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SEDIMENTOLOGY AND GEOCHEMISTRY OF THE QUEENSVILLE BOREHOLE, YONGE STREET AQUIFER, ONTARIO

N. Popović[1], L.M. Coffin[1], R.D. Knight[1], N.D. Prowse[2], and H.A.J. Russell[1]
1- Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, Ontario
2- Department of Earth Sciences, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario

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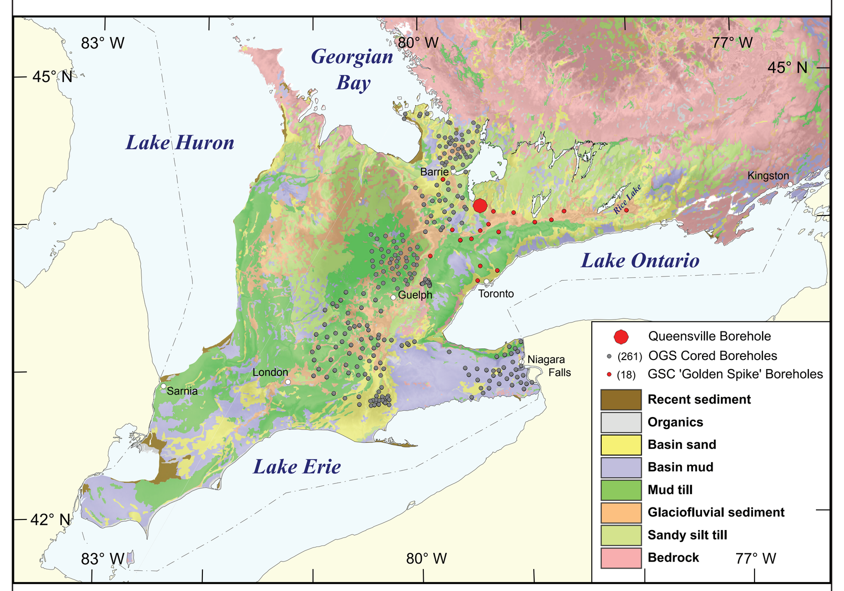

Figure 1: Simplified surficial geology of Southern Ontario. Modified from Barnett et al. 1992

Introduction

The development of predictive hydrogeological models is essential to support effective regional ground water management strategies. To better identify and assess aquifer resources, an understanding of local hydrogeology is imperative. In areas of limited hydrogeological data, aquifer potential of a sedimentary basin may be determined from sedimentological, geochemical and stratigraphic data. Cored boreholes provide stratigraphic control that permits integration of related monitoring and hydraulic test data in a stratigraphic and/or hydrostratigraphic framework for hydrogeological characterization and analysis. The addition of geochemical analysis defines the chemical and mineralogical variations of sediment and aids province interpretation, and can support improved understanding of water chemistry. Used in conjunction, lithological descriptions and geochemical analysis can assist in stratigraphic correlations and provide information on basin architecture, sedimentology, and genesis. The collection of continuous core is a critical step in developing a sound 3-D geological framework and defendable predictive models (Sharpe et al., 2002). Data collected from continuously-cored boreholes assists in both 2- and 3-D geological model development by:

i) Providing a framework to interpret lower-quality data (e.g. water well records)

ii) Verifying geophysical data, and

iii) Constructing and testing regional conceptual geological models.

The objective of this study is to document litho-stratigraphic and geochemical data obtained from a 96.2 m deep borehole drilled near Queensville, Ontario (Figure 1). The sediment log was produced from bed by bed description of lithofacies, sedimentary structures, and from drill site inspection and drilling rate for unrecovered core. Data presented here adds to the body of knowledge of the Young Street Aquifer.

Regional Setting

Regional mapping, terrain analysis and subsurface studies in the Greater Toronto Area indicate a sedimentary succession of up to 200 m. Figure 2 illustrates the generalized stratigraphy consisting of six major packages: Paleozoic bedrock, lower sediment (e.g. Scarborough, Thorncliffe formation), Newmarket Till, channel sediment, Oak Ridge Moraine sediment, and overlying Halton Till. An element of the stratigraphy is a number of regional unconformities, the most noteworthy of which is eroded into Newmarket Till and also forms the base of a series of large northeast to southwest trending tunnel valleys beneath the Oak Ridges Moraine.

Queensville Stratigraphy

Four stratigraphic units are observed in the Queensville borehole, from the base these include: 1) limestone of the Georgian Bay Formation, 2) Thorncliffe Formation, 3) Newmarket Till, and 4) modern soil weathering profile. This borehole is dominated by the Thorncliffe Formation (~82 m thick), which consists of a fining upward succession of sand- gravel capped by 59 metres of mud. The overlying Newmarket Till is ~7 m thick and consists of a sandy-silt diamicton with cobbles, pebbles and granules. The top ~2.5 m of the borehole is made up of the modern soil profile.

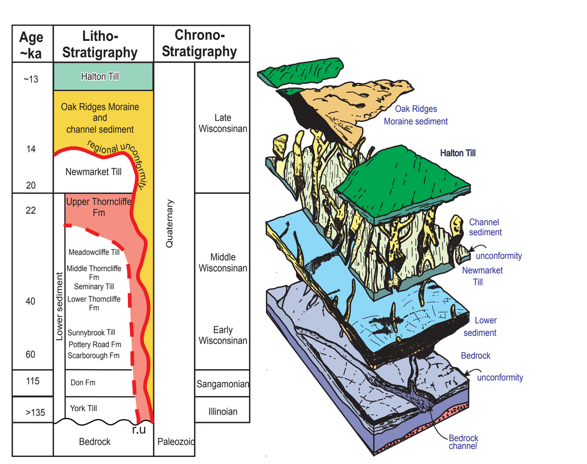

Figure 2: The regional stratigraphic framework of the study area. A) Lithostratigraphy and chronostratigraphy (modified from Karrow, 1974; ages from Barnett, 1992). B) Conceptual stratigraphic architecture (modified from Sharpe et al., 1997;2011).

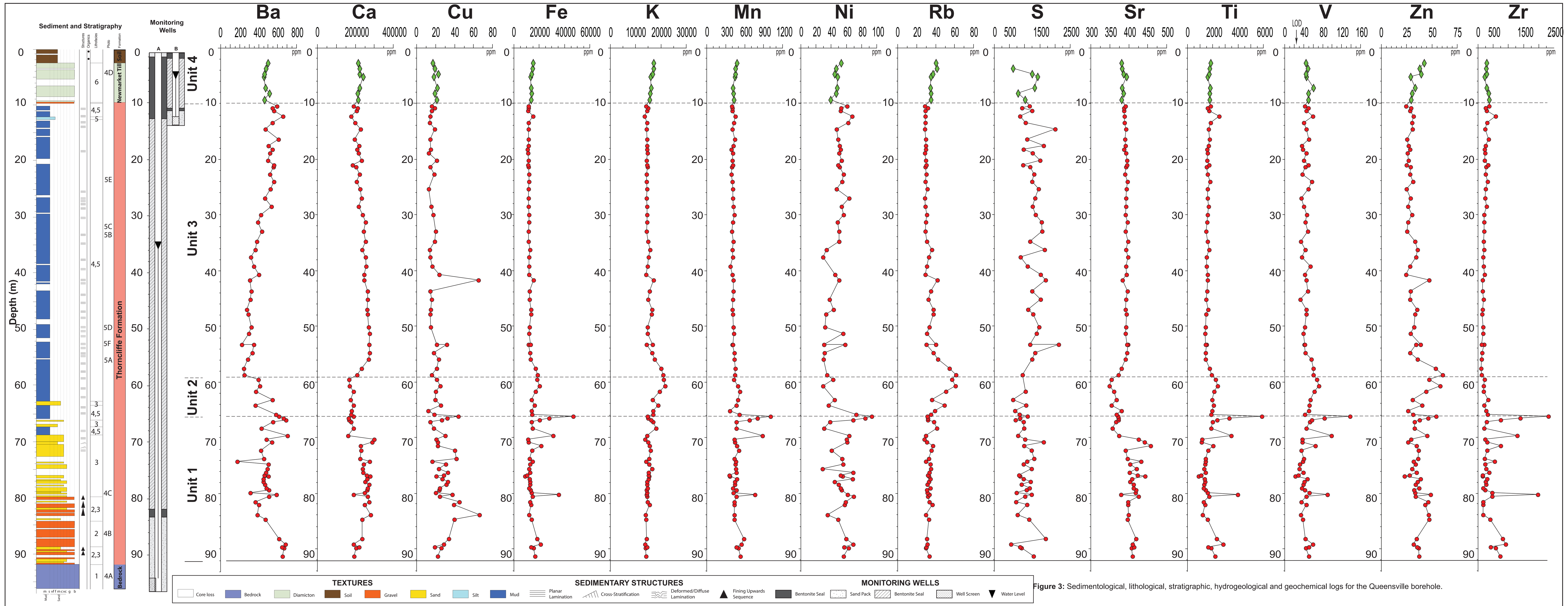

Figure 3: Sedimentological, lithological, stratigraphic, hydrogeological and geochemical logs for the Queensville borehole.

Lithofacies Descriptions

Facies 1: Limestone Bedrock
This facies occurs at the base of the borehole and is comprised entirely of pale grey limestone/dolostone with dispersed fossilized skeletal fragments over a ~4m interval from the end of the hole.

Facies 2: Gravel
The gravel facies occurs as sharp based 18 to 300 cm thick beds composed of granules to cobbles but dominated by pebbles (>80%). Matric content of the gravel may be underrepresented due to poor recovery. Grain shape varies from sub-angular to rounded with the grains being predominantly composed of limestone/dolostone (~70%) and Precambrian shield (~30%). The facies is commonly interbedded with sand beds (facies 4) and occurs directly on bedrock up to 80 m depth and as a thin bed at 11 m depth.

Facies 3: Sand
The sand facies consists of individual beds 18 to 50 cm thick, display sharp and gradational lower contacts, and commonly fine upwards. Grain size ranges from very coarse to medium sand at the base, fining upwards to medium- to fine- sand. Sub-rounded to rounded granules and pebbles are locally concentrated at the base of beds and gradually decrease in abundance stratigraphically upwards. Sedimentary structures are predominantly mm-scale planar laminations and ripple-scale cross-stratification that are defined by the concentration of dark heavy minerals. This sand facies is interbedded with gravel beds (facies 5) and occurs within a 12 m thick fining-upwards succession that uncomfortably overlies bedrock.

Facies 4: Massive Mud
This facies is composed of 1 to 4 cm thick dark brown/grey massive mud horizons that gradationally or abruptly overlie planar laminated mud of Facies 5.

Facies 5: Planar Laminated
The planar laminated mud facies has an abrupt basal contact with the underlying fine sand and consists of 1 to 20 cm thick, light grey beds with discontinuous dark grey mm-scale silt laminations and localalized mm-scale ripple cross-lamination (Figure 5A-F). Bed thickness increases from 1 cm near the bottom of the borehole to 20 cm near the top. Within the facies, lamination thickness increases upward from sub mm-scale to cm-scale in concert with increasing bed thickness. The lower contact between the massive mud facies and planar laminated mud facies varies from abrupt to gradational and in some cases loaded beds are observed at the contact. Variations between the mud facies associations are discussed in further detail below.

Facies 6: Diamicton
The diamicton facies consists of abundant silt and minor very fine sand matrix with dispersed angular granules and pebbles (up to 4 cm in diameter, ~ 10% of the total bed volume)(Figure 4a). Clast lithology is ~15% Precambrian Shield rocks and 85% limestone/dolomite similar to the bedrock in this borehole. This facies occurs as a single massive unit between 10 and 2.5 m depth, the lower contact was not recovered due to core loss. Matrix colour ranges from light to grey at the base to pale brown towards the top, which is interpreted to be due to modern surficial weathering rather than changes in sediment provenance.

Mud Facies Association
The planar-laminated-to-massive mud facies (Facies 4 and 5) form a series of rhythmic couplets comprising a 59 m thick unit from 69 m to 10 m depth. Although all couplets are similar in that they are bipartite, variations in couplet thickness, bed spacing, grading and sedimentary structures produce a multitude of different rhythmite deposits (Figure 5). Within the Queensville borehole, there are six variations of rhythmites:

a) Light-grey, diffusely planar laminated, silty-mud abruptly overlain by a 2-4 cm thick massive mud cap; couplets range from 2-7cm thick (Figure 5a);

b) Light-grey, silty-mud interstratified with few millimeter to 2 cm thick dark-brown mud. A succession of these rhythmites is commonly capped with a 2-5 cm thick mud bed. Unit thickness ranges from 10-40 cm (Figure 5b);

c) Light grey massive or diffusely laminated, silty-mud overlain by massive mud. Base of the unit is dominated by light-grey, silty-clay with very thin (few mm thick) massive mud laminations. Mud content increases upwards. These rhythmites are commonly capped with a 2-5cm thick mud layer. Unit thickness ranges from 10-40 cm thick (Figure 5c);

d) Rhythmites with gradational contacts: Light grey, planar laminated, silt-rich mud, 1- 10 cm thick that is gradationally overlain by a 2- 4 cm thick clay-rich mud. In general, thicker silt-rich mud beds (5- 10 cm thick) are locally ripple cross-laminated with sets up to 3 cm thick, and thinner silt-rich mud beds (< 5 cm thick) are mm-scale planar laminated (Figure 5d);

e) Rhythmites with loading structures: Light grey, massive mud (0.5-1 cm thick) abruptly overlain by 0.5- 1 cm thick dark grey mud. Contact between these two elements is characterized by loading structures such as ball and pillow structures or flames accompanied by local scouring. In some instances, loading and scouring cuts through to the underlying couplet resulting in structures up to 15 mm deep (Figure 5e);

f) Rhythmites with abundant soft sediment deformation may be present in any of the above mentioned rhythmite variations. Deformation is likely drilling induced:(Figure 5f).

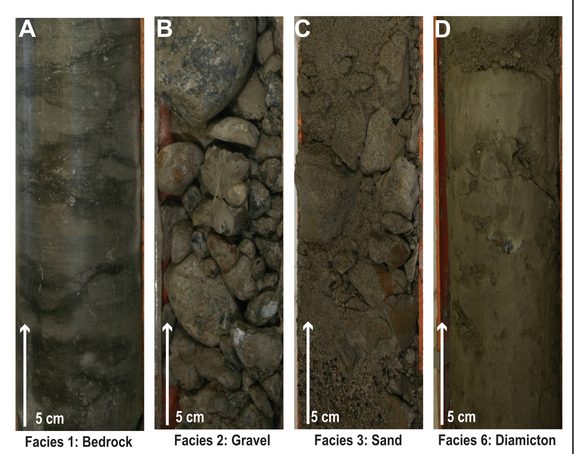

Figure 4: Representative core photos of Facies 1, 4, 5 and 6.

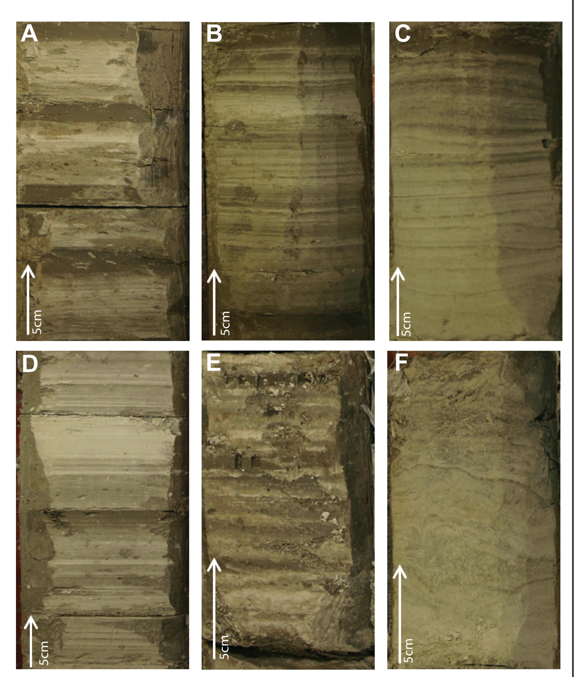

Figure 5: Six variations of rhythmites described throughout the Queensville borehole.

Depositional Setting

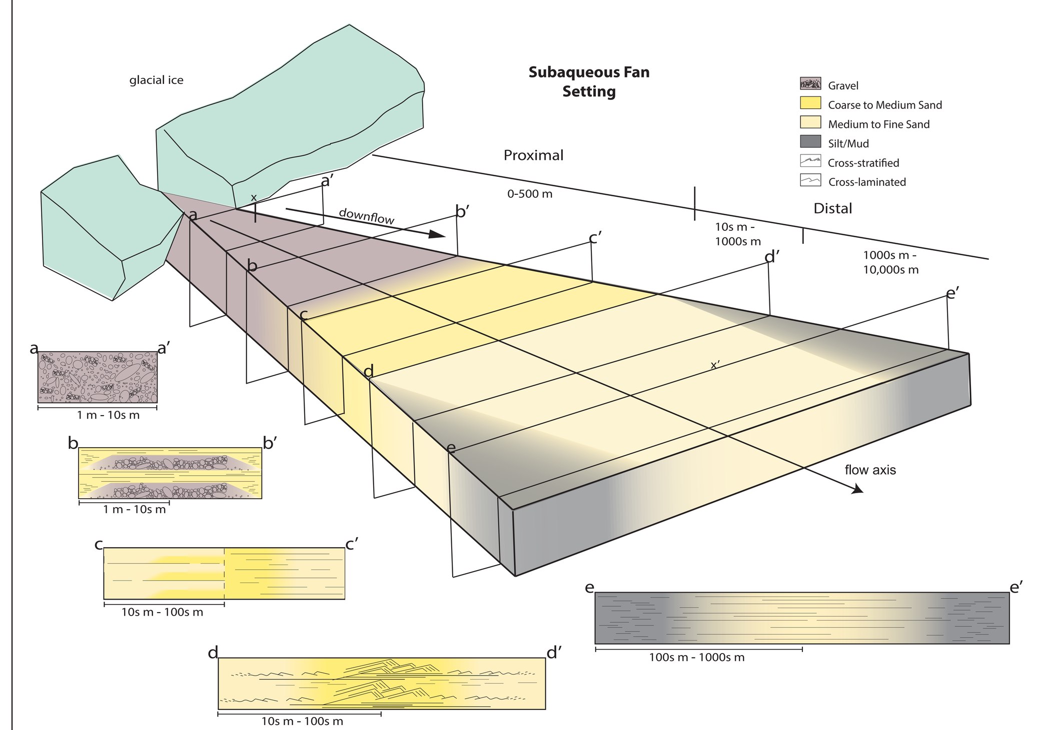

Figure 6: Depositional facies model of a subaqueous fan, depiciting downflow and lateral facies transitions.

Thorncliffe Formation
On the basis of stratigraphic position, topographic position, bed thickness, grain size and stratigraphic upward fining to muds, the Thorncliffe Formation is interpreted to form two elements within a depositional continuum: i) an ice-marginal grounding line in a subglacial conduit to proximal subaqueous fan setting and ii) an overlying glaciolacustrine basinal mud succession (Sharpe et al., 2002). The lower ~25 m thick sand and gravel succession is dominated by gravel beds generally fining upward to cross-stratified or planar laminated sand beds in 1-3 m thick units over the basal 12 m of the borehole. Small-scale fining upwards sequences are observed locally within individual beds as well as superimposed over the 25 m sequence; this possibly indicates discontinuous sedimentation or short-term episodic events relating to changes in flow velocity, sediment supply and accommodation space. The change to predominantly sand (at 80-70m depth) is interpreted to be the result of lateral movement of the subaqueous fan efflux jet.

Rhythmites are characterized by couplets of light grey planar laminated silty-mud beds (facies 5) and massive dark grey mud beds (facies 4). The fine-grained composition of the rhythmites indicates that there was very little influx of sediment, coarse silt laminae were likely deposited by density underflows and suspension deposition in a quiescent environment, of either a subglaical or proglacial lake (Figure 7). In glacial lacustrine environments such bimodal cyclic deposits are commonly interpreted to be varves representing diurnal and seasonal meltwater production reflecting a melt season and winter season. During the summer, underflows deposit multiple laminae of silt, followed by the deposition of more clay-rich massive beds in the winter months as melting ceases and water column turbulence is low due to ice cover.

Newmartket Till
The Newmarket Till is regionally extensive and is interpreted to represent a thick sheet of till incrementally deposited through subglacial traction process and release from ice via melting (regelation, etc) (Sharpe et al., 2002; Boyce and Eyles, 2000). The fractured and angular nature of the clasts and large grain size distribution within this unit is indicative of glacial abrasion and crushing and supports the interpretation that sediment deposition was not the result of sorting by fluvial or subaqueous processes.

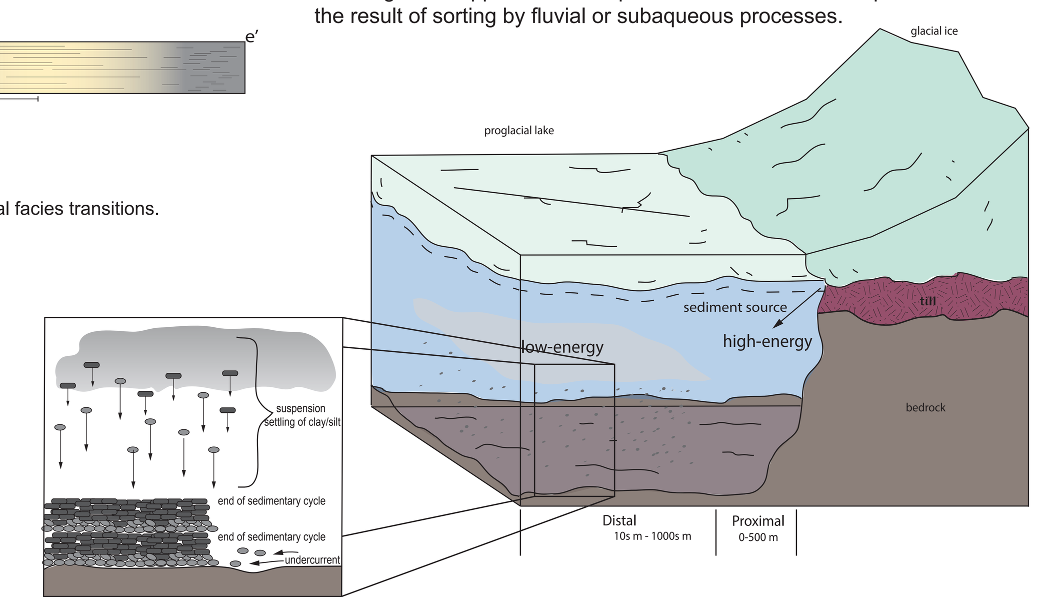

Figure 7: Depositional setting of clay rhythmite facies.

Geochemistry

Borehole	Queensville	Size Fraction:	<0.063 mm
Location	Newmarket, ON	Original Material:	Disaggregated, seived
Project :	Groundwater Assessment	Vial Window Material:	4 micron SpectroCertified Mylar polypropylene
Study Area	Oak Ridges Moraine	pXRF:	Niton XL3t GOLDD, 50-kV Cygnet X-ray tube
Easting:	626 499 m	Dwell Time:	60 seconds per High, Main, and Low filter
Northing	4 889 266 m	Mode Type:	Soil Mode, Compton normalization
UTM Zone	17		
Datum :	NAD83		
Date Drilled:	November 2009		
Date Logged	January 2015		
Depth Drilled:	96.2 m		

Portable X-ray fluorescence spectrometry has proven to be a successful tool to characterize the chemostratigraphy of glacial derived sediments (Knight et al., 2015) and to augment the interpretation of downhole geophysics, micropaleontology results, and pore water geochemistry (Mediloi et al., 2012). This method is best suited to the <0.063 mm size fraction (Plourde et al., 2012, Knight et al., 2012) of unconsolidated sediment that represents crushed bedrock detritus and reworked surficial sediments. The resulting data sets from these studies provided fundamental information used to define chemical and mineralogical variations within aquifers and aquitards.

The pXRF derived data was interpreted using single element trends from the base to the top of the borehole. Fourteen elements (Ba, Ca, Cu, Fe, K, Mn, Ni, Rb, S, Sr, Ti, V, Zn, and Zr) were detected in sufficient quantities to produce meaningful results using the pXRF spectrometer. Three elements (As, Th, and U) were consistently measured below the limit of detection and are not included. Complete results as well as precision and accuracy using standard reference materials are compiled in Knight et al. (2015a).

Chemostratigraphy of the Queensville borehole can be divided into 4 units. Three of these units correspond to the Thorncliffe Formation and the fourth unit represents the overlying Newmarket Till. Unit 1:, from 92 to 66 m depth displays a high degree of variability in element concentrations (e.g. Ba, Cu, V, Zr) that most likely reflects the small scale fining upwards sequences observed during core logging and attributed to dynamic changes in depositional processes. Some elements such as Ca, Fe, K Mn, and Rb; however, display minimal variability throughout the unit. The contact between unit 1 and unit 2, at a depth of 66 meters, corresponds to the change in grain size between the gravel/sand interbeds and the overlying silt/clay rhythmites. This contact is also reflected by a spike in the geochemical signature (e.g. Cu, Fe, Mn, Ti, V, Zn and Zr). For most elements, other than K, Rb and to a lesser degree Fe, variable concentrations in the lower sediments of the Thorncliffe Formation (unit 1) confirm a high degree of variability in sediment provenance, as noted during the core logging. Potassium and Rb concentrations most likely represent a stable and continuous input of sediment from shield terrain whereas variations in Ba and Ca most likely represent fluctuations in sediment input from carbonate terrains.

Rhythmites of unit 2 , from 66 to 59 m depth, are transitional from unit 1 and are thinner and more frequent than the overlying rhythmites of unit 3.Unit 2 displays much less variability in elemental concentrations compared to the underlying unit 1 sediments (e.g. Fe, S, Ti, V, Zr). The change in elemental concentrations between unit 2 and unit 3 is most notable for Ca and Sr where there is an overall increase in concentration over a few meters (59-56 m) whereas K, Rb, Ti, V, Zn display a decrease in concentrations over the same interval. For some elements (Ca, Fe, K, Mn, Sr, Ti, Zr) concentrations remain similar throughout the remainder of unit 3 . Barium is the only element that displays a constant increase in concentration from the base of unit 3 (~200 ppm) to the base of unit 4 (~600 ppm). At a depth of 42 meters there is a spike in Cu and Zn and to a lesser degree in Rb, K, and S and there is a departure from the trends throughout unit 3. It should be noted, however, that the sediments just below the base of unit 4 were not recovered.

Geochemically there is minimal elemental signal change between unit 3 (Thorncliffe Formation) and unit 4 (Newmarket Till). Barium and Ni both display a decrease in concentration at the contact; however, the remaining elements display little if any change in concentration from the underlying unit 3 sediments. This suggests that the <0.063 mm size fraction of unit 4 (Newmarket Till) has the same provenance as the underlying unit 3 (Thorncliffe Formation) sediments or that the matrix of the Newmarket Till is overwhelmingly derived from the Thorncliffe Formation.

References

Barnett, P.J., 1992. Quaternary geology of Ontario in Thurston, P.C., Williams, H.R., Sutcliffe, R.H. and Stott, G.M., eds., Geology of Ontario: Ontario Geological Survey, Map 2560, scale 1:50,000.

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

Knight, R.D., Valiquette, L.J., and Russell, H.A.J., 2015. Portable XRF spectrometry of glacial derived sediment from the Queensville borehole, Young Street Aquifer, southern Ontario: data release; Geological Survey of Canada, Open File 7855, 9 p. doi:10.4095/

Knight, R.D., Reynen, A.M.G., Grunsky, E.C., and Russell, H.A.J., 2015. Chemostratigraphy of the late Pleistocene Dashwood Drift to Capilano Sediment succession using portable XRF spectrometry, Nanaimo, British Columbia, Canada; Geological Survey of Canada, Open File 7651. 1 .zip file. doi:10.4095/295688

Knight, R.D., Kjarsgaard, B.A., Plourde, A.P., and Moroz, M., 2013. Portable XRF spectrometry of standard reference materials with respect to precision, accuracy, instrument drift, dwell time optimization, and calibration; Geological Survey of Canada, Open File 7358. doi:10.4095/292677

Knight, R.D., Moroz, M., and Russell, H.A.J., 2012. Geochemistry of a Champlain Sea aquitard, Kinburn, Ontario: portable XRF analysis and fusion chemistry; Geological Survey of Canada, Open File 7085. 1 CD-ROM doi:10.4095/290969

Medioli, B. E., Alpay, S., Crow, H. L., Cummings, D. I., Hinton, M. J., Knight, R. D., Logan, C., Pugin, A. J-M., Russell, H. A. J., Sharpe, D. R., 2012. Integrated data sets from a buried valley borehole, Champlain Sea basin, Kinburn, Ontario. Geological Survey of Canada, Current Research 2012-3, 20p., doi:10.4095/289597

Plourde, A.P., Knight, R.D., and Russell, H.A.J., 2012. Portable XRF spectrometry of insitu and processed glacial sediment from a borehole within the Spiritwood buried valley, southwest Manitoba; Geological Survey of Canada, Open File 7262. doi:10.4095/291922

Russell, H.A.J. and Arnott, R.W.C., 2003. Hydraulic-Jump and Hyperconcentrated-Flow deposits of a glacigenic subaqueous fan: Oak Ridges Moraine, Southern Ontario, Canada; Journal of Sedimentary Research, v. 73 n. 6, p. 887-905.

Sharpe, D.R. and Barnett, P.J. (comp.), 1997. Where is the water? Regional geological/hydrogeological framework, Oak Ridges Moraine area, southern Ontario; Geological Association of Canada, Joint annual Meeting, Ottawa '97, Field Trip A1, Guidebook, 49 p.

Sharpe, D.R., Hinton, M.J., Russell, H.A.J., and Desbarats, A.J., 2002. The Need for Basin Analysis in Regional Hydrogeological Studies: Oak Ridges Moraine, Southern Ontario; Geoscience Canada, v. 29 n. 1, p. 3-20.

Sharpe, D., Pullan, S., and Gorrell, G., 2011. Geology of the Aurora high-quality stratigraphic reference site and significance to the Yonge Street buried valley aquifer, Ontario; Geological Survey of Canada, Current Research 2011-1, 20p. doi: 10.4095/286289

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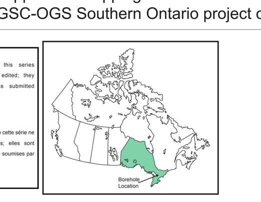

For more information, please contact H.A.J. Russell (hazen.russell@canada.ca)

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