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

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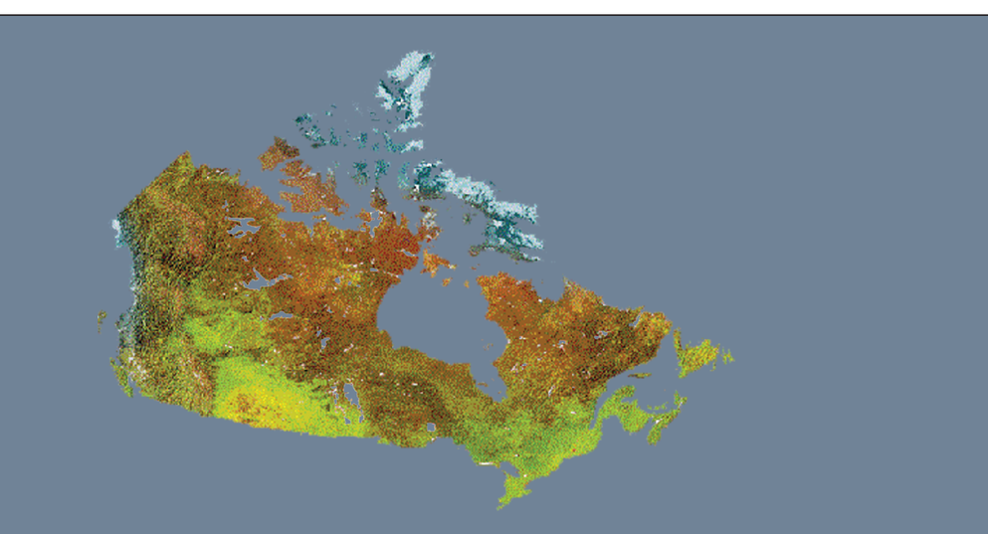

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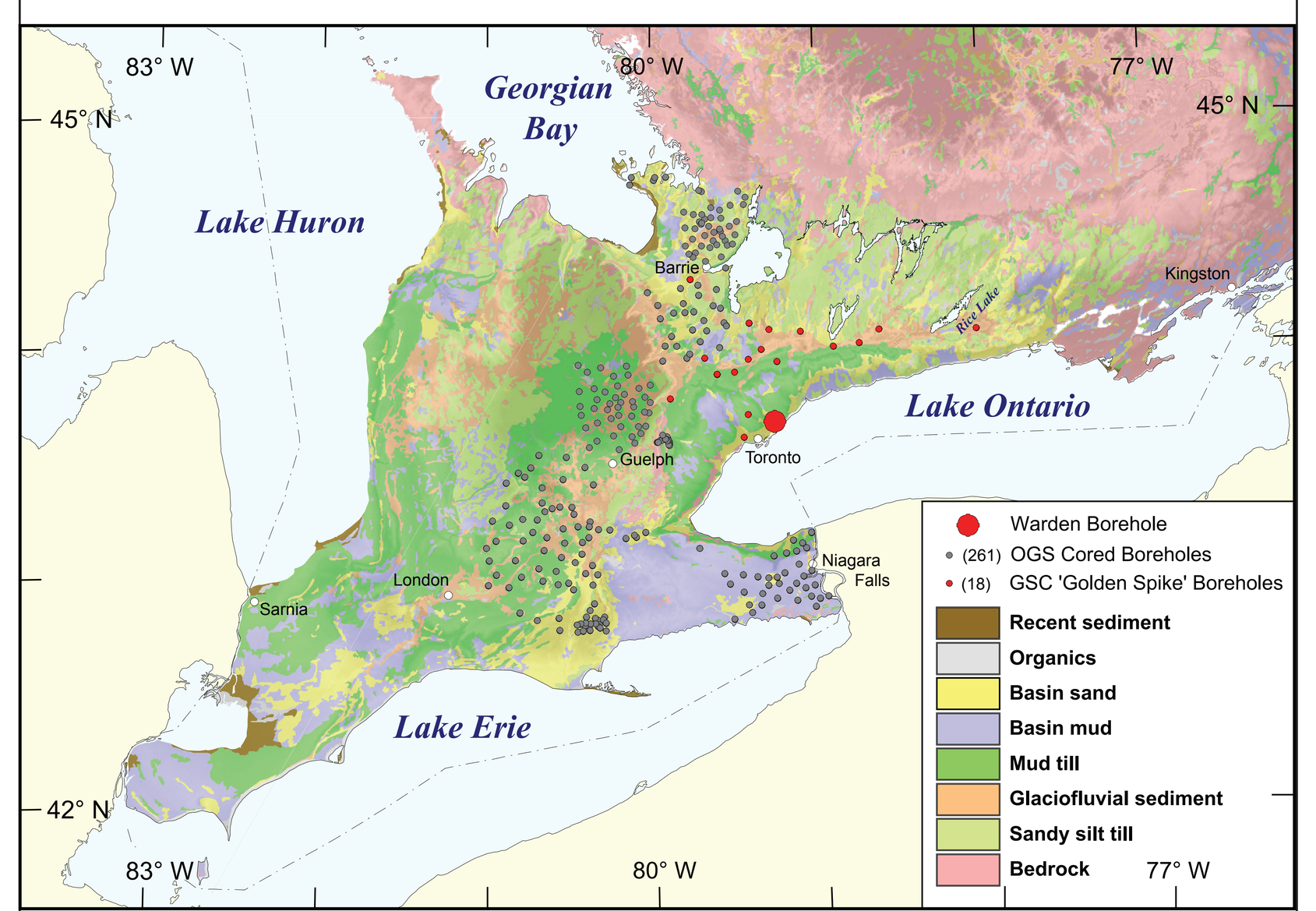

Figure 1: Simplified surficial geology of Southern Ontario.Modified from Barnett et al. 1992

Introduction

The development of predictive hydrogeological models is essential to the creation of 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 in provenance 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 provides a framework for both 2- and 3-D geological model development by:

i) Providing interpretation of lower quality archival data (e.g. water well records)

ii) Verifying geophysical data, and

iii) Constucting and testing regional conceptual geological models.

The objective of this study is to document litho-stratigraphic and geochemical data obtained from a 80.5 m deep borehole drilled at the Warden Ave Junior Public School, 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.

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 displays the generalized stratigraphy consisting of six major sediment 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.

Warden Stratigraphy

Four stratigraphic units are observed in the Warden borehole, from the base these include: 1) Blue Mountain Formation 2) Scarborough Formation, 3) Thorncliffe Formation and 4) Newmarket Till. The Scarborough Formation consists of a 36 m coarsening upwards succession of mud, silt and sand that has abundant detrital and in-situ organics. The overlying 35 m thick Thorncliffe Formation consists of multiple coarsening-upwards successions from coarse sand to mud, which is capped by a ~ 9 m thick massive diamicton unit (Newmarket Till).

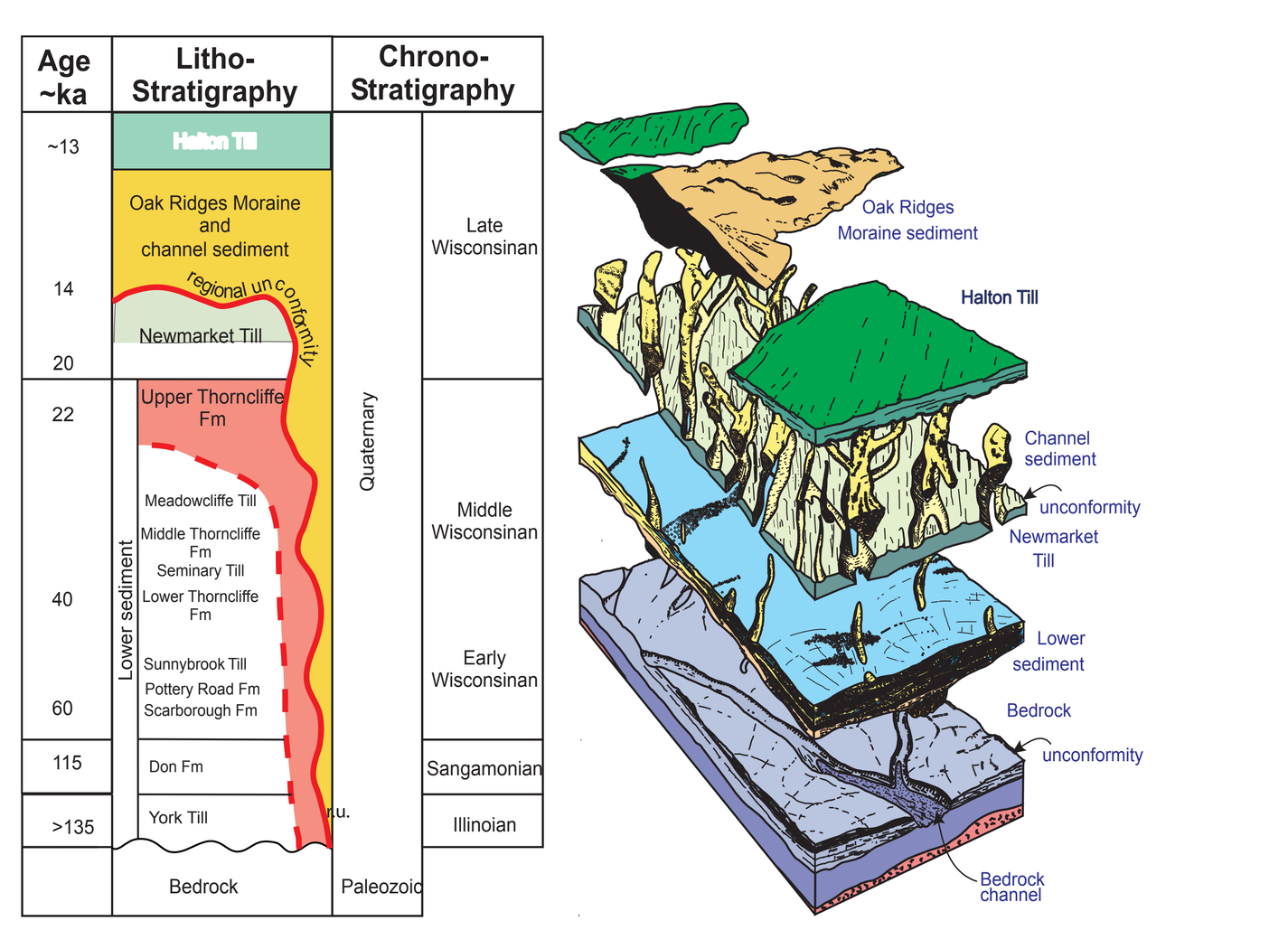

Figure 2: The regional stratigraphic framework of the study area. A) Lithostratigraphy and chronostratigraphy (modified from Karrow, 1974; ages from Barnett, 1992). B) Conceptual stratigraphic architecture (modified from Sharpe et al., 1997).

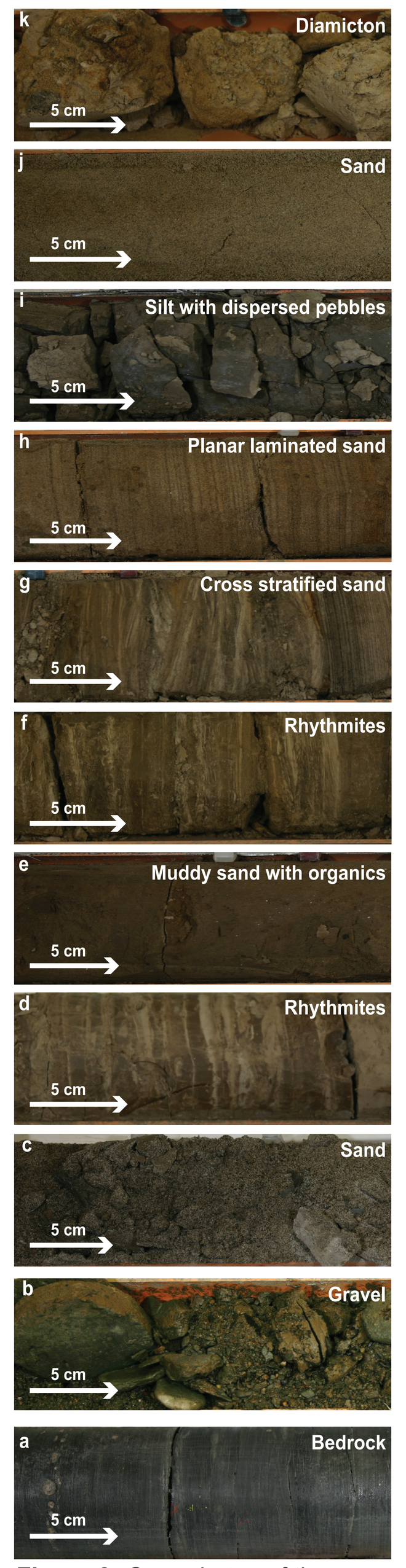

Figure 3: Core photos of the various facies (described below).

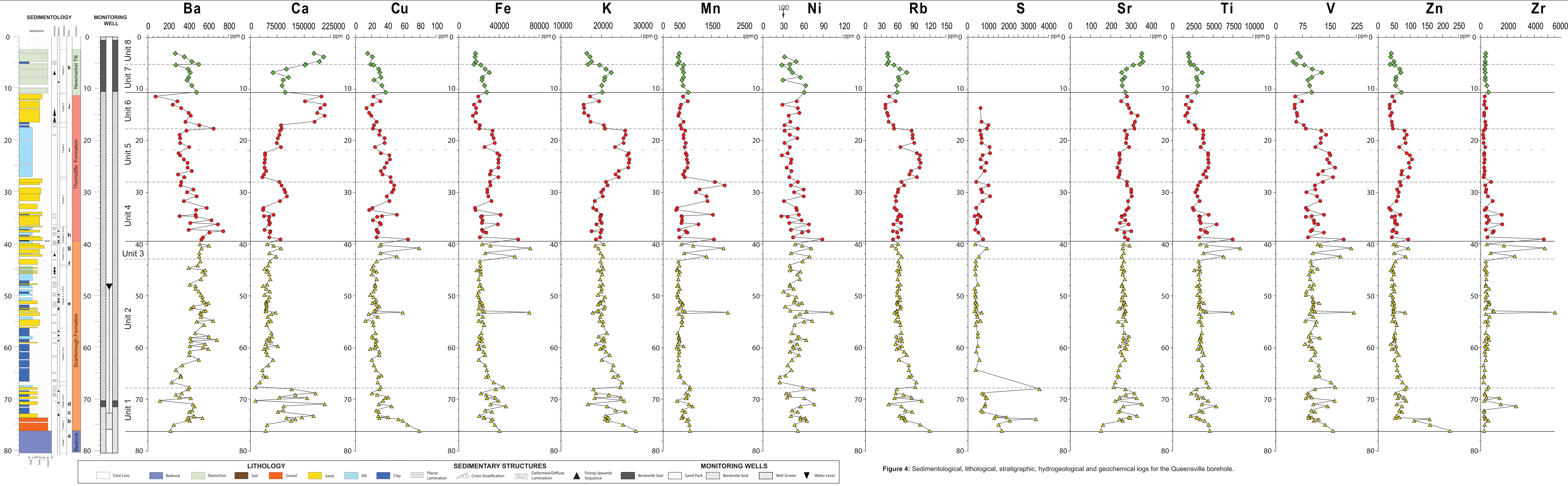

Figure 4: Sedimentological, lithological, stratigraphic, hydrogeological and geochemical logs for the Queensville borehole.

Lithofacies Descriptions and Depositional Interpretations

Facies 1: Bedrock
Bedrock occurs at the base of the borehole and consists of black, fissile, petroliferous shale. On the basis of the petroliferous character (Armstrong and Dodge, 2007) it is correlated with the Blue Mountain Formation.

Facies 2: Gravel
The gravel facies occurs as a single sharp based 2.2 m thick, ungraded unit composed of unconsolidated granule to cobble sized clasts, predominantly pebbles (>80%). Matrix content of the gravel may be under represented due to poor recovery. Limestone/dolostone grains (10%) vary from subrounded to rounded, granite/Precambrian grains are less than 5% and angular shale grains account for 85% of the facies.

Facies 3: Sand
This facies consists of individual beds generally > 50 cm in thickness, lower contacts are sharp and gradationally. Grain size ranges from very coarse - to medium - sand at the base fining upwards to medium-to fine-sand. Subrounded to rounded granules and pebbles are locally concentrated at the base of beds and gradually decrease in abundance upwards. Sedimentary structures are predominantly mm-scale planar laminations and ripple scale cross-stratification that is defined by the concentration of dark heavy minerals. Sand beds are commonly interbedded with massive and rhythmitic silt and clay horizons (Facies 2 and 3) throughout the lower 53m of the core. At a depth of 36 metres there is a 9 m thick succession of coarsening upwards planar laminated sand beds. Normal grading within individual beds is observed although an overall coarsening from fine sand to coarse sand occurs over this interval. At 16 metres depth, there is a single, 5.5 m thick sand bed that coarsens upwards from medium to coarse sand. This bed is largely massive with weakly defined cross bedding observed in the upper 2 metres.

Facies 4: Muddy sand with organic material
The muddy sand facies consists of 30-90 cm thick beds of massive, fine-grained sand with mud clasts and flecks dispersed throughout the bed. These sediments abruptly overlie rhythmite successions and gradationally overlie medium-grained sand. Flecks of irregularly- shaped organic material up to 3 mm in diameter are commonly present in the sand beds. This facies only occurs stratigraphically below the peat facies.

Facies 5: Silt with dispersed pebbles
This facies is characterized by a 9 m thick unit between17.5 - 27 m depth of dark brown to grey, well consolidated silt, with sparsely dispersed rounded pebbles (1-3 cm in diameter). There is limited variability within the clast concentration and distribution throughout the unit, although rare >3 cm sub-rounded clasts of shale are sporadically dispersed at irregular intervals.

Facies 6: Peat
Peat occurs as a 6 cm thick unit at 39.5 m depth and is characterized by low-density organic material that has been partially compacted and lithified. It occurs at the top of a silt-clay rhythmite succession and marks the top of the Scarborough Formation.

Facies 7: Massive Mud
The massive mud 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 2, in some instances, facies 2 fills scours in the top of the massive mud beds.

Facies 8: Cross-Stratified to Planar Laminated Mud
The cross-stratified to planar laminated mud facies consists of 1 to 15 cm thick, light grey sediments with discontinuous dark grey mm-scale silt laminations. Bed thickness increases from 1 cm near the bottom of the borehole to 15 cm near the top with laminar spacing increasing with bed thickness from sub mm-scale to cm-scale. Cross-stratification is generally characterized by 1-30 mm thick sets of ripples, with rare climbing ripples forming in the thicker beds near the top of the unit. The lowermost contact between mud and fine sand is abrupt; however the lower contact between massive mud and planar laminated mud varies from abrupt to gradational with rare loaded beds at the contact.

Facies 9: Diamicton
The diamicton facies consists of subangular to subrounded granules and pebbles up to 7 cm in diameter that form approximately 10% of the facies in a dense silt-to very fine-sand matrix. Clast lithology is ~25% Precambrian Shield rocks, 70% limestone/dolomite and 5% shale. This facies occurs as a single massive unit between 11 and 3 m depth, both the upper and lower contacts were not recovered due to core loss at those intervals. Matrix ranges from light greyish brown at the base to light rust- coloured brown towards the top. This colouration is most likely due to weathering of iron-rich minerals within the diamicton.

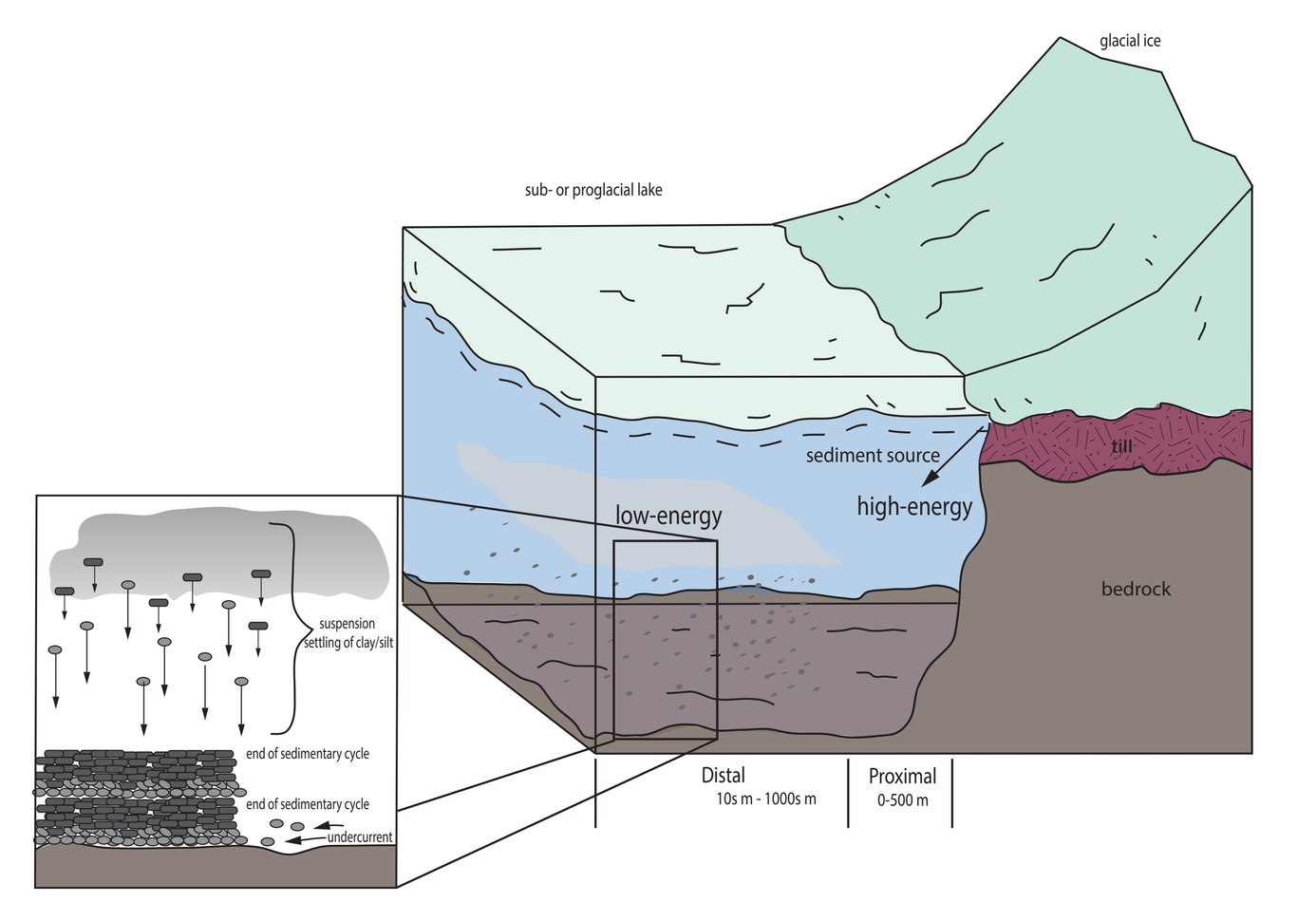

Figure 5: Depositional setting of clay rhythmite facies and the diamicton facies.

Mud facies Association
The cross-stratified to planar laminated mud and massive mud facies form a series of rhythmic couplets varying from 0.5 m to 7 m in thickness. Variations in couplet thickness, bed spacing, grading and sedimentary structures produce a number of different rhythmite deposits. Within the Warden borehole, there are five common variations of rhythmites:

a. Light grey, diffusely planar and cross –laminated mud (2-15 cm thick) that is abruptly overlain by a 1-2 cm thick dark grey massive mud cap. Couplets range in thickness from 3-17 cm.

b. Light grey, massive to diffusely laminated, mud overlain by massive mud. Couplets range from 0.5 to 4 cm thick. The base of these rythmites are dominated by light-grey, silty-clay with very thin (few mm) massive mud. Towards the top of the rythmites mud content increases and basal light-grey beds thin. Successions of these rhythmites are commonly capped by a 2-5 cm thick mud bed. Unit thickness ranges from 4-10 cm thick.

c. Light grey, massive mud abruptly overlain by a few millimeter to 2 cm thick dark grey, massive mud cap. Couplets range from 0.5 to 4 cm thick, a succession of these rhythmites is commonly capped with a 2-5 cm thick dark grey mud bed. Unit thickness ranges from 1-10 cm thick

d. 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 and scouring, in places cutting through to the underlying couplets (scours may range up to 15 mm deep).

e. Light grey, planar laminated to cross-laminated, silt and mud 1- 10 cm thick that is gradationally overlain by a 2 - 4 cm thick clayey mud. In general, thicker silt and mud beds (5-10 cm thick) are ripple cross-laminated with sets up to 3 cm thick. Thinner silt and mud beds (< 5 cm thick) are planar laminated and mm in scale.

Scarborough Formation
The Scarborough Formation is interpreted as a proglacial lake basin, with frequent deposits of coarser grained gravity flows (Facies 2, 3 and 4) (Kelly and Martini, 1986). The Scarborough Formation is interpreted to form two elements within a depositional continuum: i) at an ice-marginal grounding line in a subglacial conduit to proximal subaqueous fan setting and ii) an overlying glaciolacutrine basinal mud succession (Figure 5; e.g. Sharpe et al., 2002).

Intercalated graded, structureless sand beds (Facies 3) are interpreted to be deposited by density currents, specifically moderately concentrated hyperpycnal flows emanating from a subglacial conduit. These flows were generated by highly concentrated sediment plumes associated with subaqueous fan sedimentation, most likely signalling the presence of a hydraulic jump within the transition zone of a plane-wall jet (e.g. Russell and Arnott, 2003; figure 6: c-c').

Newmarket Till
The Newmarket Till is regionally extensive and is interpreted to represent a till sheet deposited incrementally by subglacial processes (Sharpe et al., 2002; Boyce and Eyles, 2000). The clast angularity and large range in grain size indicate glacial abrasion and crushing suggesting that these sediments are not the result of sorting by fluvial or subaqueous processes. The thickness and topographic location of the massive unit does not support an interpretation of deposition from gravity flows, unless in a direct ice marginal position. The drumlinized upland indicates deposition prior to deglaciation

Thorncliffe Formation
The Thorncliffe Formation is characterized by a sequence of rhythmites comprising alternating light grey planar laminated silty-mud beds (facies 8) and massive dark grey mud beds (facies 7). The fine grain size suggests very little (if any) traction deposition of sediment indicating settling of fine-grained sediment in a quiescent environment, such as a subglacial / proglacial lake (Figure 5) or by the tail ends of low-density turbidity currents.

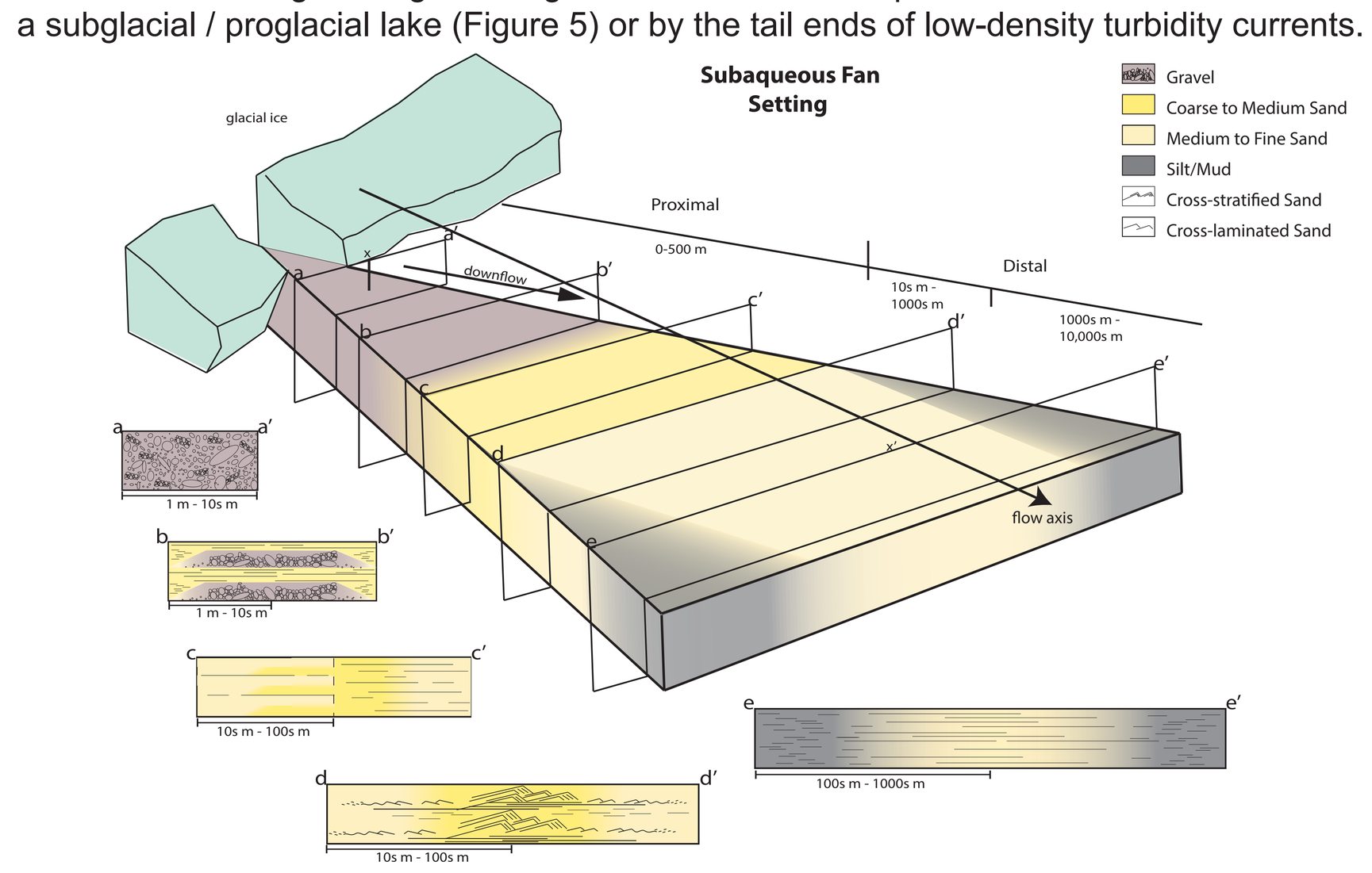

Figure 6: Depositional facies model of a subaqueous fan, depicting downflow and lateral facies transitions. Facies 2, 4, and 5 are interpreted to have been deposited in this type of environment

Geochemical Data (pXRF)

Borehole:	Warden	Easting:	638 868 m	Vial Window Material:	4 micron SpectroCertified Mylar polypropylene	Date Drilled:	January 2010
Location:	Toronto, ON	Northing:	4 840 084 m	pXRF:	Niton XL3t GOLDD, 50-kV Cygnet X-ray tube	Date Logged:	February 2015
Project:	Groundwater Assessment	UTM Zone:	17	Dwell Time:	60 seconds per High, Main, and Low filter	Depth Drilled:	80.5 m
Study Area:	Oak Ridges Moraine	Datum:	NAD83	Mode Type:	Soil Mode, Compton normalization		
Original Material:	Disaggregated, seived	Size Fraction:	<0.063 mm				

Portable X-ray fluorescence spectrometry (pXRF) has been successfully used to characterize the chemostratigraphy of glacial basin sediments (Knight et al., 2015a) and to complement the interpretation of downhole geophysics, micropaleontology, and pore water geochemistry (Medioli et al., 2011). To maximize the analytical accuracy and precision the pXRF analysis is best completed on the <0.063 mm size fraction (Plourde et al., 2012, Knight et al., 2012). Generally, in this size fraction, the mechanically crushed bedrock detritus has not been exposed to long periods of chemical weathering following deposition in glacial basins. Data derived from pXRF spectrometry is 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. Four elements (Cu, Ni, S, and V) returned some values below the limits of detection.. Complete results as well as precision and accuracy using standard reference materials are compiled in Knight et al. (2015b). In the South-central part of Ontario Na and K likely represent granitic provenance, while Ca represents carbonate terrains. It is important to note that without mineralogical characterization pXRF spectrometry can only infer generalizations with regards to source rock types. Chemostratigraphy of the Warden borehole can be divided into 8 units (Fig. 6). The three lowermost units correspond to the Scarborough Formation, the overlying 3 units to the Thorncliffe Formation, while the uppermost two units represent the Newmarket Till.

Unit 1 (~67 m depth to bedrock), displays a large variability in the concentrations of most elements (Ba, Ca, Cu, Fe, K, Ni, Rb, Sr, V and Zn) as well as the progressive decrease of elemental concentrations of Cu, Fe, K, Rb, Ti, V, and Zn as distance above bedrock increases. The variability in elemental concentrations in the unit above bedrock is likely due to the effects of groundwater flow in this coarse sand and gravel unit. Maximum element values in these sediments are detected just above bedrock and decrease in concentration stratigraphically upwards. The contact between unit 1 and unit 2 (67 m depth) corresponds to the change in texture from the muddy sand/sand interbeds and the overlying silt/clay rhythmites. Unit 2 sediments (from 43 -67 m in depth) are homogeneous and display much less variability in elemental concentrations compared to the underlying sediments of unit 1 (e,g, Fe, Mn, S, Ti, Zn, Zr). At a depth of 53 m there is a spike in Cu, Fe, Mn, Ni, Ti, V, Zn and Zr, which is likely due to a nugget effect or erroneous pXRF detection as values at this interval are a significant departure from the normal trends through the unit. Unit 2 sediments are finer grained than those of overlying unit 3 sediments, which are characterized predominantly by sand; marking the transition from the Scarborough Formation to the overlying Thorncliffe Formation. Unit 3 sediments (from 39.5 to 43 m depth), contain variable amounts of sand content and organic matter culminating with a six centimeter thick peat horizon defining the top of the Scarborough Formation. Chemically this contact is poorly defined. For some elements such as Mn the unit 3 sediments are more consistent in chemical signature to the overlying Thorncliffe Formation than with underlying Scarborough sediments. However for some elements, such as K, Rb, and Sr that are associated with a granitic provenance there is little to no change in chemical signature between the Scarborough Formation and the overlying Thorncliffe Formation.

Unit 4 (from 27.5 to 39.5 m depth), represents the lowermost sediments of the Thorncliffe formation and consists of approximately 14 meters of interbedded silt and clay to very course sand. Unit 4 sediments, for many elements (Cu, Fe, Mn, Ti, Zn and Zr) are geochemically less variable than the underlying unit 3 sediments. A sample occurring at -39.07 meters in depth contains high values in some elements (e.g. Cu, Fe, Mn, Ti, V, Zr) that is similar to the variability to the underlying unit 3 sediment but occurs stratigraphically above the peat horizon used to define the formational contacts. Unit 5 (from 17.7 to 27.5 m depth) display a decrease in Ca and Sr as well as an associated increase in Fe, K, Rb and Ti, that is attributed to a change in sediment provenance from carbonate-rich to granitic rich Precambrian Shield sediment. For the top 4 meters Ca concentrations increase markedly as the source of shield detritus is replaced by increased carbonate content. For the 28-22 meter interval a shield derived mud suspension event may have interrupted a high Ca and carbonate environment. Unit 6 (from 11.2 to17.7 m depth) is difficult to delineate from the underlying unit 5 sediments. For Ba, Cu, Fe, K, Rb, Sr, Ti, and Zn the contact occurs at a depth of 17.7 meters and corresponds to a change from silt to mud. However Ca displays no change in concentration until a depth of 16.5 meters where there is an influx of sand. Unit 6 displays significantly lower amounts of Fe, K, Rb, Ti, V and Zn than both overlying and underlying units. The top of Unit 6 also corresponds to the contact between the Thorncliffe Formation and the overlying Newmarket Till.

Unit 7 (from 5.2 to11.2 m depth) displays an abrupt decrease in Ca concentrations as well as an associated increase in Ba, Fe, K, Rb, Ti, V and Zn and suggests that the <0.063 mm size fraction of the Newmarket Till has a different provenance than the underlying unit 6 (Thorncliffe Formation) sediments, or that the matrix of the Newmarket Till is not related to the matrix of the Thorncliffe Formation. The differences in geochemical signature between units 6 and 7 indicate that the Newmarket Till had a different sediment source (Shield dominant) from the underlying carbonate dominant Thorncliffe Formation. A thin clay horizon at a depth of 5.2 m within the Newmarket Till marks the contact between Units 7 and 8.Unit 8 (from 2.5 to 5.2 m depth) is characterized by an increase in Ca concentration, which corresponds to a decrease in Ba, Fe, K, Rb, Ti, V, and Zn concentration. This change is most likely associated with a continued change in sediment provenance from shield terrain to a more carbonate-rich source.

References

Armstrong, D.K. and Dodge, J. E. P., 2007, Paleozoic Geology of Southerm Ontario Project Summary and Technical document, Ontario Geological Survey, Miscellaneaous Release- Data 129, 27 p.

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.

Boyce, J.I., and Eyles, N., 2000. Architectural element analysis applied to glacial deposits: internal geometry of a late Pleistocene till sheet, Ontario, Canada. Geol. Soc. Am. Bull. 112, 98–118

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

Kelly, R. and Martini, P., 1986. Pleistocene glaciao-lacustrine deltaic deposits of the Scarborough Formation, Onatrio, Canada; Sedimentary Geology, 47: 27-52.

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

Logan, C; Russell, H A J; Sharpe, D R; Kenny, F M; The Role of GIS and Expert Knowledge in 3-D Modelling, Oak Ridges Moraine, Southern Ontario in, GIS for the Earth Sciences; Harris, J R (ed.); Geological Association of Canada, Special Paper 44, 2006; p. 519-541, doi:10.4095/214575

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., 2011. Integrated data sets from a buried valley borehole, Champlain Sea basin, Kinburn, Ontario; Geological Survey of Canada, Current Research no. 2012-3, 20 pages, 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; Arnott, R.W.C., 2003. Hydraulic-jump and hyperconcentrated- flow deposits of a glacigenic subaqueous fan: Oak Ridges Moraine, southern Ontario, Canada; J. Sediment. Res. 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.

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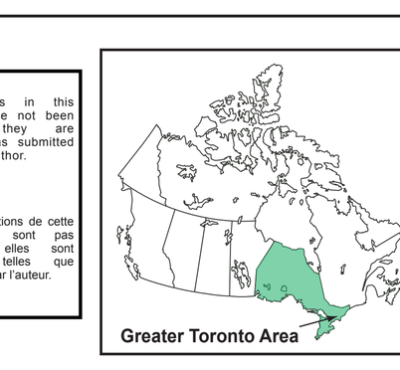

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