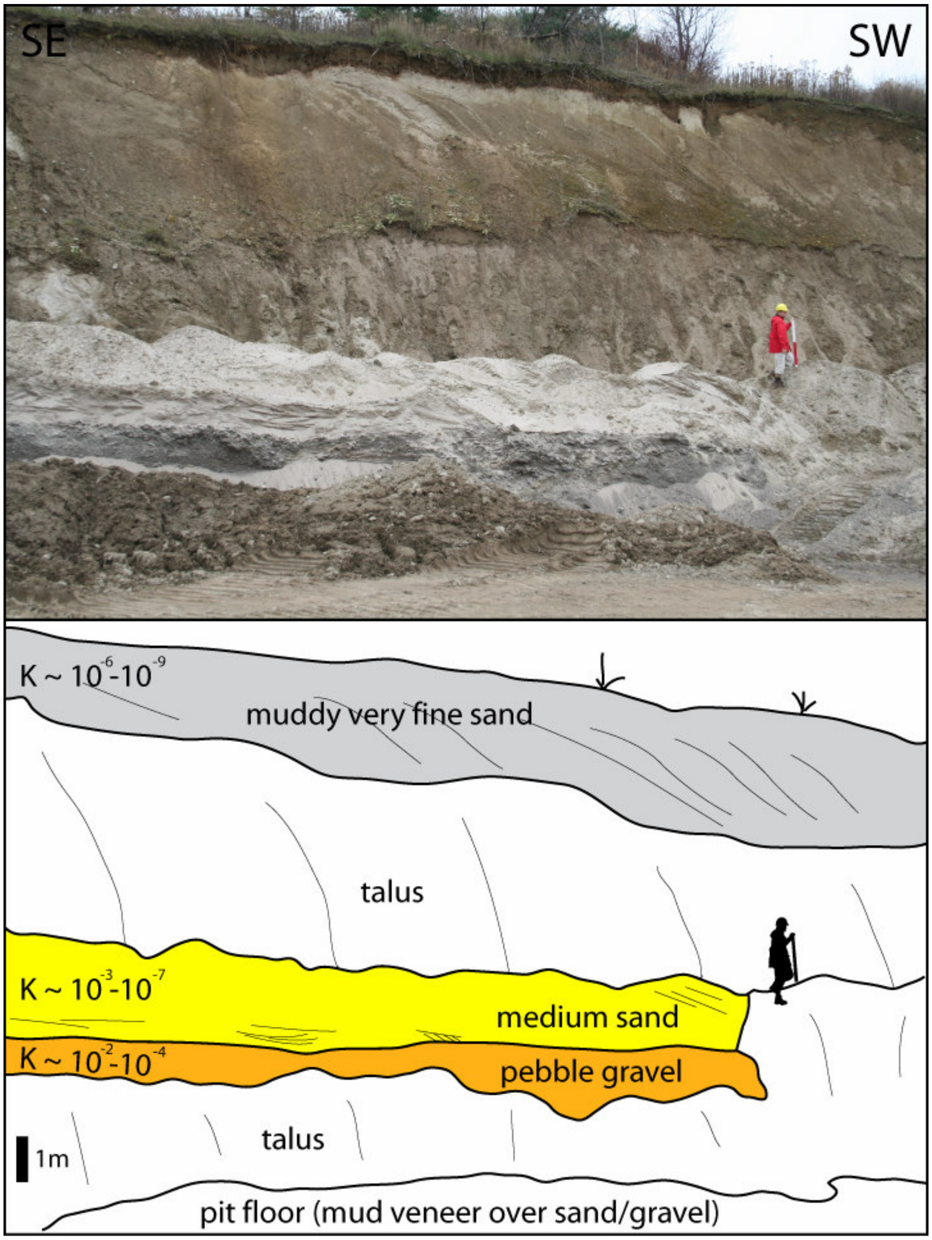

Figure 10. Dip-oriented section at the north end of Adjala property (downflow is to right, or NW), with three distinct units: gravel, medium sand and muddy very fine sand. Note large sigmoidal clinoforms in muddy sand unit.

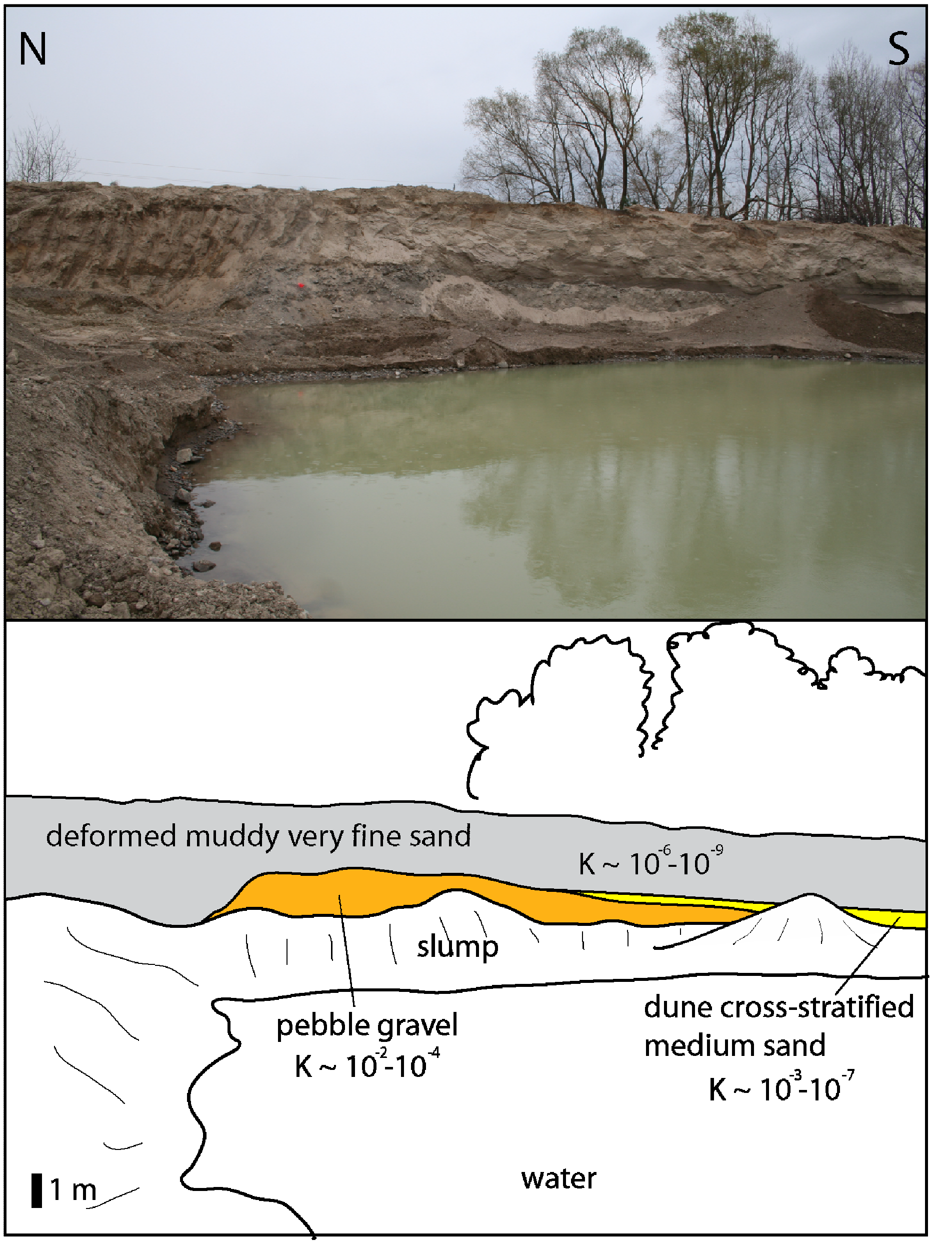

Figure 11. Strike-oriented photo from northeast end of the Adjala pit. Three units are identified (bottom to top): pebble gravel, which is distinctly mound-like, a unit of dune cross-stratified medium sand, and an overlying muddy sand unit that is soft-sediment deformed locally. Paleoflow is obliquely out of the page (toward the NW).

The complex network of active faces in the Adjala pit complicates the interpretation of the stratigraphic succession. In general, exposed faces exhibit an upward-fining trend that suggests hydraulic energy decreased over time. The latest stage event deposited muddy fine sand interpreted to be part of a large subaqueous fan. The extensive gravel deposit underlying the muddy fine sand is most likely a glacifluvial deposit of either ice-marginal or subglacial origin. (The later is perhaps more likely given the coarse caliber and local mound-shaped upper contact of the gravel.) The coarse caliber and tabular geometry of the gravel unit is abnormal relative to most exposed gravel units in the Oak Ridges Moraine. Underlying units are inadequately exposed to interpret their depositional environment. However, if the model for deposition of the

Oak Ridges Moraine proposed by Barnett et al. (1998) is applied deposition of all sediment in the Adjala pit likely occurred in an esker–subaqueous-fan environment.

Cementation of the gravel unit reduces permeability to near zero but appears to be an isolated phenomenon that may only impact aquifer potential locally. It is unclear what caused the gravel in the Adjala pit to become locally cemented with calcium carbonate. In terms of predicting the distribution of cemented gravel in a glaciated basin, it may be significant to note that carbonate-cemented Late Wisconsinan gravel in Ontario, such as those in the Adjala pit, are commonly reported to underlie mud-rich deposits (Johnston, 1917; George Gorrell, personal communication, 2007). The genetic link between stratigraphic position and the cementation process are unclear. Cemented gravel has been observed by the second author elsewhere in the Oak Ridges Moraine (e.g., Bolton pit), Paris Moraine, and Waterloo Moraine.

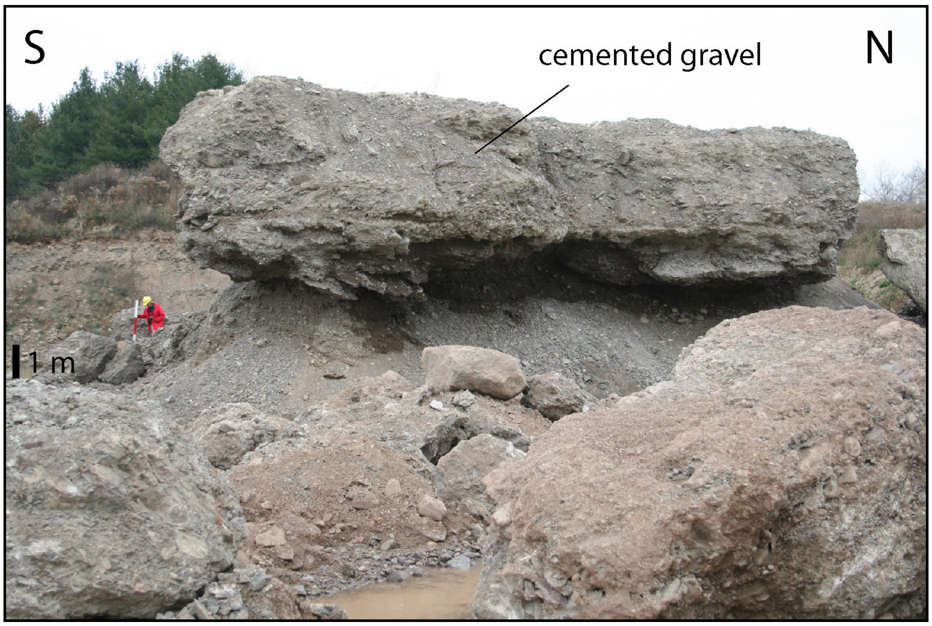

Figure 12. Carbonate-cemented siliciclastic gravel in centre of Adjala pit. Similar gravel outcrops beneath muddy fine sand in the pit face at the back of the photo. This unit is interpreted to correlate with (completely unconsolidated) gravel units exposed in other areas of the Adjala pit.

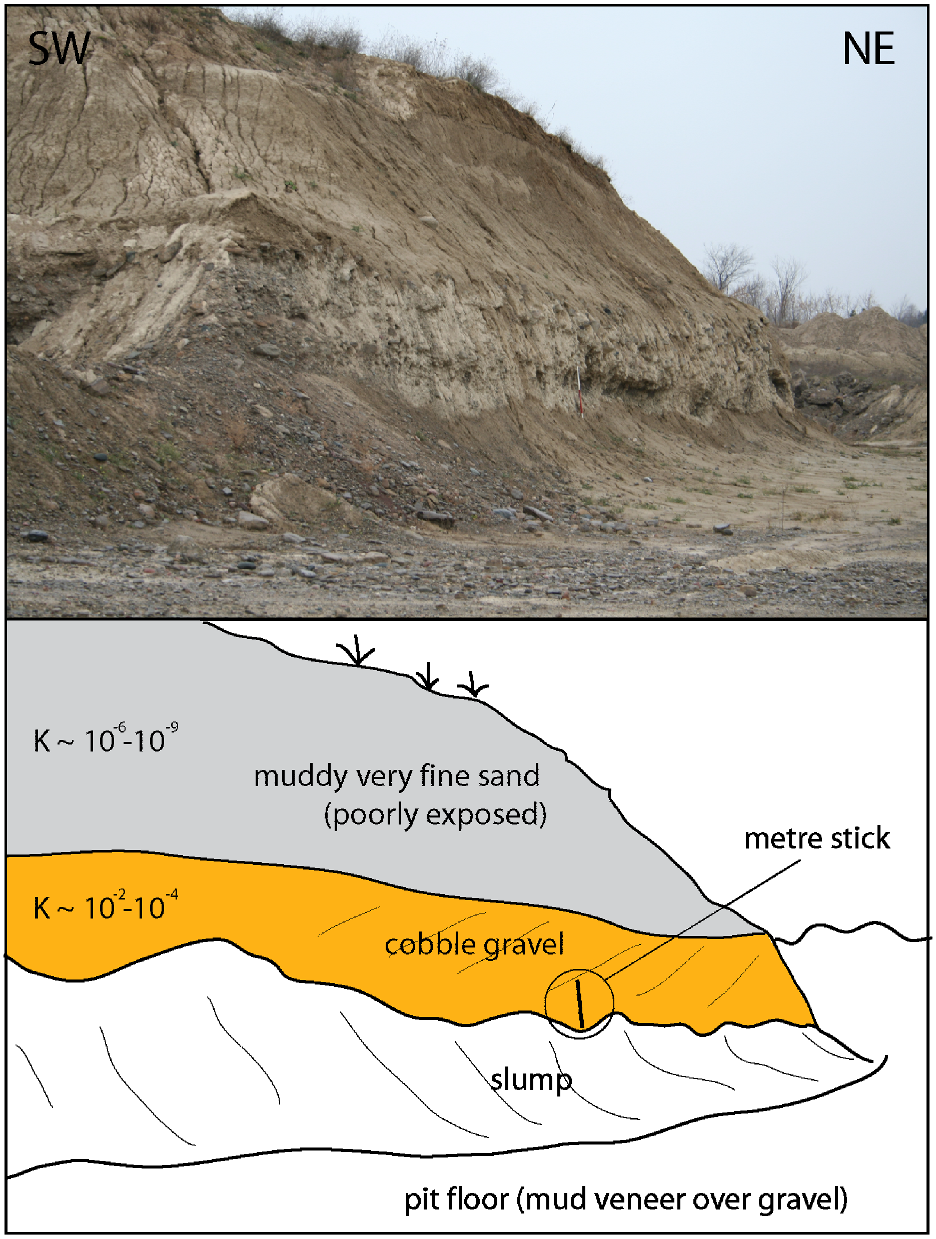

Figure 13. Figure 13. Photo from south end of Adjala pit, showing fine sand over gravel stratigraphy. Note southwestward-dipping (dune?) cross-stratification in gravel.

3. GILLESPIE PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Fine sand
Depositional environment: Subaqueous fan (mid-fan setting)
Aquifer potential: Moderate
Horizontal permeability: Moderate
Vertical permeability: Moderate

The Gillespie pit is located 3.5 km west of Orangeville on the Orangeville National Topographic System (NTS) map sheet, just north of Highway 9, in an area mapped as ice-contact stratified-sediment of the Orangeville Moraine (Cowan, 1976) (Figs. 2, 14). Exposures in the pit consist entirely of fine sand. Obvious vertical or horizontal grain-size trends were not observed (Fig. 15). Dune and climbing current-ripple cross-sets are common, and diffusely laminated fine sand was observed. The pit is relatively large, but most faces were slumped at the time of our visit. Several high-angle reverse faults were observed. This was the only pit where substantial faulting was observed. The paucity of faults suggests that buried ice was present in the region, but only locally.

The monotonic sediment caliber and predominance of climbing ripples and diffusely laminated sand suggests that deposition occurred from highly concentrated unidirectional flows that moved across the bed in an unconfined subaqueous environment. These facies are typically encountered in subaqueous-fan deposits (Russell and Arnott, 2003). The relatively fine caliber of the deposits and lack of gravel may suggest that deposition occurred in a mid-fan setting.

Although they could store abundant water, strata exposed at the Gillespie pit have only moderate aquifer potential because volumetric significant amounts of permeable gravel are absent. Given the textural homogeneity of the sand in both horizontal and vertical directions, permeability should be closer to isotropic than in other pits visited (with the possible exception of the Robinson pit—see below).

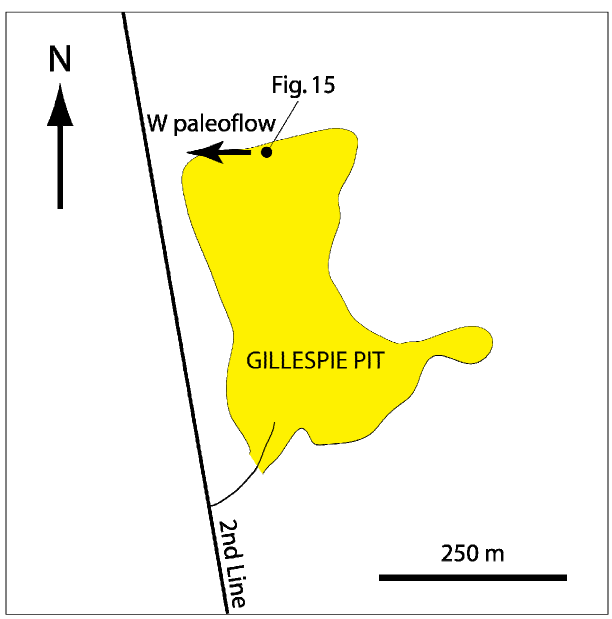

Figure 14. Overhead sketch of Gillespie pit based on satellite images obtained from Google Earth.

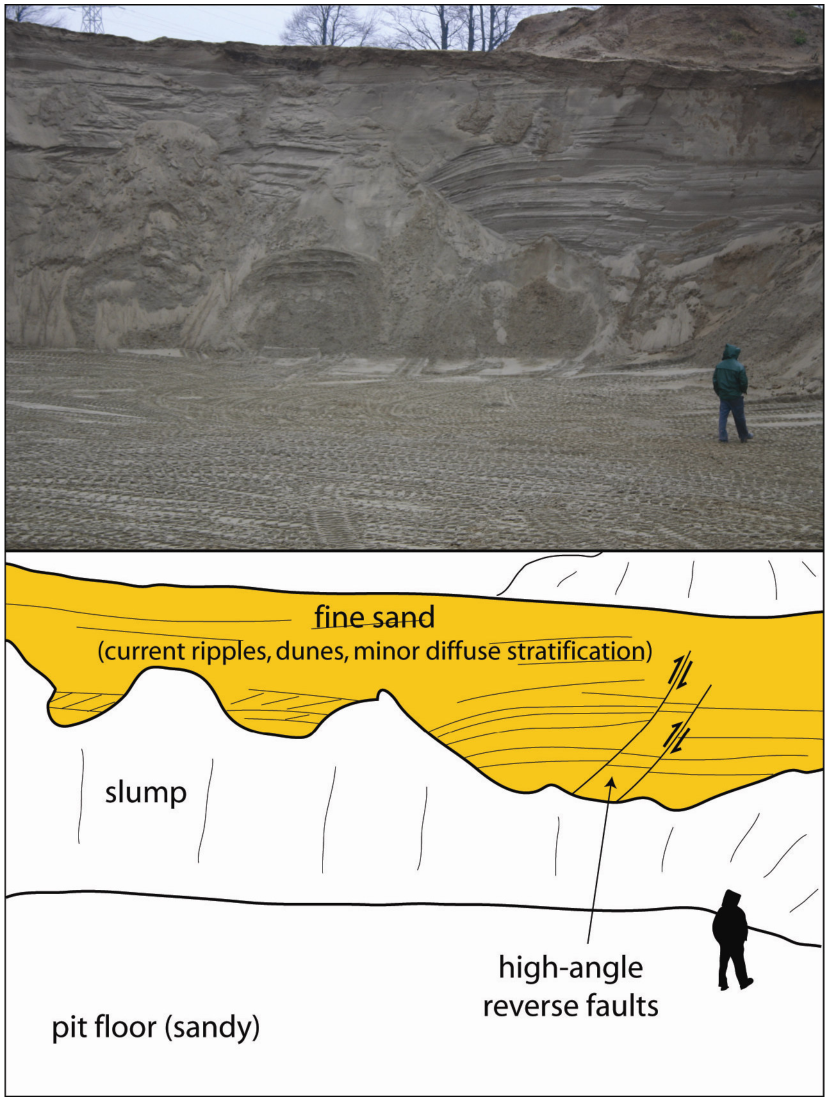

Figure 15. Representative photo of strata exposed in the Gillespie pit. Sand contains dunes, climbing current ripples, and rare diffusely stratified beds. Note the absence of vertical grain-size trends, and high-angle faults, which suggest that the sediment was deposited on buried ice that subsequently melted.

4. ROBINSON PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Fine to medium sand
Depositional environment: Subaqueous fan (mid-fan setting)
Aquifer potential: Moderate
Horizontal permeability: Moderate
Vertical permeability: Moderate

The Robinson pit is located 3.5 km southwest of Orangeville on the Orangeville NTS map sheet, in an area mapped as ice-contact stratified sediment of the Orangeville Moraine (Cowan, 1976) (Fig. 2, 16). Unlike the adjacent Rayburn pit (see below), deposits in the Robinson pit consist almost entirely of well-sorted fine and medium sand (Fig. 17), although rare gravel clasts occur at the top of the succession on the ground surface (pit operator, personal communication). Drilling by the pit operator confirmed that similar sand extends to the water table ~10 m below the pit floor. No systematic vertical or horizontal grain-size trends were observed. Much of the stratification (dunes, metre-wavelength low-amplitude wavy strata) appears diffuse.

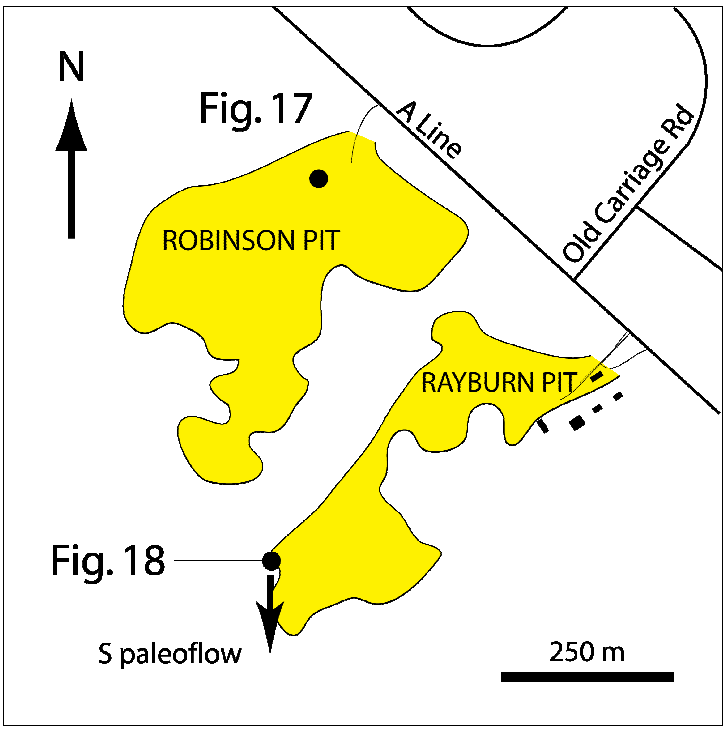

Figure 16. Overhead sketch of Robinson and Rayburn pits from satellite images obtained from Google Earth.

The presence of shallow scours/channels filled with diffusely laminated sand gives the impression that abundant sand was falling out of suspension during deposition, and the presence of climbing dunes, current-ripples and antidunes(?) indicates that traction transport was also active. The exposed facies are similar to those exposed in the Gillispie pit, and are interpreted to have been deposited subaqueously in a mid-fan setting by highly concentrated, unconfined jet–plume pairs.

Like strata in the Gillespie pit, strata exposed in the Robinson pit have the potential to store abundant groundwater, but in general have only moderate high-yield aquifer potential given the absence of thick, permeable gravel. Permeability may approach isotropic more so than in other pits (with the exception of the Gillespie pit), although horizontal permeability is still likely higher than vertical permeability given that stratification is horizontal.

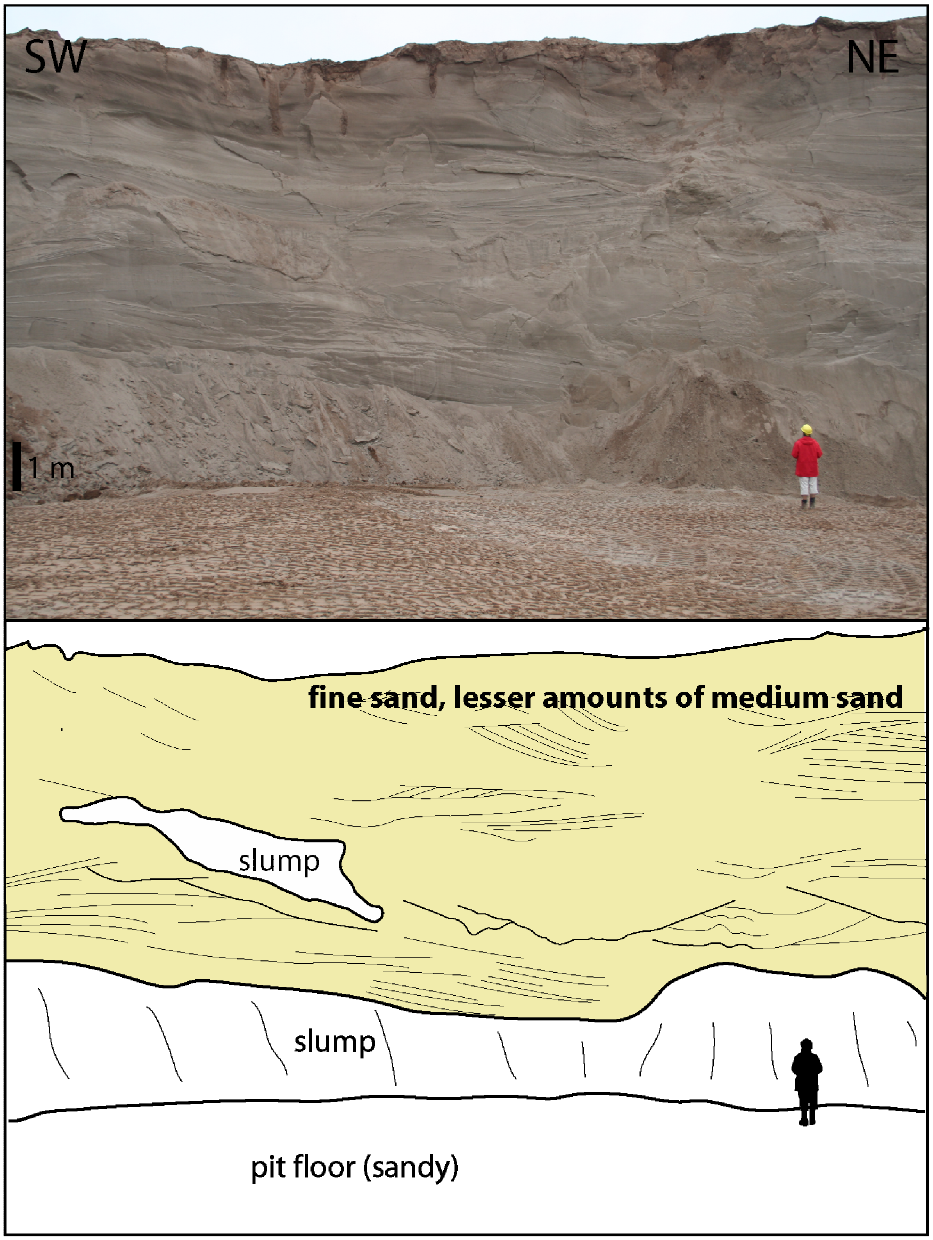

Figure 17. Representative photo of sediment exposed in the Robinson pit. The outcrop consists predominantly of fine sand. Stratification consists of metre-wavelength low-angle "wavy" lamination (antidunes?), dune and climbing-ripple cross-stratification, and diffusely laminated sand that commonly fills scours. Much of the stratification (dunes, metre-wavelength low-amplitude wavy strata) appears diffuse.

5. RAYBURN PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Sand, pebble–boulder gravel
Depositional environment: Subaqueous fan (mid-proximal setting)
Aquifer potential: Very good
Horizontal permeability: High
Vertical permeability: Moderate

The Rayburn pit is located 3.5 km southwest of Orangeville on the Orangeville NTS map sheet, in the same map unit and landform as the Robinson and Gillespie pits (Figs. 2, 16). It is located downslope and adjacent to the Robinson pit. Most of the pit exposure occurs beneath the level of the Robinson pit floor, suggesting that strata in the Rayburn pit sits stratigraphically below that in the Robinson pit. A single pit face that extended 500 m from the A Line toward the southwest was examined. The face was well exposed, ~16 metres high, and had 1–3 metres of slump at the base.

Strata exposed at the Rayburn pit consist of sand with an intervening 1–5 m thick, >500 long, irregular-based gravel unit that spans the entire pit face (Fig. 18). Sand at the base of the succession is fine to medium caliber and contains dune and climbing ripple cross-sets, planar laminated beds, and diffusely graded intervals. The gravel unit that sharply overlies the sand is irregular and vaguely sheet-like, and varies from massive to vaguely horizontally stratified to dune cross-stratified along its length. The most conspicuous aspect of the gravel is that it contains abundant angular to subrounded gravel-sized sand clasts derived from the underlying unit. These clasts range in diameter from centimeters to ~4 meters. They occur throughout the gravel unit, although larger “truck-sized” clasts are concentrated near the base of the gravel unit. The unit therefore exhibits coarse-tail grading: the largest clasts are concentrated near the base of the unit, but the “matrix”—the coarse sand and pebbles that volumetrically makes up most of the unit—is ungraded. Upper fine to medium sand sharply overlies the gravel unit. Like the sand at the base of the unit, it contains ripple and dune cross-stratification, planar laminated beds, and diffusely graded intervals.

The marked and abrupt vertical changes in grain size in the vertical succession at the Rayburn pit suggest that the meltwater flows were highly unsteady. The sedimentology of the gravel unit suggests it was deposited by an extremely energetic, extremely short lived and highly sediment-charged (“hyperconcentrated”) flow. The sedimentology and angularity of the sand rip-up clasts in the gravel unit indicate that they were eroded from the underlying sand unit and transported only a short distance. Given their large size and apparently unstable orientation, it is difficult to explain how they would have been transported as clasts that rolled along the bed, as larger clasts commonly do in rivers undergoing flood. Rather, it is more reasonable to suspect that they were carried in suspension a highly concentrated zone at the base of the flow, supported by high bed-normal dispersive pressures from grain-on-grain impacts, and that the entire gravel sheet—sand megaclasts and gravel—was deposited all at once, or “*en masse*”. *En masse* deposition is commonly inferred to occur in gravitationally driven debris flows that contain large (“outsized”) isolated clasts. However, given the lack of significant slope at the Rayburn pit, in addition to the well-sorted, mud-poor nature of the gravel, it seems more reasonable to suspect that the intraclast-bearing gravel unit was deposited by a high-energy, inertia-driven jökulhlaup-type meltwater outburst, not a gravity-driven debris flow. In addition, the meltwater outburst likely occurred into a standing body of water: the gravel unit is overlain and underlain by climbing-current-ripple cross-stratified fine sand. As such, the gravel unit is hypothesized to be a proximal subaqueous-fan deposit. Its erosive juxtaposition over climbing-current-ripple cross-stratified fine sand interpreted to be mid–distal subaqueous-fan deposits provides strong support for the argument that catastrophic meltwater discharges contributed, at least in part, to moraine building in the region.

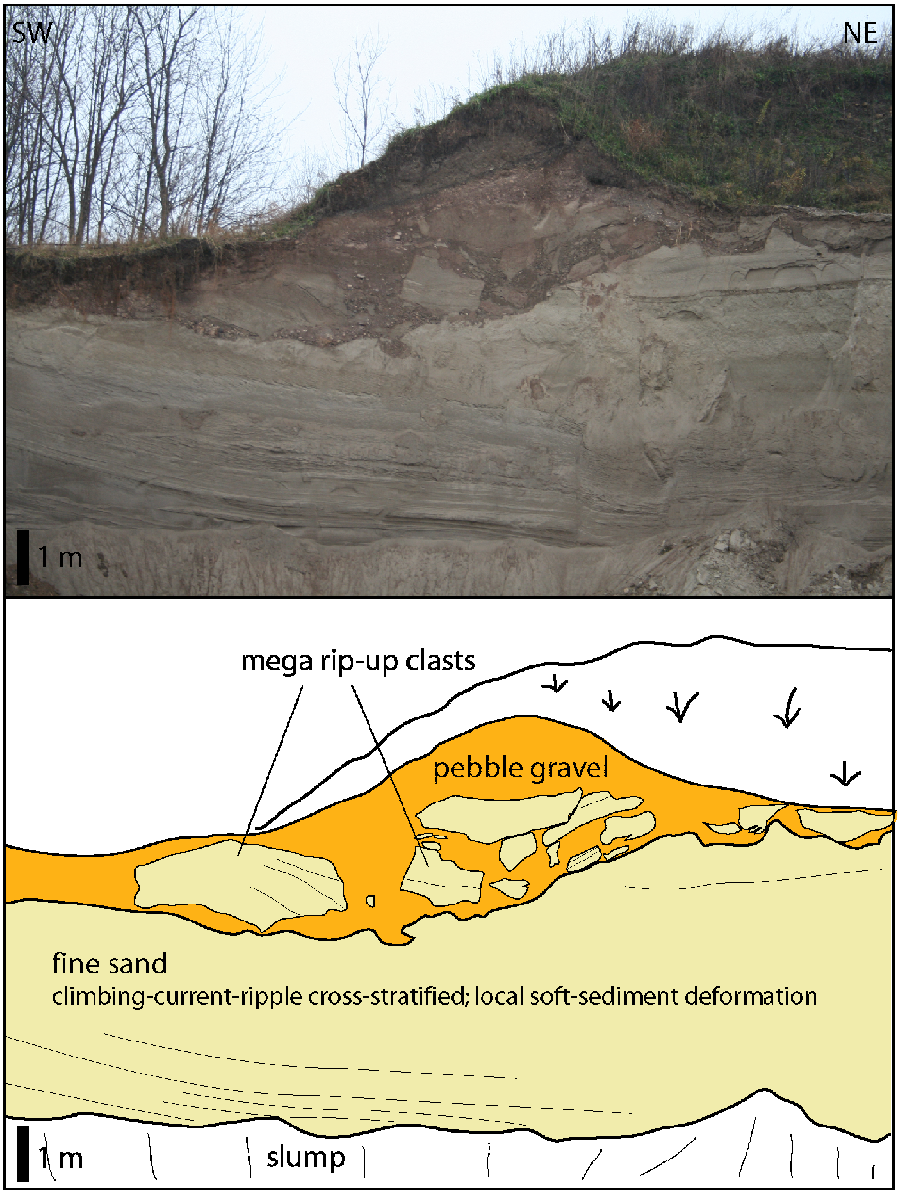

Figure 18. Large, isolated, angular unconsolidated sand “megaclasts” in pebble gravel in the Rayburn pit.

6. LAUREL PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Sand, pebble gravel
Depositional environment: Subaqueous fan
Aquifer potential: Very good
Horizontal permeability: High
Vertical permeability: Moderate to high

The Laurel pit is located 11 km west of Orangeville on the Orangeville NTS map sheet, in an area mapped as ice-contact stratified sediment (Cowan, 1976) (Fig. 2). The only exposure at the time of our visit consisted of rhythmic interbeds of fine sand and pebble gravel (Figure 19). The exposed strata have very good aquifer potential, given the presence of the gravel units.

Figure 19. Rhythmically bedded fine sand and pebble gravel in the Laurel pit.

7. GREENWOOD PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Sand, pebble gravel
Depositional environment: Subaqueous fan (outwash? fan-delta?)
Aquifer potential: Good
Horizontal permeability: Moderate to high
Vertical permeability: Moderate to low

The Greenwood pit is located 12 km north of Orangeville on the Dundalk NTS map sheet, in an area mapped as ice-contact stratified sediment of the Orangeville Moraine (Gwyn, 1972) (Figs. 2, 20). The active face is currently 5–7 m high and consists of cross-stratified medium sand, pebbly gravel, and climbing current-ripple cross-strata (Figs. 15). No vertical grain-size trends are observed. Diffusely graded sandy scour-fills and planar laminated medium sand beds with well defined heavy mineral concentrations are present locally (Fig. 21). Climbing-ripple cross-stratified fine sand is interbedded locally with the coarser deposits (Fig. 22).

Given the presence of diffusely graded sand and climbing ripples—facies that are ubiquitous in subaqueous-outwash fan deposits (Russell and Arnott, 2003)—strata exposed in the Greenwood pit are interpreted to have been deposited, at least in part, in standing water, possibly as subaqueous outwash, or, at a minimum, in the subaqueous portion of a fan-delta. The aquifer potential of the strata is good (good storage potential, moderate to good permeability), but not excellent given the absence of laterally extensive coarse gravel units. On an aquifer-scale, vertical groundwater flow would be impeded primarily by the laterally continuous interbeds of climbing ripple cross-stratified silty fine sand (50–75 cm thick).

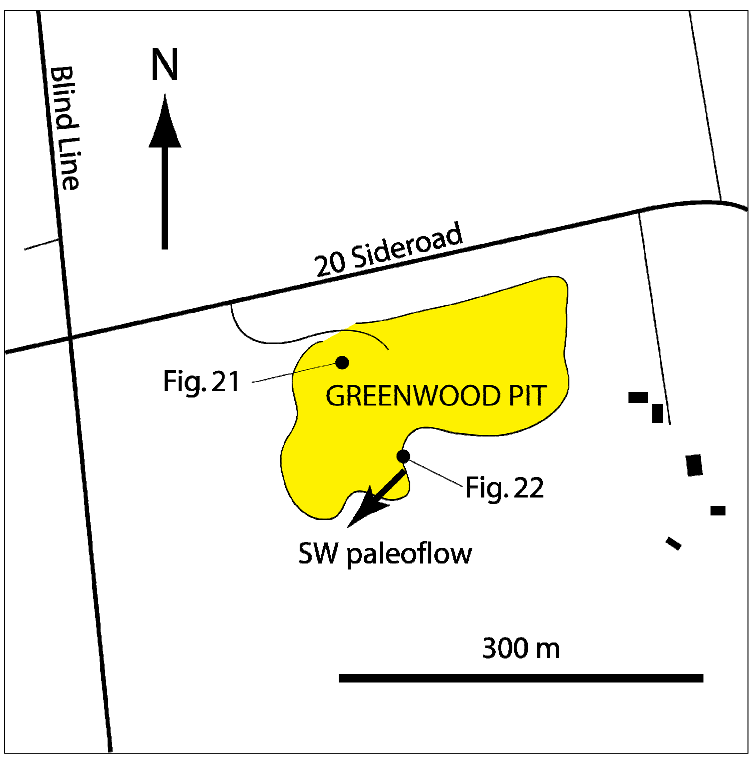

Figure 20. Overhead sketch of Greenwood pit based on satellite images obtained from Google Earth.

Figure 21. Greenwood pit in the Orangeville Moraine with diffusely laminated fine sand infilling scours.

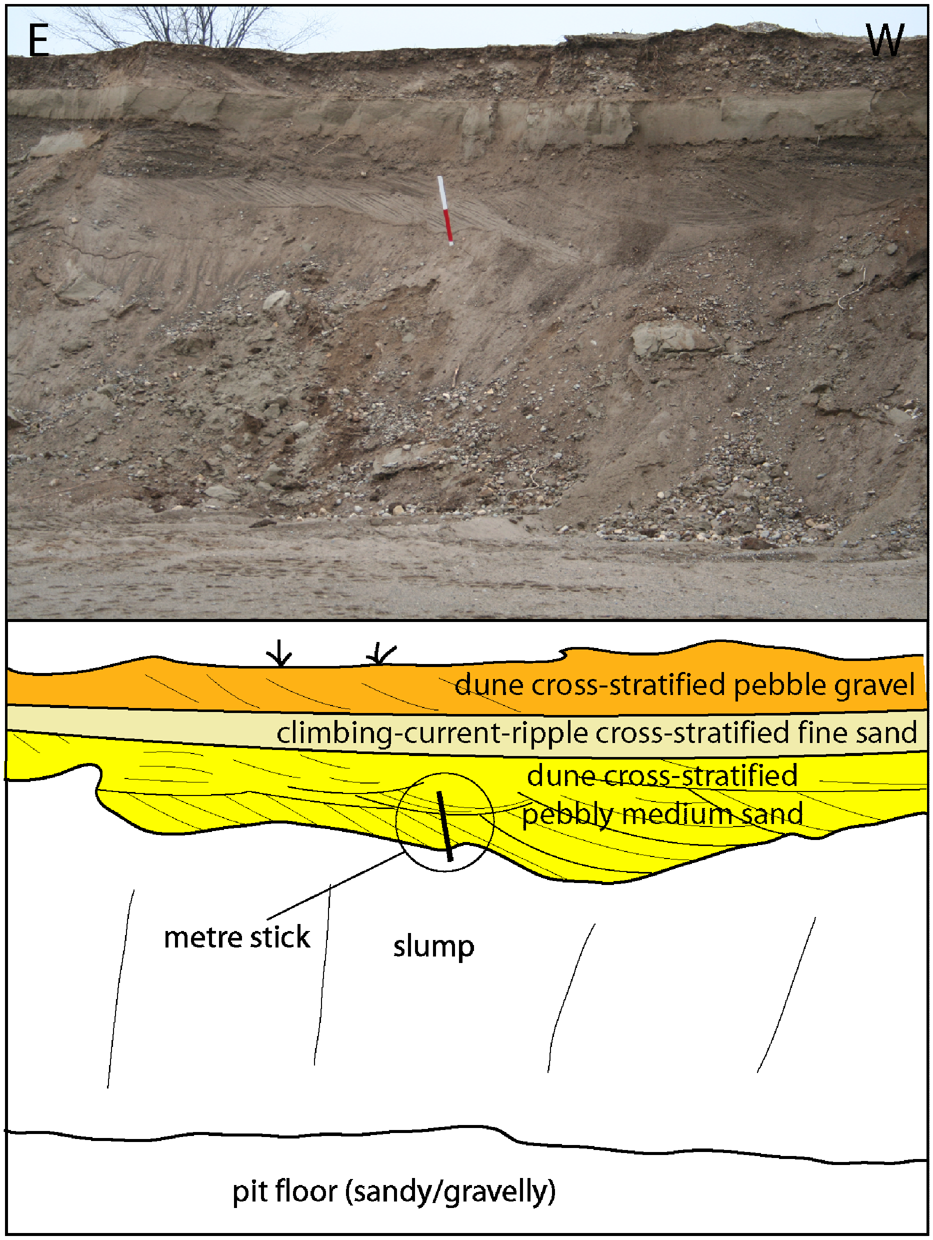

Figure 22. Strike-section at the Greenwood pit in the Orangeville Moraine. Paleoflow is approximately obliquely to right or southwest direction. Note the pebbly medium sand overlain by lower permeability climbing cross-stratified fine sand overlain by pebbly gravel.

8. STRADA PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Pebble gravel
Depositional environment: Subaerial outwash? Proximal subaqueous fan?
Aquifer potential: Very good
Horizontal permeability: High
Vertical permeability: High

The Strada pit is located 7.5 km north–northwest of Shelburne on the Dundalk NTS map sheet, just east of the Nelson pit, in an area mapped as ice-contact stratified sediment of the Orangeville Moraine (Gwyn, 1972) (Fig. 2). The Strada pit appears to be located in a flat, low-relief area, whereas terrain around the nearby Nelson pit is more hummocky. Pit faces are uniformly in the range of 6–7 m in height. Deposits consist of cross-stratified pebble-gravel and medium sand (Fig. 23). No vertical grain-size trends are observed. Poorly sorted clast-supported gravel with a mud-rich matrix is present in one small pit face being actively excavated. Paleoflows interpreted from dune cross-strata and pebble imbrication is southward.

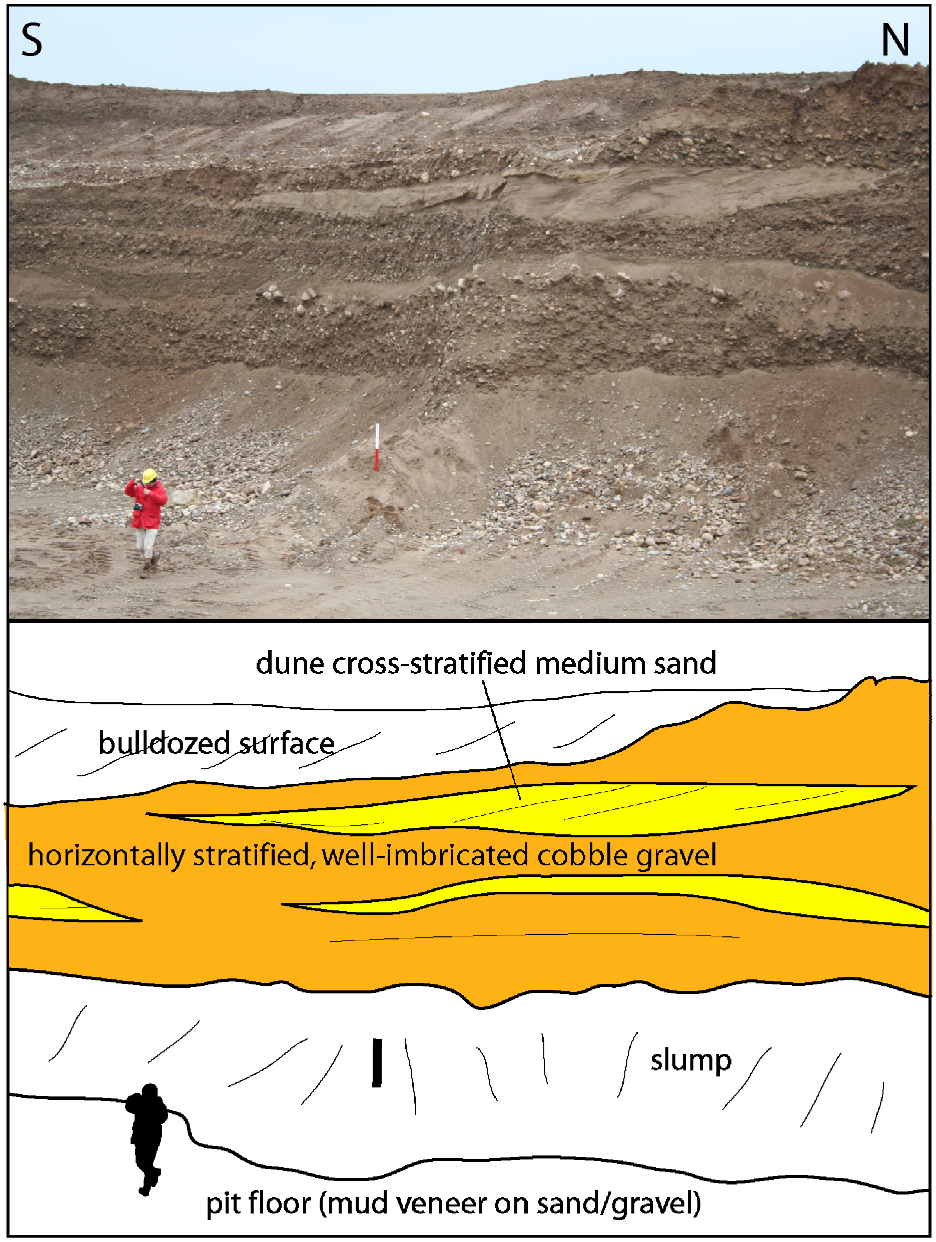

Figure 23. Cobble–pebble gravel with dune cross-stratified medium sand—a representative photo of deposits exposed in the Strada pit. Dune cross-strata in medium sand dip southward (downflow), and imbricated gravel clasts dip northeast (upflow).

Several features of strata in the Strada pit distinguish it from pits described previously. First, the strata consist almost entirely of gravel. Very little sand is present, and facies commonly associated with subaqueous fans (climbing ripples, diffusely laminated sand) were not observed. Second, the gravel unit is laterally extensive. Beds are flat-lying, and no obvious lateral-accretion clinoforms are exposed. These observations either suggest that strata were deposited in shallow (braided?) proglacial stream that aggraded while channels combed across the land surface, forming a laterally extensive gravel deposit, or that the gravel was deposited in a proximal, unconfined subaqueous fan setting that may have been proglacial or subglacial. Flows were to the south, the sediment was likely sourced from the glacier, and the glacier was likely close during deposition given the coarse grain size. Further work is needed to refine this interpretation.

9. NELSON PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Pebble gravel, sand, diamicton
Depositional environment: Subaqueous portion of fan-delta? Proximal subaqueous fan?
Aquifer potential: Good to very good
Horizontal permeability: High
Vertical permeability: Moderate

The Nelson pit is located across the road from the Strada pit, 7.5 km north–northwest of Shelburne in an area mapped as ice-contact stratified sediment of the Orangeville Moraine (Gwyn, 1972; Fig. 2). The Nelson pit is excavated into much higher relief terrain than the Strada pit. Strata in the two pits may not be correlative: the pit floor of the Nelson pit is equivalent or higher in elevation than the upper bench of the Strada pit. Pit facies in the Nelson pit are 6–7 m high. Like the Strada pit, horizontally stratified to dune cross-stratified pebble-gravel is common; by contrast, however, current-ripple cross-stratified fine sand and a muddy diamicton unit were also observed (Fig. 24). Imbricated clasts in the horizontally stratified gravel dip northeastward, and current-ripple foresets dip westward, suggesting that meltwater flowed on average towards the southwest. The diamicton has a muddy sand matrix, spherical rounded pebble-gravel clasts, and an irregular, locally channelized lower contact.

Strata exposed in the Nelson and Strada pits are similar in that dune cross-stratified gravel with southwestward paleoflows is abundant. However, as opposed to the almost sand-free nature of strata in the Strada pit, the association of gravel in the Nelson pit with current ripple cross-laminated sand beds suggests that deposition occurred in standing water, possibly in a subaqueous fan or fan delta setting. Given its channelized base, the diamicton is interpreted to be a debris flow deposit, not a subglacial till. The presence of the diamicton, in addition to the absence of diffusely laminated sand, differentiates strata in the Nelson pit from strata in pits located in the Orangeville Moraine farther south (e.g., Gillispie, Robinson, Laurel, and Rayburn pits).

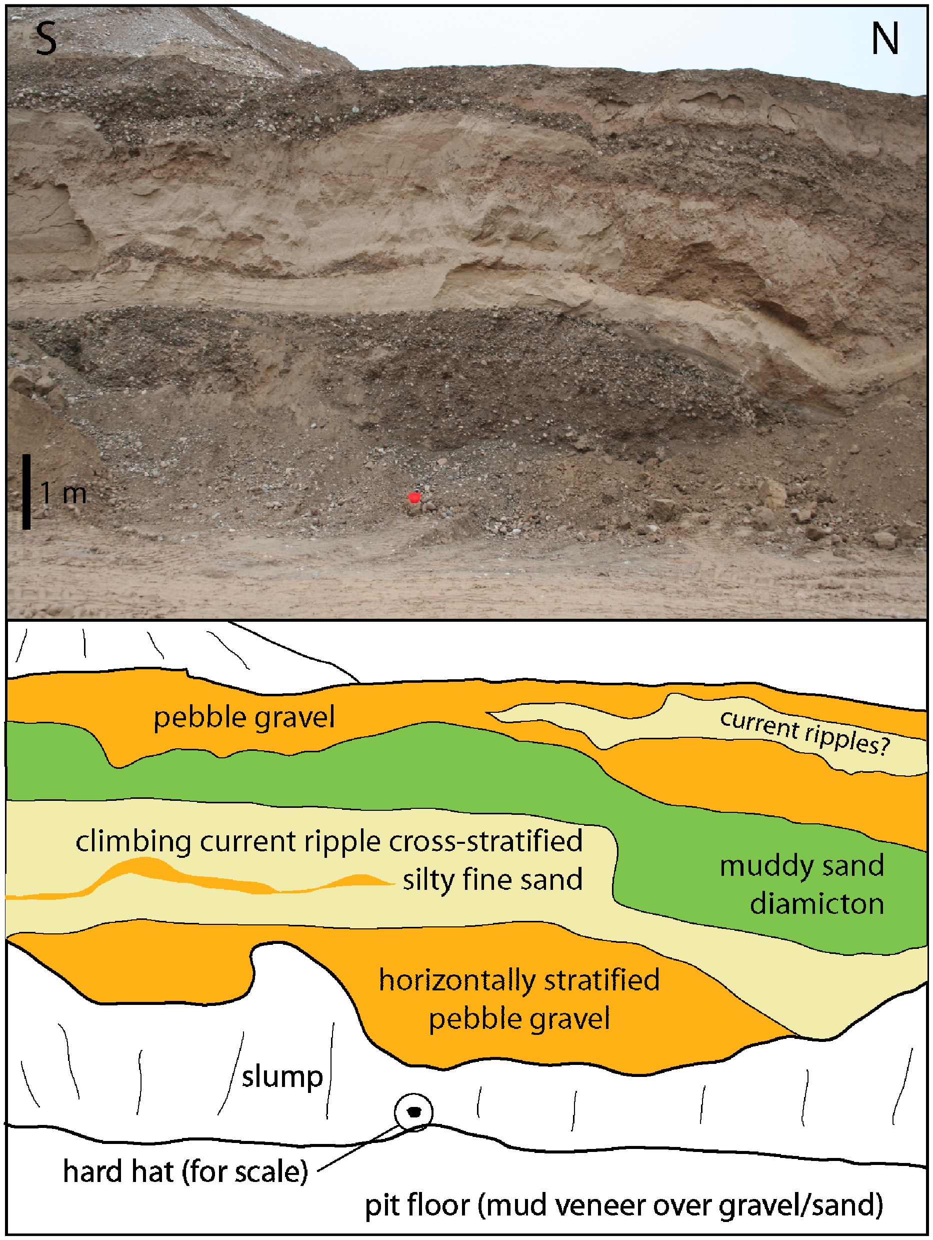

Figure 24. Representative photo of stratigraphy exposed in the Nelson pit. The succession consists of gravel, sand, diamicton, and gravel. A southwest paleoflow is interpreted from imbricated gravel clasts and current-ripple cross-stratification.

10. ESKER PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Cobble–pebble gravel
Depositional environment: Subglacial stream (R-channel)
Aquifer potential: Very good
Horizontal permeability: High
Vertical permeability: High

The "esker" pit is located 15 km north–northwest of Shelburne on the Dundalk NTS map sheet. The pit is excavated into a ridge-shaped landform mapped as an esker in an area of ice-contact stratified sediment (Gwyn, 1972). Pit faces expose the esker approximately in strike cross-section (Figs. 25, 26). The esker landform has relatively steep flanks (up to 30 dip), is less than one hundred meters wide, and appears to be composed almost entirely of well-rounded gravel (mostly cobbles). Dune-scale cross-strata are observed in a longitudinal face of the pit and dip toward the southeast (Fig. 26b). One large angular boulder was observed on the flank of the esker landform (Fig. 26c).

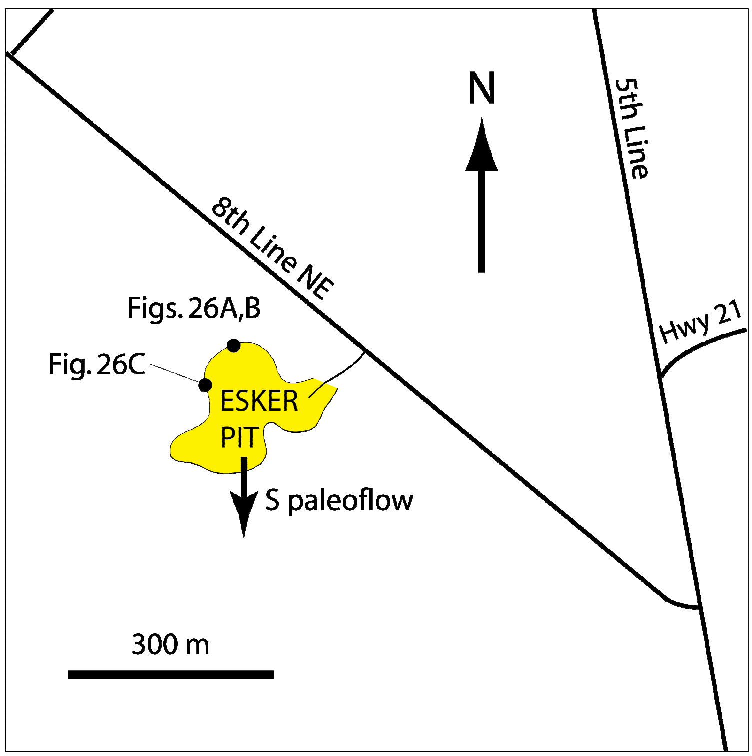

Figure 25. Overhead sketch of esker pit based on satellite images obtained from Google Earth.

The coarse grain-size, lack of a sandy (subaqueous fan) carapace, and steep, narrow morphology of the ridge suggest that this portion of the esker was deposited in a subglacial meltwater conduit. Aquifer potential is excellent, as is typical of eskers. Because clasts of equivalent size or angularity were not observed within the esker, the isolated boulder on the surface of the esker is interpreted to be a dropstone, or alternatively a large clast that melted out of ice above the debris-rich basal-ice zone. The esker was previously mapped by Gwyn (1972) as flowing southeast. This paleoflow direction is confirmed by large cross-sets observed in November 2006 (Fig. 26b).

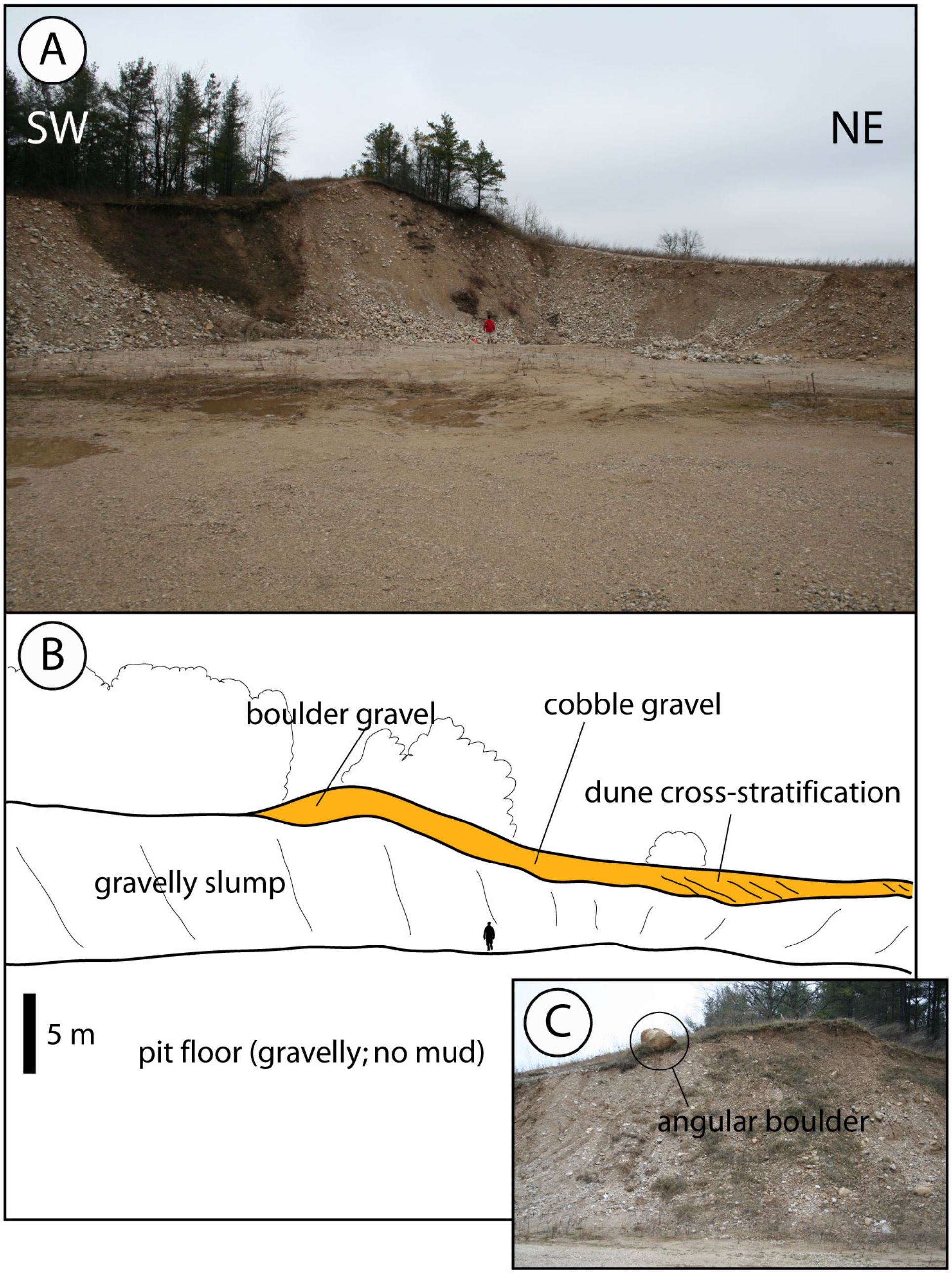

Figure 26. Pit in esker at the western margin of the Nottawasaga River watershed. (A) Cross-section of esker. Esker is composed predominantly of pebbly cobble gravel. (B) Line drawing and interpretation of (A). (C) Angular boulder (interpretation: dropstone) located on top of esker. Paleoflow is from left to right in (A).

11. THE HOLLOWS PIT

Map unit: Ice-contact stratified sediment (Orangeville Moraine)
Stratigraphic position: Stratigraphically below Newmarket Till?
Sediment exposed in pit: Sand
Depositional environment: Subaqueous fan (mid fan)
Aquifer potential: Moderate
Horizontal permeability: Moderate
Vertical permeability: Moderate

The Hollows pit is located ~7 km northwest of the Gwillimbury pit on the Alliston NTS map sheet, just east of Highway 400, in an area mapped as ice-contact stratified sediment (Russell and Dumas, 1997) (Fig. 2). The pit appears to occur in an erosional depression cut into a Newmarket Till upland. Although the site was inactive and undergoing rehabilitation in 2006, the pit was visited in 1994 by the second author. At that time, active faces were ~3 metres high, and a sandy succession was exposed that contained planar laminated, diffusely graded, and current ripple cross-laminated beds (Fig. 27). Rare dune cross-stratified medium sand beds were also observed. The sedimentary structures and relatively fine-grained texture suggest that deposition occurred in a mid subaqueous-fan setting. Although the exposed strata could store abundant groundwater, their aquifer potential is reduced by the absence of thick, laterally extensive, permeable gravel beds.

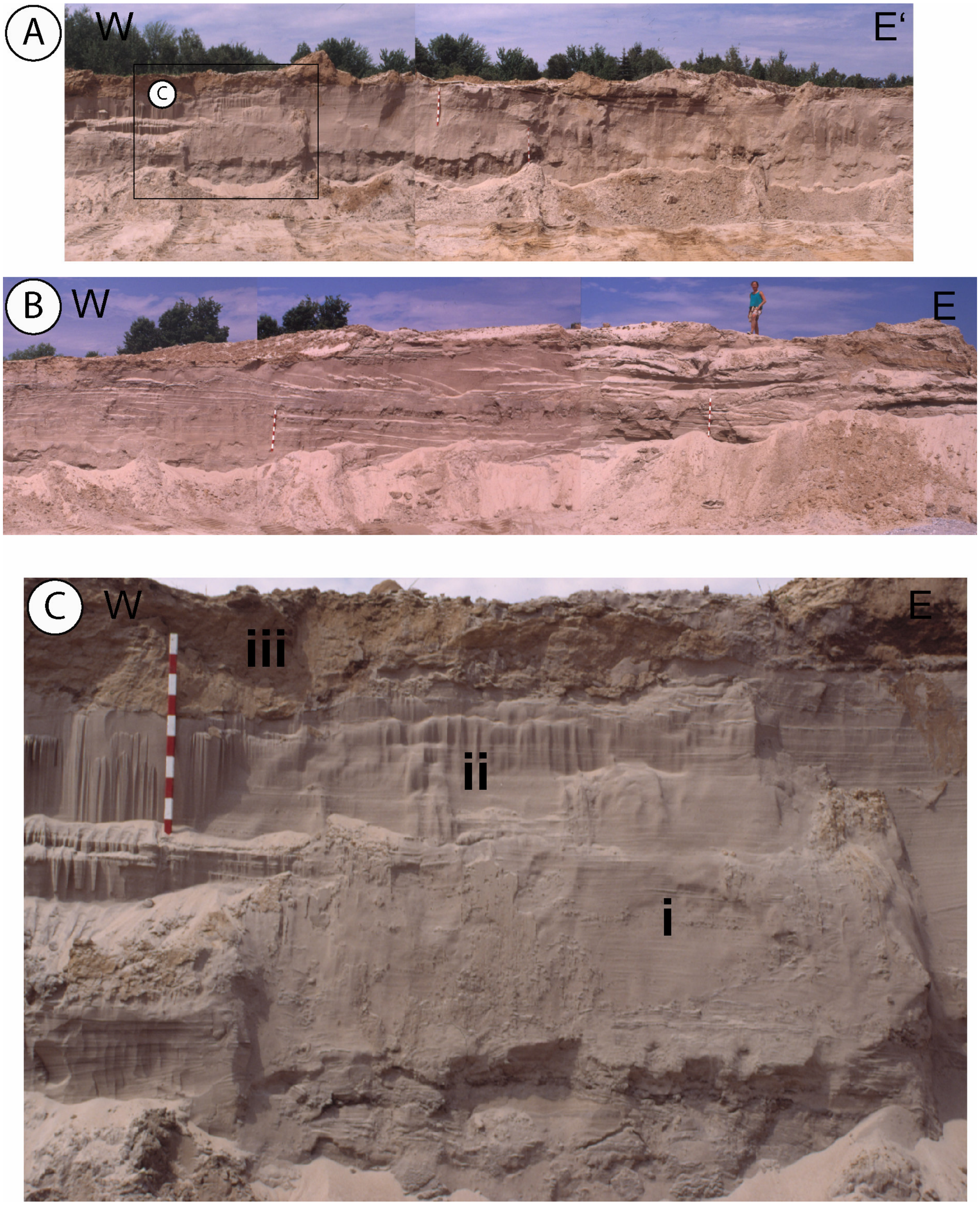

Figure 27. Representative photos of strata exposed in the Hollows pit in 1994. Images (A) and (B) form a photo mosaic at E' in (A). In (A) and (B) note the monotonic fine sand caliber in both vertical and horizontal directions. (C) Details of the bedding and sedimentary structures, showing i) plane bed, ii) diffusely graded sand, iii) pedogenically altered fine sand. Metre stick for scale (each red and white increment is 10 cm long).

Glacifluvial Deposits

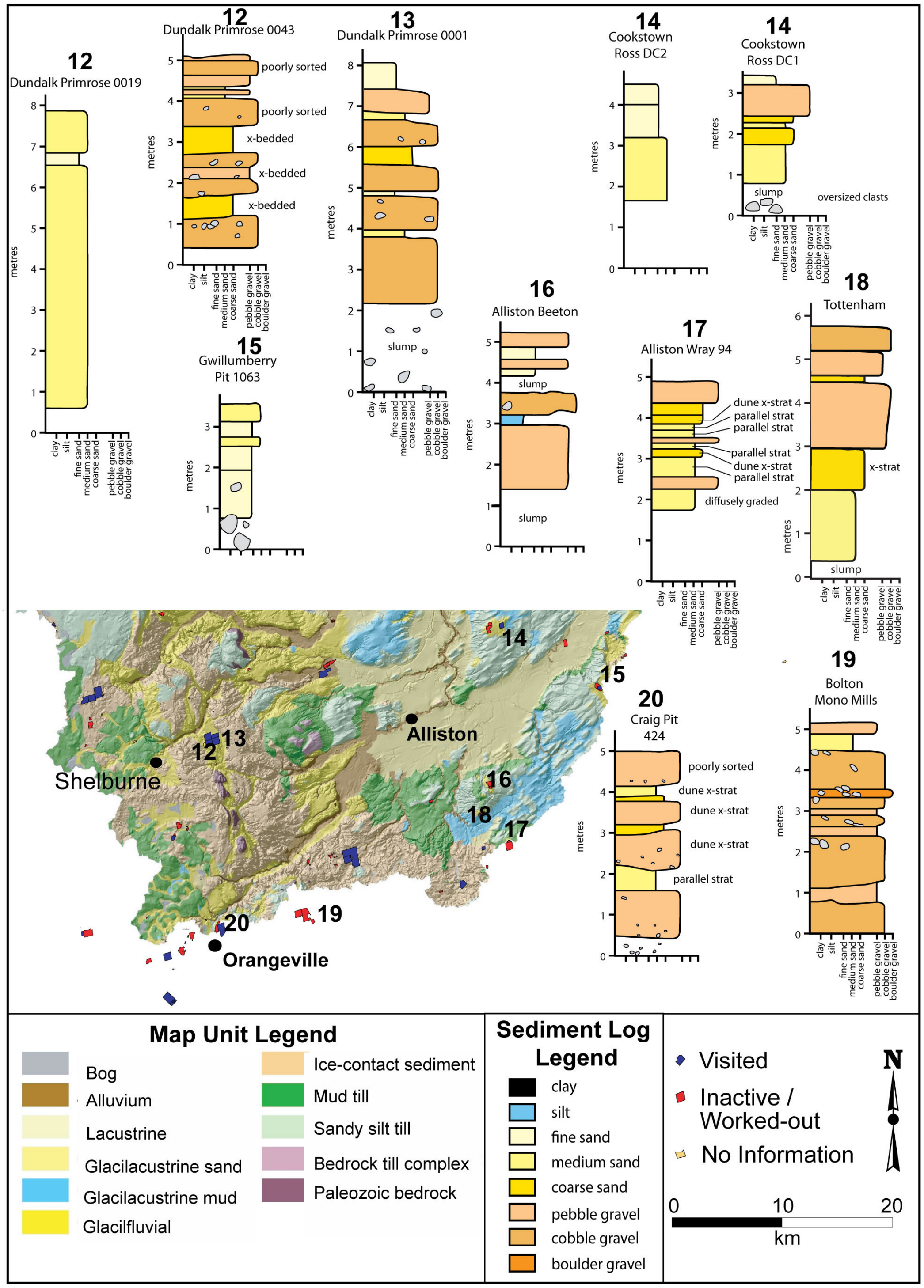

Figure 28. Summary display of graphic logs for sites visited in glacifluvial sediment deposits. Note variability in textures of deposits and depth of exposure. Numbers indicating sites refer to heading numbers in text.

12. PRIMROSE PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Pebble gravel, sand
Depositional environment: Subaerial outwash fan, possibly a fan-delta
Aquifer potential: Very good to good
Horizontal permeability: High to moderate
Vertical permeability: High to moderate

The Primrose pit is located 9.5 km east of Shelburne on Highway 89 on the Dundalk NTS map sheet, in an area mapped as glacifluvial outwash (Gwyn, 1972) (Figs. 2, 29). The pit is excavated into a relatively flat-topped deposit confined to a north-south channel-like depression that is partially bounded by bedrock of the Niagara Escarpment. A prominent scarp is present to the north of the pit. The scarp trends SW–NE, dips northwest, and is apparently cored with Quaternary sediment.

Pit faces are ~7 m in height and good exposure was present over ~500 m distance. Strata consist largely of dune cross-stratified pebble–cobble gravel (Fig. 30). Paleoflows interpreted from dune cross-beds are roughly southwestward. In pit faces parallel to paleoflow, proximal pebble–cobble gravel (Fig. 31A) interfingers abruptly downflow with distal current-ripple- and dune cross-stratified sand (Fig. 31). There is a surprising amount of mud on the pit floor given the coarse texture of sediment exposed pit faces—the mud is likely being winnowed from finer matrix sediment (predominantly coarse sand) that partially fills the space between gravel clasts. Given the high gravel-to-sand ratio in the pit, in addition to the southward paleoflows, the scarp may record the position of grounded ice from which meltwater emanated at the time of deposition. Since the deposit appears to be relatively flat-topped and dune cross-stratification is particularly abundant, the gravel may have been deposited in a subaerial setting; the abrupt downflow transition to sandy beds may suggest that the subaerial glacifluvial outwash plain terminated in standing water (i.e., the sediments were deposited in a fan-delta environment). The exposed strata have a very good aquifer potential given the abundance of gravel.

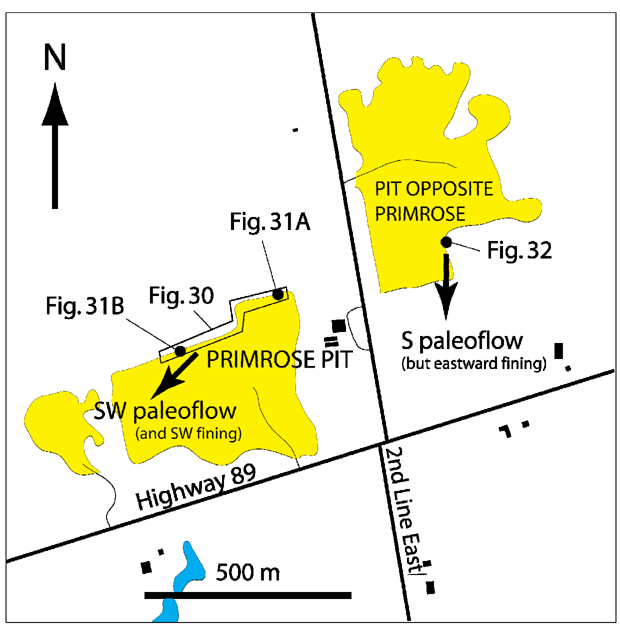

Figure 29. Overhead sketch of Primrose pit and unnamed pit adjacent to Primrose pit from Google Earth satellite images.

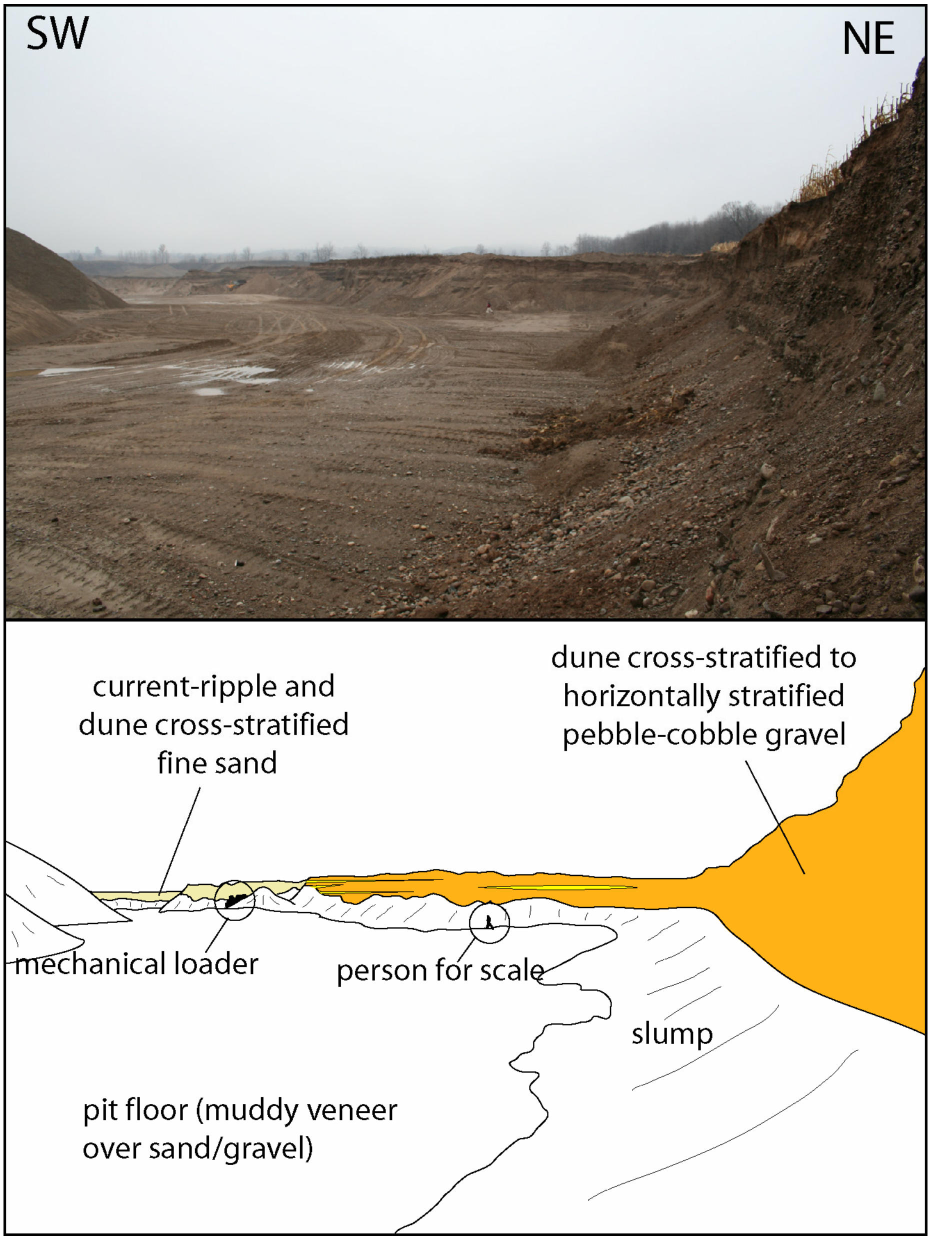

Figure 30. Panoramic shot of the north and western wall of the Primrose pit, looking downflow (south westward). Average height of pit faces is 7–8 m. Note the abrupt, interfingering, downflow transition between the pebble–cobble gravel unit (proximal) and current-ripple and dune cross-stratified unit (distal).

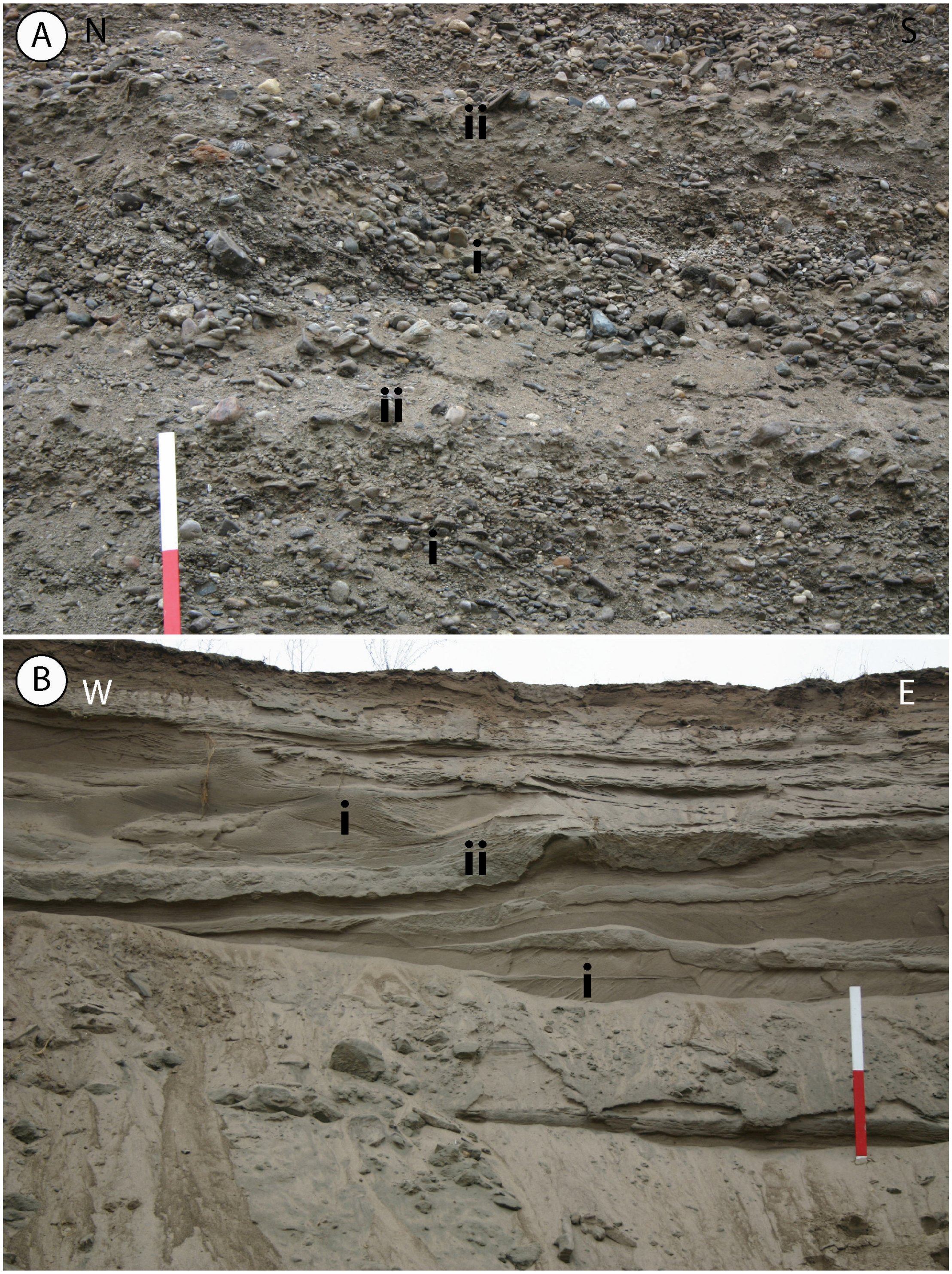

Figure 31. Close-up photos of representative sections from the Primrose pit. (A) Succession of gravel facies, i) cross-stratified gravel, ii) poorly sorted massive gravel. (B) Sand succession from south western part of pit, i) dune–scale cross-stratified fine-medium sand, ii) small-scale cross-laminated fine sand. Cross-strata indicate a south to south-west paleoflow for (A) and (B). Division on scale stick is 0.5 m.

13. PIT OPPOSITE PRIMROSE PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Pebble gravel
Depositional environment: Subaerial outwash fan
Aquifer potential: Very good
Horizontal permeability: High
Vertical permeability: High

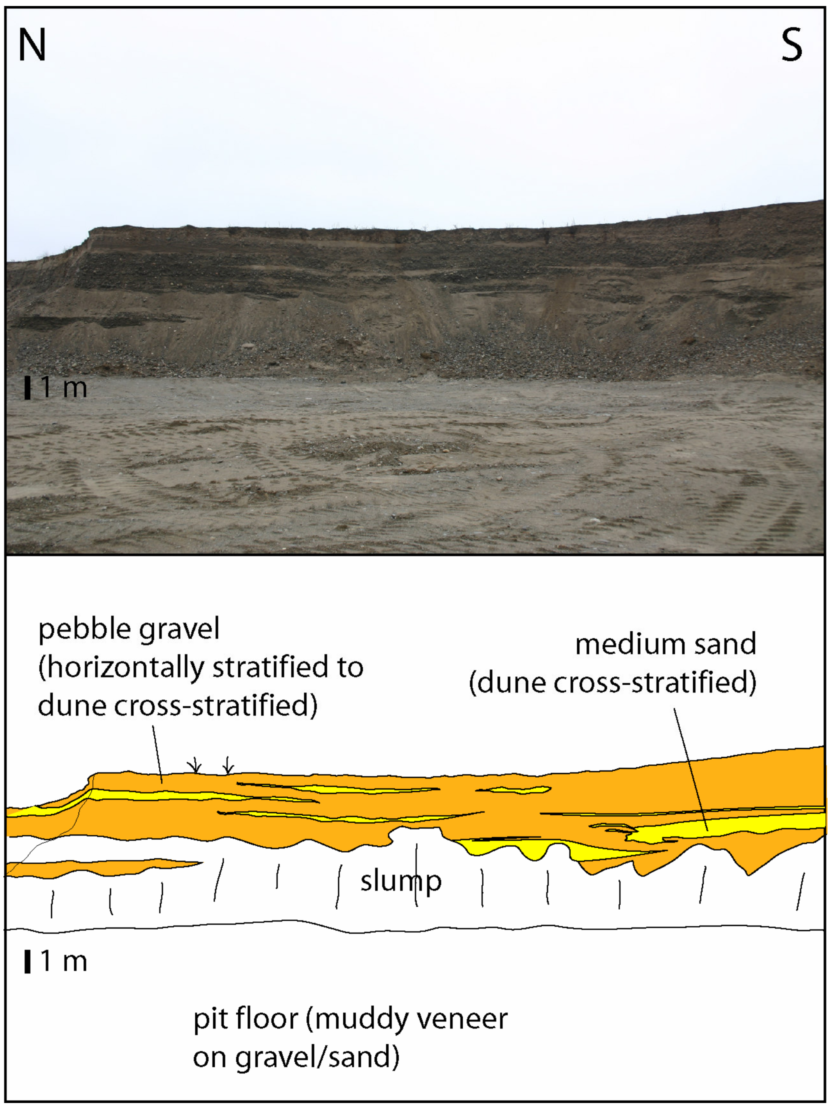

Figure 32. Representative photo from pit to the east of the Primrose pit. The deposit consists predominantly of dune-scale cross-stratified pebble gravel with minor dune-scale cross-stratified medium sand, similar to deposits in the nearby Primrose pit. Paleoflow is to the right (southward).

A large aggregate pit. here referred to as pit opposite Primrose pit, is located immediately east, on the opposite side of the 2nd Line East road from the Primrose pit on the Dundalk NTS map sheet (Figs. 2, 29). The pit occurs in the same flat-topped landform as the Primrose pit, which has been mapped as glacifluvial outwash (Gwyn, 1972). Pit faces are ~7 m high but not as laterally extensive as in the Primrose pit. However, like the Primrose pit, deposits consist predominantly of dune cross-stratified pebble gravel with minor dune cross-stratified medium sand (Fig. 32). Downflow-fining trends are less obvious than at the Primrose pit. Paleoflows from dune cross-strata suggest deposition from southward-flowing meltwater.

The gravely texture of the deposit, style of bedding, and association with a flat-topped landform suggest that the exposed strata are glacifluvial, and that they may have been deposited in a braided glacifluvial valley train setting.

14. COOKSTOWN PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Sand, pebble gravel
Depositional environment: Subaqueous fan
Aquifer potential: Good to very good
Horizontal permeability: Moderate to high
Vertical permeability: Moderate to high

The Cookstown pit is located 4 km northwest of Cookstown and north of Highway 89 on the Alliston NTS map sheet. It is situated on a Newmarket Till upland overlain locally by thin (< 5 m) accumulations of glacifluvial and glacilacustrine sediment (Russell and Dumas, 1997). The pit is moderate in size, and pit faces are < 3 m high. A distinct horizontal grain-size trend is visible: in a northwest direction, sediments grade from thick, horizontal beds of dune cross-stratified pebble gravel and medium sand (Fig. 34) to thin beds of dune cross-stratified medium sand that are inclined gently (< 10^{o}) downflow (no photo) to climbing-ripple cross-stratified fine sand (Fig. 35). Paleoflows interpreted from dune and current-ripple cross-strata are consistently northwest (i.e., parallel to downflow fining/thinning trend). Based on these observations, the downflow fining/thinning sediment package at the Cookstown pit is tentatively interpreted to be a subaqueous fan deposit. Although gravel is present locally in the Cookstown pit, it does not extend across the entire exposure. This ultimately reduces the aquifer potential of strata exposed.

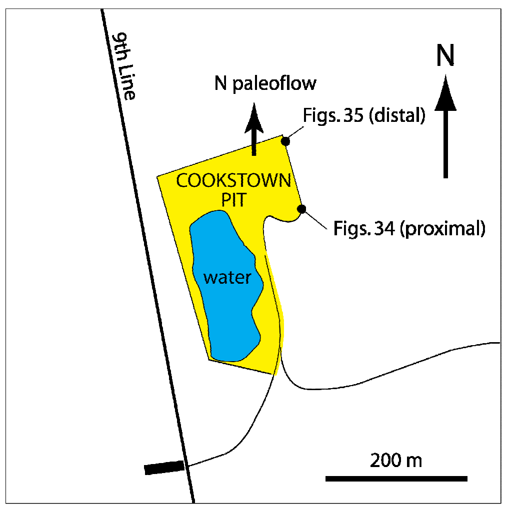

Figure 33. Overhead sketch of Cookstown pit based on satellite images obtained from Google Earth.

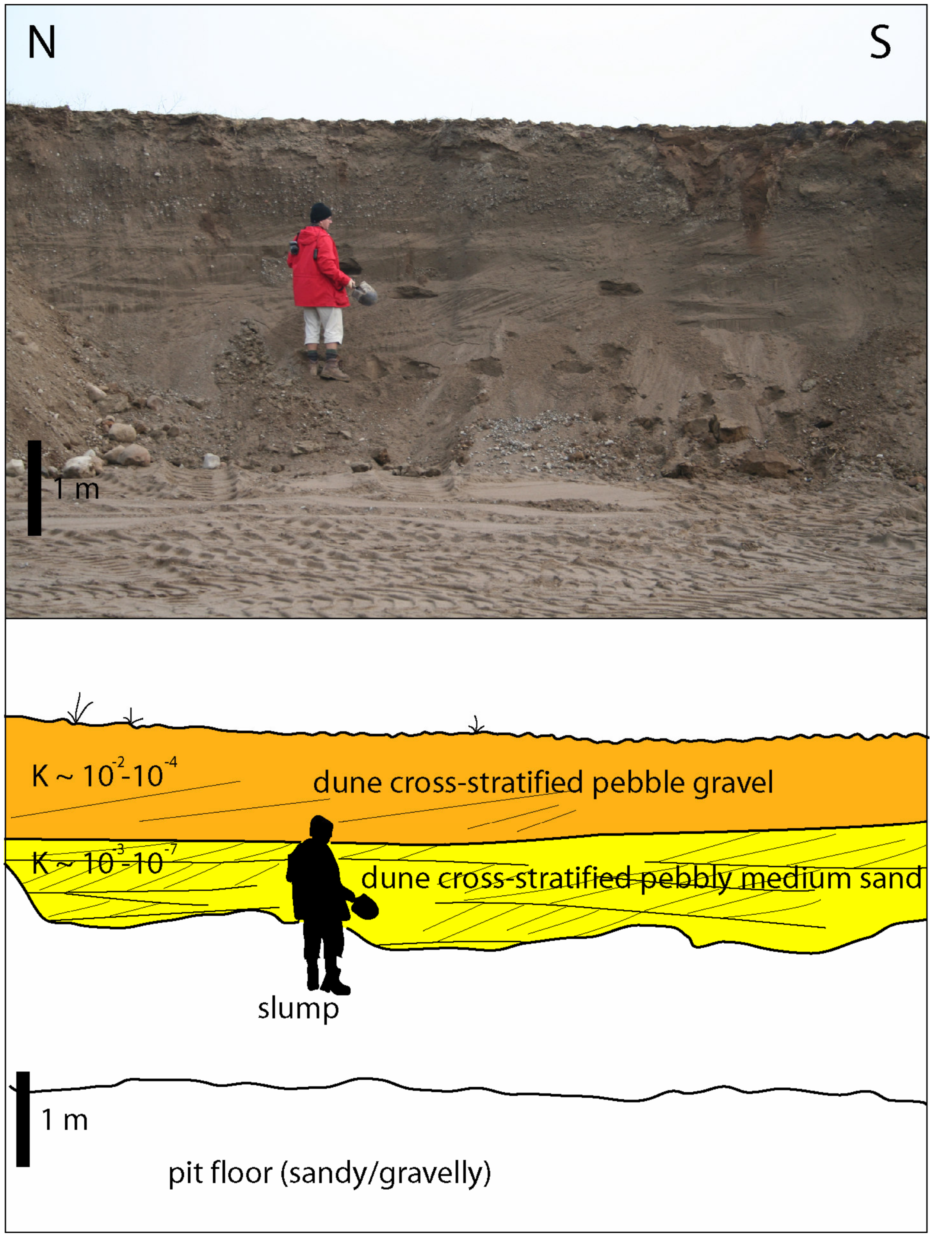

Figure 34. Representative photo and interpretative sketch of coarse-grained (proximal) facies exposed in the Cookstown pit. Interbedded dune-scale cross-stratified pebble gravel and dune cross-stratified medium sand interpreted to be mid-proximal subaqueous fan deposits. Note the northward dip of dune cross-strata.

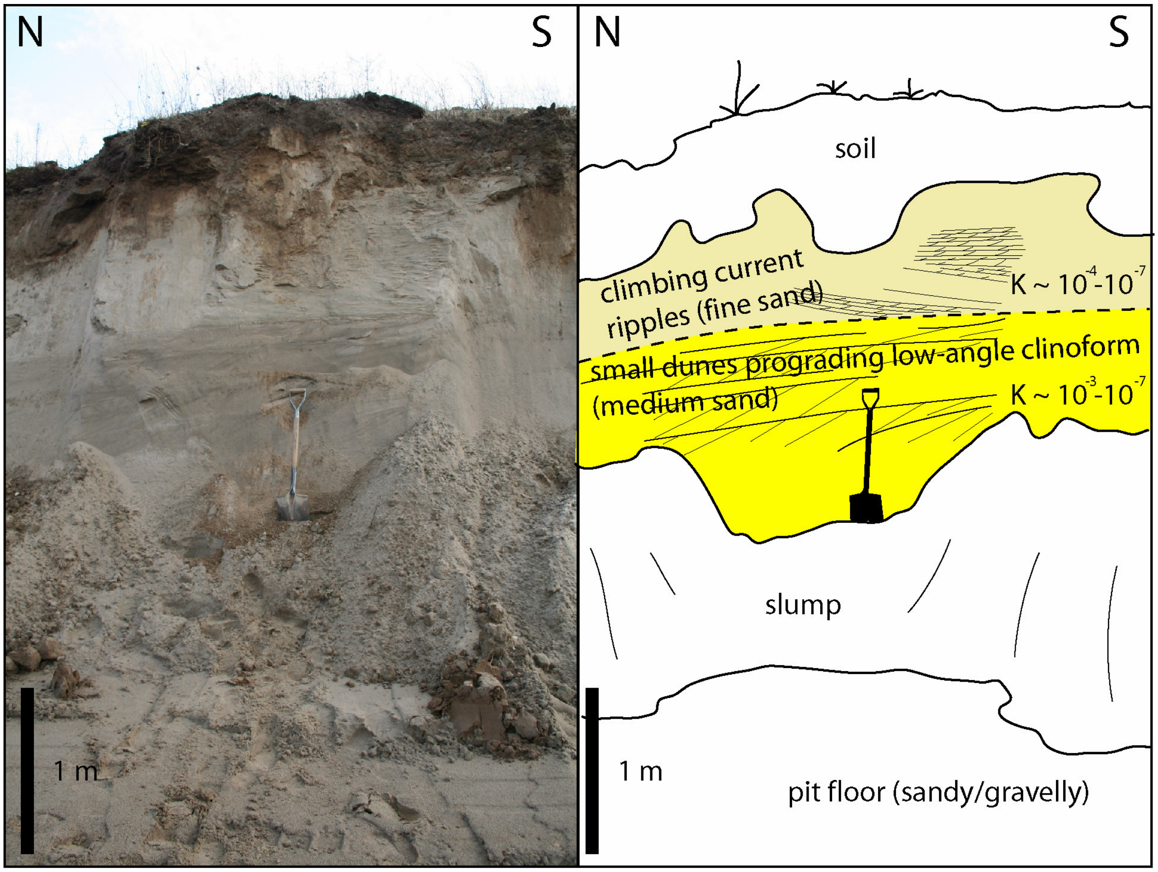

Figure 35. Representative photo and interpretive sketch of fine-grained (distal) facies in the northern part of the Cookstown pit. Climbing-ripple cross-stratified fine sand (interpretation: mid-distal subaqueous fan deposits) that conformably overlies thin dune cross-stratified medium sand beds that outbuild a low-angle (<10) clinoform (interpretation: mid subaqueous fan deposits).

15. GWILLIMBURY PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Sand (gravel was stripped from top)
Depositional environment: Subaqueous fan?
Aquifer potential: Moderate
Horizontal permeability: Moderate
Vertical permeability: Moderate

The Gwillimbury pit is located 6 km northwest of Bradford on the Alliston NTS map sheet (Figs. 2, 36). It is situated atop a Newmarket Till upland overlain locally by thin (< 5 m) accumulations of glacifluvial and glacilacustrine sediment (Russell and Dumas, 1997). The Gwillimbury pit is located in an area mapped as glacifluvial sediment. The pit was a site of extensive aggregate extraction during the construction of Highway 400 (pit operator, personal communication, 2006), and has subsequently been rehabilitated, except for a small area toward the south west corner which is operated by the Gwillimbury municipal council. The pit is relatively small in aerial extent, and pit faces are < 3 meters high. Small test pits suggest that a diamicton (interpreted to be Newmarket Till) forms the floor of the pit. Clear blue water occurs in the small excavations suggesting that the pit floor coincides with the water table.

At present, the exposed strata consist entirely of well-sorted fine to medium sand (Fig. 37). (According to the pit operator 1–2 m of gravel had been stripped from the top of the pit during construction of Highway 400). The sand is predominantly current ripple cross-stratified, although rare dune cross-sets were observed. Beds are inclined, forming thick (2–3 m) low-angle clinoforms. An isolated boulder occurs in the succession. Deformation is relatively minor and includes ball and pillow structures and small-scale faults with several centimeter offset. Based on a limited (< 10) number of measurements of both current-ripple cross strata and clinoforms, the paleoflow is interpreted to be northwestward.

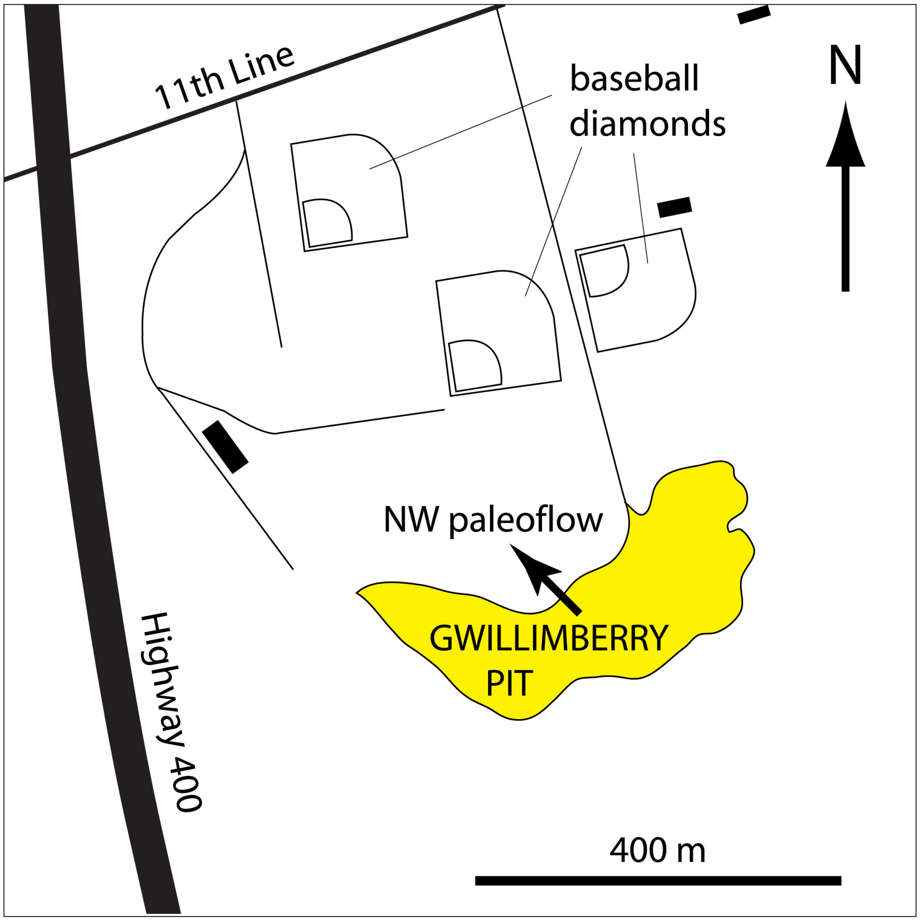

Figure 36. Overhead sketch of Gwillimbury pit from satellite images obtained from Google Earth.

Thin stratified deposits atop the Newmarket Till, such as those exposed in the Gwillimbury pit, have previously been interpreted as proglacial outwash (Gwyn and White, 1973). Alternatively, they were deposited subaqueously during the waning stages of a subglacial sheet flow prior to or coincident with incision of the adjacent tunnel channels (Russell, 2001; Russell et al., 2003). Although the exposure is relatively small, the sediment caliber and sedimentary structures in the Gwillimbury pit are similar to those observed in strata in other pits interpreted to be subaqueous fan deposits. The isolated boulder within the sand is interpreted to be a dropstone.

Because the Gwillimbury pit is floored by Newmarket Till, which generally functions as an aquitard except where fractured, precipitation that falls in the vicinity of the pit likely contributes only limited recharge to the sub-till aquifer.

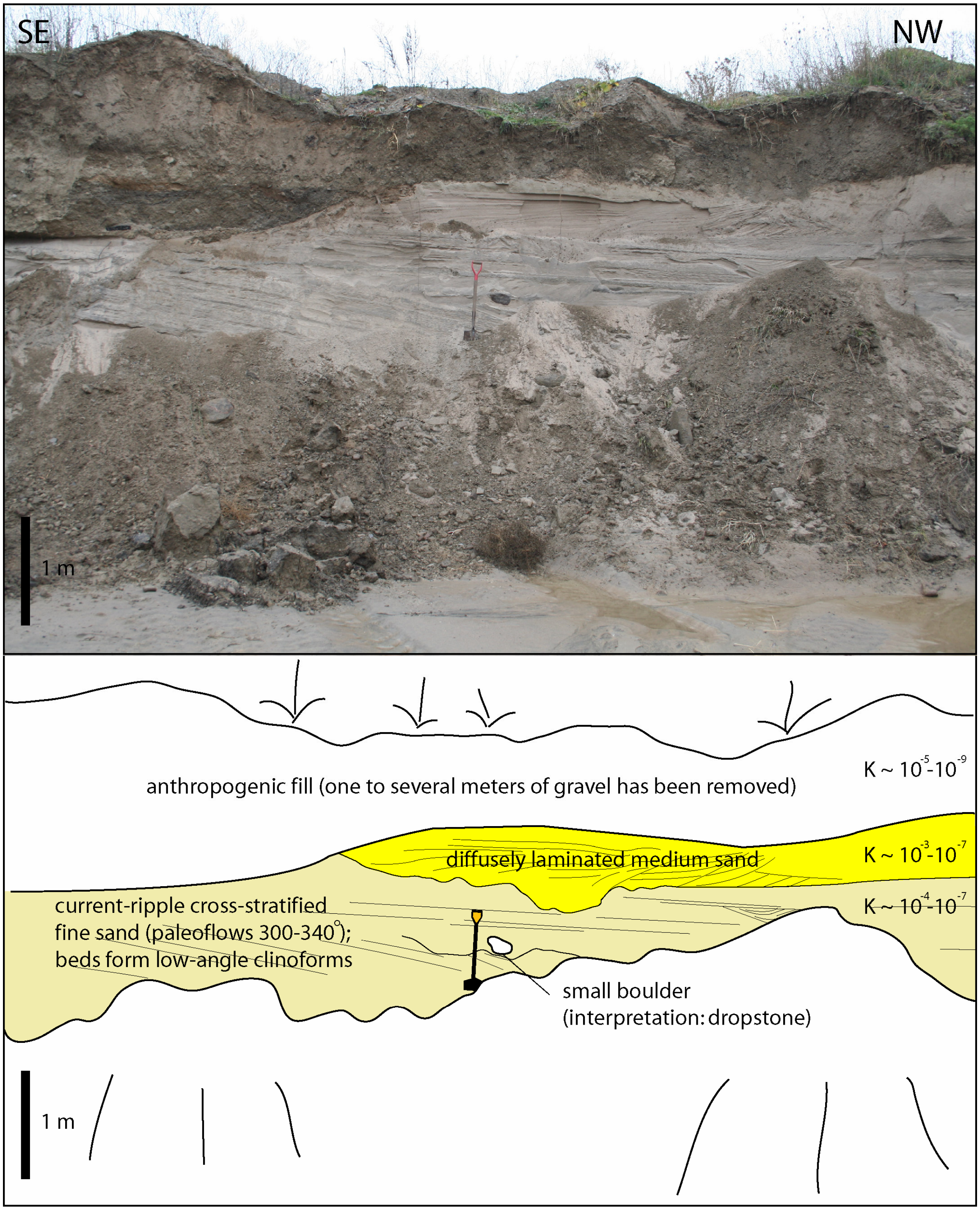

Figure 37. Representative photo of strata exposed in the Gwillimbury pit. A gravel unit was once present over the sand, but was stripped and used in the construction of nearby Highway 400 (pit operator, personal communication, 2006).

16. BEATON PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Pebble gravel, sand, mud
Depositional environment: Glacifluvial?
Aquifer potential: Moderate
Horizontal permeability: Moderate to high
Vertical permeability: Low

The Beaton pit is a small pit located 2.5 southeast of Beaton on the Alliston NTS map sheet, in an isolated oblate upland mapped as Newmarket Till and glacifluvial sediment (Fig. 2, 38). The stratigraphic setting of the sediment exposed in the pit is poorly constrained; it is assumed here to overlie Newmarket Till. The pit is largely inactive, and exposure is poor. It is currently used as a municipal storage for road materials. In a ~3 m high partially slumped face, a tripartite tabular stratigraphy of gravel, mud and sand is observed. The mud unit is approximately ~20 cm thick and has an undulating geometry (Fig. 39). The poor exposure precludes a definitive depositional interpretation.

The presence of the mud layer within an otherwise coarse-grained succession illustrates the potentially complex relationship between aquifer and aquitard on a bed-scale (i.e., centimeters to decimeters thick). The mud layer significantly affects the aquifer potential of the exposed strata: it reduces vertical permeability considerably, and would compartmentalize the aquifer into an upper and lower flow unit.

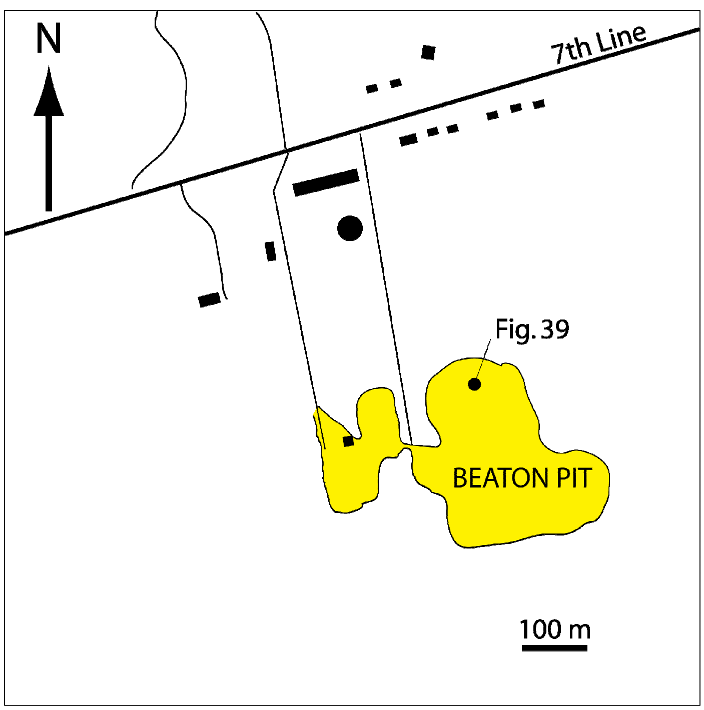

Figure 38. Overhead sketch of Beaton pit from satellite images obtained from Google Earth.

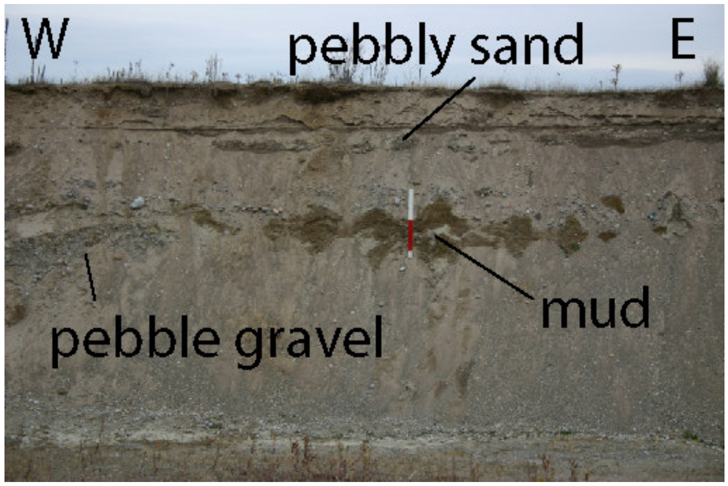

Figure 39. Beaton pit, extensively slumped exposure with tripartite succession of gravel, mud and pebbly sand. The mud unit could form a significant flow barrier which would compartmentalize the deposit. Scale stick is 1.2 m long.

17. WRAY PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Sand, minor gravel
Depositional environment: Glacifluvial deposits (proglacial? subglacial?)
Aquifer potential: Moderate
Horizontal permeability: Moderate
Vertical permeability: Moderate

The Wray pit is located ~5 km northeast of the Gormley pit on the Alliston NTS map sheet, on a till upland in an area mapped as glacifluvial deposits (Russell and Dumas, 1997) (Fig. 2). In 2006 the pit was completely worked out. However, in 1994 the excavation was still relatively small yet active (Fig. 40). Depth of excavation was limited to ~4 metres by an underlying diamicton (till). Two similar sand-rich units separated by a low-angle, northward dipping discontinuity was observed. Strata in both units consisted of fine sand to pebble gravel. Current-ripple and dune cross-stratified beds were common, as were planar-laminated beds and rare diffusely graded sand intervals. Sandy bedsets commonly consisted of one to several dune cross-sets overlain by planar-bedded sand. Larger erosional contacts were generally low-angle, with steeper-angled scours < 1 m in length and 20–30 cm deep locally.

The strata that were exposed in 1994 are interpreted to have been deposited in a glacifluvial environment that may have either been proglacial or subglacial. The homogeneous grain-size, absence of oversized clasts, and sedimentary structures suggest a moderate-energy depositional setting.

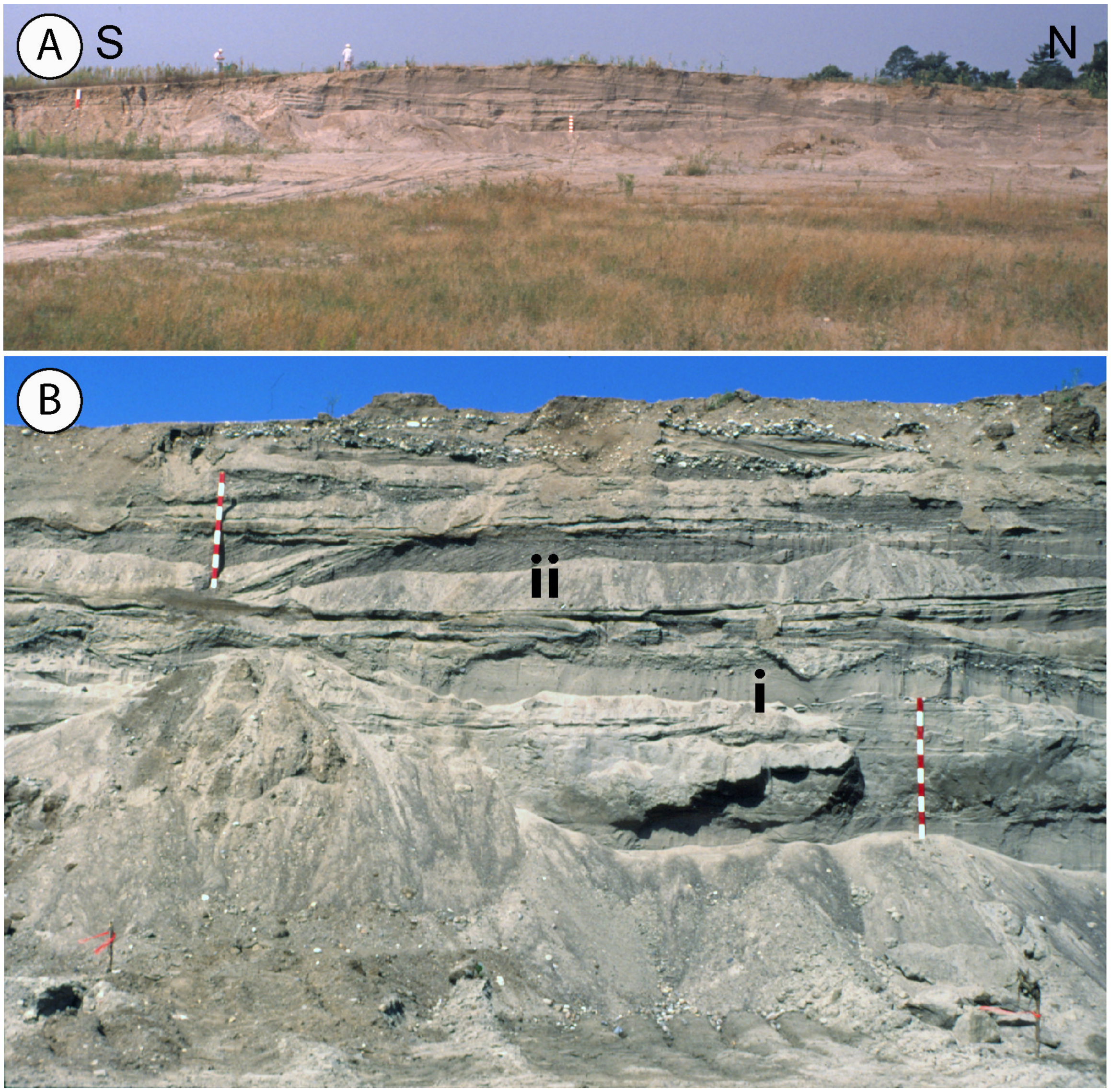

Figure 40. Photos taken in the Wray Pit in 1994. (A) Overview photo of ~80 percent of the exposed pit face. Note the low-angle discontinuity descending across the section from left to right. (B) Close-up of bedding thickness, texture and stratification types i) diffusely graded medium sand, ii) dune-scale cross-strata overlain by plane-bed.

18. TOTTENHAM PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Sand, pebble gravel
Depositional environment: Ice-contact delta
Aquifer potential: Good
Horizontal permeability: Moderate to high
Vertical permeability: Moderate to high

The Tottenham pit is located 3 km northeast of Tottenham, on the Alliston NTS map sheet, on the opposite side of the same upland as the Beaton pit, in an area mapped as glacifluvial sediment (Figs. 2, 41). The coarse-grained deposit into which the pit is excavated extends down the hillside for a couple of hundred metres to the base of the slope, where muddy glacilacustrine deposits form the surficial map unit (Fig. 2).

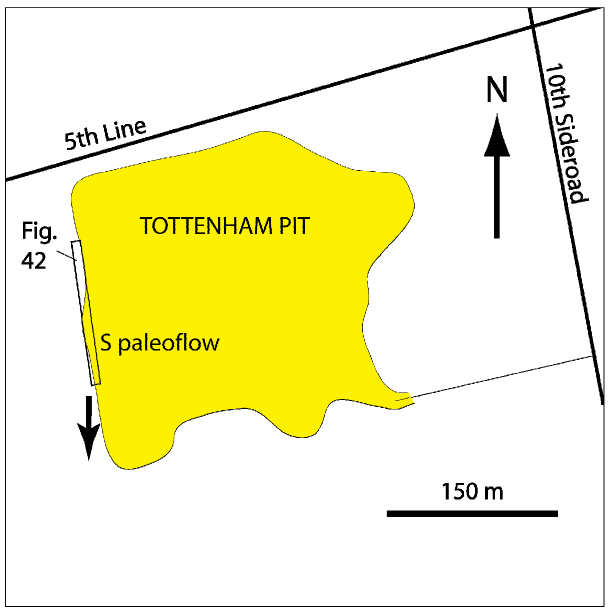

Figure 41. Overhead sketch of Tottenham pit from Google Earth satellite images.

The most conspicuous sedimentary feature observed in the pit is a thick (~7 m) package of southward-dipping sand–gravel clinoforms that can be traced downslope to the limit of the ouctcrop (Fig. 42). A thin (<2 m) package of horizontal sand–gravel beds interpreted to be topsets erosively overlies the clinoforms. The clinoform package coarsens upward, and consists of gravel fingers that pinch out down-dip into pebbly sand (Figs. 42, 43).

Given their large scale, upward-coarsening grain size, and presence of overlying topsets, the clinoform package is interpreted to have been deposited by a delta that prograded southward. Because the Tottenham pit is located just south of the crest of a hill, delivery of sediment to the prograding clinoform must have required glacier ice to be present nearby to the north at the time of deposition.

(Note that the facies boundaries in the clinoform package are diffuse and irregular: they cross-cut the more laterally-continuous bedding planes (thin black lines) that define the clinoforms (see Fig. 43). It is for this reason that bedding planes are imaged in seismic reflection data, not facies contacts (Vail et al., 1977; Cross and Lessenger, 1988). The implications of this are that facies can change along a given seismic reflection, as one can clearly imagine based on this photo.)

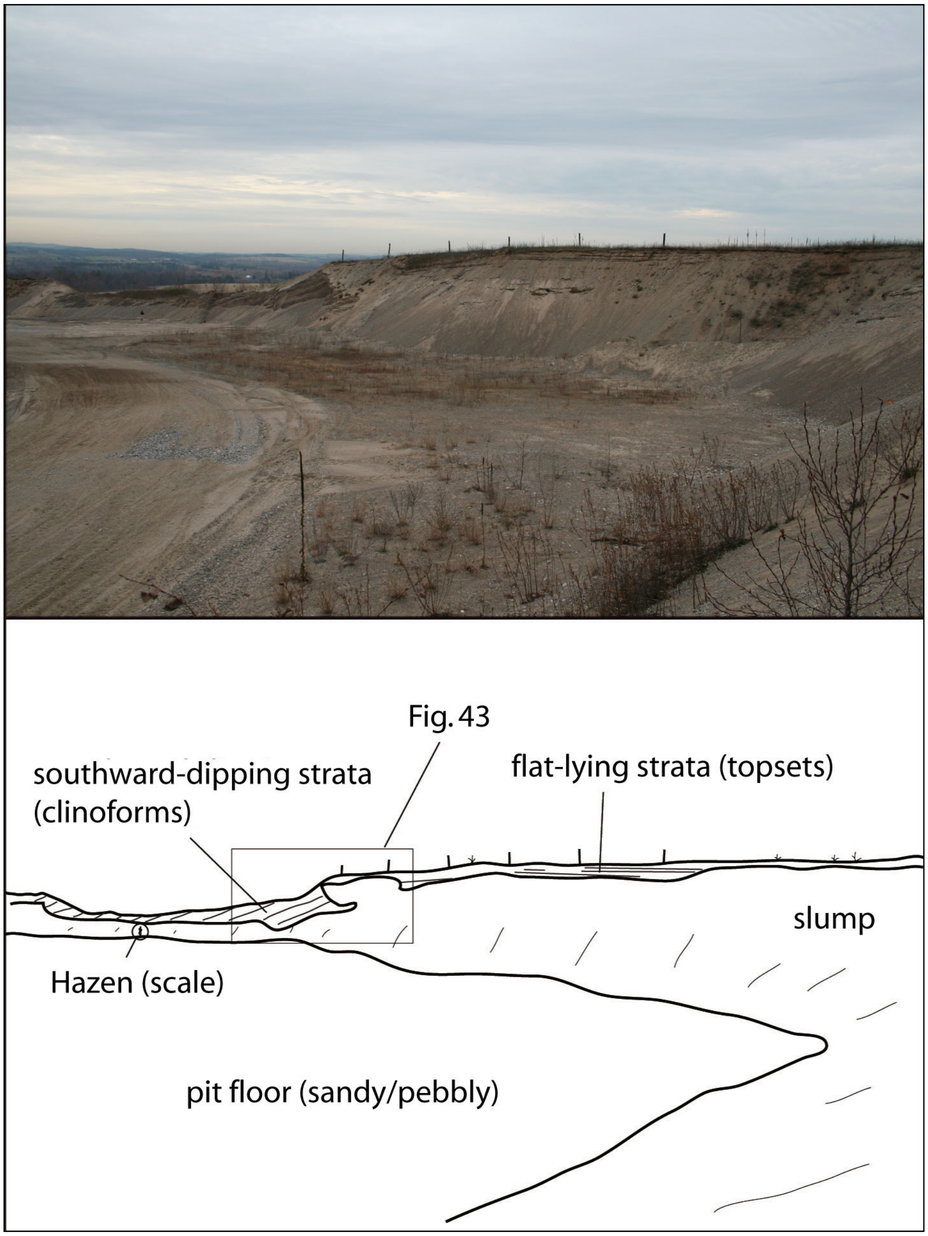

Figure 42. Photo of southward-dipping sand–gravel clinoforms and topset beds, Tottenham pit.

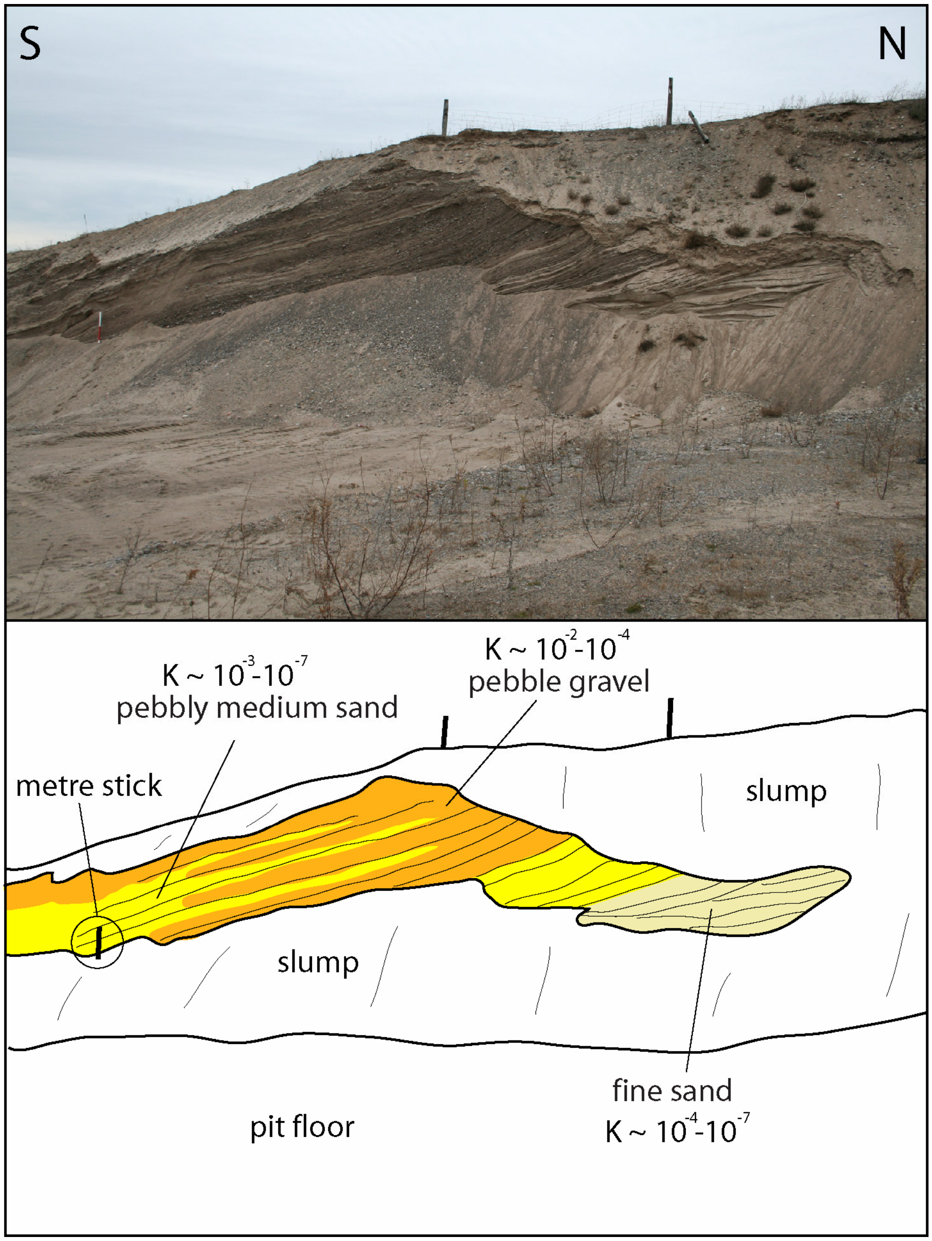

Figure 43. Facies architecture in large-scale (7 m high) clinoforms, Tottenham pit. Note upward coarsening trend.

Figure 44. Close-up of pebbly-sand clinoforms in the Tottenham pit. Lens cap for scale.

19. MONO MILLS PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Pebble–cobble gravel
Depositional environment: Glacifluvial deposits (proglacial? subglacial?)
Aquifer potential: Very good
Horizontal permeability: High
Vertical permeability: Moderate to high

The Mono Mills pit is located on the Bolton NTS map sheet, halfway in between the Adjala pit and the Craig pit at Orangeville, in an area mapped as glacifluvial deposits (Fig. 2). In 2006 the pit was closed and appeared to be worked out, but in 1994 an excavation at the southern end of the pit was active and was observed by the second author (Fig. 45A). At that time, depth of excavation was limited by an underlying red silt-rich diamicton. Most of the exposed strata consisted of poorly sorted pebble–cobble gravel with small sand lenses. In many places, abundant tabular-shaped cobbles of Paleozoic origin highlighted a well-defined imbrication. The predominant matrix was medium–very coarse sand. The top of the succession was capped by medium sand (Fig. 45B).

The strata are interpreted to have been deposited in a glacifluvial setting. Clast imbrication suggests that flow was toward the south. It is difficult to assign a more specific depositional environment based solely on the sedimentology of the exposure. Based on aerial photos, previous workers have interpreted the deposit to be proglacial outwash.

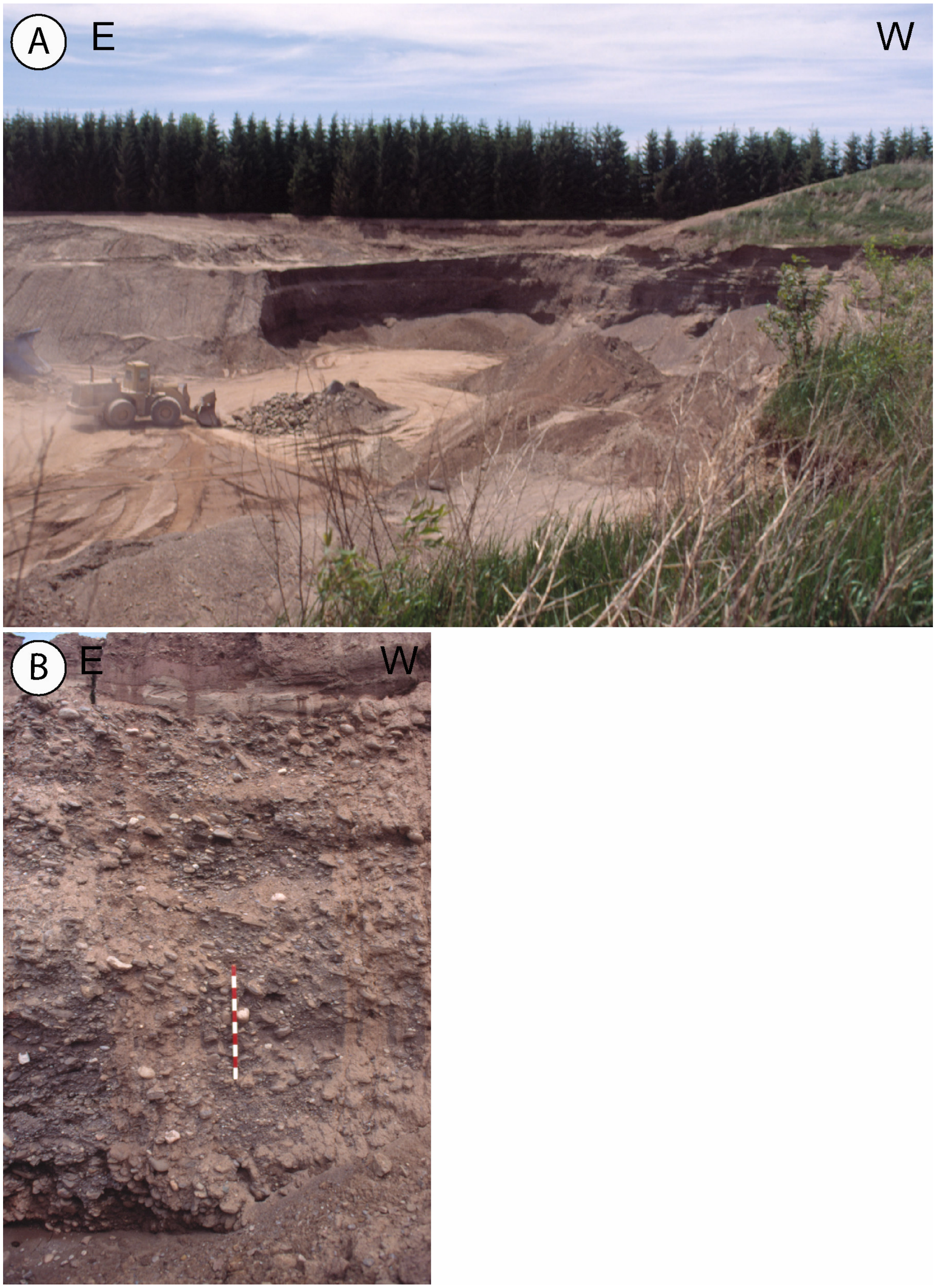

Figure 45. Mono Mills pit in 1994. (A) Overview of pit. Pit floor corresponds to the top of a silt rich diamicton. (B) Representative section of poorly sorted, vaguely horizontally stratified pebble–cobble gravel.

20. CRAIG PIT

Map unit: Glacifluvial sediment
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Pebble gravel
Depositional environment: Subaerial outwash fan
Aquifer potential: Very good
Horizontal permeability: High
Vertical permeability: High

The Craig pit is a large gravel pit located 3 km north–northeastward of Orangeville on the Orangeville NTS map sheet, in an area mapped as glacifluvial outwash. This outwash has been informally referred to as the Hockley Valley outwash by Cowan (1976) (Figs. 2, 46). Cowan (1976) reports that water wells near the pit intercept up to 30 m of gravel. Pit faces are 4–5 m high and extend laterally for 1000 m. Exposures consist almost entirely of thinly bedded dune cross-stratified pebble-gravel and medium sand (Fig. 47). The succession fines upward and bed thickness decreases upward. Pebble-rich gravel cross-beds that are up to 40–50 cm thick occur above the slump. Above this beds become finer and bed thickness decreases. Grain size is surprisingly uniform throughout the pit, both vertically and horizontally. Paleoflow directions are towards the west.

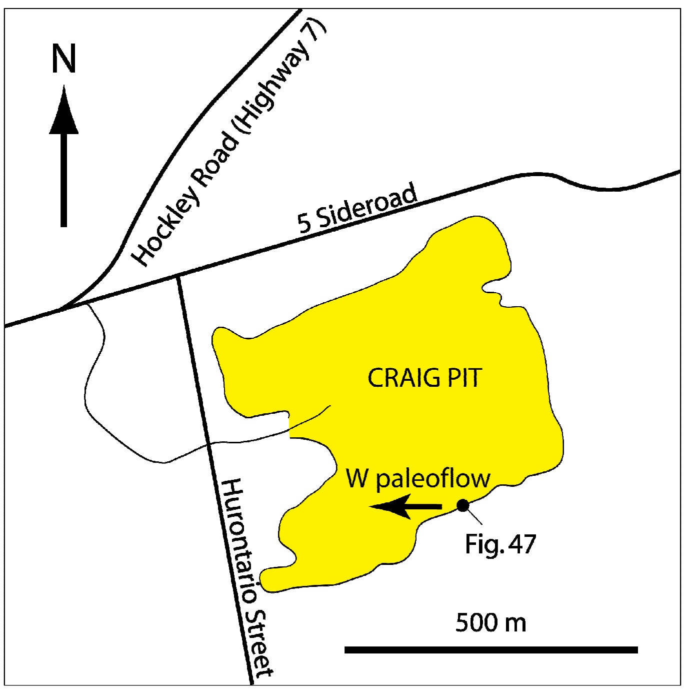

Figure 46. Overhead sketch of Craig pit based on Google Earth satellite images.

Strata exposed in the Craig pit are interpreted to be glacifluvial in origin. They may have been deposited by shallow, braided channels that combed laterally across a non-cohesive (non-muddy) outwash plain. Lack of lateral accretion deposits is striking and somewhat perplexing, as this suggests that most of the bedforms were deposited on a relatively horizontal bedding surface that aggraded vertically, not on lateral accretion surfaces (e.g., braid-bar flanks) as is common in gravely braided fluvial systems (Bridge, 2003).

Figure 47. Craig pit in glacifluvial outwash near Orangeville. Representative photo of sediment exposed in the pit. Exposed successions in the pit consist almost entirely of thinly bedded, dune cross-stratified pebble gravel and medium sand, as pictured here.

Alluvial Deposits

Alluvial deposits occur across the area and have been mapped as river deposits (Russell and Dumas, 1997). The younger deposits are generally thin, narrow deposits at similar elevations as the modern drainage systems. Older alluvial deposits associated with the early Holocene are commonly thicker and wider in extent. Only one site was visited with alluvial deposits and this is an area mapped as older alluvium southwest of Everett.

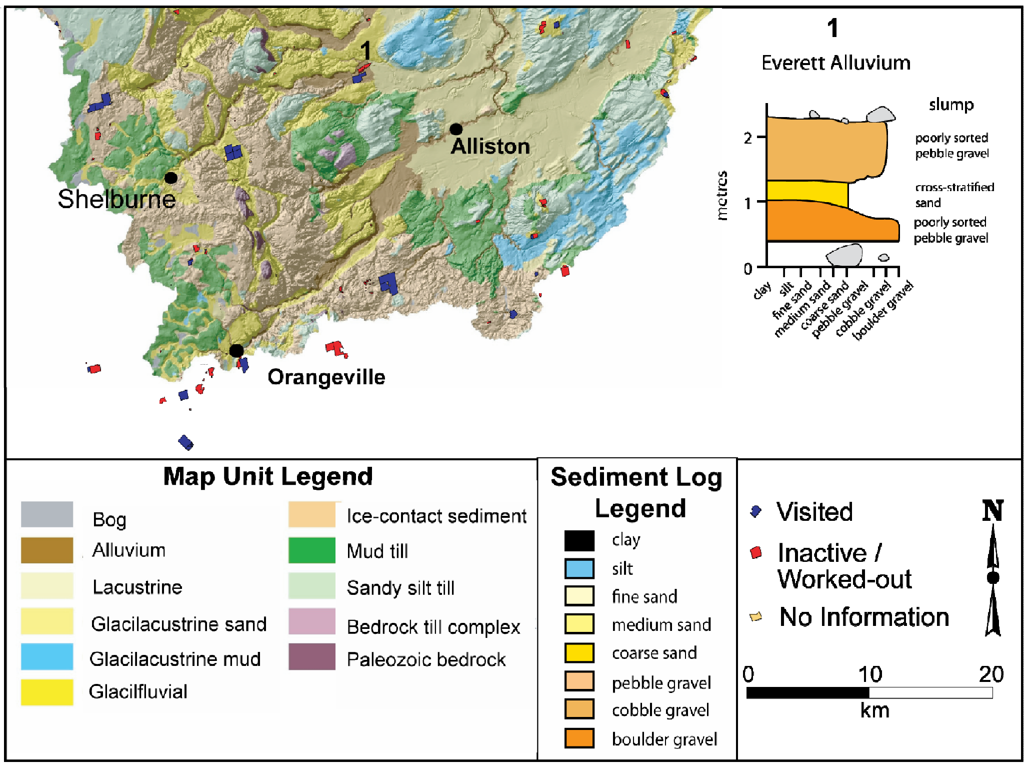

Figure 48. Summary display of graphic logs for sites visited in alluvial sediment deposits. Note variability in textures of deposits and shallow depth of exposure. Bedrock occurred at the base of the section, the zero mark on the section. Only one site was visited. It is within mapped older, raised Alluvial deposits.

21. EVERETT PIT

Map unit: Alluvium
Stratigraphic position: Stratigraphically above Newmarket Till
Sediment exposed in pit: Pebble gravel, minor mud
Depositional environment: Coarse-grained post-glacial river system
Aquifer potential: Very good
Horizontal permeability: High
Vertical permeability: Moderate to high

The Everett pit is located 3.5 km southwest of Everett on the Alliston NTS map sheet in a low-lying area mapped as older alluvium (Russell and Dumas, 1997) (Fig. 2, 48, 49). Although the pit is not small in terms of areal extent, exposures are limited in height to 1–2 metres, and bottom out on a thin mud layer that overlies the shale bedrock (Fig. 50). Over this basal mud layer, exposed sediment consists predominantly of dune cross-stratified pebble gravel (Fig. 48B). Cross-strata dip eastward, indicating paleoflows to the east. Where the pit has been excavated to bedrock, the thin (~25 cm thick), laminated mud unit is observed between the gravel and shale bedrock (Fig. 50C).

The location of the Everett pit in a NE-trending/dipping river valley (see Fig. 2), in addition to the eastward paleoflow direction, suggests that the exposed strata was deposited by a river during isostatic rebound after glacier ice had left the region and Lake Algonquin had fallen to a lower level.

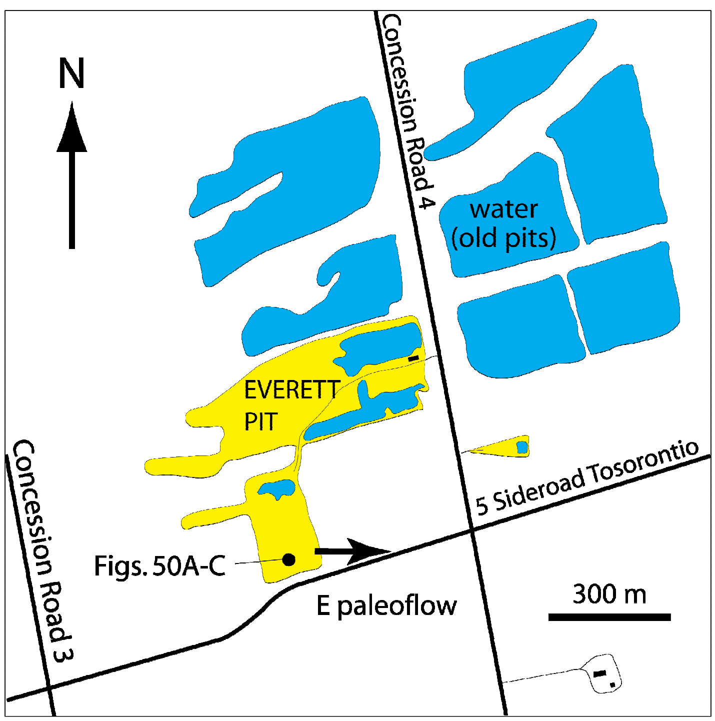

Figure 49. Overhead sketch of the Everett pit based on Google Earth satellite images.

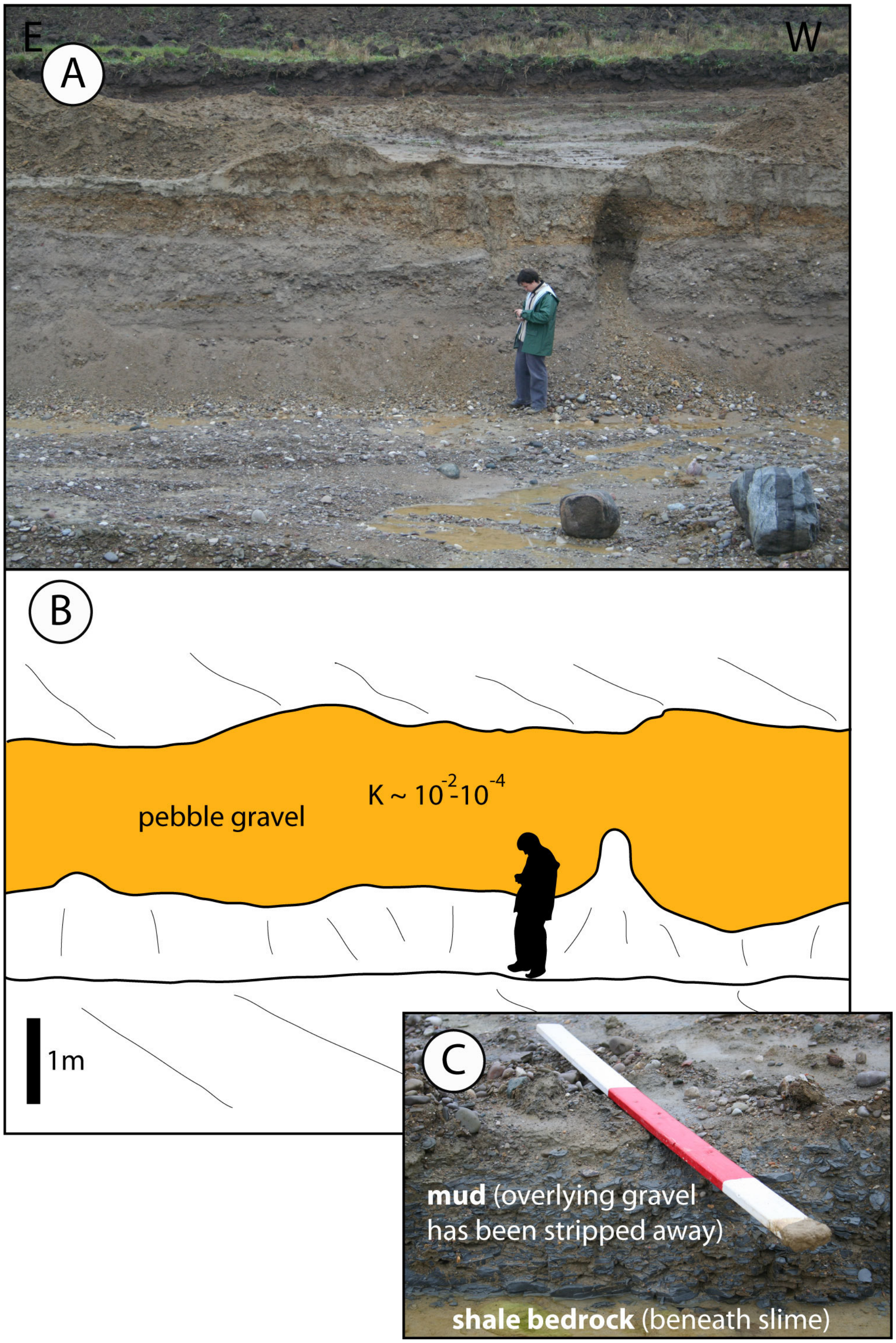

Figure 50. Everett Pit, (A) Location map, showing eastward paleoflow interpreted from dune cross-stratification in pebble gravel. (B) Dune cross-stratified pebble gravel (interpretation: fluvial deposits). Paleoflow is towards left of page (east). Note that the surficial gravel unit is very thin (<3 m)—shale bedrock is immediately below the pit floor in this photo. (C) Close-up photo of the shale bedrock.

DISCUSSION

Examination of the aggregate pit sedimentology provides an additional dataset for development of conceptual geological and hydrogeological models for the watershed. These observations also provide a detailed dataset that can prove invaluable in analysis of water wells that are screened within different geological map units.

Stratigraphic position

The Newmarket Till was not exposed in any of the pits investigated, although it is interpreted to form the floor of the Gwillimbury pit. However, previous geological mapping and subsurface investigation in the region (Sharpe et al., 1997; Barnett et al. 1998; Pugin et al., 1999; Pullan et al., 2002) strongly suggest that most if not all of the pits investigated in this study occur in stratified sediment bodies that stratigraphically overlie the Newmarket Till. Diamicton observed in the Nelson and Strada pits is interpreted to be a debrite, not a till, because it infills a channel-form depression. For two of the sites, the Hollows and Beaton pits, the correct stratigraphic assignment may need to be more completely investigated.

Map Unit Geomorphology

The landscape surrounding the pits in areas mapped as ice-contact stratified drift commonly consisted of large hummocks that are tens of metres in relief and hundreds of metres in lateral extent. This type of landscape is typically interpreted as resulting from deposition of sediment on top of ice, which then melts, generating hummocks and swales (e.g., Colgan et al., 2003). However, when the sedimentology of deposits within hummocks is examined in the pits, it is surprising how few faults occur. (Faults were only observed at one location—the Gillespie pit. See Table 2.) As such, the hummocky terrain surrounding the pits is perhaps more reasonably interpreted as being the product of sediment deposition and/or erosion, not ice let-down.

Pits within glacifluvial and alluvium map units are generally excavated into relatively low-relief landscapes confined to narrow north-south trending corridors. This morphological association provides supporting evidence of deposition in proglacial fluvial outwash plains confined to valleys.

Sediment Facies

The gravel-sand ratio appears to vary between ice-contact stratified sediment and glacifluvial/alluvial deposits in the study area: abundant sand was exposed in regions mapped as ice-contact stratified drift, whereas very little was exposed in pits in glacifluvial/alluvial map units, the later being composed predominantly of gravel (Figs. 52–54). Besides this difference, gravel facies in both map units were difficult to differentiate, although gravel with boulder-sized sand clasts was only observed in ice-contact stratified sediment deposits. Muddy units were universally uncommon, which may simply reflect the fact that mud is not typically mined in aggregate operations.

Facies Architecture

Strata in pits tended to be roughly flat lying and tabular, at least on the scale of the pit exposures (10 to >1000 metres in horizontal extent). Larger inclined foresets were only observed in the Tottenham pit, but large-scale foresets have been documented previously in the Gormley pit (Russell and Arnott, 2003). Channel-form units with pronounced convex-down bases and mounded units with pronounced convex-up tops were rarely observed.

Horizontal grain-size trends

Sediment in several gravel pits displayed pronounced downflow fining over the horizontal extent of the exposures (tens to hundreds of metres; e.g., Gormley pit, Cookstown pit). By contrast, sediment exposure in other pits lacked any substantial fining in a horizontal direction on the scale of the exposures (e.g., Nelson). In pits where downflow fining occurred, three interfingering facies were commonly observed (from proximal to distal): (1) thick (50–100 cm) beds of horizontally stratified to dune cross-stratified pebble–cobble gravel, (2) medium–thick beds (30–100 cm) of dune cross-stratified medium–coarse sand, and (3) thin beds (<10 cm) of climbing-ripple cross-stratified fine sand with local dewatering features. This type of horizontal grain-size trend is interpreted to be characteristic of subaqueous-outwash fan bodies such as that which has previously been interpreted to occur at the Gormley pit (Russell and Arnott, 2003). Sediment in pits where downflow fining was absent, by contrast, tended to consist entirely of dune cross-stratified pebble gravel with minor amounts of dune cross-stratified medium–coarse sand. Absence of downstream fining was more common in pits mapped as glacifluvial outwash or alluvium, which should be expected given that flows in such systems should be relatively steady and uniform relative to flows in subaqueous fan environments.

Vertical grain-size trends

There are few or no continuous cored boreholes in the areas visited, the exception being the Oak Ridges Moraine (ORM) unit, which is cored continuously at several locations in the Humber River watershed, south of Nottawasaga River watershed (Russell and Pullan, 1998). These data suggest the ORM sediment generally fines upward and is overlain gradationally by a diamicton known as the Halton Till. There is no evidence that the Halton Till occurs in the Nottawasaga River watershed, although it is possible that the ORM exhibits a similar vertical grain-size trend. In pit sections, vertical grain-size trends were highly variable; successions fined up, coarsened up, or were ungraded. Abrupt changes in grain-size (e.g., fine sand erosively overlain by pebble–cobble gravel) were observed in several pits. The general impression is that, although flow was relatively steady in some locations during deposition of the exposed strata, major, abrupt (jökulhlaup-type?) fluctuations in flow velocity occurred locally.

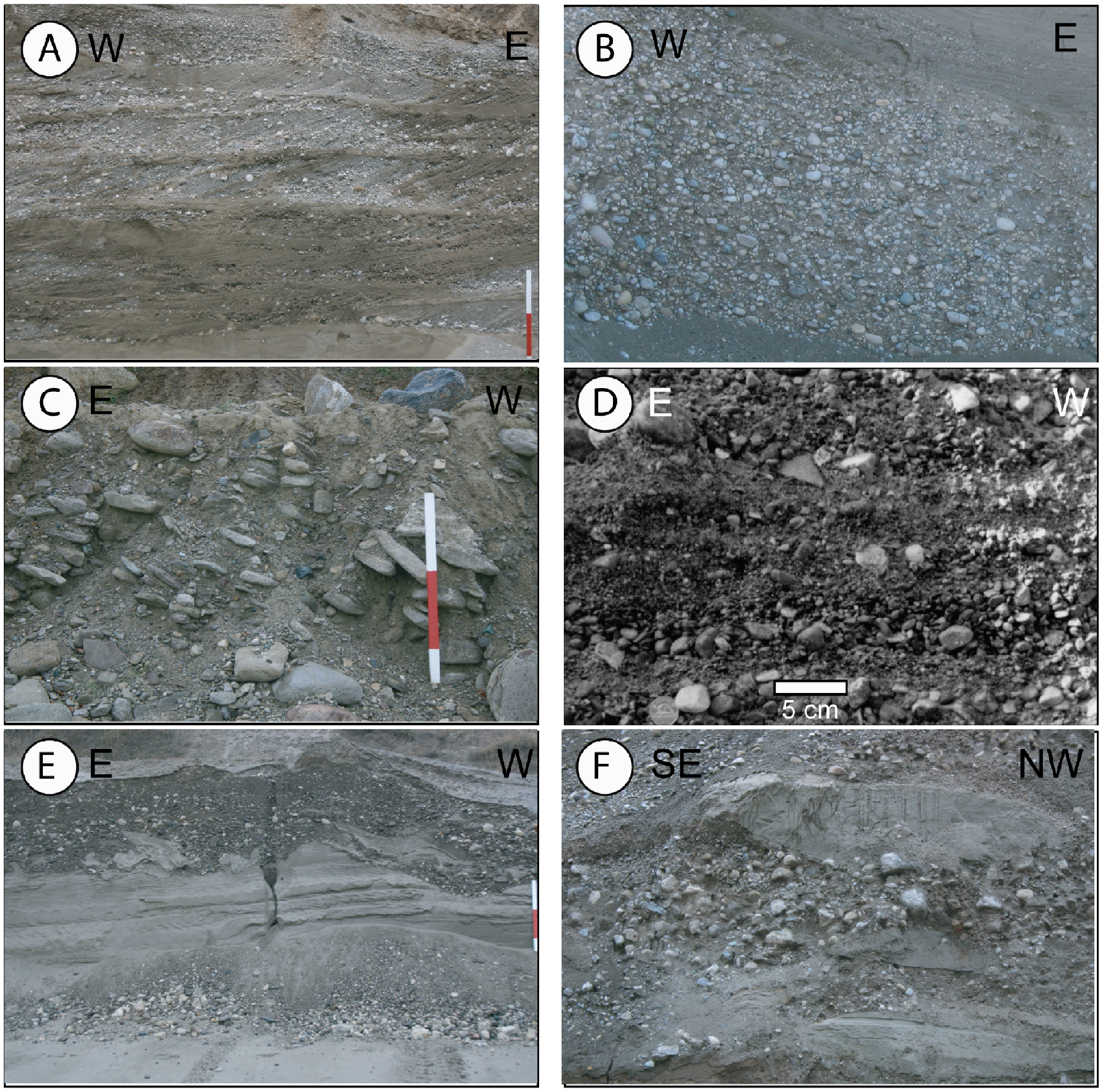

Figure 51. Illustrative gravel facies from ice-contact stratified-sediment in the Orangeville and Oak Ridges moraines. (A) Stacked, dune-scale cross-strata. (B) Massive cobble gravel. (C) cross-bedded boulder gravel. (D) Couplets of openwork gravel fining upward to gravelly sand, interpreted as antidune stratification. (E) Flames in massive gravel. (F) Large silty fine sand intraclast in massive and cross-bedded gravel

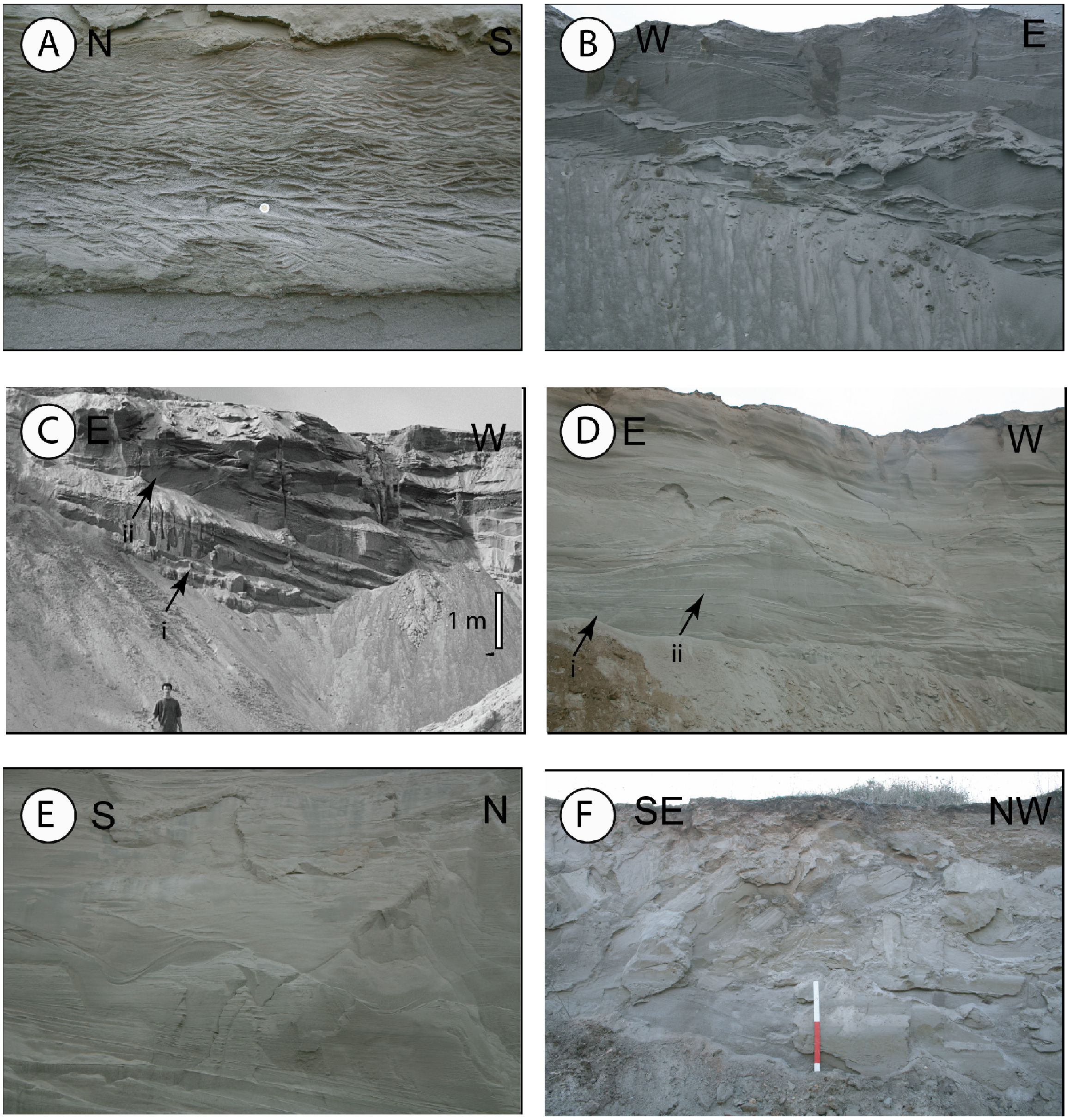

Figure 52. Illustrative sand facies observed in ice-contact stratified-sediment of the Orangeville, and Oak Ridge moraines. (A) Strike-section of small-scale trough cross-laminated fine sand, bed fines upward and has a rotation in paleoflow direction, paleoflow is predominantly out of face. (B) Dip-section climbing, stoss-erosional dune-scale cross-bedding. Flow is to west. (C) Large-scale clinoforms with down-climbing dune scale cross-stratification (i), note scours into clinoforms (ii), flow to west. (D) Low-angle cross-stratification interpreted to be antidune cross-stratification, flow is obliquely into face to the west, note transition of well defined thin laminae (i) into thicker diffuse laminae within the mound (ii). (E) Nested scours infilled with diffusely graded fine sand. (F) Breccia of fine sand intraclasts in a medium sand matrix, paleoflow is into photo.

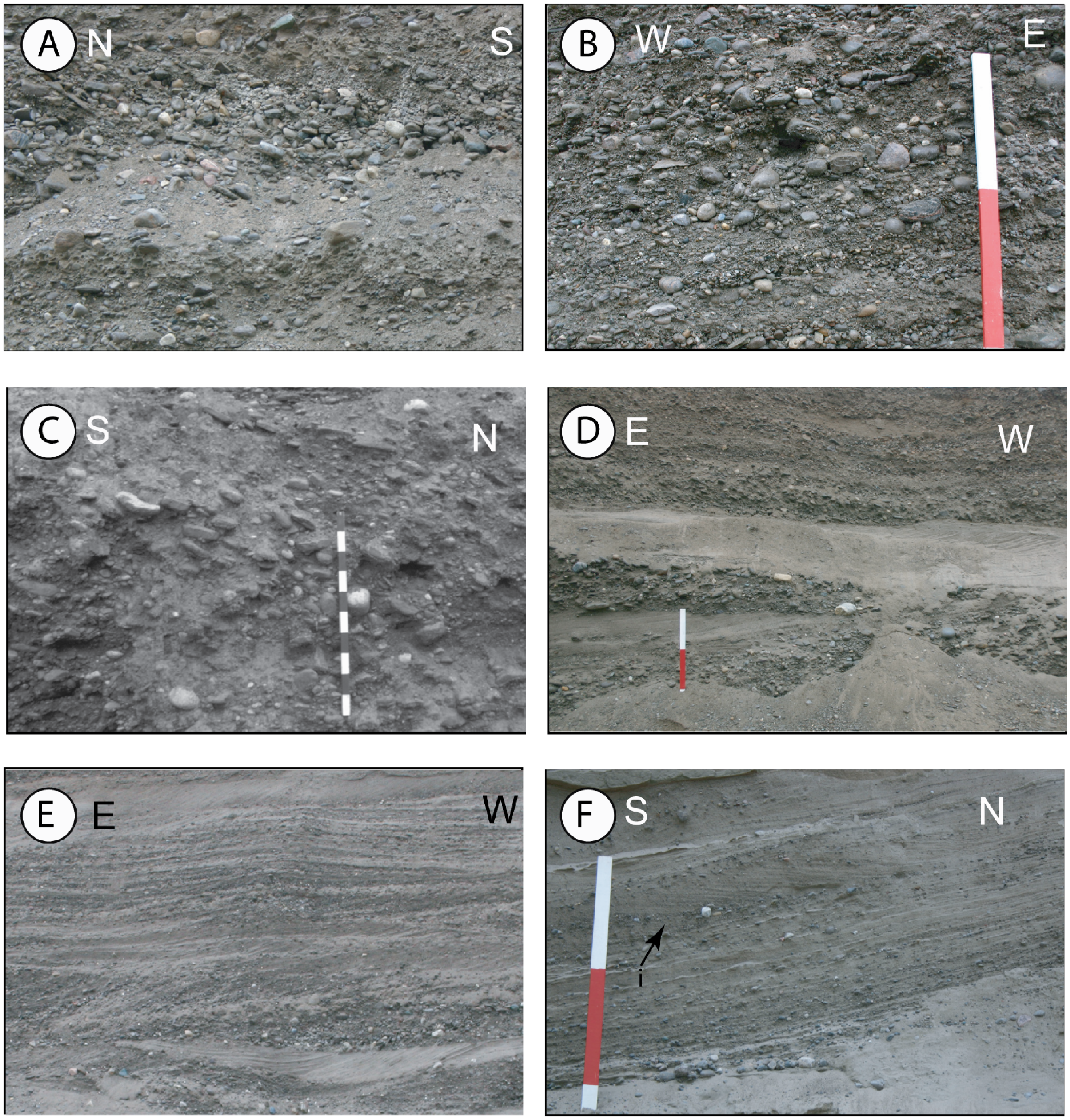

Figure 53. Illustrative sand facies from sediment mapped as glacifluvial outwash in the Niagara Escarpment area north of Orangeville. (A) Dune-scale cross-strata of openwork cobble gravel and pebble gravel, paleoflow is to south, (B) Close-up of gravel foresets in an adjacent face, paleoflow is to south. (C) Poorly sorted, framework to matrix supported, imbricate cobble gravel, metre stick has 10 cm increments, paleoflow is to south. (D) Interbeds of dune-scale cross-bedded medium scale and poorly sorted matrix supported gravel, paleoflow to southeast. (E) Succession of dune-scale cross-strata and thin beds of gravel interpreted as gravel sheets, paleoflow to southeast. (F) Sandy gravel foreset beds of a glacifluvial delta, note backset beds (i), dominant paleoflow to south.

SUMMARY: IMPLICATIONS FOR GROUNDWATER RESOURCES

Given the absence of significant mud baffles in the exposures studied, the permeability of surficial sediment above the water table in the vicinity of the gravel pits is hypothesized to be moderate to high (see Table 2 for estimates). The surficial sediment should in general pose little barrier to downward percolation of surface water (although the underlying Newmarket Till likely would). Exceptions to this general rule include the Adjala pit, where a thick (~2 m), areally extensive silt-rich fine sand unit occurs, the Gormley pit, where a similar capping mud unit is present, and the Beaton pit, where a thin (~50 cm?) mud unit is present within otherwise coarser sediment. Permeability values from gravel pits can be extended radially outward with some degree of confidence, but only when checked against geomorphological data (permeability data should not be extrapolated from one geomorphic element to the next adjacent element) and the surficial geology map.

Because thick, laterally extensive gravel units were commonly observed in the pits, the exposed strata is deemed to generally have good to very good aquifer potential. If aquifers in the region have a similar sedimentology and architecture, they should have a good capacity to store water, a limited to very good ability to transmit water vertically, and good to very good ability to transmit water horizontally.

ACKNOWLEDGEMENTS

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Table 1: Summary of sedimentological characteristics and interpretation of sites in ice-contact stratified-drift deposits.

Pit Name	Location, Geological Map Unit, Landform Name Description Interpretation	Mean paleo-flow (+/- 45^o)	Fig-ure
Gormley (3802)	Bolton map sheet, Ice-contact-stratified sediment, Oak Ridges Moraine Pebble gravel fining downflow to fine sand. INTERPRETATION: Subaqueous fan setting, see (Russell and Arnott, 2003)	W	6
Adjala (3900)	Bolton map sheet, , Ice-contact-stratified drift, Oak Ridges Moraine Muddy fine sand over pebble–cobble gravel. Gravel unit is contains dune cross-strata that dips northwest, and also fines toward the northwest. Gravel has locally become cemented and completely lithified. The overlying muddy fine sand unit, where well exposed, is typically soft-sediment deformed. Current ripples are common where undeformed. A 2–3 m thick, northwest-dipping sigmoidal dune (?) cross-set (NW dipping cross-strata) is visible in one location. INTERPRETATION: gravel feeder to finer subaqueous fan deposits	NW	7
Gillespie (3297)	Orangeville map sheet, Ice-contact-stratified drift, Orangeville Moraine Thinly bedded fine sand with high-angle reverse faults. Low-angle (<5^o) lamination that is “wavy” on a meter-scale (commonly “diffuse” looking), thin dune cross-sets and climbing current-ripples present. No net vertical or horizontal grain-size changes. INTERPRETATION: Mid-distal subaqueous fan. High-angle reverse faults suggest sediment was deposited on ice that has since melted. Note that this is the only pit where faults were observed, suggesting the depositional substrate was usually stable (i.e. not underlain by ice).	No mea-surement	16
Robinson (3296)	Orangeville map sheet, Ice-contact-stratified drift, Orangeville Moraine Thin, wavy fine sand beds, locally diffusely stratified; dune cross-sets and climbing ripples locally. Small (<3 m wide, <1 m deep) diffusely laminated sand channel fills. No net upward fining or coarsening. Only rare gravel clasts (up to boulder in size); these are always right at top (pit operator, personal communication). Drilling suggests at least 30 m of sand present at location (pit operator, personal communication). Hummocky landscape surrounds pit. INTERPRETATION: Mix of deposition from traction and suspension suggests mid–distal subaqueous fan setting, but slightly more distal than adjacent Rayburn pit given finer grain size and greater abundance of climbing ripples versus dunes. Lack of faults suggests deposition on non-ice substrate. Lack of horizontal grain-size trends suggests deposition from flow that was as wide as outcrop. Diffusely laminated sand and climbing ripples suggest high sediment-rain-out rate.	W	17
Rayburn (3241)	Orangeville map sheet, Ice-contact-stratified drift, Orangeville Moraine Fine–medium sand with one 1–3 m thick interbed of megaclast-bearing pebble gravel. Megaclasts are commonly very large and typically elongate (long axis = 0.25–3 m; short axis = 0.1–2 m), and are subrounded to subangular. They are quite obviously rip-up clasts from underlying sand unit. Gravel is locally massive in appearance and locally horizontally stratified. Although obscured in one location by slumped material, the gravel unit is interpreted to continue right across the outcrop (almost 0.5 km). Current ripple and dune cross-stratified fine to medium sand overlies and underlies the gravel unit; this sand is not as “diffuse looking” as sand in the adjacent Robinson pit. The sand unit that underlyies the gravel fines towards the south (dune and ripple cross-strata in this unit also dip southward). Hummocky landscape surrounds pit. INTERPRETATION: Mix of deposition from traction and suspension suggests mid–distal subaqueous fan setting, but slightly more proximal than adjacent Robinson pit given greater abundance of dunes relative to climbing ripples. The gravel bed is interpreted to have been deposited during a jökulhlaup-type outburst of metlwater, one that had high enough sediment concentrations (sufficient bed-normal dispersive pressure) to transport huge megaclasts in suspension. This outburst was not subaerial, as the gravel is sandwiched in between units of fine sand with abundant climbing ripples that are most reasonably interpreted as having been deposited in standing water by decelerating flows.	South	18
Laurel (3106)	Orangeville map sheet, Ice-contact-stratified drift, Thick, rhythmic interbedds of fine sand and pebble gravel INTERPRETATION: subaqueous fan deposits	No mea-surement	19

Pit Name	Location, Geological Map Unit, Landform Name Description Interpretation	Mean paleo-flow (+/- 45°)	Fig-ure
Greenwood (3680)	Dundalk map sheet, Ice-contact-stratified drift, Orangeville Moraine Thickly interbedded dune cross-stratified pebble-gravel and dune cross-stratified medium sand. Similar to pits 3685 and 3686, except there is a climbing current-ripple cross-stratified fine sand bed (suggesting standing water), and some diffusely laminated sand beds. Also, unlike pits 3685 and 3686, no mud veneer is present on the pit floor, suggesting that, unlike these other pits, gravel units in the Greenwood pit do not contain significant amounts of disseminated mud. INTERPRETATION: Mid subaqueous fan?	SW	11
Strada (3700)	Dundalk map sheet, Ice-contact-stratified drift, Orangeville Moraine Medium interbedded dune cross-stratified pebble gravel and dune cross-stratified sand INTERPRETATION: glacifluvial deposits	S	12
Nelson (3596)	Dundalk map sheet, Ice-contact-stratified drift, Orangeville Moraine Very thickly interbedded pebble gravel, fine sand and channel-fill diamicton. Pit floor is covered in a thin mud veneer, suggesting disseminated mud exists in gravel units (even though you would not think it). Sediment exposed in this pit are similar to those in the Strada pit (pit 3700) on the other side of the road. However, by contrast, there is evidence of mass movement here (channel-fill diamicton), the deposits are slightly muddier, dune cross-stratified medium sand interbeds are replaced with current-ripple cross-stratified fine sand beds, and there ratio of sand:gravel is greater. INTERPRETATION: glacifluvial deposits	S?	13
Esker (3597)	Dundalk map sheet, Ice-contact-stratified drift, Cobble gravel. Large-scale (2 m thick) dune(?) cross-strata near base of ridge dip southward. INTERPRETATION: ice-confined conduit deposit	S	14
The Hollows	Alliston map sheet, Ice-contact-stratified drift, Data collected 1994 INTERPRETATION: subaqueous fan deposits		

Beds are designated as being very thin, thin, medium, thick and very thick when they are 1–3, 3–10, 10–30, 30–100 and >100 cm in thickness, respectively. Lamina are <1 cm thick.

Table 2: Summary of sedimentological characteristics and interpretation of sites in glacifluvial deposits.

Pit Name	Location, Geological Map Unit, Landform Name Description Interpretation *	Mean paleo-flow (+/- 45°)	Fig-ure
Primrose (3685)	Dundalk map sheet, glaciofluvial, outwash Thickly bedded dune cross-stratified pebble gravel; fines laterally to thickly bedded dune cross-stratified medium sand (similar to adjacent pit number 3686). Pit floor is covered in a thin mud veneer, suggesting disseminated mud exists in gravel units (even though you wouldn't think it). INTERPRETATIONS: Subaerial outwash, given lack of downstream fining and absence of evidence of standing water (e.g., climbing ripples).	SW	9
Pit opposite to Primrose (3686)	Dundalk map sheet, glaciofluvial, outwash Thickly bedded dune cross-stratified pebble gravel (similar to adjacent Primrose pit). Pit floor is covered in a thin mud veneer, suggesting disseminated mud exists in gravel units (even though you wouldn't think it) INTERPRETATION: Subaerial outwash, given lack of downstream fining and absence of evidence of standing water (e.g., climbing ripples).	S	10
Cookstown (4176)	Alliston map sheet, glaciofluvial sediment Thickly bedded dune cross-stratified pebble gravel fining northward (downflow) to thinly bedded fine sand INTERPRETATION: small subaqueous fan	N	3
Gwillimbury (4279)	Alliston map sheet, glaciofluvial sediment. Fine–medium sand over till. Top of the till is close to the level of the pit floor. Medium-angle clinoforms with climbing small-scale cross-laminated fine sand and dune-scale cross-stratified medium sand. INTERPRETATION: subaqueous fan or sand dominated glacifluvial.	NW	2
Beaton (4165)	Alliston map sheet, glaciofluvial sediment. Gravel over mud (poor exposure) INTERPRETATION: subaqueous fan – glacilacustrine setting.	No mea-surement	4
Wray Pit	Alliston map sheet, glacifluvial outwash, INTERPRETATION: glacifluvial deposit		
Totenham (4172)	Alliston map sheet, glaciofluvial, Large sand–gravel clinoforms (5–7 m thick). Clinoforms coarsen upward from fine sand to pebbly sand to pebble gravel. Master bedding planes dip at a slope angle of 20° towards the south. No other units exposed. Thin (~1 m) topsets present, but poorly exposed. INTERPRETATION: Glacifluvial delta. Position on the side of upland with no hinterland necessitates an ice-contact origin.	S	5
Mono-Mills	Bolton map sheet, glacifluvial, outwash INTERPRETATION: Braided fluvial outwash		
Craig (3300)	Orangeville map sheet, Glacifluvial, outwash Thinly interbedded dune cross-stratified pebble gravel and medium sand. Big pit, yet very uniform sedimentology throughout, both laterally and vertically. INTERPRETATION: Likely subaerial braided fluvial outwash in a valley train.	W	15

Table 3: Summary of sedimentological characteristics and interpretation of sites in alluvial deposits.

Pit Name	Location, Geological Map Unit, Landform Name Description Interpretation	Mean paleo-flow (+/- 45°)	Fig-ure
Everett (4079)	Alliston map sheet, Alluvium, Pebble gravel over thin mud over shale bedrock INTERPRETATION: Given (1) position of pit within modern river valley, and (2) eastward-dipping dune cross-strata, the gravel unit is interpreted to be an alluvial deposit. Origin of underlying mud unknown.	E	8