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Tunnel Channels of the Greater Toronto and Oak Ridges Moraine Areas, Southern Ontario

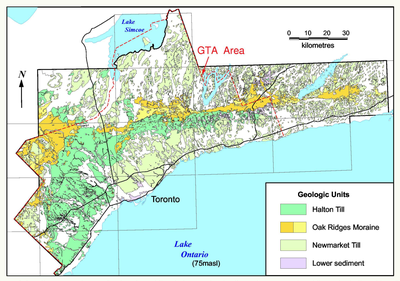

Figure 1. Location map and generalized geology of the study area showing the surface expression of the main stratigraphic units.

scale 1: 250,000

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Introduction

Large valleys north of the Oak Ridges Moraine (ORM) are occupied by misfit streams and extensive wetlands. Mapping of these valleys beneath the ORM indicates that they predate formation of the moraine (Barnett et al., 1998; Pugin et al., 1999). The valleys are interpreted to be tunnel channels eroded by subglacial meltwater (e.g. Barnett 1990; Brennand and Shaw 1994; Russell et al., 2003a). The depth of erosion and geometry of these tunnel channels have significant implications for modelling the regional stratigraphy (Logan et al., 2002) and understanding groundwater resources of the area (Sharpe et al., 1996). This poster documents the surface extent of the channel network using a map overlay on a digital elevation model (DEM). The channels are ranked by size, likelihood of breaching Newmarket Till, and probable depth of erosion. Channel geometry and setting are explained for each channel class using clips from the DEM, geologic cross-sections, seismic profiles and borehole data. The channel system mapped here is an input dataset for the version 2 of the ORM stratigraphic model (Logan et al., in press)

Regional Stratigraphic Setting

Stratigraphy

The lithostratigraphic framework of the study area (Karrow, 1967; Boyce et al., 1995) has been reinterpreted using basin analysis principles and event stratigraphic concepts (Figs. 1, 2; Sharpe et al., 1996). A key result is the mapping of a regional unconformity that is defined by drumlinized Newmarket Till and tunnel channels (Barnett et al., 1998). To permit mapping of the regional stratigraphy using archival data, the lithostratigraphic framework has been simplified to five principal units. They are, stratigraphically upward: 1) Paleozoic bedrock, 2) Lower sediment, 3) Newmarket Till, 4) Oak Ridges Moraine and channel sediment, and 5) Halton Till. Lower sediment (LS) comprises 10 poorly exposed formations representing middle Wisconsinan and older sediment (Fig. 2) described mainly from Scarborough Bluffs (Karrow, 1967; Eyles et al., 1985; Sharpe et al., 1996).

Tunnel Channel Identification and Origin

Large valleys in the area are interpreted as tunnel channels eroded by subglacial meltwater. Evidence includes:

- undersized nature and power of modern streams compared to their valleys,
- presence of organic and postglacial lacustrine sediment within most valleys,
- presence of esker ridges along floors and flanks of valleys (e.g. Bethany, Sunderland),
- incision of channels to elevations below present day Lake Ontario surface,
- undulating channel base along the course of the channel (can rise downflow),
- absence of delta deposits at proglacial and modern shorelines, or within modern lakes,
- regional paleogeographic reconstructions of ice margin retreat and proglacial lakes.

Similar tunnel channel networks have been mapped in the Kingston area (Shaw and Gilbert, 1990), westward toward Peterborough (Brennand and Shaw, 1994), from Rice Lake to Simcoe (Sharpe et al., 1996), and in the Barrie area (Barnett, 1990). All of these investigations concluded that tunnel channels are a result of erosion by meltwater when subglacial reservoirs drained catastrophically.

Stratigraphy and Geological Model

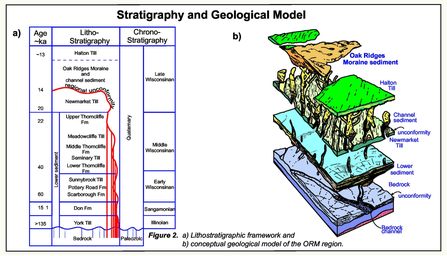


Figure 2. a) Lithostratigraphic framework and b) conceptual geological model of the ORM region.

Digital Elevation Model

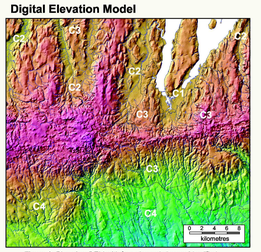


Figure 3. Plan view DEM with four channel classes identified. Colour ramp is the same as Figure 7.

Methodology

Definition of the Channel Network

Tunnel channels have been identified by using available surficial geological mapping (Sharpe et al., 1997), a 30 m grid Digital Elevation Model (Kenny et al., 1999), and field knowledge. By extracting surficial geology polygons along DEM-defined valleys a channel map was produced (Fig. 3). The resulting channel margins were then modified based on plan view and perspective view analysis of the DEM and stratigraphic cross-sections.

Channel Ranking

Channels are ranked using a combination of DEM geometry, landscape analysis, seismic profiles, and core logging. This simple ranking accommodates the range of tunnel channel geometries that can be consistently identified from the available data (Fig. 4). Four channel classes were designated on the basis of surface expression, width, length, erosional depth, depth-width ratios, substrate sediment and orientation (Fig. 5, Table 1). Some channels may have been placed into a lower classification where subsurface information was limited. Channels have only been identified where the regional unconformity is exposed at or near the surface. Channels beneath the Oak Ridges Moraine and Halton Till where the surface expression of the unconformity is buried were not mapped (Fig. 6). The channel classes occur within a regional terrain framework that, in part, controls their erosional style or pattern (Fig. 7) and thus help link them to similar channels beyond the Greater Toronto region. The extent and style of the channel network to the north and east in areas of thinner sediment cover and exposed bedrock is illustrated in Figure 8.

Buried Channels

The mapped surface tunnel channels have also been identified in the subsurface by seismic reflection and continuous cored borehole studies (Pugin et al., 1999; Russell et al., 2000; Russell et al., 2003a; Russell et al., 2003b; Sharpe et al., 2003a). These buried channels have a similar geometry and hierarchy as channels north of the moraine (e.g. Figs., 11, 14, 17), but they are difficult to map accurately due to overlying ORM sediment. Consequently, only buried channels that have been identified with high-quality data are shown on Figure 6.

Table 1. Characteristics of tunnel channel classes.

Characteristic	C1	C2	C3	C4
Substrate	LS or bedrock	LS or bedrock	Newmarket	Newmarket
Length (km)	> 40	< 25	< 10	<10
Width (km, <)	7	3	10	20
Depth (km, <)	175	100	30	50
Width/depth* (<)	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	possible	no	no	yes
Islands	very few	common	common	few-common
Branching	low	moderate	moderate	none

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

Channel Cross-section

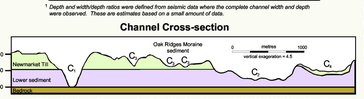


Figure 4. Schematic cross-section illustrating the scale and relationship of the four channel classes (C1-C4). Relative channel widths are provided in table 1.

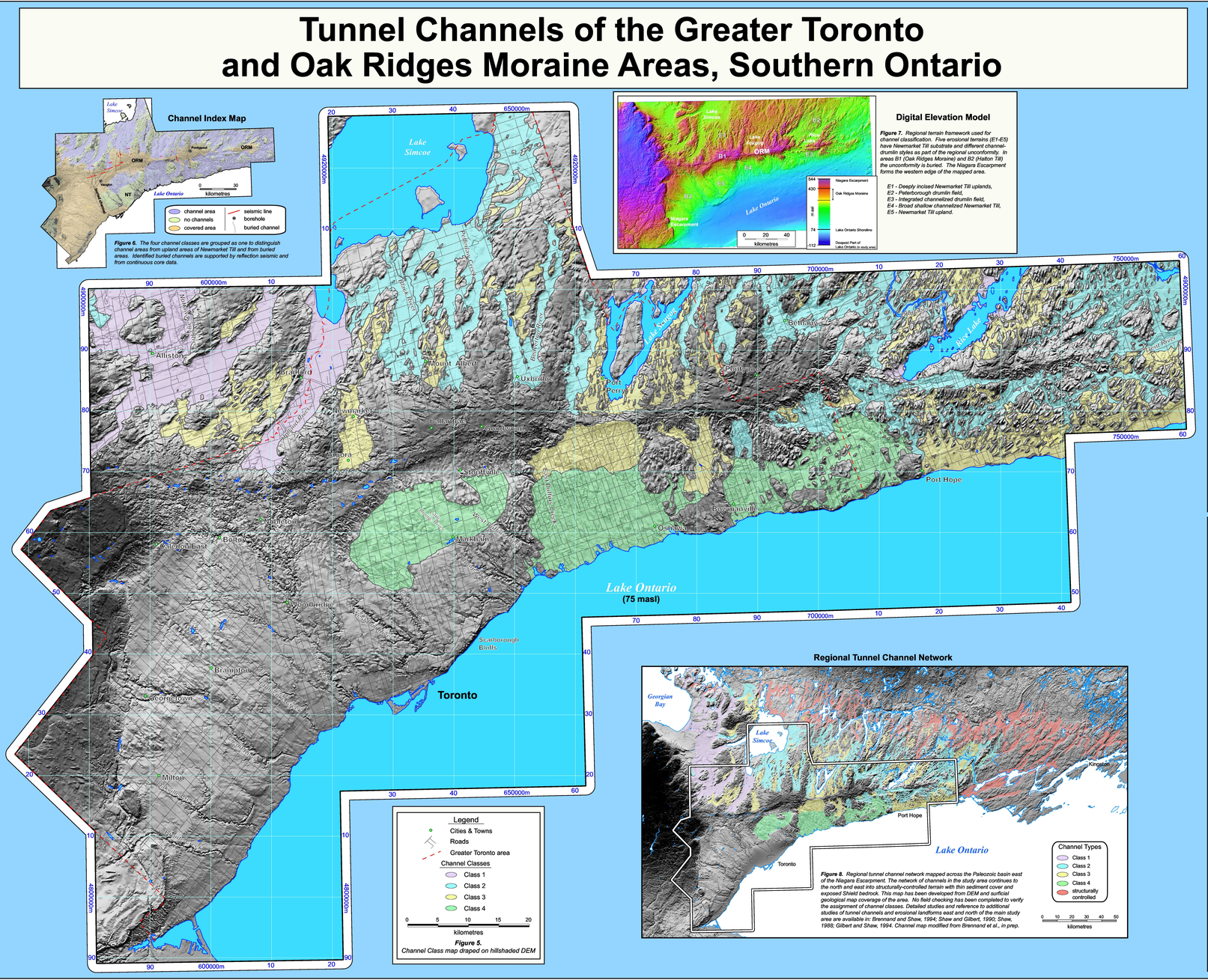


Figure 6. The four channel classes are grouped as one to distinguish channel areas from upland areas of Newmarket Till and from buried areas. Identified buried channels are supported by reflection seismic and from continuous core data.

Figure 7. Regional terrain framework used for channel classification. Five erosional terrains (E1-E5) have Newmarket Till substrate and different channel-drumlin styles as part of the regional unconformity. In areas B1 (Oak Ridges Moraine) and B2 (Halton Till) the unconformity is buried. The Niagara Escarpment forms the western edge of the mapped area.

E1 - Deeply incised Newmarket Till uplands,
E2 - Peterborough drumlin field,
E3 - Integrated channelized drumlin field,
E4 - Broad shallow channelized Newmarket Till,
E5 - Newmarket Till upland.

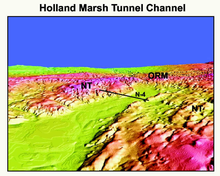
Figure 8. Regional tunnel channel network mapped across the Paleozoic basin east of the Niagara Escarpment. The network of channels in the study area continues to the north and east into structurally-controlled terrain with thin sediment cover and exposed Shield bedrock. This map has been developed from DEM and surficial geological map coverage of the area. No field checking has been completed to verify the assignment of channel classes. Detailed studies and reference to additional studies of tunnel channels and erosional landforms east and north of the main study area are available in: Brennand and Shaw, 1994; Shaw and Gilbert, 1990; Shaw, 1988; Gilbert and Shaw, 1994. Channel map modified from Brennand et al., in prep.

Figure 5. Channel Class map draped on hillshaded DEM

Class 1 Channels - Large Channels

- Large, single channels occur in <10% of the mapped landscape
- Most are deep and contain modern lakes (e.g. Simcoe, Scugog, Rice)
- Sediment fill is mainly glaciofluvial deposits overlain by organic sediment
- Predominant channel orientation is NE-SW

Holland Marsh Tunnel Channel



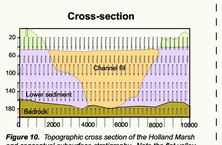


Figure 9. Perspective hillshaded DEM view of the Holland Marsh tunnel channel extending southward to the Oak Ridges Moraine. Note - Newmarket Till (NT) along both channel sides and Oak Ridges Moraine (ORM) at southern end. Colour ramp is the same as Figure 7.

Figure 10. Topographic cross section of the Holland Marsh and conceptual subsurface stratigraphy. Note the flat valley floor, step sides and asymmetry in sidewall slope and relief.

Nobleton Seismic Profile

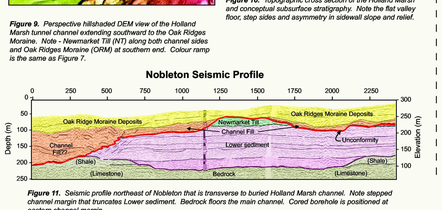
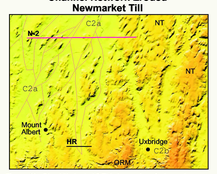


Figure 11. Seismic profile northeast of Nobleton that is transverse to buried Holland Marsh channel. Note stepped channel margin that truncates Lower sediment. Bedrock floors the main channel. Cored borehole is positioned at eastern channel margin.

Class 2 Channels - Deep Network

- Medium-scale, channels form a network covering <15% of the mapped landscape
- Channels erode Newmarket Till in 2 styles: C2a) anabranched; C2b) single channels
- Predominant channel orientation is N-S and NNE-SSW

Channel Network Eroded Newmarket Till



Cross-section

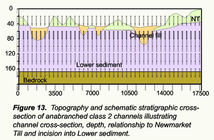


Figure 12. Plan hill-shaded DEM shows class 2 channels; broad anabranched channels (C2a) and incised single channels (C2b). Lines highlight the channel pattern. Type C2a may evolve downflow into C2b. Colour ramp is the same as Figure 7.

Figure 13. Topography and schematic stratigraphic cross-section of anabranched class 2 channels illustrating channel cross-section, depth, relationship to Newmarket Till and incision into Lower sediment.

Harold Road (HR) Seismic Profile

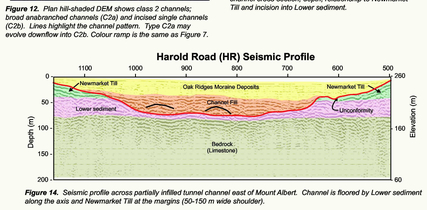
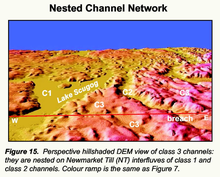


Figure 14. Seismic profile across partially infilled tunnel channel east of Mount Albert. Channel is floored by Lower sediment along the axis and Newmarket Till at the margins (50-150 m wide shoulder).

Class 3 Channels - Shallow Network

- The shallow channel network occurs over ~10% of the mapped landscape
- Shallow channels occur predominantly on Newmarket Till uplands
- Channels generally do not breach Newmarket Till
- Channels are commonly anabranched amongst drumlins

Nested Channel Network



Cross-section

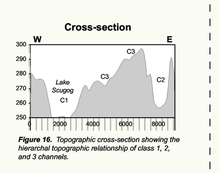


Figure 15. Perspective hillshaded DEM view of class 3 channels: they are nested on Newmarket Till (NT) interfluves of class 1 and class 2 channels. Colour ramp is the same as Figure 7.

Figure 16. Topographic cross-section showing the hierarchal topographic relationship of class 1, 2, and 3 channels.

Seismic Profile of Shallow Channels Network

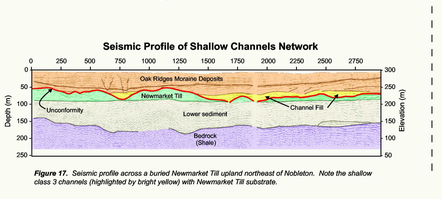


Figure 17. Seismic profile across a buried Newmarket Till upland northeast of Nobleton. Note the shallow class 3 channels (highlighted by bright yellow) with Newmarket Till substrate.

Class 4 Channels - Broad Channel Zones

- Forms a broad, shallow erosion corridor covering ~10% of the mapped landscape
- These channels are located south of ORM downflow of class 1 and 2 channels
- Broad channels only locally breach Newmarket Till and in part are controlled by an antecedent topography

Channel Network Eroded Newmarket Till

Cross-section

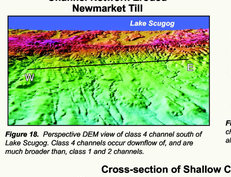


Figure 18. Perspective DEM view of class 4 channel south of Lake Scugog. Class 4 channels occur downflow of, and are much broader than, class 1 and 2 channels.

Figure 19. Topographic cross-section of broad class 4 channels. Class 4 channels are also dissected by postglacial alluvial erosion.

Cross-section of Shallow Channels Network

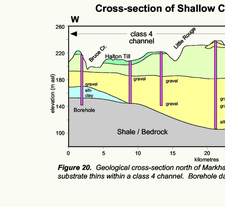


Figure 20. Geological cross-section north of Markham showing how Newmarket Till substrate thins within a class 4 channel. Borehole data from Sibul et al. (1977).

Application

Hydrogeological Connection

The classification of tunnel channels helps support improved 3-D stratigraphic mapping across the ORM region (Logan et al., in press). Channel classes 1 and 2 are deeply eroded and fully breach the regional Newmarket Till aquitard over much of the channel width (Figs. 8-10, class 1); however, islands of till are more common in class 2. Class 3 and 4 channel substrate is predominantly Newmarket Till. Breaching of the Newmarket Till improves hydraulic connectivity with Lower sediment aquifers (Fig. 21). Hydraulic connection may occur whether channels are partially (Figs. 9, 10, 12, 13) or completely filled (Fig. 11). The degree of connection and potential hydrogeological impact is dependent not only on the nature of the channel fill but also the conductivity of the Lower sediment (Sharpe et al., 2002).

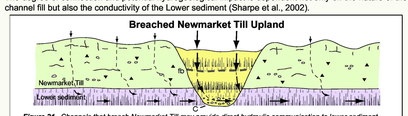


Figure 21. Channels that breach Newmarket Till may provide direct hydraulic communication to lower sediment aquifers. Modified from Sharpe et al., 2002. (fb - fine mud interval, C - coarse basal channel gravel)

Channel aquifers

Extensive channel systems with coarse fill also form important aquifer bodies. Results from long pumping tests in several channels show a strong aquifer response along a channel length. At Ballantrae, this probably indicates a coarse channel-fill sediment unit (Fig. 22; Sharpe et al., 2003b). A channel map (Fig. 5) and the knowledge of possible coarse channel sediment provide a prospecting model for identifying new water resources (Sharpe et al., 1996).

3-D Hydrostratigraphic modeling

The channel map and classification also provide a framework for ongoing improvements to the 3-D stratigraphic model (Logan et al., in press). In this case reliable data can define the boundary between channel sediment and adjacent older sediment below the channel and in new buried channel settings (Fig. 22). Channel mapping is best carried out with high-quality data that provides an unambiguous ability to distinguish channel sediment from stratigraphically older sediment. Improved 3-D mapping augments hydrogeological assessment when it is combined with nested piezometers and hydraulic testing (Fig. 22). A tunnel channel mapping protocol may also serve as a blueprint for charting and defining tunnel channels and buried valleys across the Great Lakes region (e.g. Ritzi et al., 1999; Pugin et al., 2003) and in other ice-marginal glaciated regions similar features are expected to be common.

Ballantrae Golden Spike Monitor

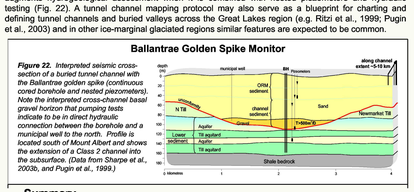


Figure 22. Interpreted seismic cross-section of a buried tunnel channel with the Ballantrae golden spike (continuous cored borehole and nested piezometers). Note the interpreted cross-channel basal gravel horizon that pumping tests indicate to be in direct hydraulic connection between the borehole and a municipal well to the north. Profile is located south of Mount Albert and shows the extension of a Class 2 channel into the subsurface. (Data from Sharpe et al., 2003b, and Pugin et al., 1999.)

Summary

This research documents the geometry of an extensive channel network in the Oak Ridges Moraine Area. Channel geometry was classified and mapped to support a revised regional 3-D stratigraphic model for the ORM area (Logan et al., in press). The channel map aids groundwater investigations by improving the ability to make thickness estimates for regional Newmarket Till aquitard, to estimate the buried subsurface continuation of tunnel channels and by providing a prospecting model for buried channel aquifers. Improved identification of the location, extent and scale of buried tunnel channels can only be achieved with the collection of new high quality reflection seismic surveying and continuous cored boreholes. The mapping protocol also has importance to buried channel studies in other regions.

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