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**GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8298**

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**R.D. Knight, D.A.J. Stepner,
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2018

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1.0 Introduction

Over the past 20 years, the Geological Survey of Canada (GSC) and the Ontario Geological Survey (OGS) have carried out extensive investigations into the glacial sediment stratigraphy of southern Ontario. Much of this work is summarized in the Canadian Journal of Earth Sciences, Special Issue: Quaternary geology of southern Ontario and applications to hydrogeology (Russell et al., 2018). These studies utilized basin analysis techniques to further understand sediments within this region, however there is a general lack of information on the regional geochemistry of sediments. Geochemical studies are crucial for defining chemical and mineralogical variations within sediments and supplement sediment description, grain size data, downhole geophysics, stratigraphic correlations (Pullan et al., 2002; Crow et al., 2015a; 2015b) and provide a geochemical baseline for interpreting host sediment (rock) composition and ambient groundwater chemistry (e.g. Hamilton, 2015). Geochemical data collected from cores (Fig. 1) provide the opportunity to establish a chemo-stratigraphic framework that complements other stratigraphic correlation tools, such as litho-stratigraphy, event stratigraphy, and biostratigraphy.

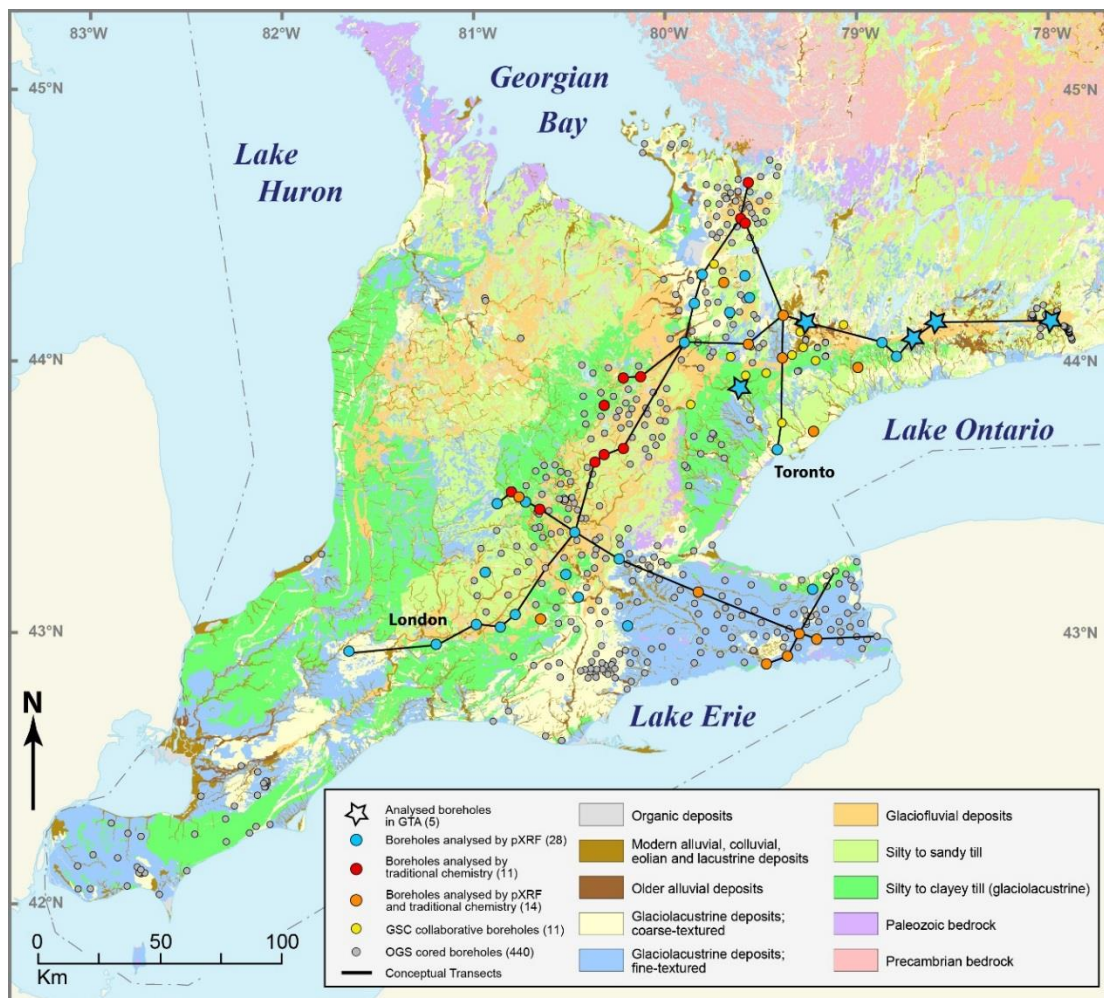


Figure 1. Surficial geology of southern Ontario showing the locations of the Greater Toronto Area boreholes reported in this open file in relation to other cored borehole sites. Conceptual transects for this study shown as solid lines. Surficial geology modified from OGS MRD128-Rev, (2010).

For groundwater studies, the collection of sediment geochemistry data is often beyond the scope and budget, of many programs. Portable X-ray fluorescent (pXRF) spectrometry has proven to be a successful and cost effective tool for characterizing the chemostratigraphy of glacially derived sediments (e.g. Crow et al., 2012; Knight et al., 2015a, 2015b). In addition, it has improved the interpretation of downhole geophysics, micro-paleontologic results, and pore water geochemistry (Medioli et al., 2012). Data collected using this method is now a routine part of borehole studies within the Groundwater Geoscience Program at the GSC (Knight et al., 2012, 2015a, 2015b).

The objective of this Open File is to publish geochemical data for 867 samples retrieved from five boreholes drilled in the Greater Toronto Area, and associated QA-QC collected data. These boreholes include, Kleinburg, Mount Albert, Grasshopper, Pontypool, and Rice Lake (Fig. 1 and 2). The report documents the contribution of these data to an emerging subsurface chemostratigraphic database for Southern Ontario.

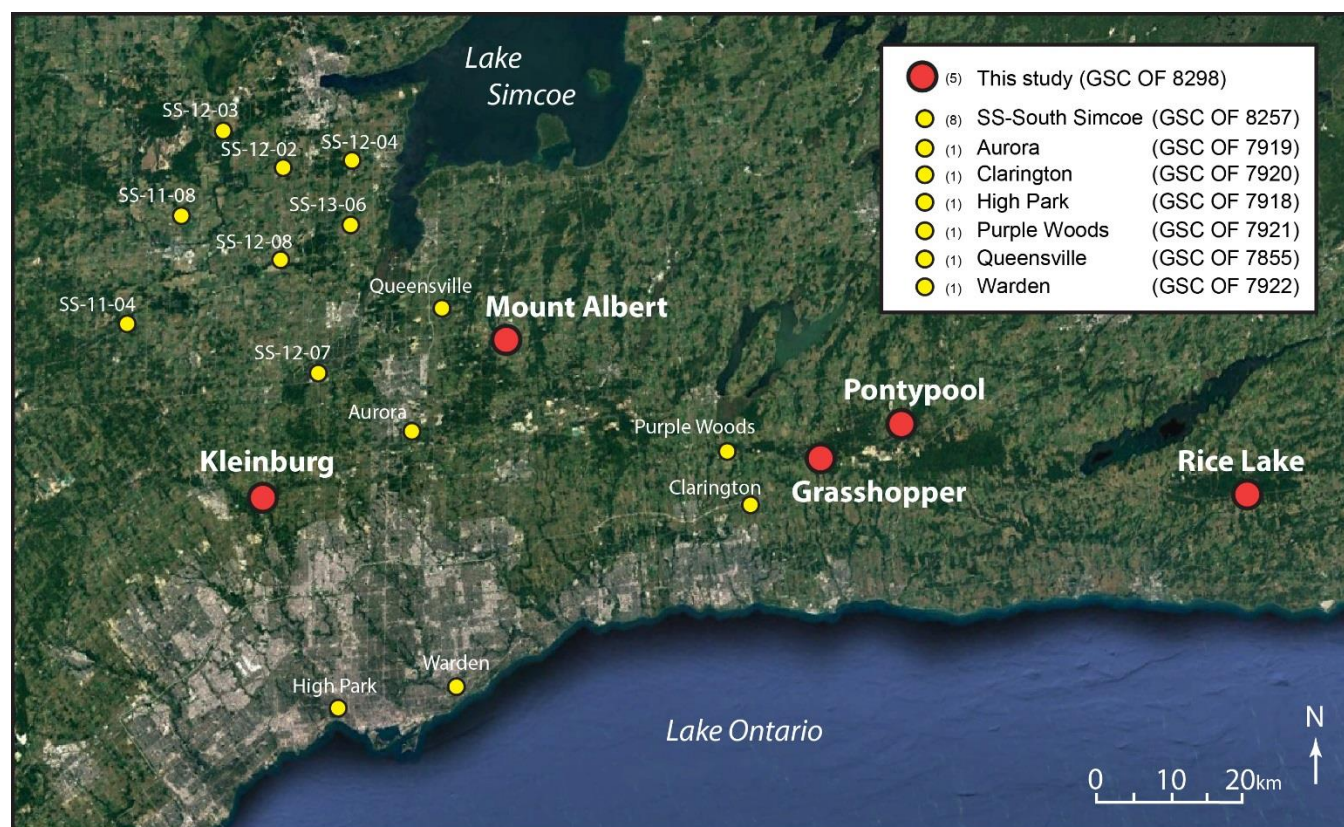


Figure 2: Location of chemostratigraphic boreholes within the Greater Toronto Area and South Simcoe (SS). Boreholes labelled with red dots represent this open file. Yellow dots represent the location of previously published chemo-statigraphic boreholes as listed in the legend. Image from Goggle Earth, 2017.

2.0 Study Area Geological Setting

Borehole location and elevation are listed in Table 1 and illustrated in Figure 2. Discussion of the Quaternary stratigraphy overlying bedrock has been simplified by Sharpe et al., (2002, 2004) to four major units and two regional erosional surfaces (unconformities).

Table 1 – Borehole location and elevation.

Borehole ID	Depth (m)	Number of Samples	Easting	Northing	Elevation (m.asl)
GSC-BH-GHP-01	139.8	185	679505	4879974	291.9
GSC-BH-PON-01	171.1	150	689068	4886446	348.3
GSC-BH-KLN-01	104.9	162	608497	4859678	250.7
GSC-BH-MTA-01	98.9	92	635892	4886251	274.6
GSC-BH-RLK-01	181.6	170	735964	4887130	299.4

Bedrock: Most of the GTA is underlain by sub-cropping bedrock that is part of the Blue Mountain and Georgian Bay formations (Armstrong and Dodge, 2007). The Blue Mountain Formation consists of dark blue-grey, brown to black shale with thin interbeds of limestone or calcareous siltstone. The Georgian Bay Formation gradationally overlies the Blue Mountain Formation and consists of interbedded grey-green to dark grey shale and fossiliferous calcareous siltstone to limestone. The bedrock surface is a regional unconformity with numerous valleys. The general location of valleys on this surface are identifiable on the regional bedrock surface DEM (Gao et al., 2006). In the GTA the most notable is the Laurentian Trough extending from Georgian Bay to Lake Ontario (Fig. 2; Sharpe et al., 2018).

Lower sediment: Lower sediment is a group of ten formations of Illinoian to mid-Wisconsinan age (~30-50 Ka) that overlies bedrock and is stratigraphically below the Newmarket Till. It forms ~70% of total sediment volume in the area and is up to 150 m thick (Sharpe et al., 2005). Lower sediment has been extensively described from the Scarborough Bluffs (Karrow, 1967), in seismic profiles (Pugin et al., 1999) and in borehole cores and geophysical logs (Eyles et al., 1985; Sharpe et al., 2013). Regionally, the two most significant units are the Scarborough and Thorncliffe formations and equivalents (e.g. Brookfield et al., 1982).

Newmarket Till: Newmarket Till is a regionally extensive, dense, stony, silty sand drumlinized diamict. At the Purple Woods Conservation Area, north of Pickering, 68 m of Newmarket Till has been measured in a borehole (Knight et al., 2016), however regionally Sharpe et al., (2018) identify the till to be <50 m thick. The Newmarket Till forms the surface unit north and predominantly south of the ORM and has been traced beneath the moraine (e.g., Sharpe et al., 2002). The basal contact is commonly planar and generally undeformed. It contains locally significant (up to 5 m thick) sandy inter-beds, rare horizons of thin rhythmites or isolated clay laminae and stone horizons (Boyce and Eyles, 2000; Sharpe and Russell, 2016). Newmarket Till is characterized by high seismic velocities in downhole seismic logs (2000-3000 m/s) (Boyce et al., 1995; Pugin et al., 1999). It contains a number of secondary minerals that form interstitial cement (Kjarsgaard et al., 2016). The unit was most likely deposited by a variety of subglacial processes including lodgement, meltout or debris flow processes (Boyce and Eyles, 2000; Sharpe et al., 2005). Locally interbedded diamict is the result of debris flows. Newmarket Till forms a regional aquitard separating near-surface aquifers from deeper, lower aquifers.

Truncating the Newmarket Till surface is a regional unconformity with several orders of relief. North of the Oak Ridges Moraine (ORM) undulating 40 m relief consists of drumlins on inter-channel uplands (e.g. Kenny et al., 1999; Boyce and Eyles, 2000). The larger topographic relief is defined by partially filled, south-southwest-oriented channel network that occurs north of the ORM (Russell et al., 2003). The channels at surface are 1-5 km wide and ~10-50 m deep. The surface expression of the channels disappears beneath the ORM (Sharpe et al., 2002). In the subsurface, their geometry is 1-2 km wide and 10-150 m deep (Pugin et al., 1999). This erosional surface is considered to have been formed by subglacial sheet flows, producing drumlins (Shaw and Sharpe, 1987), followed by waning-stage, entrenched flow, producing channels (Brennand and Shaw, 1994; Russell et al., 2003) or, alternatively, subglacial deformation processes (Boyce and Eyles, 2000).

Oak Ridges Moraine (ORM) sediments: The ORM is a 160 km long and 5-20 km wide stratified sediment complex formed of four fan-shaped sediment wedges each widening westward (e.g., Barnett et al., 1998). The ORM is up to ~150 m thick where it fills tunnel channels and occurs extensively beneath Halton sediments (Russell et al., 2004). Core logging indicates that moraine sediments consist of 2-3 fining-upward sequences (Gilbert, 1997; Barnett, et al., 1998; Russell et al., 2004). The lower contact of the ORM occurs on a channelized, regional unconformity truncating Newmarket Till, lower sediment and locally intercepting bedrock. The lowest, coarse sediment fills of tunnel valleys have NE-SW paleoflows, and consist of cross-bedded gravels (Shaw and Gorrell, 1991; Pugin et al., 1999; Sharpe et al., 2003). Filled channels mainly contain sandy sediments (Russell et al., 2003) and are capped by 10-20 m thick mud intervals (Russell et al., 2003). The channel network is attributed to subglacial floods (e.g. Shaw and Gilbert, 1990; Barnett, et al., 1998) and the sediment fill to waning flow (e.g. Shaw and Gorrell, 1991). Within the ridge element, rhythmically interbedded fine sands and silts are dominant, but coarse, diffusely-bedded sands and heterogeneous gravels are prominent locally (e.g., Russell and Arnott, 2003).

The deposits are interpreted as glaciofluvial, transitional to glaciolacustrine subaqueous fan, and minor delta sediments, deposited in a glacial lake ponded between the ice and the >400-m asl high Niagara Escarpment to the west (Barnett et al., 1998). The ORM forms the major shallow aquifer and recharge-discharge complex in the region.

Halton sediment: Halton sediments include several local units (Kettleby and Wildfield tills) that overlie ORM deposits (Fig. 3). It is most extensive west of Toronto to the Niagara Escarpment. This unit is commonly < 15 m thick but locally is up to 30 m thick (Sharpe and Russell, 2016). It consists of massive clay-silt diamicton, locally laminated and inter-bedded diamicton, silt-clay, and sand and gravel (Sharpe and Russell, 2016). Halton sediment drapes hummocky, kettle terrain along southern ORM flanks, thickens in local basins and thins across bedrock platforms. The sediment facies, thickness variability, and geometry, support an ice-contact glaciolacustrine environment (Sharpe and Russell, 2016).

3.0 Sample Collection, Processing and Analytical Methods

The boreholes were drilled by partners of the Oak Ridges Moraine Groundwater Program (ORMGP), and transported to the GSC where they were logged, sampled and stored between 2001 and 2006. The borehole depths and number of samples per borehole are provided in Table 1. A total number of 867 samples were collected for analysis. To eliminate nugget effects of sand size and gravel grains common in unconsolidated or crushed bedrock detritus, samples are sieved to <0.064 mm (silt and clay) size fraction.

The analysis on this normalized size fraction provides fundamental information used to define chemical and mineralogical variations within the stratigraphy.

The sieved samples were placed in 23 mm diameter plastic vials to an approximate thickness of 30 mm. This thickness has been found to meet the requirement of the pXRF manufacture for an infinitely thick sample (Knight et al., 2017c). The vials are sealed with 4 μ m thick Chemplex Prolene Thin-Film. Portable XRF data were acquired using a handheld Thermo Scientific, Niton XL3t GOLDD spectrometer equipped with Cygnet 50 kV, 2-watt Ag anode X-ray tube and a XL3 silicon drift detector (SDD) with 180,000 counts per second (cps) throughput, mounted to a test stand (Fig. 3). A 60 second dwell time per filter (Main, Low, High) was used in soil mode, in order to follow suite with previous borehole studies (Knight et al., 2015a, Knight et al., 2012, Plourde et al., 2012), for a total of 180 seconds. In mining mode 45 second dwell times were used per filter, to allow for a similar total of 180 seconds of analysis. The two modes of analysis use different calibration methods; Soil Mode uses Compton Normalization which is recommended for elements expected to occur with < 1% concentration while Mining Mode uses Fundamental Parameters which is recommended for elements expected to exceed >1% concentration. A summary list of elements detected and their X-ray intensities are presented in Table 2. Twenty elements (Al, As, Ba, Ca, Cr, Cu, Fe, K, Mn, Ni, Pb, Rb, S, Si, Sr, Th, Ti, V, Zn, and Zr) had sufficient quantities to produce results in soil mode and mining mode, however in mining mode As, Cu, Ni and V did not produce meaningful results.

Table 2: Elements and corresponding X-ray energy intensities used to determine concentrations in Mining Mode (m) and Soil Mode (s), as provided by Thermo Scientific.

Element	Line	Energy (keV)	Window Low (keV)	Window High (keV)	Filter
Al	--	--	--	--	Light
As	K α_1	10.54	10.33	10.73	Main
Ba	K α_1	32.19	31.70	32.70	High
Ca	K α_1	3.69	3.50	3.89	Low
Cr	K α_1	5.41	5.24	5.59	Low
Cu	K α_1	8.05	7.84	8.24	Main
Fe	K α_1	6.40	6.20	6.60	Main
K	K α_1	3.31	3.10	3.49	Low
Mn	K α_1	5.90	5.70	6.10	Main
Ni	K α_1	7.48	7.35	7.67	Main
Pb	L β_1	12.61	12.40	12.80	Main
Rb	K α_1	13.39	13.18	13.60	Main
S	K α_1	2.31	2.20	2.45	Low
Si	--	--	--	--	Light
Sr	K α_1	14.16	13.95	14.38	Main
Th	L α_1	12.97	12.80	13.15	Main
Ti	K α_1	4.51	4.21	4.70	Low
V	K α_1	4.95	4.75 (m) 4.80 (s)	5.15 (m) 5.10 (s)	Low
Zn	K α_1	8.64	8.49	8.83	Main
Zr	K α_1	15.77	15.53	15.98	Main

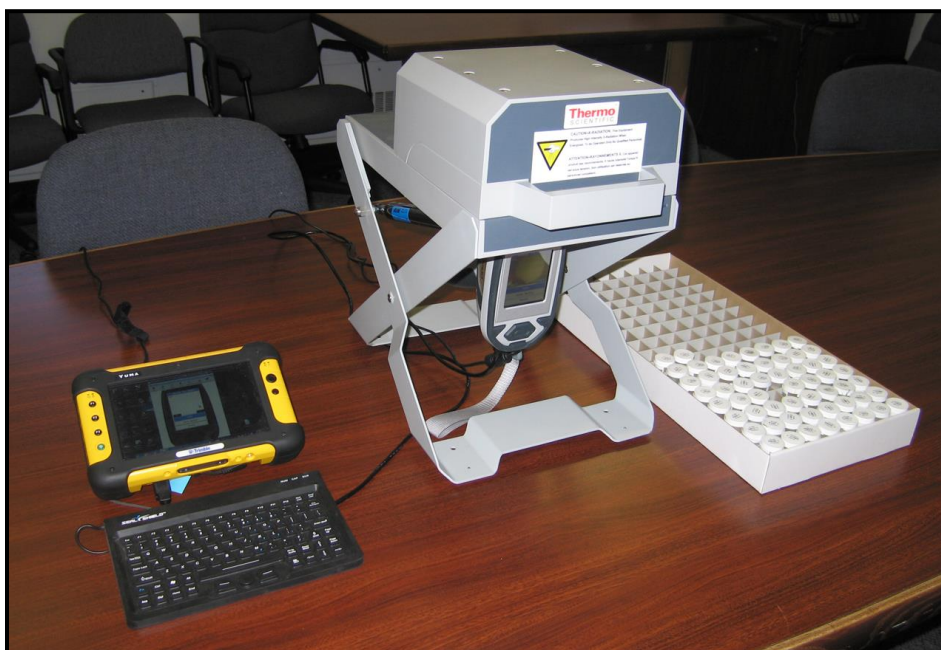


Figure 3: Example of pXRF spectrometer mounted in a test stand with microcomputer for analysis of processed sediment samples.

3.1 Reproducibility and Precision of Standards

Three standards (Till-1, Till-4, and TCA 8010) and 2 blanks (SiO_2 and Teflon) were analyzed at the beginning and at the end of each analytical session as well as repeatedly throughout. The SiO_2 and Teflon blanks were monitored to ensure the cleanliness of the pXRF window and sample stand environment; after approximately 10 analyses the operating environment (test stand) was cleaned with compressed air and Kimwipes. Commonly the Teflon blank returns values in the 10's of ppm Ti and may return trace amounts of Mo. The SiO_2 blank when analysed in soil mode, returned values for Cd, Hg, K, Pd, Sr, and V below the recommended limits of detection ($<\text{LOD}$, see pXRF Data in Appendix A). When analyzed in mining mode the SiO_2 blank also resulted in Al values below LOD. These elements are not listed as known impurities on the Chemplex® Prolene® thin-film, which may contain trace amounts of Ca, P, Fe, Zn, Cu, Zr, Ti and Al, and most likely represent internal detector noise. On occasion, the SiO_2 blank returned values for Ca and Fe above the limits of detection and may be associated with the impurities in Chemplex® Prolene® thin-film or represent contamination of the thin film. We recommend that the Chemplex® - Prolene® thin-film be replaced on a regular bases to avoid perpetual contamination. A study into the precision, accuracy, instrument drift, dwell time optimization and calibration of pXRF spectrometry for reference materials including Till-1, Till-4, and TCA 8010 is available from Knight et al., (2013).

For each element detected in a given standard, the count, minimum value, maximum value, mean, standard deviation, relative standard deviation (%RSD), error and recommended values as determined by traditional wet chemistry methods are listed for both soil and mining mode for Till-1, Till-4 and TCA 8010 below each dataset collected from ORM boreholes in Appendix A. The percent error row contains the difference between the mean and recommended value. Low absolute values in this column indicate that the element is measured accurately; high absolute values indicate that a calibration curve is required to correct the data or that the data are not reliable. It is important to note that precision and accuracy are affected by concentration. Lower concentrations, especially those near the limit of detection (LOD) tend to result in lower precision and thus higher %RSD.

3.2 Limit of Detection

Thermo Scientific provides a list of the sensitivity or limits of detection of individual elements for the pXRF (Thermo Scientific, personal communication). The pXRF provides an error as 2 standard deviations for each element analysed. Some elements return results that are lower than the LOD. When this occurred, the point was plotted on the chemostratigraphy graph using a value equal to half the LOD and an arrow and title (LOD) was placed on the X-axis depicting the recommended LOD value.

3.3 Data Delivery

For each of the five boreholes all results are provided in Appendix A and subfolders. A Microsoft Excel® file contains two worksheets with data for five analyzed boreholes and for data quality control standard reference materials. The first worksheet is for data collected in mining mode, the second worksheet is for data collected in soil mode. There are also individual files for mining and soil mode as .csv files of the same data. The chemostratigraphic profiles have single element trends from the base to the top of the borehole. On these graphs solid horizontal lines indicate formational boundaries as defined by lithostratigraphy, while dashed horizontal lines correspond to changes in geochemical trends not associated with defined lithostratigraphic boundaries. Although care must be taken when interpreting data with a high error it may be useful to plot these elements to see if their relative changes in chemostratigraphy correlate with those of other more reliable elements.

4.0 Results and Surficial chemostratigraphy

The following borehole discussion relates to analyses carried out in Mining mode. Although the pXRF data are obtained from the <0.063 mm size fraction, there is an apparent relationship between geochemistry and grain size, particularly clay content, associated mineralogy, and depositional processes. For example, an increase in clay content results in an increase in the elemental concentration of Al. The following borehole discussion relates to analyses carried out in Mining mode.

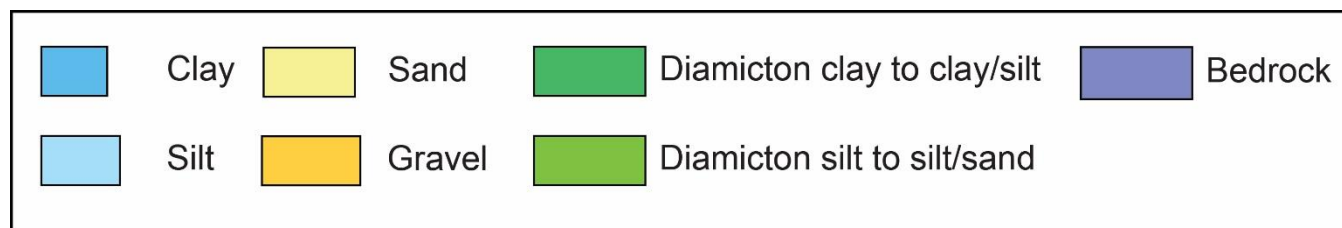


Figure 4: Generalized sedimentology for borehole stratigraphic Figures 5-9.

4.1 Kleinburg

Stratigraphy of the ~104 m deep Kleinburg borehole (Figure 5) is summarized in Sharpe et al., (Table 4, 2018) and supersedes the interpretation of the unconformity location presented in Sharpe et al., (Figure 18, 2013). Geochemical analyses were carried out on 163 samples. The lowermost geochemical analyses comprises bedrock. Bedrock samples were crushed to mud fraction for geochemical analysis. The diamicton unit immediately above bedrock incorporates an abundant amount of bedrock clasts. The initial 10 m over bedrock consists of diamicton with minor sand and silt horizons that have an increasing upwards trend in the concentration of Ba, Ca, and Sr and a decreasing trend in Al, Fe, K, Rb, Ti and Zn. A two meter thick diamicton fining upwards to sand and silt overlies these sediments. Three samples analysed from these sediments do not have similar trends as the underlying sediments. Overlying this unit at 93 m depth is a 20 m thick gravel and coarse sand with poor core recovery and no samples. From a depth of 84 – 72 m gravel to sand and silt fine upward. Many elements, such as Al, Ca, Fe, K, Fe, Rb, S, Sr, and Zn, have consistent concentration throughout this interval. For the upper 3 m K, Rb, and Sr have either higher or lower values than the underlying and overlying sediments. A diamicton occurs from a depth of 72 – 68 m and is distinguished by a decreasing upwards concentration of Al, Ba, Rb, and Zr and a corresponding upwards increasing of Ca, Sr, and Zn.

At 68 m depth a 32 m thick sequence of interbedded sand silt and clay has variable concentrations for some elements, such as Ca, S, Zn, and Zr that most likely relate to corresponding variability in grain size. Other elements, such as Al, Fe, K, Pb, Rb, and Sr have consistent values throughout this interval. At 36 m depth a 3m thick diamicton. Most other elements have no change in concentration across the till boundary. Slight difference in concentrations of elements within alternating till and silt horizons are depicted on the graphs in Appendix A by dashed lines (for example see Ca). Overlying the diamicton is a muddy diamicton to the surface with minor mud units. There is little to no change in elemental concentrations from the underlying diamicton. From the top meter of core two samples have considerable decrease or increase in concentration for As, Ca, Mn, Pb, Si, Sr and Zn

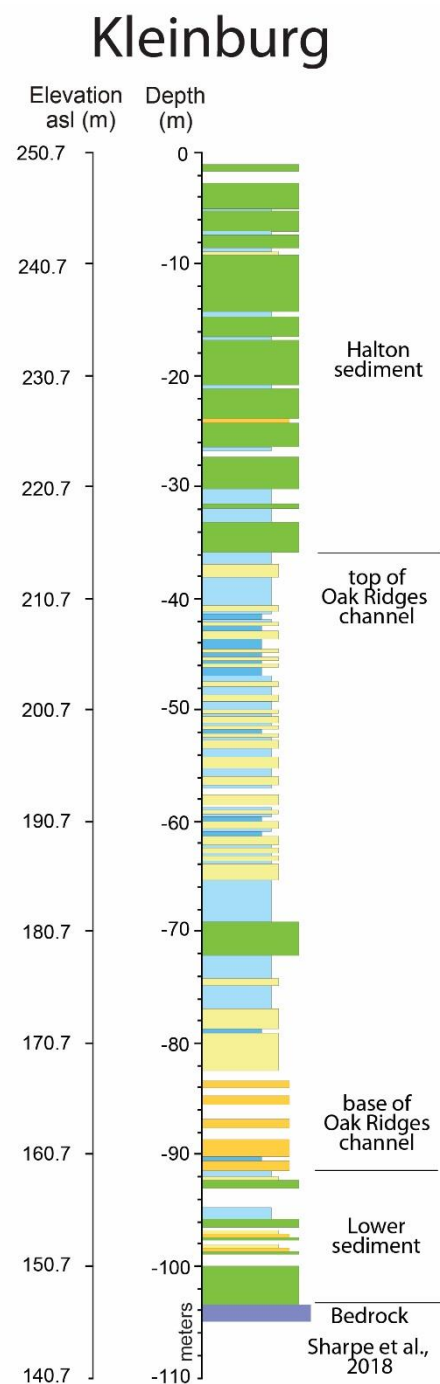


Figure 5. Generalized sedimentology and stratigraphy for the Kleinburg borehole.

4.2 Mount Albert

Generalized sedimentology and stratigraphy of the ~98 m deep Mount Albert borehole is shown in Figure 6. The base of the borehole intersects limestone bedrock. Geochemical analyses were carried out on 92 samples. Thin Newmarket Till was intercepted at the surface of a drumlinized upland and below 7 – 8 m depth the remainder of the stratigraphy to bedrock is assigned to Lower Sediment. Overall there is very little variation in the geochemical signature of the sedimentary sequence. The lowermost 2 samples have significantly different concentrations for As, Fe, K, Mn, Pb, Rb, and S. The overlying sandy to silty diamicton has higher values for Al, Fe, K, Rb, and Si compared to the overlying 35 plus metres of sand. The geochemical signature of the sand is consistent for all elements except Al and Si that have lower concentrations above 62 m depth. The sand has slightly elevated Ca and Sr and lower Fe and K. The sand is overlain by a ~45 m succession of silt, sand, and gravel with similar elemental concentrations as the underlying sediments (except Al and Si). At a depth of 5 m a thin, ~1 m, diamicton is assigned to be Newmarket Till. It is overlain by sand and silt to the surface. For most elements (e.g., Ca, Fe, K, Sr, Zr) the concentrations do not change across these two intervals.

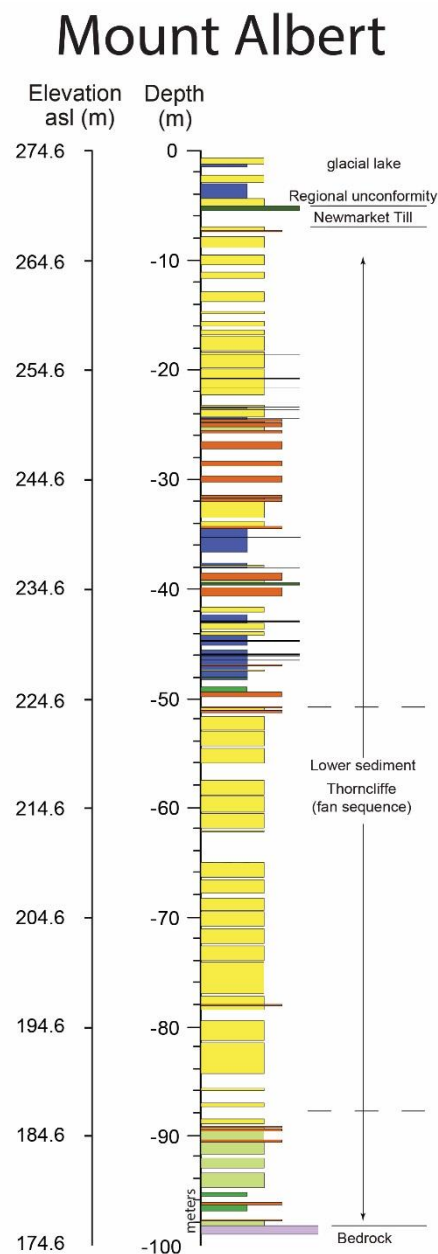


Figure 6. Generalized sedimentology and stratigraphy for the Mount Albert borehole.

4.3 Grasshopper

Generalized sedimentology and stratigraphy of the ~140 m deep Grasshopper borehole is shown in Figure 7 is linked to a seismic profile (Sharpe et al., 2003). The base of the borehole intersects limestone bedrock. Geochemical analyses were carried out on 185 samples. From bedrock upward to 95 m depth sediments are assigned to the Thorncliffe Fm. The lowermost ~14 m comprise a silt unit that fines upwards to clay. These sediments have consistent concentrations for Al, Ca, K, Rb, Si, Zn, and Zr. Overlying the silt unit is a 3 m thick sand with minor silt and no clay that has depleted concentration of K, Rb, and an increase in Zr; however, for many elements (Al, Ca, Fe, Mn, Pb, S, Si, Sr, Zn) there is no discernable change in concentration between the sand and the underlying clay. The sand unit is overlain by ~14 m of rhythmically bedded silt and clay and 3 m of sand that has a definitive change in elemental concentration from the underlying sand and silts in total carbon, Ca, Fe, and Si. This unit also has an upwards decrease in Al, Fe, K, Rb and Zn that may be related to the upward decrease in clay content over the same interval. These sediments are overlain by 3 m of clay rich/sand poor diamicton that compared to the underlying and overlying sediments have elevated concentrations of Al, Ba, Fe, K, Rb, Si, and Zn with decreased concentrations of Ca and Sr. From a depth of ~101-81 m sediments are assigned to Newmarket Till and consist of silt, sand, gravel, and diamicton horizons that have similar element concentrations to the lowermost fining upwards silt unit. From a depth of 81 m to the surface Oak Ridges Moraine sediment consist of a succession of discrete lithological units. The lowermost 3 m consists of a sand to silt succession that has elevated concentrations Al, Fe, K, Rb, and Zn. This is overlain by a fining upwards sequence from diamicton, to sand, and minor silt that show similar elemental concentrations as the underlying Newmarket Till. Overlying these sediments, from 55 m depth upward for 33 m thickness is a gravel interval with no sample analyses due to poor core recovery. The upper 22 m of core consists of sand with minor silt, gravel, and one thin diamicton horizon. Elemental concentrations are variable with low concentrations of Ca and high Si occurring at a depth of 22 and 26 m corresponding to low sand and high silt content at the same depths. Within the top meter of the borehole 4 samples have significant increases in Al, Fe, K, Mn, Pb and Si with decreases in Ca.

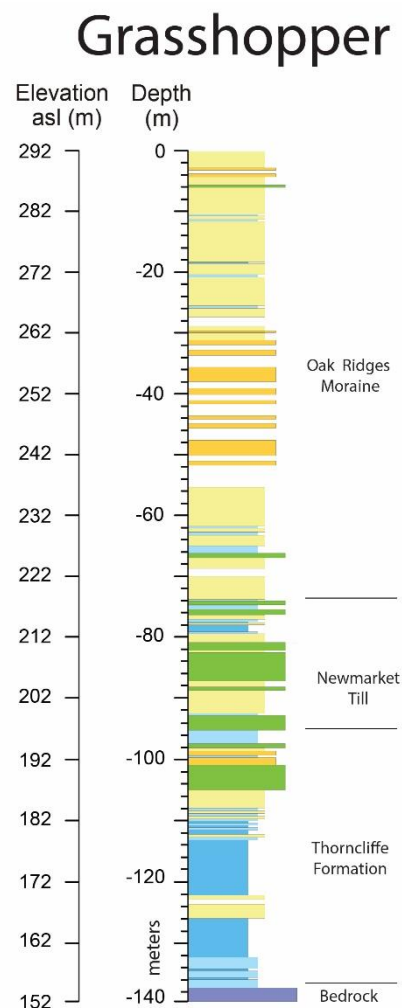


Figure 7. Generalized sedimentology and stratigraphy for the Grasshopper borehole.

4.4 Pontypool

Sedimentology and stratigraphy of the ~171 m deep Pontypool borehole is presented in Figure 8. Geochemical analyses were carried out on 150 samples. The base of the borehole intersects limestone bedrock. Lower sediments of silt, sand and diamicton below 96 m depth are overlain by predominantly sand with minor gravel and silt of the Oak Ridges Moraine. The basal 3 samples collected at the contact between bedrock and the overlying diamicton has a distinct elemental signal differentiating it from the overlying sediment. Upward to 142 m are a succession of mud and sand units that are in turn overlain by diamicton. A single upward coarsening mud succession to 150 m depth has an upward decrease in Ba, Rb, and Zn and an upward increase in S. Other elements such as Ca, Fe, Mn, Sr, and Zr have no variability in concentration. Overlying the silt sequence is a 6 m thick sand horizon that has increased values of Ba, Th, Ti, and Zr. This sand is in turn overlain by 2 m of silt that for some elements such as Al and Ca returns similar concentrations as the underlying sand; however, for K, Fe, and Zr the concentrations are similar to the overlying diamicton. From a depth 142 m a series of diamicton interbedded with silt and sand have a 46 m thickness and form the upper succession of Lower Sediment. The variability of grain size and sediment type results in variable concentrations for most elements. The lower and upper diamicton can be separated from the middle silt and sand units by the variability in Al, Ca, Fe K, and Zr.

From a depth of 96 m to the surface sand, minor gravel, silt and diamicton are assigned to the Oak Ridges Moraine. Compared to the underlying sediments the clay content is low. Concentrations for K, Rb, and Sr have little variability throughout this sequence however Ba, Fe, Th, Ti, and Zr have significant variability between samples. The uppermost 2 samples vary considerably from the underlying sediments for all elements except Ba and Th that already have a high degree of variability.

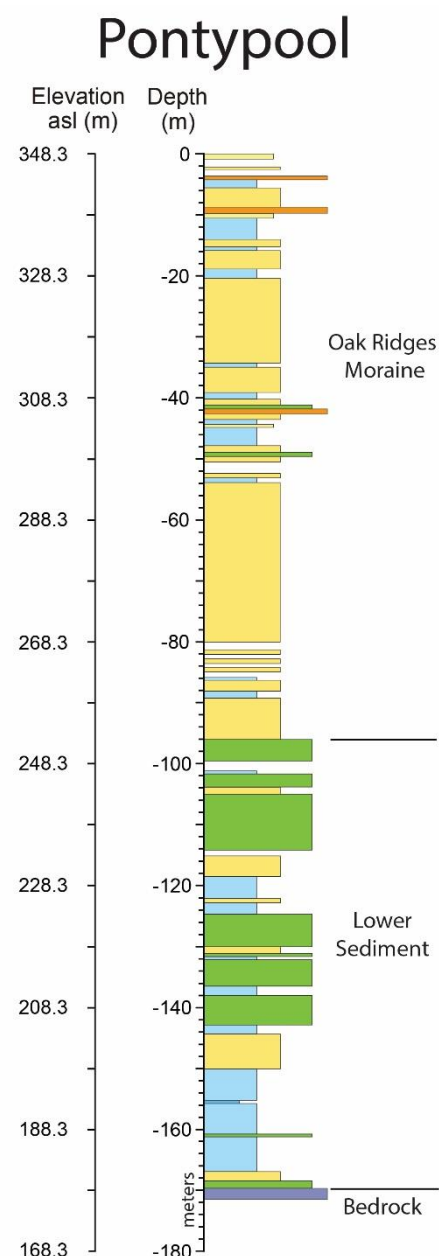


Figure 8. Generalized sedimentology and stratigraphy for the Pontypool borehole.

4.5 Rice Lake

Generalized sedimentology and stratigraphy of the ~182 m deep Rice Lake borehole is shown in Figure 9. The base of the borehole intersects limestone bedrock. Geochemical analyses were carried out on 170 samples from three stratigraphic units, Lower Sediment, Newmarket Till and Oak Ridges Moraine. Several distinct chemostratigraphic packages are visible in the borehole and defined by changes in both grain size and elemental chemistry. From the bedrock contact upward to 172 m depth a sequence of silt to diamicton and sand has higher sand content and lower concentration of Al, Fe, K, Rb, Si, Ti, Y, and Zn compared to the overlying silt sequence. From 172 m depth a 20 m thick mud unit has a steady increase in clay content upward. This is reflected in a decrease in the Al, Fe, K, Rb, Si, Ti, Y, and Zr and an increase in Ca, S, and Sr. A thin diamicton/silt horizon at a depth of 152-149 m have chemical concentrations that are similar to the underlying sediments (e.g. Al, Fe) and to the overlying sediments (e.g. Ca, Si). The overlying diamicton occurs from a depth of 149 – 115 m and has a distinct chemical signature with elevated concentrations of Al, Fe, K, Rb, Zn and lower concentrations of Sr. The diamicton is overlain by ~8 m thick sequence of sand with minor silt that have the first variation in Zr concentrations. This unit also has elevated concentrations of S, Ti, and Y. Other elements such as Al have no unit specific variation. From a depth of 108 – 28 m there is an overall coarsening upwards sequence of clay interbedded with silt to silt interbedded with sand and sand interbedded with gravel. This succession can be separated into 3 units based on changes in concentrations of several elements (e.g. K, Rb, S, Zr); however, not all elements have a change with each unit. For example the upper 2 units for Rb are similar where as there is a significant change in the elemental concentration of S for these 2 units. Above this stratigraphic sequence from 28 m is ~10 m of interbedded silt, sand, and diamicton assigned to be Newmarket Till. For some elements such as Al and Ca the diamicton diverge in elemental concentrations from the mud and sand. Many elements such as, Fe and Zn have no change in concentration. From 18 m depth to the surface sand and minor gravel are assigned to the Oak Ridges Moraine. These sediments have lower concentrations of Ba and K and higher concentrations of Ca and Zr than the underlying sediments.

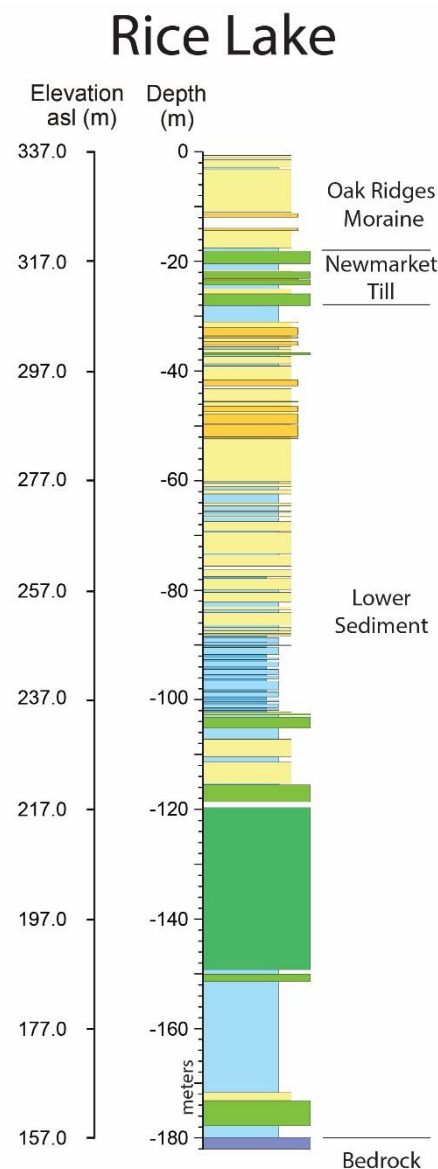


Figure 9. Generalized sedimentology and stratigraphy for the Rice Lake borehole.

5.0 Summary

This geochemical study expands the range of sediments that has been analyzed as part of an effort to characterize surficial sediment aquifers and aquitards across Canada and more specifically in southern Ontario. The boreholes contain till units assigned to Lower sediments, Thorncliffe Formation, Newmarket Till, Oak Ridges Moraine and the Halton Formation. For many elements (see Al, Ca, Si), variations in concentrations most likely reflect subtle changes in provenance. The descriptions presented in this open file are brief, and are provided as general contextual information to support the data release. Greater detail on shifts in elemental concentrations and geochemical relationships can be deciphered from a detailed examination of the numerical data present in Appendix A.

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