Structural Model of the Greater Toronto and Oak Ridges Moraine Areas, Southern Ontario: Oak Ridges Moraine Sediment

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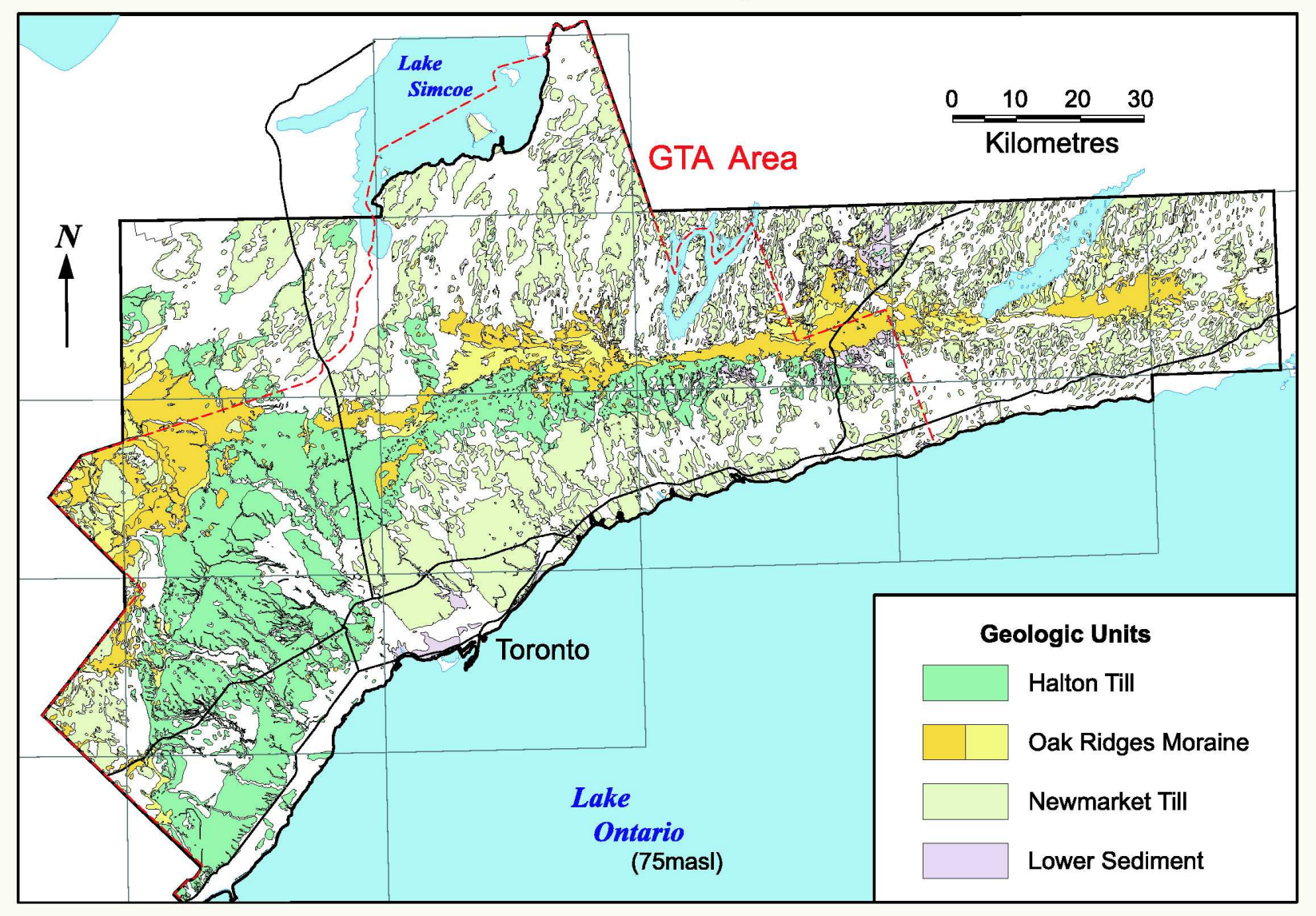

Figure 1. *Location map and generalized geology of the study area showing the surface expression of the main stratigraphic units.*

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Introduction

As part of a regional geological study (Sharpe et al., 1997, 2002) of the 11,000 km² Oak Ridges Moraine and Greater Toronto areas (Figs. 1, 2) a 3-D stratigraphic model has been developed (Logan et al., 2005). This poster is one of four that document the geology of the respective stratigraphic units (Table 1). The central figure of each of the four posters is a sediment thickness (isopach) map. The surrounding information provides a description of the stratigraphic context, data support, confidence estimate of the surface, and overview of the geology. Two related posters, based on earlier modelling, document the bedrock surface and Quaternary sediment thickness (Brennand et al., 1998; Russell et al., 1998).

Information on the composition and geometry of geological strata are important for regional groundwater resource assessment and management. The 3-D structural model can serve as a regional stratigraphic framework that provides context for site-specific work and supports the development of a hydrostratigraphic framework. These frameworks provide vital input for groundwater flow modeling (e.g. Holysh et al., 2004).

Digital Elevation Model

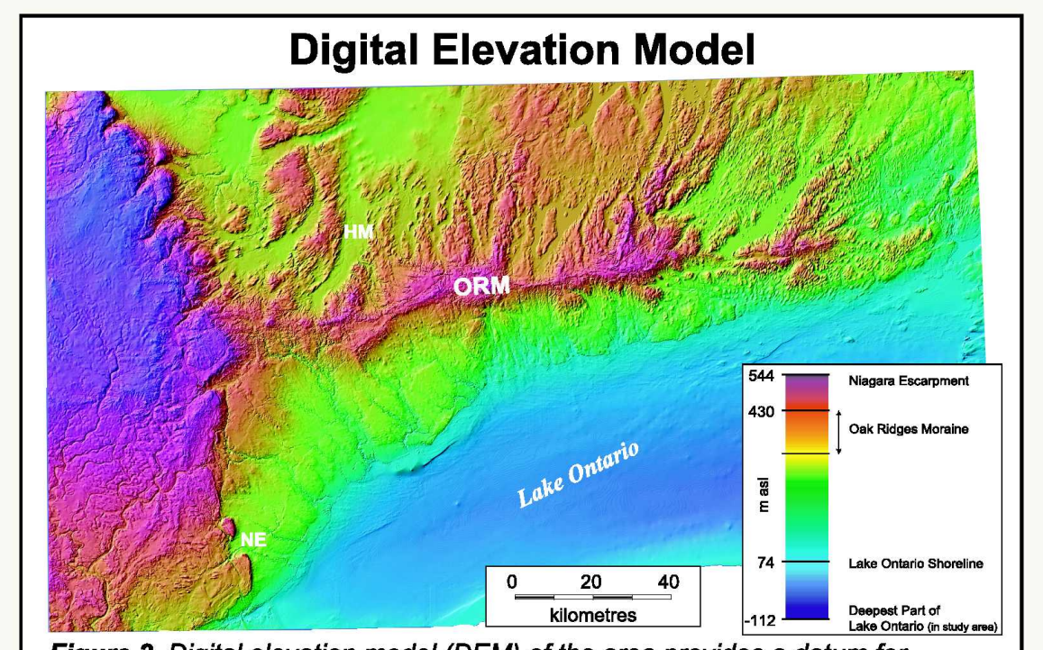

Figure 2. *Digital elevation model (DEM) of the area provides a datum for structural surfaces and to characterize surface landforms (e.g. Holland Marsh (HM) channel). Niagara Escarpment (NE) bounds the Oak Ridges Moraine (ORM) to the west.*

Regional Stratigraphic Framework

The lithostratigraphic framework of the study area (Karrow, 1967; Boyce et al., 1995) has been reinterpreted using basin analysis principles and event stratigraphic concepts (Fig. 3; Sharpe et al., 1996, 2002). A key revision is the mapping of a regional unconformity that is defined by drumlinized Newmarket Till and tunnel channels (Barnett et al., 1998; Russell et al., 2003; Sharpe et al., 2004). To permit mapping of the regional stratigraphy using archival data, the lithostratigraphic framework was 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 has limited subsurface data and groups 10 formations found beneath Newmarket Till (Fig. 3), described mainly from exposures at Scarborough Bluffs (Karrow, 1967).

Stratigraphy and Geological Model

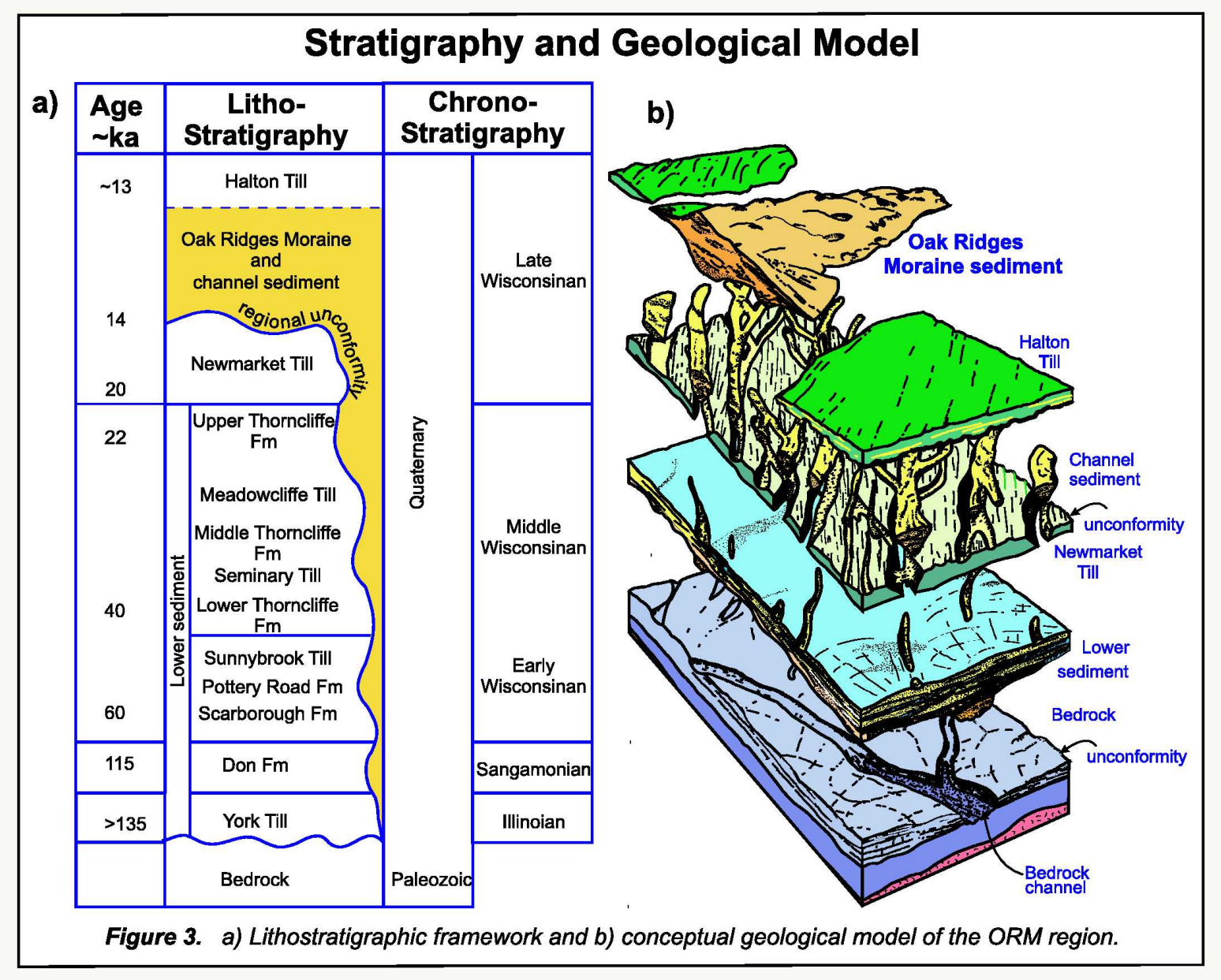

Figure 3. *a) Lithostratigraphic framework and b) conceptual geological model of the ORM region.*

Development of the 3-D model

The regional stratigraphic framework helped guide an automated expert system to construct a 3-D stratigraphic model, using MapInfo Pro® and Microsoft® Access© (Fig. 4; Logan et al., 2005). Primary training data (e.g. ~5000 geotechnical, hydrogeological and sedimentologically logged boreholes, measured bluff sections and reflection seismic profiles) were interpreted stratigraphically (Table 2). Location verification and declustering routines were used to reduce >60,000 Ontario Ministry of the Environment water well records to 22, 000 records (Kenny et al., 1997) tagged with a standard material code (Russell et al., 1998). Using detailed geological mapping (Sharpe et al., 1997) and a 30m-grid digital elevation model (DEM) (Kenny et al., 1999) for surface control, a set of stratigraphic training surfaces were interpolated (Fig. 4). Guided by this training framework, water well records were interpreted stratigraphically by an automated expert system (Logan et al., 2005). All data were then used to interpolate final stratigraphic surfaces at a 30 m grid cell size (Fig. 4).

Stratigraphic Training Model

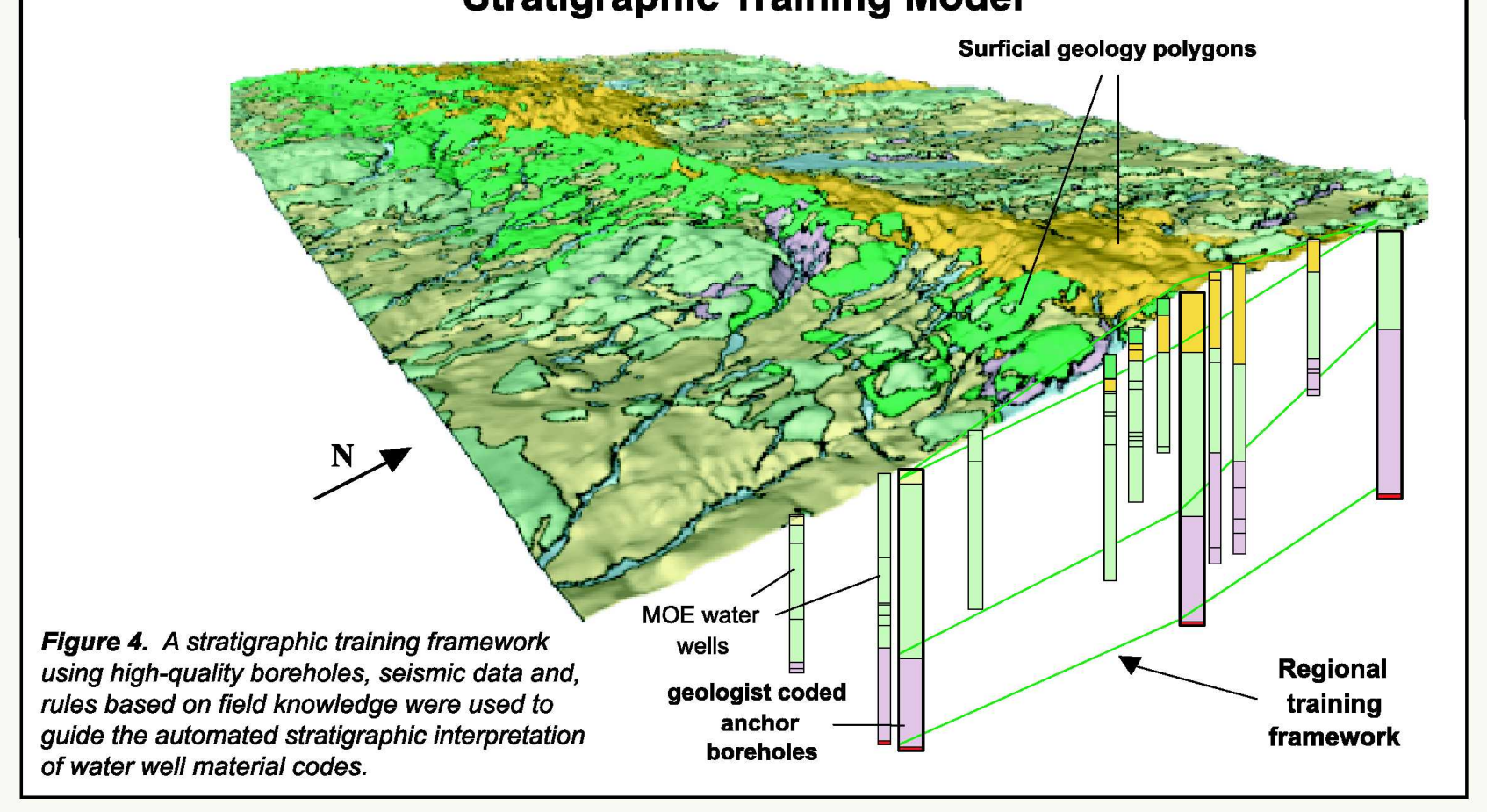

Figure 4. *A stratigraphic training framework using high-quality boreholes, seismic data and, rules based on field knowledge were used to guide the automated stratigraphic interpretation of water well material codes.*

Table 1. *ORM Structural map series*

Title	Open File	Scale	Title	Open File	Scale
Halton Till Structural Model	5064	1: 250,000	Lower Sediment Structural Model	5067	1: 250,000
Oak Ridges Moraine Structural Model	5065	1: 250,000	Drift Thickness	2892	1: 200,000
Newmarket Till Structural Model	5066	1: 250,000	Bedrock Topography	3419	1: 200,000

Table 2. *Subsurface data support for ORM sediment isopach. Note: Mapped units (Fig. 1) also help constrain the geometry of the isopach (Logan et al., 2005).*

Data Class	Full Unit Penetration	Partial Unit Penetration
Training Data	1153	784
MOE Waterwells	10429	4449

ABOUT THE ISOPACH MAP

- The isopach surface covers an area of >2500 km².
- ORM sediment is mapped in only 10% of tunnel channel area because of poor data coverage and quality.
- ORM landform isopach (~2000 km²) covers twice the area of the surface exposure.
- Maximum thickness for the ORM landform is >200m.
- The thickest 10% of the ORM landform is >62 m.

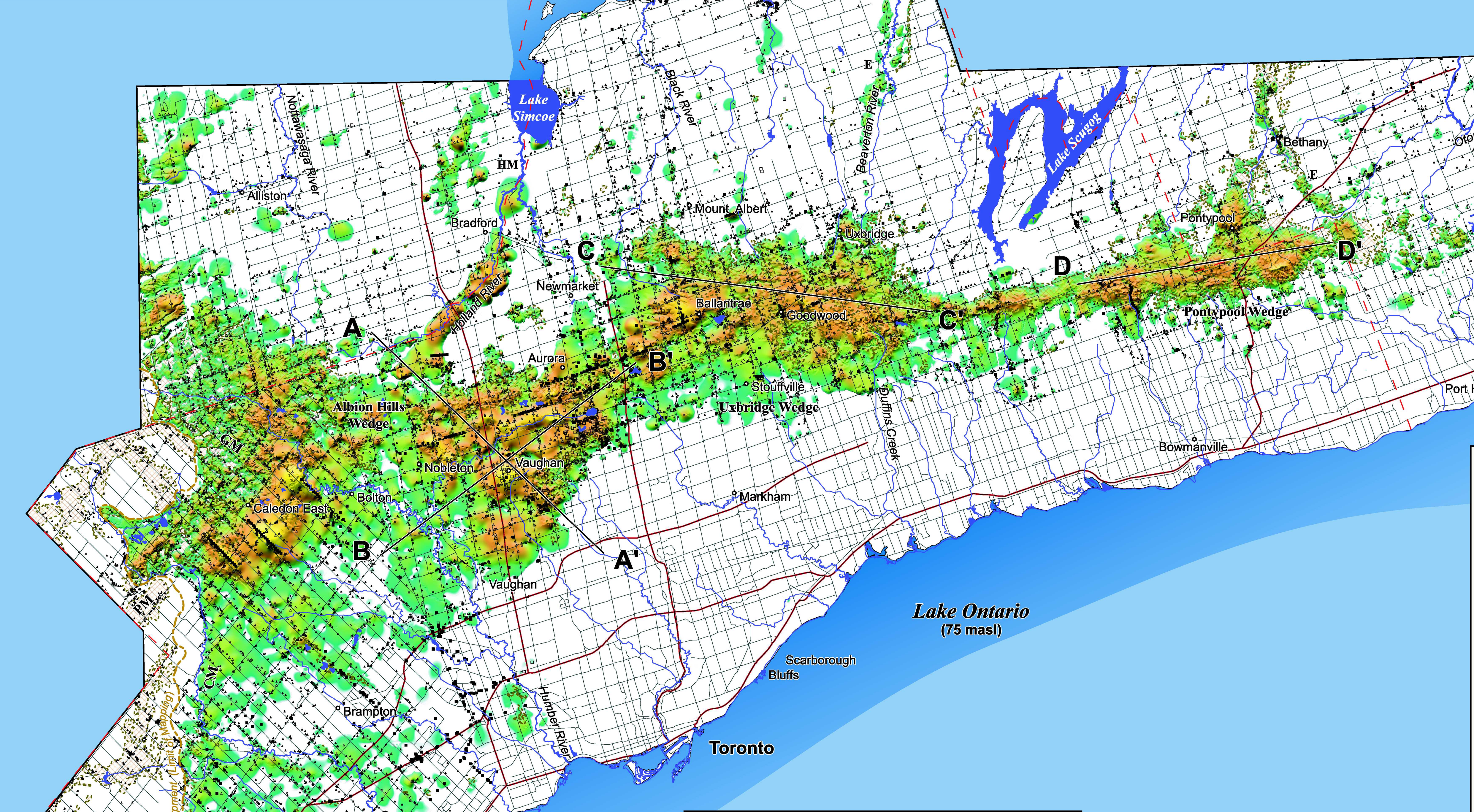

Figure 5. *Isopach or thickness map of ORM sediments.*

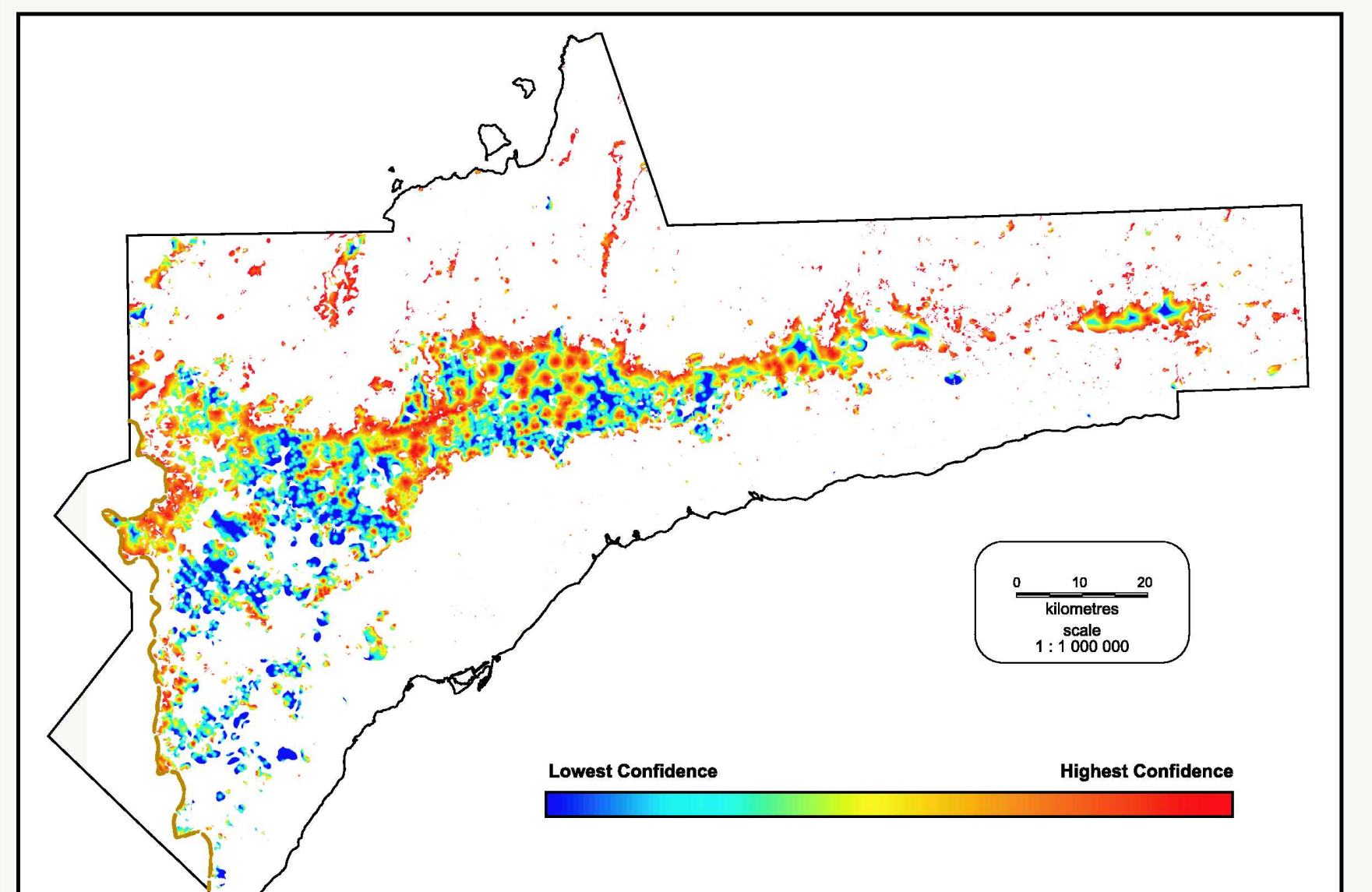

Figure 6. *Confidence map showing data coverage for the ORM sediment stratigraphic unit.*

Confidence Estimation

The accuracy of the model is directly related to the proximity and relative quality of data control points. Confidence grids were produced for each stratigraphic surface to establish an estimation of potential error. For Oak Ridges Moraine sediments, a 2 km buffer grid was produced around each data point accounting for the lower accuracies perceived for water well records and data that only partially pennetrates the unit. Confidence grids were converted to values ranging from 0 to 1, representing lowest to highest confidence. The estimate for highest confidence relates to an error of +/- 1 m, increasing to +/- 10 m for lowest confidence.

ORM Sediment Thickness

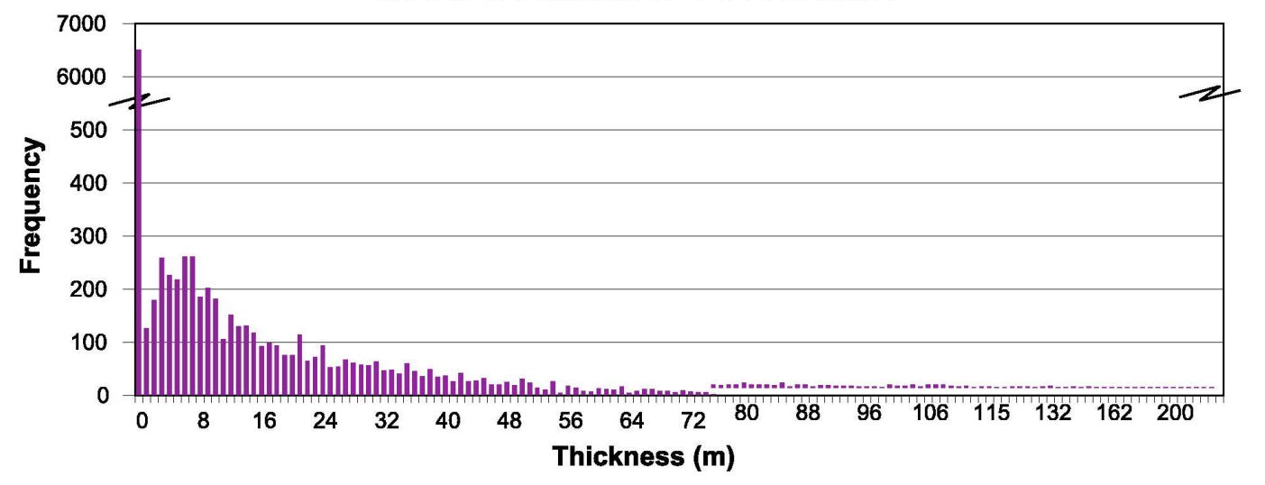

Figure 7. *Data-derived ORM sediment thickness histogram*

Geological Characterization of Oak Ridges Moraine Sediment

Introduction

Oak Ridges Moraine (ORM) landform forms the dominant east-west trending topographic feature in the Greater Toronto Area (GTA) (Fig. 1). This elevated sandy landform is the principal recharge region for the GTA (Sibul et al. 1977) and a prominent unconfined aquifer (~60,000 water wells) used for domestic and municipal water supply (Turner, 1977). The extent, geometry and variability of this aquifer complex controls flow within the regional groundwater system (Gerber et al., 2001).

Definition and extent

The isopach unit includes sand and gravel deposits that are younger than Newmarket Till and older than Halton Till. It covers ~25 % of the study area, half of which is exposed at the surface. The (Fig. 3b) element of the isopach is the ORM landform; however, the isopach includes deposits beyond the ORM landform boundary, for example, tunnel channel fill, eskers (e.g. Brampton esker), and other moraines (e.g. Paris and Gibraltar moraines).

The ORM landform extends ~160 km eastward from the Niagara Escarpment to Trenton with a surface area of ~1000 km². It consists of four sediment wedges (Albion Hills, Uxbridge, Pontypool, and Rice Lake (Fig. 1); Barnett et al. 1998) that are up to 30-40 km long and 20 km wide. The extent of the moraine has been variously defined using mapped outcrop (Sharpe et al. 1997), hummocky terrain (White 1975) or elevation.

Description of ORM form and sediment

ORM morphology is controlled by the topography of the underlying regional unconformity, depositional processes, and postglacial erosion. The primary geological control on the unit thickness is valleys (channels) that are completely buried beneath ORM. Seismic profiles show ORM sediment infilling steep-walled, tunnel channels that are up to 5 km wide (Fig. 8; Pugin et al. 1999; Russell et al. 2003c). The unit is thickest (up to 245 m) along buried bedrock channels and sediment hosted channels (e.g. Caledon East, Nobleton). The unit thins to the south beneath Halton Till and to the north as it offlaps on Newmarket Till. Along the Niagara Escarpment the unit includes sediment adjacent to the ORM ridge that is part of other moraine complexes (e.g. Gibraltar and Cheltenham). Local ORM landform detail may be identifiable (e.g. Holt fan), yet features <1 km (erosional ridges) are rarely visible on the isopach map.

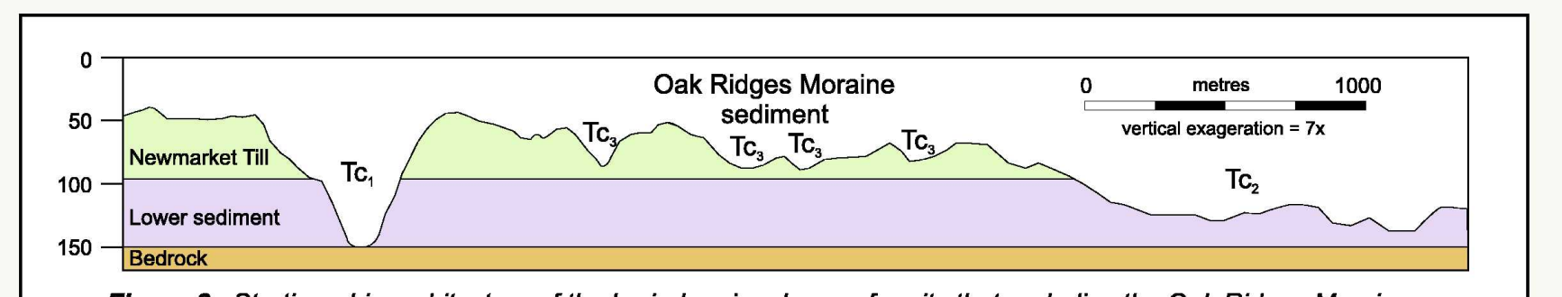

Figure 8. *Stratigraphic architecture of the buried regional unconformity that underlies the Oak Ridges Moraine synthesized from reflection seismic data. Note the different form and scale of tunnel channels (Tc).*

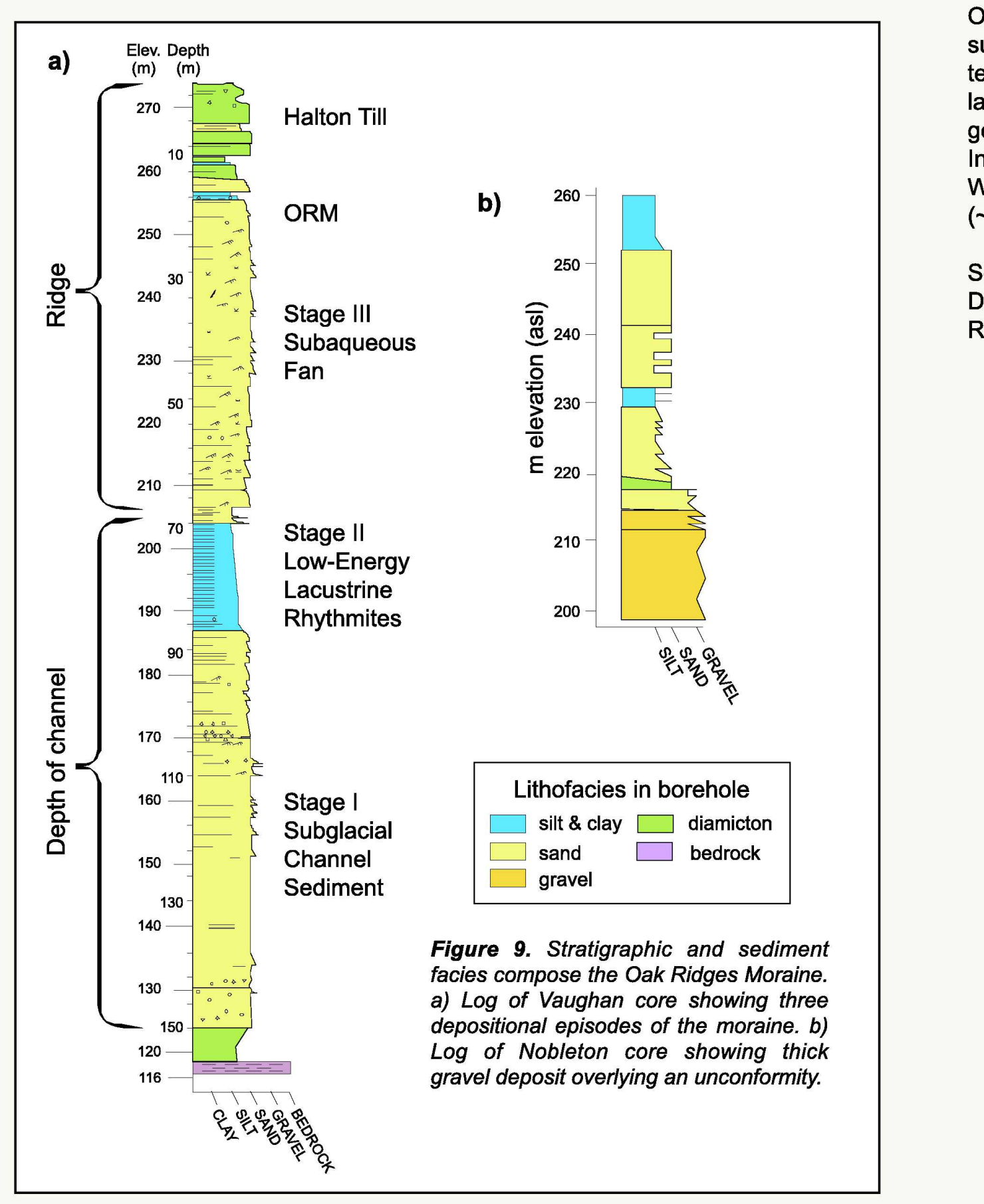

Figure 9. *Stratigraphic and sediment facies compose the Oak Ridges Moraine. a) Log of Vaughan core showing three depositional episodes of the moraine. b) Log of Nobleton core showing thick gravel deposit overlying an unconformity.*

ORM surface sediment is mostly silt and fine sand (Sharpe et al. 1997). These textures continue in the subsurface where borehole data suggest that the moraine is ~30-60 % silt and fine sand (Fig. 9). ORM texture is highly variable, however, and sediment facies range from massive cobble gravel to clay laminae. Major sediment facies can be correlated with seismic facies (Pugin et al. 1999) and downhole geophysical signatures (Hunter et al. 1998). The ORM sediment has two distinct fining-upwards trends. In channels it fines upward from gravel to sand to silt; and along the ridge, it fines from east to west. Water well data can overestimate ORM clay content by an order of magnitude compared to GSC data (~27% vs 1%, Fig. 11; Russell, 2001) because poor aquifer sediment is commonly reported as clay.

Sediment data have been used to infer several modes of moraine formation (Barnett et al. 1998; Duckworth 1979; Gilbert 1997; Paterson and Cheel 1997; Russell 2001; Russell and Arnott, 2003; Russell et al. 2003).

Oak Ridges Moraine Lithofacies

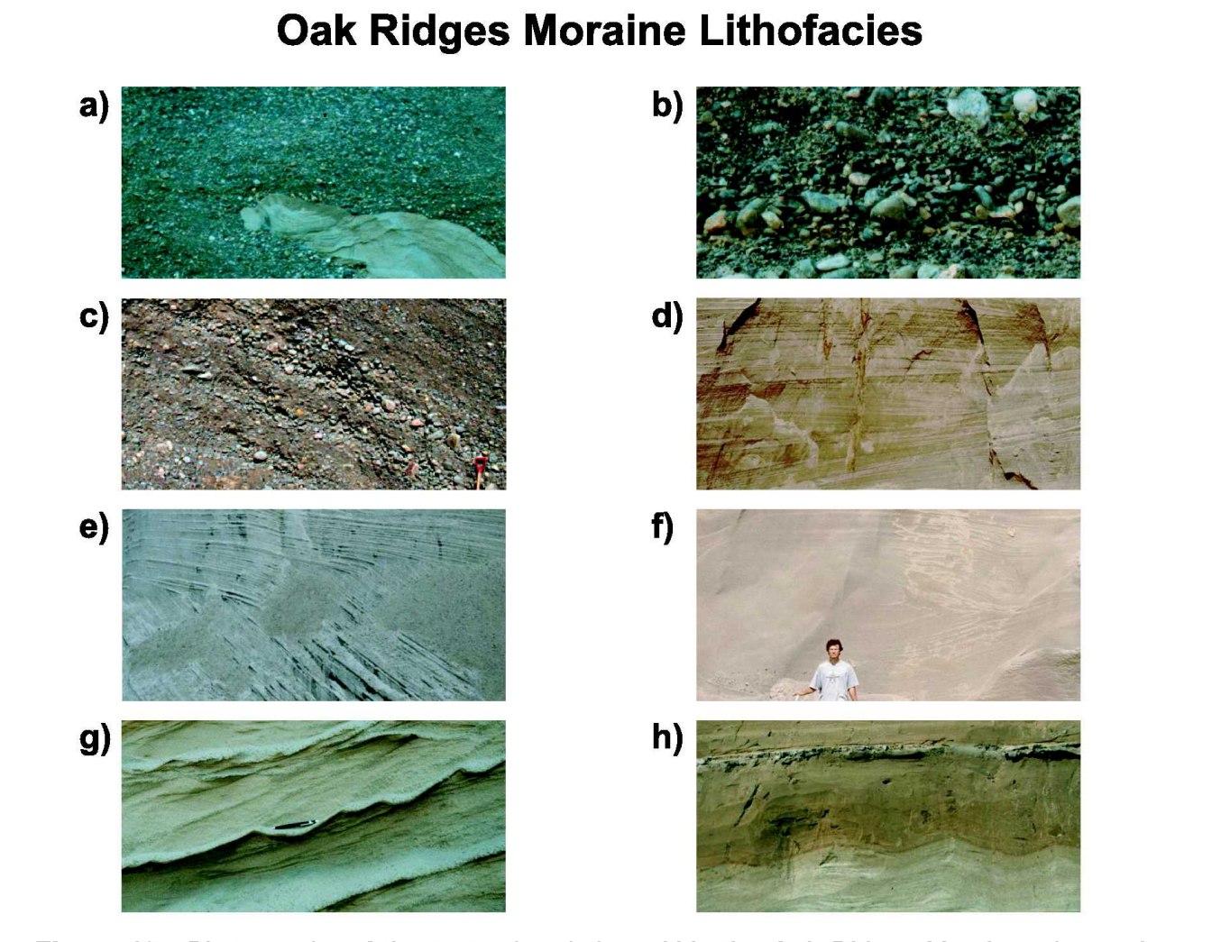

Figure 10. *Photographs of the textural variation within the Oak Ridges Moraine. a) massive gravel with sand intraclast, b) planar-bedded, open-work gravel, c) cross-stratified gravel, d) low-angle cross-stratified medium sand, e) cross-stratified medium sand, f) diffusely-graded sand, g) climbing, small-scale, cross-laminae, h) graded fine sand, silt with overlying clay laminae.*

Stratigraphic architecture

The ORM consists of three stratigraphic elements associated with distinct sedimentary episodes (Russell et al. 2003): i) tunnel channel sediment, ii) basin rhythmites, iii) ridge-building sediment. This detailed stratigraphic information is mainly available for ORM sediments west of Uxbridge.

i) Channel sediment: Gravel deposits up to 30 m thick (Fig. 10a,b,c) are closely associated with the regional unconformity (Russell et al. in press). Deeply incised tunnel channels also contain diffusely graded fine sand that may be > 50 m thick (Fig. 9). There is little data on the lateral extent of sediment facies within tunnel channels. Seismic data, however, indicate that sand facies may extend up to several kilometres and gravel facies >0.5 km wide and 1-2 km long (Pugin et al. 1999).

ii) Rhythmites: The rhythmite interval is characterized by a ~10-20 m thick sequence of micro-laminated fine sand to silt and clay (Fig. 10h). Core data indicate a discontinuity in strata from settings within channels to inter-channel uplands.

iii) Ridge sediment: Ridge sediment shows a range of textures with rapid lateral facies changes (Fig. 10). Sediment facies are part of subaqueous fan and eskerine settings that are aligned both perpendicular and parallel to the moraine ridge (Russell and Arnott, 2003; Paterson and Cheel, 1997; Barnett et al. 1998).

Moraine Composition

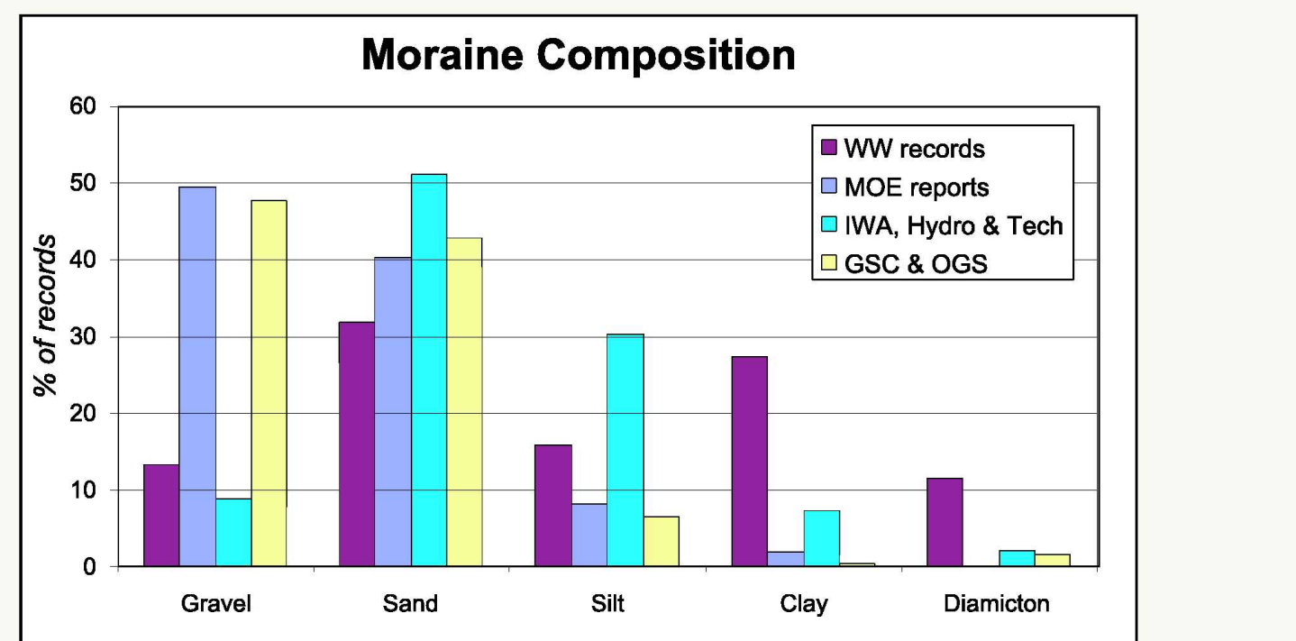

Figure 11. *Moraine composition based on various data sources. Note difference in apparent composition depending upon data source. For example, water well records overestimate clay by over an order of magnitude as compared to GSC data from continuous core.*

Oak Ridges Moraine Sediment Thickness Variation

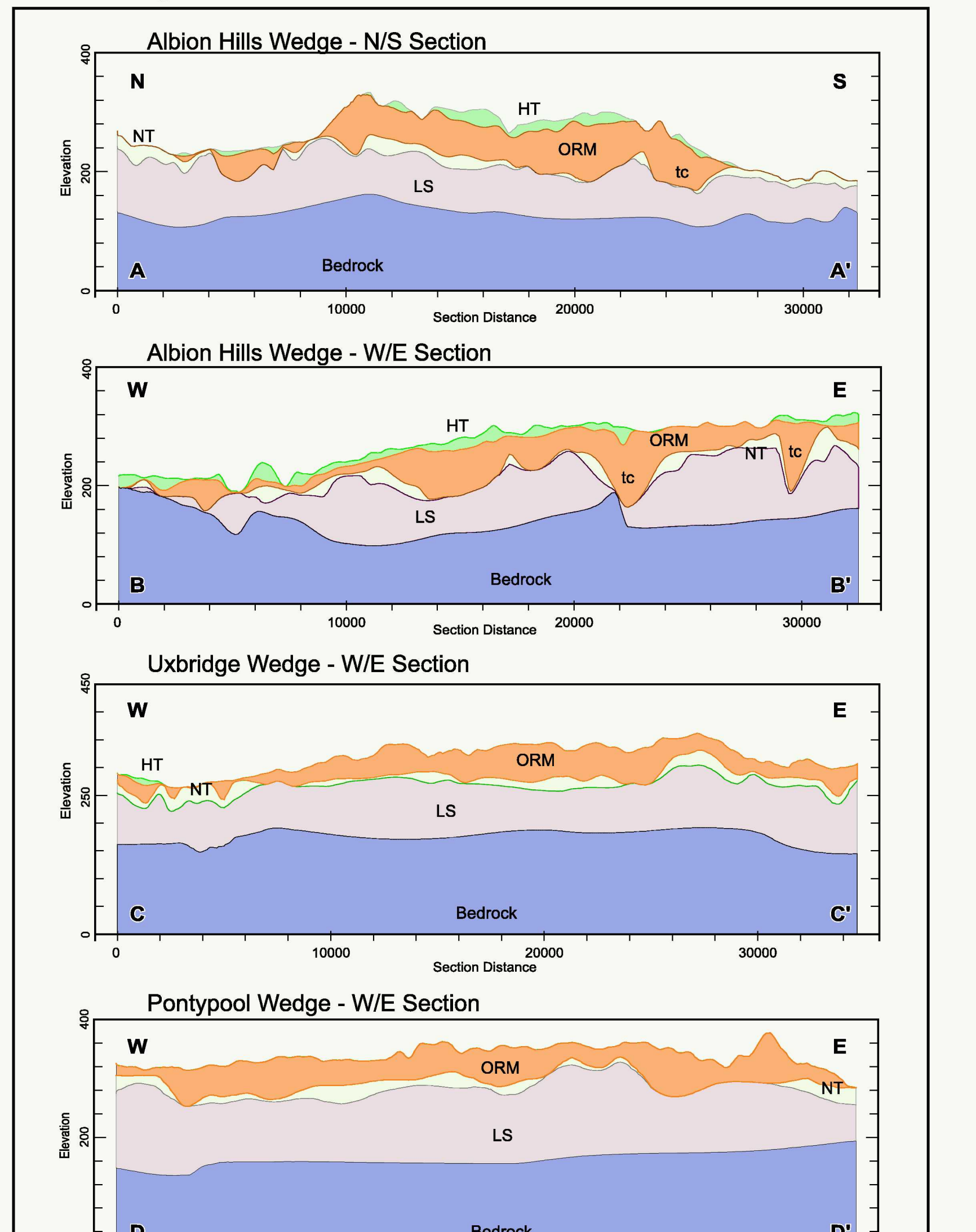

Figure 12. *Four our cross-sections of the ORM isopach surface showing regional variations in the ORM thickness and geometry. Note that the thickest sediment occurs in basin lows (tunnel channels - tc) beneath the moraine ridge. A-A' north-south cross-section; B-B', C-C', and D-D' west-east cross-sections.*

Hydrogeological implications

Most rivers in the study area have their headwaters in thick sandy ORM ridge sediment. Baseflow from the moraine contributes up to 50% of steam flow throughout the year. Headwater streams can make the largest contribution to baseflow per unit area of a watershed (Hinton, 1995). For example, in Duffins Creek, ORM headwaters contribute 39% of total baseflow from only 9% of total catchment area. Structural, directional and sediment facies trends, as summarized in sedimentary models (e.g. Fig. 13), control the hydraulic variability and groundwater flow paths within and between watersheds.

Depositional Model :
subaqueous fan

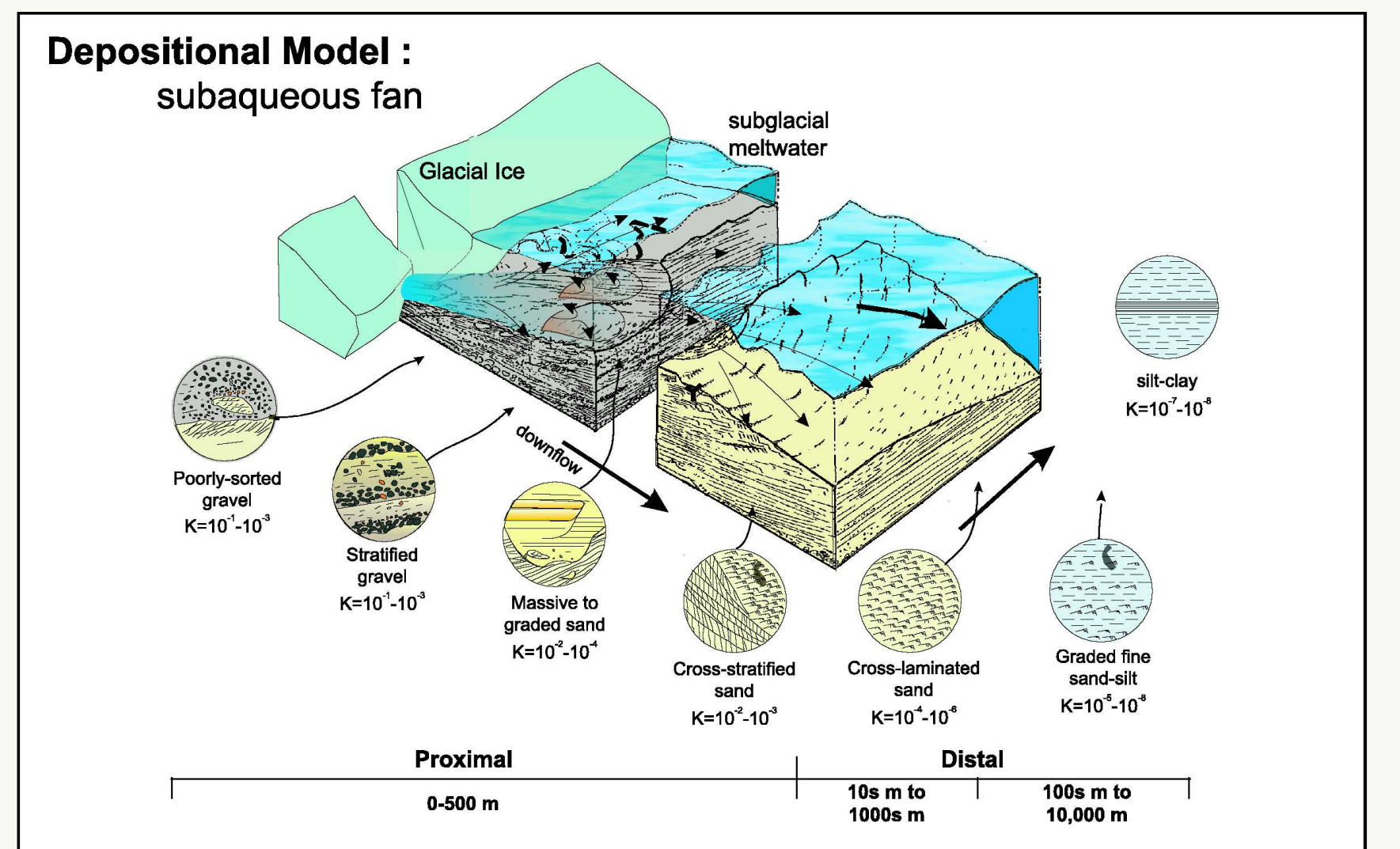

Figure 13. *Depositional model illustrating a subaqueous fan element of the Oak Ridges Moraine (from Russell, 2001). Note: i) rapid downflow facies changes from gravel to fine sand; ii) K values (m/s) of major facies are from Freeze and Cherry, 1979; iii) sand changes rapidly to silt-clay facies perpendicular to main flow.*

Summary

ORM isopach map of the ORM landform and associated sediment documents the distribution of moraine and correlative strata in the study area. Seismic reflection data and continuous cored boreholes support the isopach map patterns. ORM is predominantly silt, sand and gravel and it forms an aquifer complex that has a significant role in the distribution of recharge to streams and to deeper aquifers. Unit architecture consists of three stratigraphic elements associated with distinct sedimentary sequences: i) tunnel channel sediment, ii) basin rhythmites, and iii) ridge sediment. The spatial heterogeneity within each of these moraine elements, however, requires further definition.

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