Tunnel Channels of Central Southern Ontario: Character, Genesis and Glaciodynamic Implications

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Goal

- Central southern Ontario (Fig. 1) exhibits a regional Late Wisconsinan unconformity that truncates Paleozoic bedrock and a thick Quaternary sediment cover (Figs. 2, 3) [1]
- This unconformity is composed of drumlins, s-forms and valleys (Fig. 4)
- This study explores the character, genesis and glaciodynamic implications of the valleys

Figure 1. Location of the study area (red box) within the Great Lakes basin and in relation to the Late Wisconsinan ice limit (blue line) shown on an SRTM elevation model (http://photojournal.jpl.nasa.gov/catalog/PIA03377).

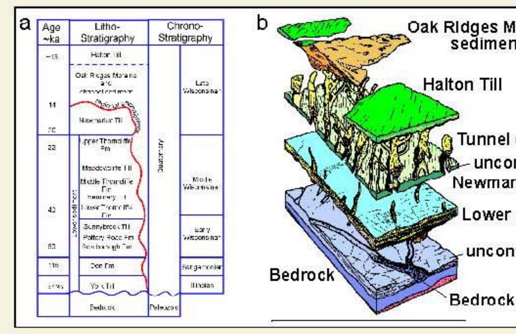

Figure 2. Central southern Ontario (a) stratigraphy and (b) conceptual geological model [1].

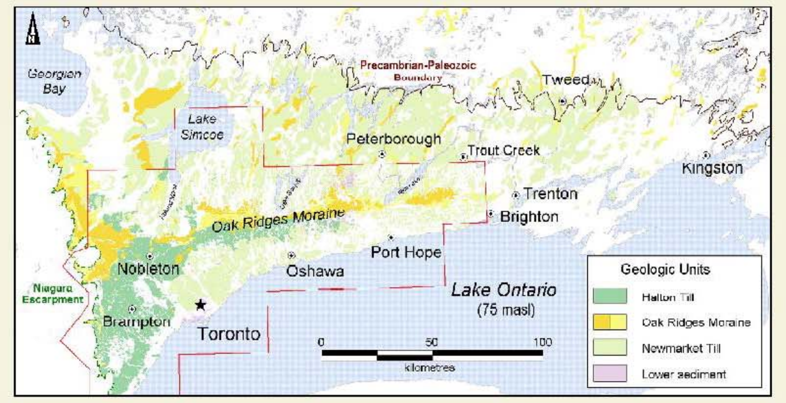

Figure 3. Generalized geology showing the surface expression of the main stratigraphic units. Mapping at 1:200,000 [11] within and 1:1,000,000 [12] outside the red box. Geology is not shown west of the Niagara Escarpment. Refer to Figure 1 for location.

Why?

- Regional valley system passes through a densely populated area (Greater Toronto Area) reliant on groundwater and aggregate from glacial sediment
- Knowledge of channel distribution and fill has economic and societal implications associated with watershed management - groundwater resources, waste disposal, aggregate extraction and gas reservoirs (Fig. 5) [1]

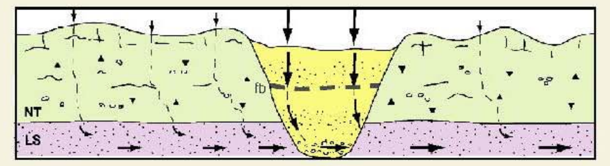

Figure 5. Channels that breach Newmarket Till may provide direct hydraulic communication to Lower sediment aquifers (modified from [1]). fb, fine-grained sediment beds.

How?

- Surface valleys were mapped from aerial photographs, satellite images, DEMs and field surveys [2]
- Buried valleys were mapped by seismic reflection profiling, and outcrop and drillcore sedimentology [3]
- A regional tunnel channel map was compiled from DEMs and surficial geology guided by this knowledge (Fig. 6) [4]

Channel Classes

Five channel classes are identified based on their geomorphology, boundary material and orientation (Figs. 6, 7; Table 1) [4]

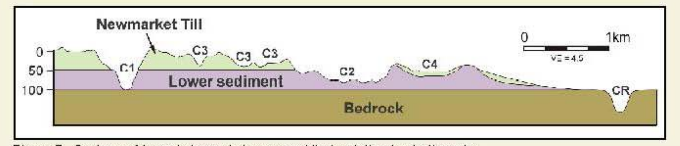

Figure 7. Cartoon of tunnel channel classes and their relation to stratigraphy.

Table 1. Sediment-walled tunnel channel characteristics based on three-dimensional hydrostratigraphic mapping in the GTA-ORM area [4].

Characteristic	C1	C2	C3	C4
Substrate	LS or bedrock	LS or bedrock	Newmarket	Newmarket
Length (km)	> 40	< 25 km	< 10	< 10
Width (km, <)	7	3	3	20
Depth[1] (m, <)	175	100	30	50
Width/depth[1] (<)	47	23	29	
Surface relief (m, <)	50	50	20	40
Side-wall slopes (°, <)	20	15	10	5
Orientation	NNE-SSW	N-S; NNE-SSW	N-S	N-S
Area (km²)	675	1400	900	850
Antecedent topography	probable	no	no	yes
Islands	very few	common	common	few common
Branching	low	moderate	moderate	none

1 Depth and width/depth ratios were defined from seismic data where the complete channel width and depth were observed. These estimates are based on a small amount of data and are an approximation.

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Acknowledgments

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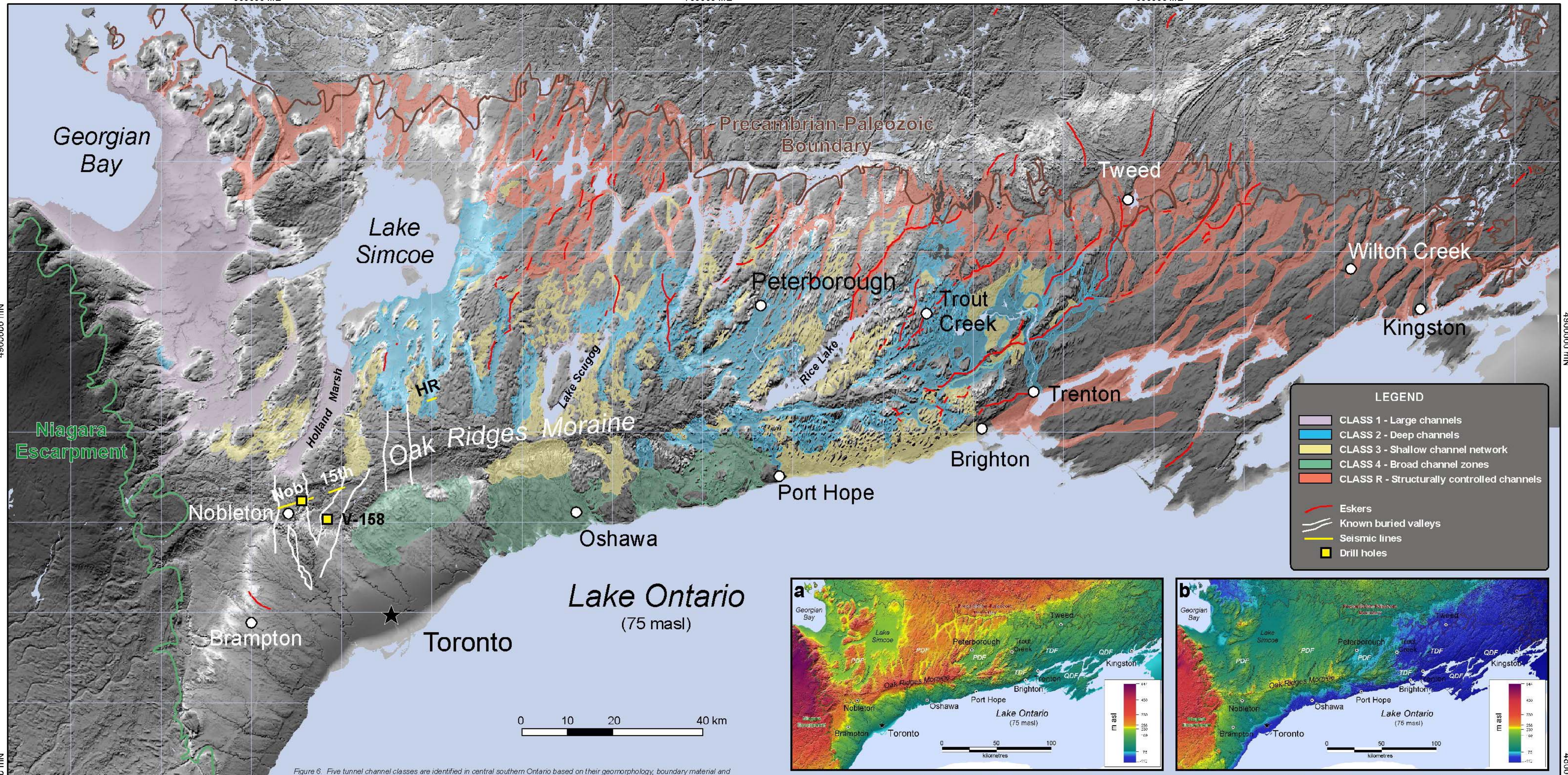
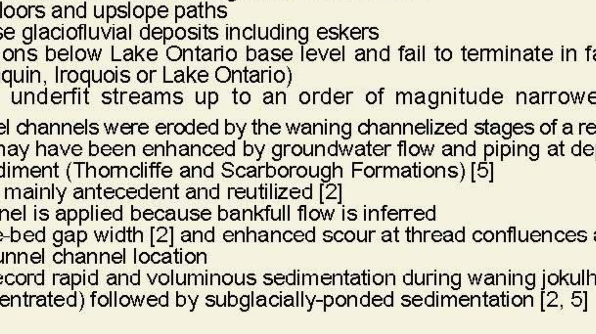


Figure 6. Five tunnel channel classes are identified in central southern Ontario based on their geomorphology, boundary material and orientation (Fig. 7; Table 1). Channels are not mapped west of the Niagara escarpment. Structurally controlled channels are incompletely mapped north of the Precambrian-Paleozoic boundary.

Figure 4. Colour-classed elevation and hillshaded DEMs of the regional landscape (a) today, and (b) ~12ka BP (regional DEM retilted using early Lake Iroquois isobases [10]). Channels do not follow the regional slope and some channels take upslope paths through drumlinized uplands. PDF, Peterborough drumlin field; TDF, Trenton drumlin field; QDF, Quinte drumlin field.

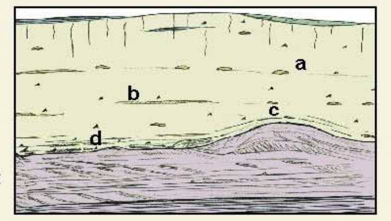
Tunnel Channel Genesis

- Valley network records a tunnel channel system eroded and/or reutilized by subglacial meltwater flow during the Late Wisconsinan [2] because valleys:
  - are incised into Late Wisconsinan, drumlinized till (Newmarket Till), are locally buried by Oak Ridges Moraine sediment and contain deglacial lake sediment
  - have undulating floors and upslope paths
  - are filled by coarse glaciofluvial deposits including eskers
  - are cut to elevations below Lake Ontario base level and fail to terminate in fans or deltas at shorelines (Algonquin, Iroquois or Lake Ontario)
  - contain modern underfit streams up to an order of magnitude narrower than valleys
- Sediment-walled tunnel channels were eroded by the waning channelized stages of a regional meltwater underburst. Erosion may have been enhanced by groundwater flow and piping at depth in the sandy beds of the Lower sediment (Thorncliffe and Scarborough Formations) [5]
- Bedrock valleys were mainly antecedent and reutilized [2]
- The term tunnel channel is applied because bankfull flow is inferred
- Bedrock structure, ice-bed gap width [2] and enhanced scour at thread confluences and hydraulic jumps [5] controlled tunnel channel location
- Tunnel channel fills record rapid and voluminous sedimentation during waning jokulhlaup flow (both fluidal and hyperconcentrated) followed by subglacially-ponded sedimentation [2, 5]



Glacial Event Sequence

1. Deposition of Newmarket Till

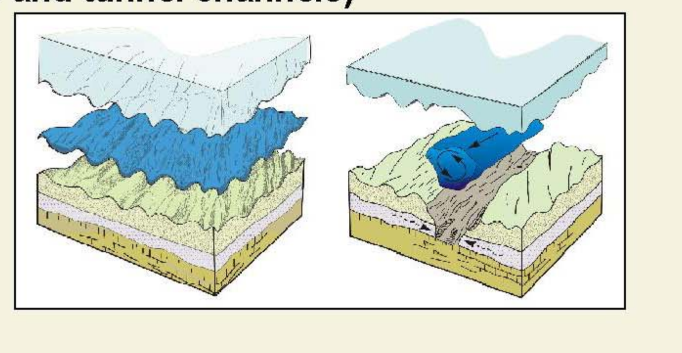


a. Boulder pavement
b. Sand lenses
c. Sharp conformable contact
d. Interbedded contact

Late Wisconsinan ice advance deposited Newmarket Till as a thick (generally 10 - 50 m), regional (>8000 km²) stony (5-15%) sandy silt diamicton [1]. Its lower contact is planar, locally doming over subaqueous fan wedges (Thorncliffe Formation), or is interbedded. Newmarket Till records passive to active basal sedimentation as ice advanced to the southwest into a large proglacial lake. Early debris flow facies are replaced by later lodgement and deformed lodgement facies. Thin (<1 m) and discontinuous (<20 m long) sand and silt strata and striated clast pavements separate Newmarket Till into beds 3-5 m thick. Sorted sediment and striated clast pavements record periodic local ice-bed decoupling and recoupling, and meltwater scour and sedimentation [1].

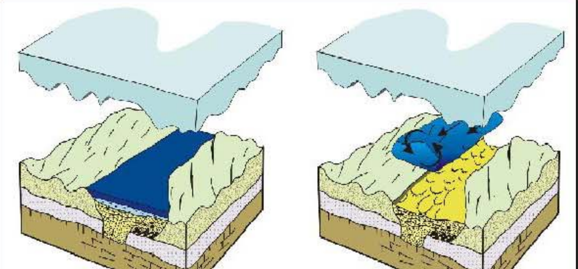
2. Formation of a regional unconformity (drumlins, s-forms and tunnel channels)

The subglacial landsystem is attributed to erosion by a regional, turbulent meltwater underburst – the Algonquin event [6] - ~14 ka BP that unsteadily evolved from sheet to channelized flow, focused along fewer, progressively larger channels as flow waned [2]. Turbulent sheet flow eroded drumlins in Newmarket Till (oriented NE-SW, becoming NW-SE southward [7]) and s-forms on bedrock. Structurally controlled valleys were occupied and further eroded by turbulent meltwater flows. In areas of thick sediment cover, turbulent channelized flow first eroded shallow channel networks. These shallow channels evolved with incision into deep channel networks and then large channels as flow waned. Bedrock structure, ice-bed gap width and enhanced scour at thread confluences and hydraulic jumps controlled tunnel channel location [2, 5]. Flow resisted channelization (broad scour zones) toward proto-lake Ontario because the ice remained hydraulically jacked (during the Ontario meltwater event). During Algonquin-flow collapse, as tunnel channels were eroded north of the ORM, a sub-regional underburst – the Ontario event [6] - eroded drumlins (oriented ~ENE-WSW along the floor of Lake Ontario [8]) and swept most sediment westward through Lake Erie. Tunnel channels oriented sub-parallel to the lake-floor drumlins [9], record the subsequent collapse of the Ontario event. During these meltwater events, the ice was decoupled from its bed, causing ice evacuation, thinning (fast ice flow) and crevassing.



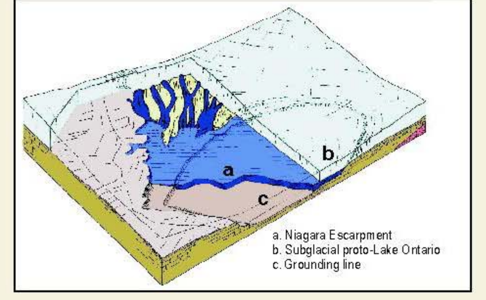
3. Rapid sedimentation in tunnel channels

Thick channel fills (up to 160 m) record rapid and voluminous sedimentation during waning jokulhlaup flow [2, 5]. In general, channel fills fine upward from gravel sheets and mesoforms (dunes) to sand dunes and ripples. Along deep channel axes, thick beds of graded to massive sand may break this sequence and record rapid sedimentation from a hyperconcentrated flow perhaps associated with flow expansion following enhanced scour into Lower sediment sand beds or facilitated by hydraulic damming from the Ontario event. Channel flow becomes ponded as ice reattaches to its bed and seals channels south of the Oak Ridges Moraine (ORM). Rhythmites record several decades of seasonal melt cycles and highlight the role of crevasses in delivering supraglacial meltwater to the bed. At channel margins and interfluves, thin cold ice froze-on and minor ice movement re-mobilized Newmarket diamicton along channel flanks. Some Newmarket diamicton may have been remobilized in slumps.



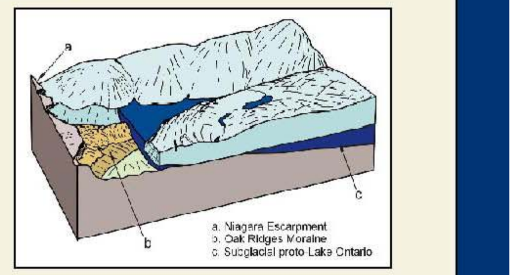
4. Subglacial proto-Lake Ontario

Meltwater from the Ontario event was not entirely evacuated from the Lake Ontario basin; a large subglacial meltwater reservoir - proto-Lake Ontario – was retained beneath an extended and much thinner ice sheet. As the Ontario event waned, the proto-Lake Ontario grounding line (a spatially complex zone of grounded and decoupled ice) migrated from the vicinity of the current Oak Ridges Moraine to south of the modern Lake Ontario shoreline. ENE-WSW tunnel channels formed under the grounded ice and the ice lid sagged over the subglacial reservoir. Ice lid sagging basinward of the grounding line produced a major fracture zone at the subsequent location of the ORM. Continued meltwater drainage and crevassing facilitated delivery of subglacial and supraglacial melt to proto-Lake Ontario and its water level progressively rose.



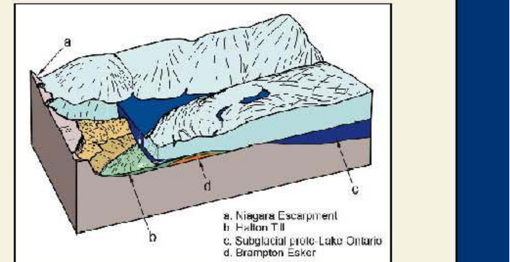
5. Formation of the Oak Ridges Moraine

Formation of the ORM ~13-14 ka BP represents a fundamental re-organization of the drainage system north of proto-Lake Ontario from ~N-S flow during Algonquin tunnel channel fill to ~E-W during ridge construction. This transition occurred in a closely-timed sequence that may have included the following events. The landward fracture zone formed a low pressure axis along which meltwater was focused and ice was thinned. Catastrophic release of supraglacial and/or remnant subglacial meltwater reservoirs eroded a single E-W tunnel channel south of Rice Lake and deposited gravel in an E-W R-channel (early esker phase of the ORM). Erosion of ice along this meltwater pathway resulted in the formation of an ice-contact lake, particularly to the west toward the Niagara escarpment dam. Subaqueous fans and sand-silt-clay rhythmites were deposited in this perched lake and complete the ridge-building episode of the ORM. The east-west meltwater corridor and lake basin widened more rapidly to the south and west as the rim of grounded ice around proto-Lake Ontario was lifted off or melted back.



6. Deposition of Halton Till

South of the ORM, the Halton Till complex was emplaced by (i) suspension settling from a mud cloud in the perched lake, and (ii) debris and turbidity flows associated with periodic local decoupling events of the grounded ice rim of subglacial proto-Lake Ontario as water levels fluctuated. Northwest ice motion, during local ice-bed recoupling and/or due to compressive flow in the grounded ice rim sealing proto-Lake Ontario, resulted in minor glacitectonic deformation and till fabric realignment (SE-NW) along the Lake Ontario bluffs. Northwest paleoflows in the sandy Brampton esker underlying Halton Till record R-channel flow through the grounded ice rim sealing proto-Lake Ontario.



7. Final ice stagnation and lid detachment

North of the ORM, ice stagnated over drumlins and tunnel channels, melting down and back. Eskers formed in R-channels that drained remaining subglacial and supraglacial melt, and crevasse-fill ridges squeezed into stagnant ice. South of the ORM, crevasse-fill ridges record final stagnation of the proto-Lake Ontario grounded ice rim prior to ice lid flotation and melt.

CLASS 1 Large Channels

- large, flat-floored, steep-sided, deep, sediment-walled valleys oriented NE-SW
- incised deeply into Lower sediment and often to bedrock

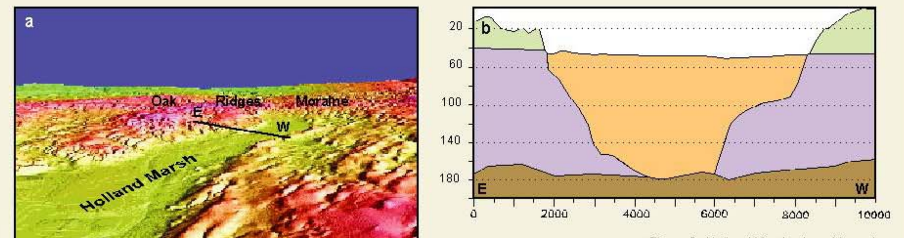


Figure 8. Holland Marsh, class 1 tunnel channel: (a) perspective view south; (b) schematic cross-section. Valley walls are steep and asymmetrical. Newmarket Till outcrops along channel flanks. Refer to Figure 6 for location.

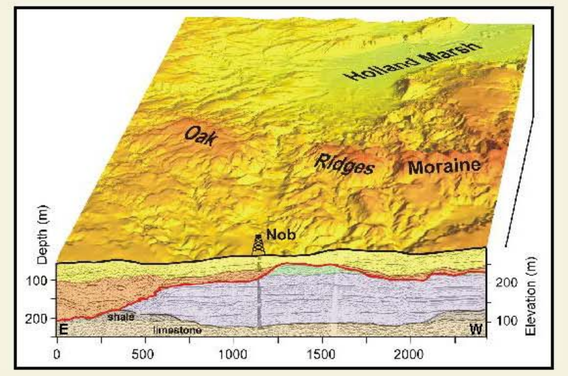


Figure 9. Nobleton seismic profile (Fig. 6; [16]) located in the ORM and transverse to the buried southerly extension of Holland Marsh tunnel channel. Stepped channel margin truncates Lower sediment and bedrock floors the main channel. Nob drillhole is positioned at the eastern channel margin.

CLASS 2 Deep Channel Network

- intermediate-scale anabranched channel network (C2a) or single channels (C2b) oriented N-S to NNE-SSW
- incised shallowly into Lower sediment

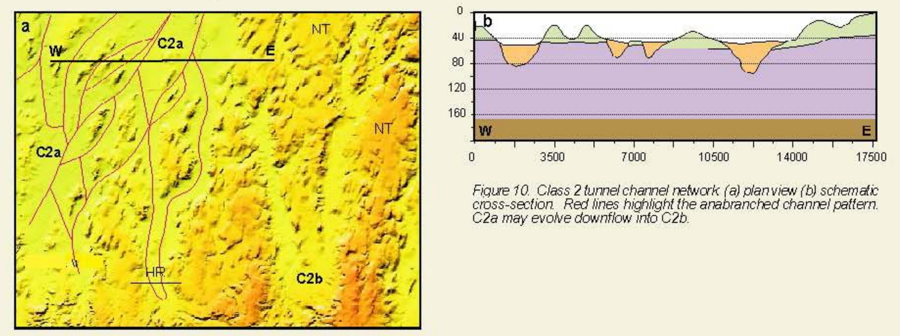


Figure 10. Class 2 tunnel channel network: (a) plan view (b) schematic cross-section. Red lines highlight the anabranched channel pattern. C2a may evolve downflow into C2b.

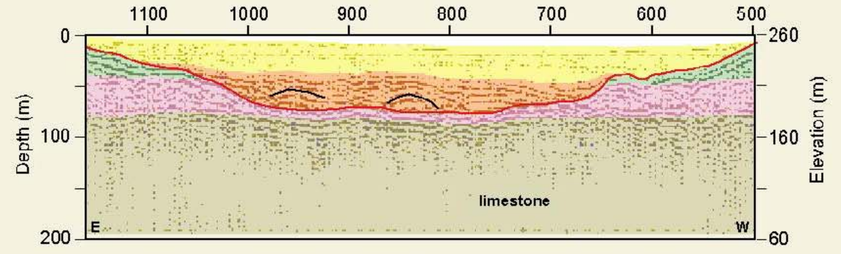


Figure 11. Harold Road seismic profile (HR, Figs. 6, 10a; [14]) located across partially in-filled class 2 tunnel channel south of Lake Simcoe. Channel is floored by Lower sediment and Newmarket Till at its margins (50-150 m wide shoulder).

CLASS 3 Shallow Channel Network

- small-scale, shallow anabranched channel network
- only partially breaches Newmarket Till

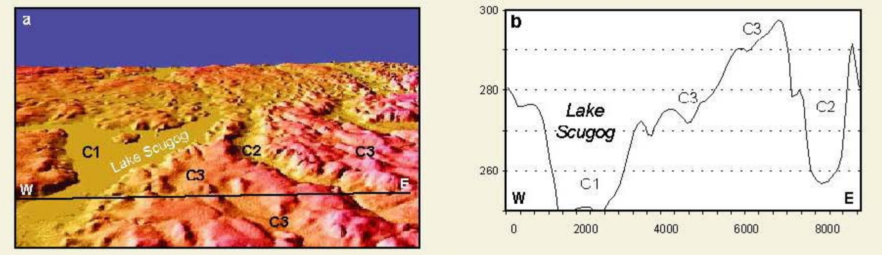


Figure 12. Class 3 tunnel channel network nested on the Newmarket Till interfluves of class 1 and class 2 tunnel channels: (a) perspective view north; (b) topographic cross-section.

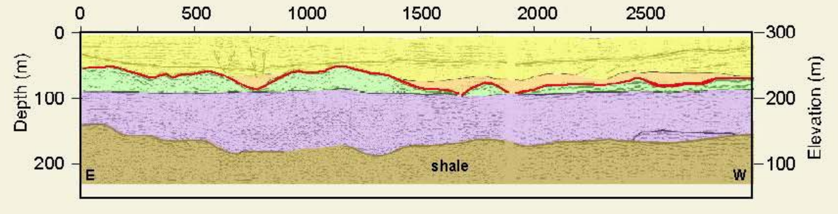


Figure 13. 15th Side Road seismic profile (Fig. 6; [16]) across a buried class 3 tunnel channel network northeast of Nobleton. Newmarket Till floors shallow channels.

CLASS 4 Broad Channel Zones

- broad, shallow erosion corridors south of the Oak Ridges Moraine
- only locally breach Newmarket Till

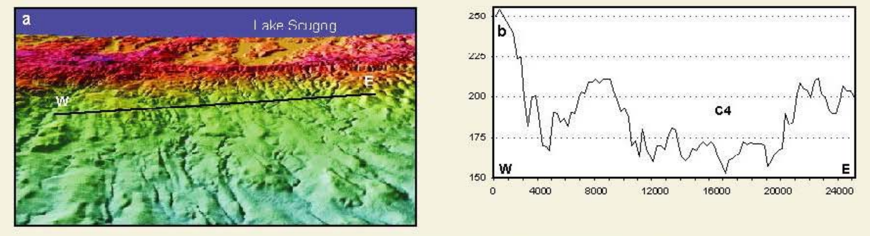


Figure 14. Class 4 channel zone south of Lake Scugog: (a) perspective view north; (b) topographic cross-section.

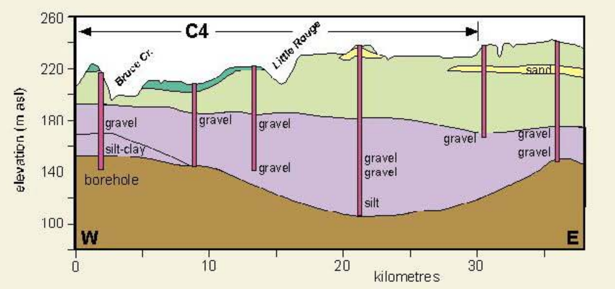


Figure 15. Geological cross-section of class 4 channel zone west of Oshawa. Newmarket Till substrate thins within channel zone (borehole data from [13]).

CLASS R Structurally Controlled Channels

- bedrock valleys or bedrock valleys with a thin sediment cover
- steep-sided bedrock valleys form an anabranched NE-SW system north and east of sediment-walled valleys
- bedrock valley walls are ornamented by s-forms

Figure 16. Bedrock erosion marks at Wilton Creek: (a) large open flutes; (b) small braided flutes.

Valley Fills

Valley fills (up to ~150 m thick) overlie bedrock, Lower sediment or Newmarket Till and include:

- Oak Ridges Moraine hydrostratigraphic unit sediment
  - tunnel channel fills (20-60 m thick) - gravel sheets, dunes, lags and eskers; sandy hyperconcentrated flow deposits, dunes and ripples; silt-clay rhythmites
  - ridge-building sediments (generally <50 m thick) - mainly eskers, subaqueous fans and silt-clay rhythmites
- Halton Till complex (<30 m thick) - interbedded silty diamicton, silt, clay, minor sand and gravel
- deglacial lake sediment (<2 m thick) - sand, silt, clay
- post-glacial lake sediment, alluvium and organics (<2 m thick) - silt, clay, sand, gravel, organics

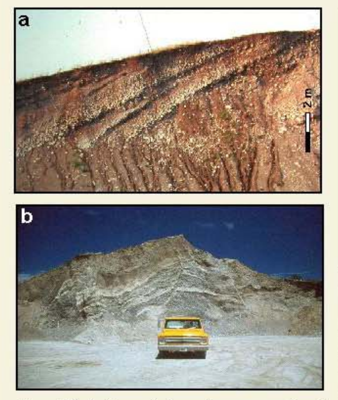


Figure 17. In the east, the surface expression of channel fill deposits includes (a) gravel macroforms (Trout Creek) and (b) eskers (Campbellford esker).

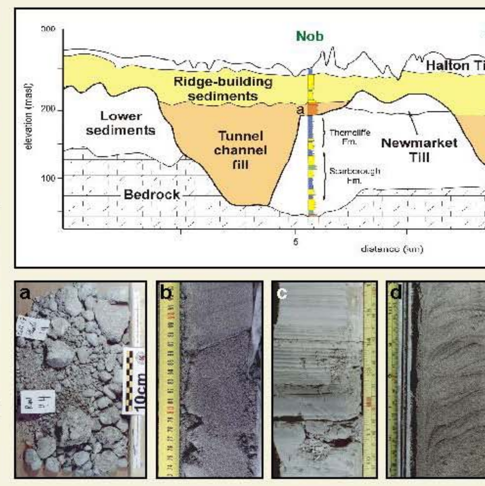


Figure 18. Schematic cross section across buried portions of the Holland Marsh and King City tunnel channels constructed from drill holes (Nob and V-159) and seismic profiles (Nobleton and 15th Side Road). These channels are filled with (a) bedded granule to cobble gravel, (b) diffusely graded sand, (c) silt-clay rhythmites and (d) cross-laminated and cross-stratified sand [5].