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[1]Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario
[2]Oak Ridges Moraine Groundwater Program, 101 Exchange Ave., Toronto, Ontario

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1.0 Introduction

The Groundwater Geoscience Program of the Geological Survey of Canada (GSC) has concentrated efforts on constructing and compiling a 3-D map of the subsurface beneath southern Ontario. Part of the program focused on establishing a regional-scale geochemical framework of unconsolidated glacial derived sediments that overlie bedrock in this region. Prior to this project, there was a general lack of information on the regional geochemistry of these sediments. Geochemical studies are crucial for advancing knowledge of chemical and mineralogical variations within sediments and supplement sediment description, grain size data, downhole geophysical and stratigraphic correlations (e.g. Crow et al., 2015). They also provide a geochemical baseline for assessing the interaction between host sediments and ambient groundwater chemistry. Geochemical data collected from cores provide the opportunity to establish a chemo-stratigraphic framework that complements other stratigraphic correlation tools, such as litho-stratigraphy, event stratigraphy, and biostratigraphy.

The GSC, in collaboration with the Ontario Geological Survey (OGS) and a number of other organizations, has spearheaded the application of portable X-ray fluorescence (pXRF) spectrometry as an alternative to expensive traditional laboratory based geochemical methods. Analyses by pXRF have produced data that approaches the quality of laboratory data for some elements for a fraction of the cost of traditional techniques. Portable XRF has proven to be a successful tool to characterize the chemo-stratigraphy of glacially derived sediments (e.g. Crow et al., 2012; Knight et al., 2015a, 2015b). The objective of this Open File is to release sediment lithology type, drilling notes, core photographs, geochemical data, borehole logs and associated QA-QC data for 111 closely-spaced sediment samples retrieved from three adjacent boreholes located north of Pickering, Ontario (Figs. 1 and 2). The graphic representation of geochemical data is displayed next to magnetic susceptibility, conductivity, and natural gamma geophysical graphs. Data associated with these geophysical graphs are not presented in this Open File. This report documents the contribution of these reference data to an emerging subsurface chemostratigraphic database for southern Ontario (Table 1).

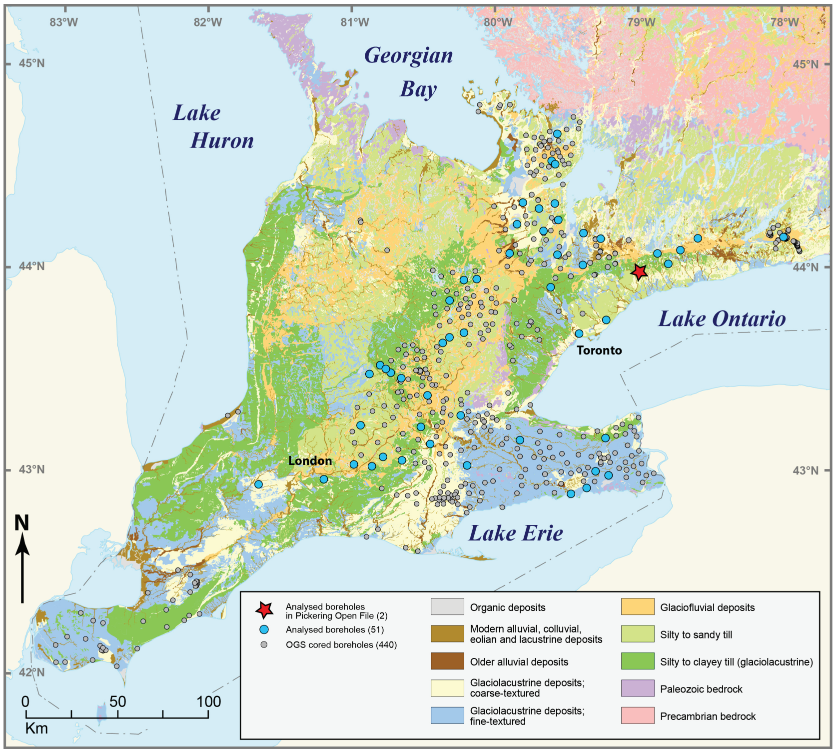


Figure 1. Location of Pickering boreholes (red star) with 51 other boreholes (blue dots) analysed as part of the Groundwater Initiative. Surficial geology of southern Ontario modified from Barnett et al., (1991).

Figure 2: Location of the Pickering boreholes in relation to neighboring boreholes of the Groundwater Initiative. The red dot represents the location of the Pickering boreholes, white dots represent the location of previously published chemo-statigraphic boreholes as listed in the legend. Image from Google Earth, 2017.

Table 1. Summary of southern Ontario boreholes with geochemical analysis completed as part of a regional geochemical framework. Geochemical data from boreholes by pXRF methods are referenced in the right hand column. The following short form names under Source agency refer to GSC- Geological Survey of Canada, OGS – Ontario Geological Survey, CAMC- Conservation Authorities Moraine Coalition, UTRCA – Upper Thames River Conservation Authority, CLOCA – Central Lake Ontario Conservation Authority, U of Guelph – University of Guelph, U of Ottawa – University of Ottawa.

Borehole Name	Borehole ID	Easting	Northing	Depth (m)	Source Agency	Number of samples	pXRF	Laboratory Chemistry	Reference
Aurora	GSC-BH-AUR-01	626120	4871860	141	GSC	120	120	32	Knight et al., 2015a
Brantford-Woodstock	BW-07-05	504440	4784065	67.2	OGS	44	44		Knight et al., 2018c
	BW-07-06	516750	4766800	79.7	OGS	53	53		
	BW-07-07	527089	4764908	61.6	OGS	42	42	42	
	BW-07-09	510649	4761686	55.1	OGS	40	40		
	BW-07-15	542576	4773875	38.4	OGS	35	35		
	BW-07-17	537484	4783222	61.2	OGS	43	43		
	BW-07-20	559256	4789517	65.8	OGS	34	34		
	BW-08-06	500814	4762673	36.2	OGS	29	29		
Clarington	GSC-BH-CLA	672905	4872453	127	U of Guelph	96	96		Knight et al., 2016e
Dundas Valley	DV-05	541105	4800483	103.1	OGS	60	60		Stepner et al. 2018
	DV-06	518276	4814982	78.2	OGS	94	94	94	
	DV-08	520975	4812880	75.7	OGS	81	80		
Gads Hill	GH-10-01	509313	4812153	56.9	OGS	40	40		Knight et al., 2018b
GTA - Grasshopper	GSC-BH-GHP-01	679505	4879974	139.8	CAMC / GSC	185	185		Knight et al., 2018a
GTA - Kleinburg	GSC-BH-KLN-01	608497	4859678	104.9	CAMC / GSC	162	162		
GTA – Mount Albert	GSC-BH-MTA-01	635892	4886251	98.9	CAMC / GSC	92	92		
GTA - Pontypool	GSC-BH-PON-01	689068	4886446	171.1	CAMC / GSC	150	150		
GTA - Rice Lake	GSC-BH-RLK-01	735964	4887130	181.6	CAMC / GSC	170	170		
High Park	GSC-BH-HPK-01	624104	4834313	43.8	CAMC / GSC	58	58		Knight et al., 2016c
Strathroy	GSC-BH-SRY	448621	4751759	68.7	UTRCA / GSC	118	118		
London, Westminster	GSC-BH-WMR	484324	4754562	70.5	UTRCA / GSC	108	108		

Niagara Peninsula	BH13-NP-2014	628215	4749786	45.7	OGS	47		47	
	BH14-NP-2014	640187	4756676	42.1	OGS	38		38	
	BH27-NP-2014	633076	4758904	51.1	OGS	52		52	
	BH32-NP-2014	619599	4746591	46.4	OGS	41		41	
	BH33-NP-2014	638538	4777117	53.1	OGS	48	48		
	BH59-NP-2015	591658	4776011	42.2	OGS	39	39	22	
	BH77-NP-2015	562792	4762132	33.25	OGS	27	27		
Orangeville	BH09-OF-2008	553171	4852413	52.8	OGS	46		46	
	BH20-OF-2009	561002	4863630	22.5	OGS	25		25	
	BH23-OF-2009	568074	4864148	74.4	OGS	66		66	
	BH25-OF-2009	553103	4832245	31.7	OGS	29		29	
	BH27-OF-2009	561045	4834791	46.7	OGS	38		38	
	BH43-OF-2010	549394	4829200	36.7	OGS	43		43	
Oro	BH-30-AKB-2006	612147	4943667	54.9	OGS	66		66	
	BH-32-AKB-2006	609032	4928931	70.5	OGS	61		61	
	BH-37-AKB-2006	610966	4927024	102.1	OGS	94		94	
Pickering	GSC-BH-PIK1	657068	4867918	71.6	GSC/CAMC/ U of Ottawa	97	97	97	
	GSC-BH-PIK2	657061	4867916	11.4	GSC/CAMC/ U of Ottawa	14	14	14	
Purple Woods	GSC-BH-PWD	666973	4878158	151.8	CLOCA / GSC	135	135		Knight et al., 2016a
Queensville	GSC-BH-QUE	626499	4889266	96.2	CAMC / GSC	87	87	32	Knight et al., 2016b
South Simcoe	SS-12-02	602163	4902748	161.2	OGS	98	98	98	Knight et al., 2018d
	SS-11-04	586055	4878237	124.4	OGS	86	86		
	SS-11-08	590082	4894188	145.6	OGS	91	91		
	SS-12-03	593299	4906003	91.1	OGS	48	48		
	SS-12-04	610758	4905514	153.9	OGS	85	85		
	SS-12-07	612194	4877514	95.2	OGS	60	60	60	
	SS-12-08	604560	4890531	68.7	OGS	40	40		
	SS-13-06	612674	4896493	174.4	OGS	138	138		
Warden	2010-WAR	638868	4840084	80.5	CAMC / GSC	119	119	37	Knight et al., 2016d
Waterloo	OGS-03-04	526733	4809858	292	OGS	57		57	
	OGS-03-05	515170	4816991	244	OGS	46		46	

2.0 Study Area Geological Setting

The Quaternary stratigraphy overlying bedrock has been simplified by Sharpe et al., (2002, 2004) to four major units and two regional erosional surfaces (unconformities).

Lower sediment:
Lower sediment is a group of ten formations of Illinoian to mid-Wisconsinan age (~30-50 Ka) that overlies bedrock and stratigraphically sits below the Newmarket Till. Lower sediment can be >100 m thick and covers a large area (Sharpe et al., 2005b; 2018). It 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, Thorncliffe Formation is the most significant formation (Sharpe et al., 2018; Mulligan et al., 2018), whereas to the west at Scarborough Bluffs, the most significant units are the Scarborough and Thorncliffe formations and equivalents (Karrow, 1967). Scarborough Formation sediment has not been observed along the Bowmanville bluffs, although ~20-30 m of Thorncliffe formation sediment is present (Brookfield et al., 1982; Martini and Brookfield, 1995; Brennand et al., 1995), to the east of the study area.

Newmarket Till:
The Newmarket Till is a regionally extensive, dense, stony, silty sand drumlinized diamicton. In a borehole at the Purple Woods Conservation Area, north of Pickering, 68 m of Newmarket Till has been measured (Knight et al., 2016), however, Sharpe et al., (2005a; 2018) identified the till to be typically <50 m thick. The Newmarket Till forms the surface unit to the north of and is also mapped as the surficial unit to the south of the Oak Ridges Moraine (ORM) (Sharpe and Barnett, 1997) and has been traced beneath the moraine (Sharpe et al., 2002; 2005a). The Newmarket Till basal contact is commonly planar, is locally deformed, but it can be disconformable where thick Thorncliffe sediments are not present (Sharpe et al., 2018). It contains locally significant (up to 9 m thick) sandy inter-beds, rare horizons of thin rhythmites or isolated clay laminae, and stone horizons (Boyce and Eyles, 2000). Newmarket Till is characterized by high seismic velocities in downhole seismic logs (2000-3000 m/s) (Brennand et al., 1995; Boyce et al., 1995; Pugin et al., 1999). The unit was most likely deposited by a variety of subglacial processes including lodgement, meltout or debris flows (Boyce and Eyles, 2000; Sharpe et al., 2005b). Locally interbedded diamicton is interpreted as a result of debris flows. Newmarket Till forms a regional aquitard separating near-surface aquifers (e.g. ORM) from deeper, lower aquifers (Gerber and Howard, 2000).

Truncating the Newmarket Till surface is a regional unconformity with up to ~100 m of relief (Sharpe et al., 2002). North of the ORM, 40 m of undulating relief is due to drumlins on inter-channel uplands (e.g. Kenny et al., 1999). The increased topographic relief is defined by partially filled, south-southwest-oriented channel networks that occur north of the ORM (Russell et al., 2003). The channels at surface north of the ORM are ~1-5 km wide and ~10-50 m deep. The surface expression of the channels disappears beneath the ORM (Barnett et al., 1998). In the subsurface, their geometry is ~1-5 km wide and 10-150 m deep (Pugin et al., 1999). This erosional surface is considered to have formed by subglacial sheet flows, (Shaw and Sharpe, 1987), followed by a waning-stage and entrenched flow which produced subglacial channels with rapidly-deposited gravel and sand (Brennand and Shaw, 1994; Russell et al., 2003). Alternatively, subglacial deformation processes (Mulligan et al., 2018) formed these large valleys.

Halton Till:
Halton sediments are most extensive west of the Humber valley to the Niagara Escarpment (Fig. 1), and only cover small areas east of the Humber valley (Sharpe and Barnett, 1997), including a thin strip south of ORM, and north of the Pickering borehole. Locally, Halton sediments overlies Newmarket Till. Along the south flank of the ORM, Halton sediments overlie ORM sediments creating confined conditions. These sediments thicken in local basins and thin across bedrock platforms. 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, and locally laminated and inter-bedded diamicton, silt-clay, and sand and gravel (Sharpe and Russell, 2016). The sediment facies, thickness variability, and geometry, are interpreted to support an ice-contact glaciolacustrine environment (Sharpe and Russell, 2016).

3.0 Sample Collection, Processing and Analytical Methods

Three boreholes with a diameter of 122.6 mm were drilled in October, 2017 under the supervision of Toronto and Region Conservation Authority (TRCA) staff (Don Ford, Kristina Anderson) and Rick Gerber of the Oak Ridges Moraine Groundwater Program (formerly known as CAMC/YPDT) using a truck mounted CME-75 drill rig and PQ (85 mm diameter) coring equipment owned and operated by Aardvark Drilling Inc. A wireline system was used to retrieve 1.524 (5 foot) long core barrels. Light mud was used to keep the borehole open when permeable horizons were intersected.

Sediment cores were sampled onsite by University of Ottawa researchers (Tom Al, Ramina Rashtchi) for chemical/isotopic analyses (see Appendix A - GSC-BH-PIK-1 University of Ottawa notes). Resulting sediment gaps in the core where filled with Styrofoam “pool noodles”.

The borehole was named CAMC/YPDT-Sideline4-2017 by the Conservation Authorities Moraine Coalition (CAMC) and York, Peel, Durham, Toronto (YPDT) municipalities. To be consistent with previous boreholes compiled within a GSC database the boreholes name was altered to GSC-BH-PIK-1, -2, -3, to represent the 3 boreholes. Borehole GSC-BH-PIK-1 was drilled to 73.152 m (240 feet) however no field notes were recorded from 4.572-12.192 m (15-40 feet). Borehole GSC-BH-PIK-2 was drilled to ~11.9 m (39 feet).

Sediment obtained from drilling was placed in PVC tube and sealed with heavy duty food wrap. Tube ends were sealed with PVC caps. End caps and PVC core barrels were further sealed with duct tape. Sealed core tubes were placed and secured on palettes. Sediments obtained from 2 boreholes were transported by truck from the Pickering drill site to the Ottawa GSC storage facility in November, 2017 where they were opened and visually logged and photographed. Sediment from a third borehole (GSC-BH-PIK-3) was not sent to the GSC although drillers notes were obtained and a graphic borehole log was produced. Borehole data are shown in Table 2.

The boreholes intersected two of the four units mentioned above, including Lower sediment and Newmarket Till.

Table 2 – Borehole location and elevation for the 3 boreholes drilled at site CAMC/YPDT-Sideline4-2017

Borehole ID	Date Drilled	Depth (m)	Number of Samples	Piezometer Groundwater Level (m)	Piezometer Screen (m)	Easting	Northing	Collar Elevation (m.asl)
GSC-BH-PIK-1	Oct. 23-24, 2017	71.6	97	12.350	67.073 - 70.122	657 068	4 867 918	188
GSC-BH-PIK-2	Oct. 26-30, 2017	11.9	14	0.671	9.909 - 11.433	657 061	4 867 916	187
GSC-BH-PIK-3	Oct. 30 2017	50.3	0	10.398	49.231 - 50.305	657 065	4 867 917	187

On September 26, 2018 natural gamma, apparent bulk conductivity and magnetic susceptibility logs were acquired by the GSC using downhole geophysical tools. A detailed description of the logging tools and methodology employed can be found in Crow et al. (2015). The geophysical logs provide a means of identifying and characterizing lithological units based on variations in their *in situ* chemical and physical properties.

During sediment core logging at the GSC in Ottawa, a total of 97 samples were collected from borehole GSC-BH-PIK-1 at approximately 50 cm intervals, with additional detailed sampling below and above recognizable contacts. This sampling pattern was replicated in GSC-BH-PIK-2 where a total of 14 samples were acquired. The 111 samples were crushed and sieved to a <0.063 mm size fraction, which served to eliminate nugget effects that can occur with pXRF analysis of sediments that include sand and gravel sized particles (Plourde et al. 2013).

The processed samples were placed in 23 mm diameter plastic vials, which were filled to an approximate height of 30 mm. This thickness meets the requirements of the pXRF manufacturer for an infinitely thick sample (Knight et al., 2015c). The vials were sealed with 4 µm thick Chemplex Prolene® Thin-Film. Elemental concentration data was collected 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). In Soil Mode, a 60 second dwell time per filter (Main, Low, High) was used for a total of 180 seconds, following the protocols developed in previous borehole studies (Knight et al., 2012, Knight et al., 2015a, Plourde et al., 2012). In Mining Mode, a 45 second dwell time was used per filter (Main, Low, High, and Light) for a total of 180 seconds of analysis. Soil Mode uses Compton normalization that is recommended by the manufacturer for elements expected to occur with < 1% concentration (trace elements). Mining Mode uses Fundamental Parameters which is recommended for elements expected to exceed 1% concentration (major elements). Table 3 presents a summary list of elements detected and their X-ray intensities.

Following pXRF analysis, the same samples were sent to Bureau Veritas Commodities Ltd. (formerly ACME), in Vancouver for traditional laboratory geochemical analyses. Two mineral laboratory analytical procedures were employed: (1) multi acid, a hot dissolution in HNO_3-$HClO_4$-HF, dried to a residue and then dissolved in HCl, followed by ICP-MS analysis; and (2) a lithium metaborate/tetraborate fusion followed by dilute nitric acid digestion of the fused disc, and analysis by Inductively Coupled Plasma Emission Spectroscopy ICP-ES (major elements) and ICP-MS (trace elements).

Figure 3: Example of XRF spectrometer mounted in a test stand with microcomputer for analysis of processed sediment samples. Photograph by R.D. Knight. NRCan photo 2020-926.

Table 3: A selection of key elements and corresponding X-ray energy intensities used to determine elemental concentrations, as provided by Thermo Scientific – Niton (2010).

Element	Line	Energy (keV)	Window Low (keV)	Window High (keV)	Filter
As	$K\alpha_1$	10.54	10.33	10.73	Main
Ba	$K\alpha_1$	32.19	31.70	32.70	High
Ca	$K\alpha_1$	3.69	3.50	3.89	Low
Cr	$K\alpha_1$	5.41	5.24	5.59	Low
Cu	$K\alpha_1$	8.05	7.84	8.24	Main
Fe	$K\alpha_1$	6.40	6.20	6.60	Main
K	$K\alpha_1$	3.31	3.10	3.49	Low
Mn	$K\alpha_1$	5.90	5.70	6.10	Main
Ni	$K\alpha_1$	7.48	7.35	7.67	Main
Pb	$L\beta_1$	12.61	12.40	12.80	Main
Rb	$K\alpha_1$	13.39	13.18	13.60	Main
S	$K\alpha_1$	2.31	2.20	2.45	Low
Sr	$K\alpha_1$	14.16	13.95	14.38	Main
Th	$L\alpha_1$	12.97	12.80	13.15	Main
Ti	$K\alpha_1$	4.51	4.21	4.70	Low
V	$K\alpha_1$	4.95	4.80	5.10	Low
Zn	$K\alpha_1$	8.64	8.49	8.83	Main
Zr	$K\alpha_1$	15.77	15.53	15.98	Main

3.1 Reproducibility and Precision of Standards

A single set of three standards (Till-1, Till-4, and TCA 8010) and 2 blanks (SiO_2 and Teflon) were analyzed approximately every 20 samples, and at the beginning and end of each analytical session. The SiO_2 and Teflon blanks were monitored to ensure the cleanliness of the pXRF window and sample stand environment. 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 analyzed in Soil Mode commonly returned values for Cd, Hg, K, Pd, Sr, and V below the recommended limits of detection (< LOD). When analyzed in Mining Mode the SiO_2 blank also resulted in Al values below the recommended limits of detection. 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. This may be associated with the impurities in Chemplex® Prolene®thin-film or represent contamination of the thin film. It is recommended that the Chemplex® Prolene®thin-film be replaced every few months of use 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 provided by Knight et al., (2013).

Appendix A contains tables for Soil Mode and Mining Mode analyses of Till-1, Till-4, and TCA 8010. These tables list the number of samples analyzed (count), minimum value, maximum value, mean, standard deviation, relative standard deviation (%RSD), error, and recommended values as determined by traditional laboratory chemistry methods. 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.

3.2 Limit of Detection

Thermo Scientific provides a list of the sensitivity or limits of detection for the pXRF (Thermo Scientific, personal communication) that are presented with the geochemical data in Appendix A. During analyses, the pXRF provides an error of each individual measurement taken throughout the 180 second analysis. For this study, the error was recorded as 2 standard deviations. 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

Data delivery is provided through a series of nested folders and files as detailed in the of_8511_read_me file. Appendix A consists of GSC-BH-PIK-1, PIK-2 and PIK-3, with similar files folder and file structure. For GSC-BH-PIK-1 there are four subfolders:

1) GSC-BH-PIK-1 Core photographs,
2) GSC-BH-PIK-1 Drilling notes, (including percentage of core recovery),
3) GSC-BH-PIK-1 Geochemistry, grain size, TOC,
4) GSC-BH-PIK-1 University of Ottawa notes.

The core photographs folder contains .jpg images of the core as logged by the GSC after drilling site sample collection for diffusion studies by the University of Ottawa (Tom Al, Ramina Rashtchi). Each photo contains a run number that is identified on stratigraphic logs presented in Appendix B. The drilling notes folder contains a .pdf file of notes taken on-site by the Toronto Region Conservation Authority when the core was removed from the borehole. The geochemistry, grain size, TOC folder contains five Microsoft Excel® workbooks, a Microsoft Word® file describing the column headings for the pXRF data, and a subfolder containing individual Microsoft Excel® worksheets in .csv format. Subsets of this data are presented graphically in Appendix B. The traditional laboratory chemistry Microsoft Excel® workbook contains geochemical results for the same samples analysed by pXRF. Lithium fusion total whole rock characterization method is represented by LF200 data and multi-acid ultra trace is represented by MA250 data.

For the pXRF data in both Mining Mode and Soil Mode each Microsoft Excel® workbook contains six worksheets produced in the order below:

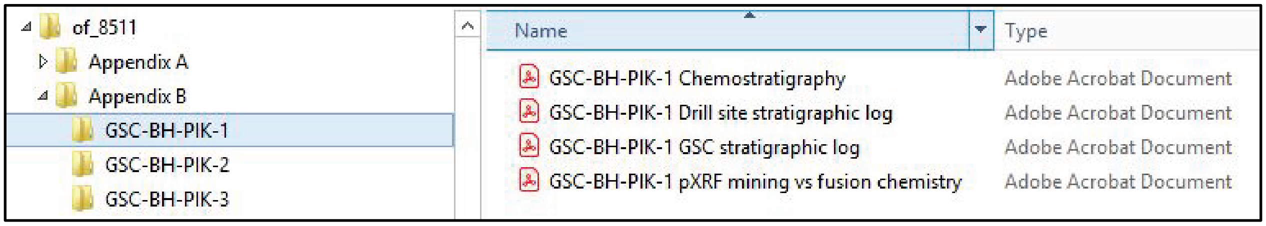
1) Mining/Soil Mode – Calibrated, consists of data that has been adjusted using the values collected for the CRM/SRM plotted with the recommended value to obtain a calibration equation used to enhance data accuracy.

2) Mining/Soil Mode – Not calibrated, consists of the raw data that has been cleaned and sorted in alphabetical order of elements detected. Error values associated with < LOD analyses have been deleted, and significant digits have been addressed.

3) Raw data comprises data obtained by pXRF spectrometry in the order that samples were analyzed including blank samples, reference materials, and system checks.

4) Till 1 - Summary, Till 4- Summary, and TCA 8010 – Summary. Each of these three worksheets contains summary statistics associated with the collection of the CRM/SRM data and recommended values used to produce the calibration equations applied to the non-calibrated data.

Appendix B contains graphical representations of on site drilling notes and the numerical data presented in Appendix A. The Appendix contains a .pdf file depicting a composite stratigraphic log, predominantly based on GSC-BH-PIK-1 plus 3 subfolders (GSC-BH-PIK-1, GSC-BH-PIK-2, GSC-BH-PIK-3). The contents of Appendix B, subfolder GSC-BH-PIK-1 are shown in Figure 4.



- of_8511
  - Appendix A
  - Appendix B
    - GSC-BH-PIK-1
    - GSC-BH-PIK-2
    - GSC-BH-PIK-3

Name	Type
GSC-BH-PIK-1 Chemostratigraphy	Adobe Acrobat Document
GSC-BH-PIK-1 Drill site stratigraphic log	Adobe Acrobat Document
GSC-BH-PIK-1 GSC stratigraphic log	Adobe Acrobat Document
GSC-BH-PIK-1 pXRF mining vs fusion chemistry	Adobe Acrobat Document

Figure 4: Partial folder and file structure for of_8511 highlighting the hierarchy for Appendix B for GSC-BH-PIK-1.

Graphical representations of the on-site drilling notes for GSC-BH-PIK-1 and GSC-BH-PIK-3 are presented as "Drill site stratigraphic log". It should be noted that there may be incomplete recovery for some runs and that the stratigraphic log is illustrated to shorter lengths when specified by the notes. There are no on-site drilling notes for GSC-BH-PIK-2.

The GSC compiled stratigraphic logs display all information collected during core logging, including sediment contact type, core recovery, sediment description, run numbers, associated run photo numbers, sample numbers, and locations in the core for samples collected for chemistry in black and sample type and location in core for samples collected by the University of Ottawa in crimson red. In run 24 of the composite log at a depth of 35.25-35.63 m there is a zone of no recovery that occurs in all three boreholes. The GSC stratigraphic logs were compiled using the measured amount of core (in cm) recovered in each 1.524 m (5 foot) run including sediment beyond the 1.524 m (5 foot) length that often occurred up to 10 cm run which accounts for "tip recovery". Core associated with some runs may have expanded since recovery resulting in greater lengths of core for some runs compared to what is recorded in the on-site drilling log.

Due to missing core and discrepancies between run lengths from the on-site drilling notes and the GSC logging notes as well as fixed contacts determined from downhole geophysical data, a composite stratigraphic log was compiled. The top and bottom of the borehole are pinned using data acquired from the drilling notes and the geophysical logs. Depths for several stratigraphic horizons mainly the bottom of the Newmarket Till and distinct clay, silt and sand units below the Newmarket Till, were also pinned to the geophysical logs. These contacts are highlighted with a red line on the left side of the graphical representation of the composite core. The composite stratigraphic core, presented as an individual .pdf file in Appendix B, places the stratigraphy within these constraints. This composite core is generalized and presented as the stratigraphic log for the chemostratigraphy, grain size, and TOC log for GSC-BH-PIK-1 (see Appendix B / GSC-BH-PIK-1 Chemostratigraphy.pdf).

For GSC-BH-PIK-1 and GSC-BH-PIK-2 a chemostratigraphic file (Chemostratigraphy.pdf), represents a graphical display of the pXRF derived geochemical data and corresponding sand, silt, clay content and total carbon (TOC) content. For GSC-BH-PIK-1 graphical representation of downhole geophysical data for magnetic susceptibility, conductivity, and natural gamma are depicted for comparison.

For GSC-BH-PIK-1 following pXRF analysis, samples were re-analyzed using traditional laboratory methods. Results for comparing pXRF mining mode data to fusion chemistry are shown graphically as scattergrams in "GSC-BH-PIK-1 pXRF mining vs fusion chemistry".

For geochemical data presented in Appendix B the chemostratigraphic profiles display single element trends from the base to the top of the borehole. 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.

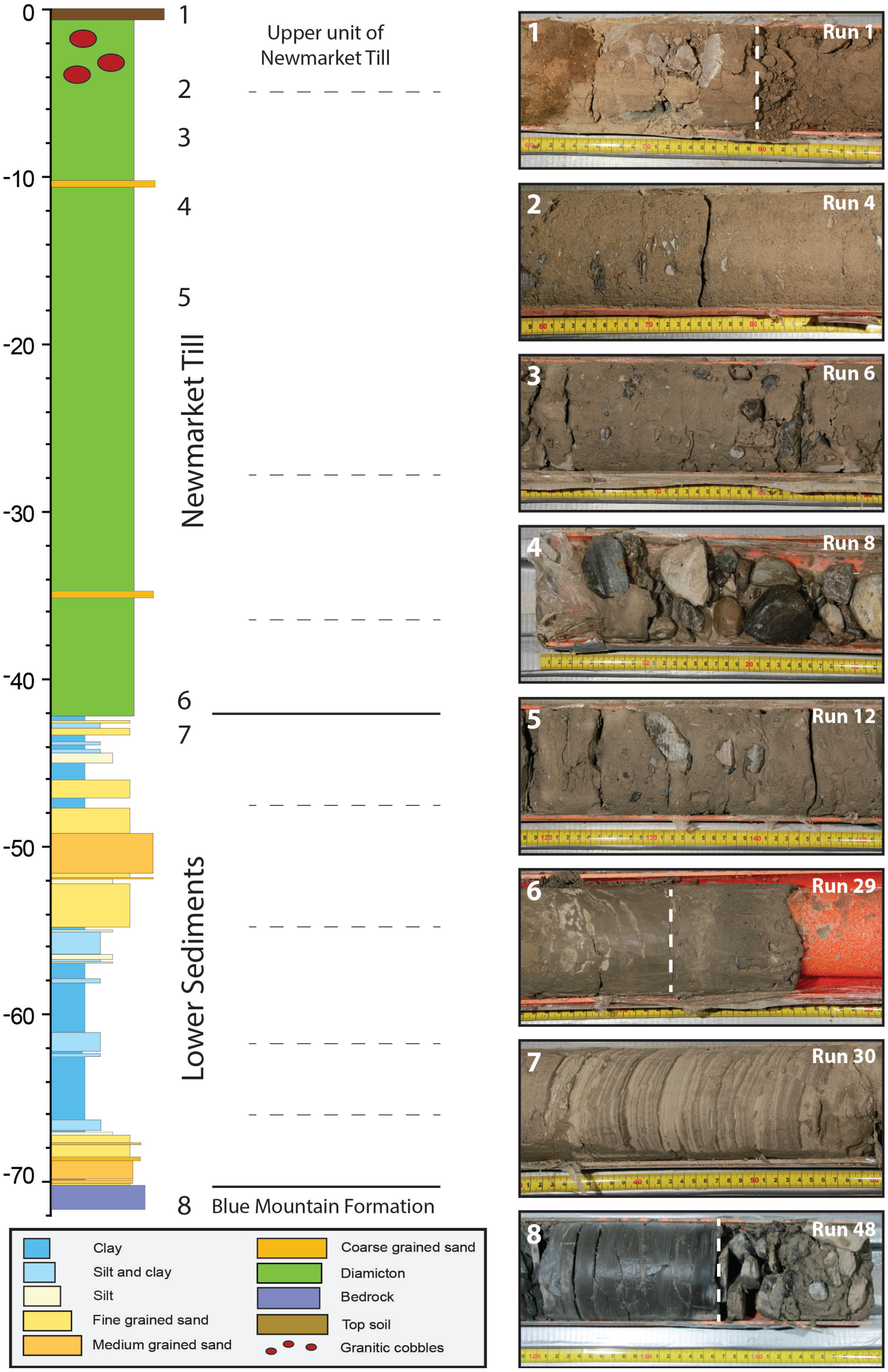


Figure 5. Generalized composite stratigraphic log with representative photos obtained from borehole GSC-BH-PIK-1. Photographs by R.D. Knight. 1- NRCan Photo 2020-927; 2- NRCan Photo 2020-928; 3- NRCan Photo 2020-929; 4- NRCan Photo 2020-930; 5- NRCan Photo 2020-931; 6- NRCan Photo 2020-932; 7- NRCan Photo 2020-933; 8- NRCan Photo 2020-934.

4.0 Pickering Borehole Lithology

4.1 Bedrock

The base of the Pickering borehole (GSC-BH-PIK-1) sampled approximately 1.4 m of Blue Mountain Formation rocks, described by Armstrong and Dodge (2007); a uniform sequence of dark grey to black shale with numerous thin interbeds of a lighter limestone or calcareous siltstone.

4.2 Lower Sediment

The Lower sediment is separated from the underlying bedrock by an erosional surface marked by a ~10 cm thick rubble/broken/fragmented siltstone horizon in GSC-BH-PIK-1 as displayed in Figure 5, photo 8. Lower sediment is approximately 27.7 m thick and is composed of 2 sand sequences separated by massive clay and silt units. The lowest sand unit is in direct contact with the rubble/broken/fragmented siltstone horizon overlying bedrock. This sand unit is a fining upwards sequence from coarse- to fine-sand over approximately 2.6 m. The upper ~ 14 cm of this sand shows weak planar bedding with thin beds of a darker grey (organic rich?) sediment. The two sand units are separated by ~12.6 m of interbedded silts and clays, often showing strong evidence of both semi-solid/soft deformation and numerous occurrences of micro faulting. The presence of a small number of pebbles, both granitic and carbonate, occurs consistently through the top third of this clay/silt succession. Evidence of an organic-rich clay, with possible roots or root spicules, was observed roughly 14 m from the base of the core. It could not be determined if this material was in situ or rafted into this location during sediment deposition.

The second recognizable sand sequence is ~8.0 m thick, which is a coarsening upwards sequence that ends with a thin coarse sand with pebble horizon that is overlain by a fining upwards sequence to the top of this sand unit. Discrete bedding planes are more identifiable below the gravel horizon and exhibit considerable evidence of deformation. A number of these beds show soft sediment deformation and slumping as well as numerous micro-faults that are observed directly below the gravel horizon. Above the gravel horizon a number of pebbles are observed within the coarse sands, but the number of pebbles decreases upwards until the sands appear to be pebble-free approximately 1 m above the gravel horizon. The sands can be separated into a lower and an upper sand, the latter with no pebbles and more pronounced bedding. Crossbedding is observed in the top ~20cm of each of these two sands. Finely laminated, micro-faulted, silt with minor clay occurs near the top of the Lower sediment as observed in Figure 5, photo 7.

Preliminary stratigraphic assignment interprets Lower sediment as Thorncliffe Formation, indicated by interbedded sand and mud representative of subaqueous fan sedimentation (Sharpe et al., 2018). The presence of detrital organics in both Thorncliffe and Scarborough formations means that the latter may not be ruled out (Karrow, 1967); however, it should be noted that Scarborough formation beds wedge out rapidly east from Scarborough to Bowmanville bluffs (Martini and Brookfield, 1995; Brennand et al. 1995).

4.3 Newmarket Till

In borehole GSC-BH-PIK-1 the Newmarket Till is a ~ 41 m thick, stony sandy silt diamicton with minor sand-mud inter-beds and minor stone lines as shown in Figure 5, photo 5. The basal contact is at approximately 42 m depth; the contact is planar and un-deformed overlying a ~3 cm horizon of deformed silts and clays topping the Lower sediment. The contact is visible in Figure 5, photo 6. Newmarket Till contains 2 thin (12 cm and 35 cm) sandy gravel horizons and a number of thin sand horizons with increased pebble contents. Sediments of the uppermost gravel horizon are shown in Figure 5, photo 4. Carbonate and shield-sourced pebble count ratios vary dramatically through the section in both size and abundance.

Rounded and spherical pebbles within the till are shown in Figure 5, photo 3. The upper ~4.5 m intersected a diamicton composed of a clay poor, sandy silt matrix, with fewer and smaller pebbles than below, as shown in Figure 5, photo 2. This upper till has a deeper reddish-brown coloration compared to Newmarket Till below this unit, and, it has an increase in pebble content and some cobbles. These lithic fragments consisted of larger (2-20 mm), generally rounded shield-type granules, pebbles, and cobbles, as well as smaller (0.5-2 mm), generally angular carbonate sand. Uppermost sediments of the borehole (~70 cm) show weathering characteristics and soil forming processes of sandy silt parent material, Newmarket Till, (Figure 5, photo 1).

The upper 4.5 m of diamicton is interpreted as Newmarket Till (Fig. 5) due to its similar dense sandy silt matrix (Sharpe and Russell, 2016) and the significant amounts of Shield clasts of northern provenance.

5.0 Geochemical Variation in Cored Rock and Sediment

Geochemistry provides an additional opportunity to identify characteristics (or changes) of matrix composition, mineral proportions, sediment facies, and depositional environments that aren't readily identifiable in the macro scale. 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 K and Rb, however Fe shows an inverse relationship to silt and mimics the sand content closely. The following descriptions pertain to geochemical variations of samples collected from borehole GSC-BH-PIK-1 and analyzed using a Niton pXRF in Mining mode (Appendix B).

5.1 Bedrock

The lowermost unit in the borehole consists of Blue Mountain Formation finely laminated shale. The lowermost sample plotted on the chemo-stratigraphic logs in Appendix B at a depth of 70.39 m consists of crushed bedrock. A white vertical dashed line demarcates the contact between Blue Mountain Shale and overlying fragmented and fractured siltstone, in photo 8 of Figure 5. Although the overlying sediments contain fragments of the bedrock the elemental concentrations of the bedrock differ considerably from the immediate overlying sediments (e.g. Ba, Ca, K, Rb, Sr).

5.2 Lower Sediment

Based on variations in individual elemental concentrations, the Lower sediment can be subdivided into five units.

Unit 1: 66-70 m, cross-bedded medium-grained sand to massive medium and fine grained sand show lower Al, Si, and Zn, and higher concentrations of Ca and Sr compared to the overlying sediments of unit 2.

Unit 2: 62-66 m, shows an increase in the concentration of Al, Fe, K, Rb, and Zn with a decrease in Sr and grain size.

Unit 3: 55-62 m shows a general increase in silt content with decreasing depth. Many elements such as Al, Ca, Fe, K, Mn, and Rb are very consistent in concentration throughout this unit and either higher or lower in concentration than the sediments stratigraphically below or above. Si and Zr show similar concentrations to the underlying unit 2 sediments.

Unit 4: 48–55 m, fine to medium-grained sands are shown by the high sand and low silt content with little to no clay. Geochemically this is reflected in higher, yet variable, concentrations of Fe, Mn, Ti, and Zr from both the underlying unit 3 sediments and overlying unit 5 sediments. Several elements such as Al, Ba, K, Si, and Sr show a general upwards decrease in concentration while Ca shows an increase in concentration.

Unit 5: 42-48 m, alternating silt and clay laminations as shown in Figure 5, photo 7 form the uppermost unit in the Lower sediment. Compared to the underlying unit 4 sediments, unit 5 shows an increase in total carbon (inorganic) and lower concentration of Fe, Mn, Zn and Zr. Several elements such as Al, Ba, and Si show an upwards decrease in concentration from the base of the underlying unit 4 sediments at a depth of 55 m through to the top of unit 5 at 42 m. Through out this same interval Ca shows an upwards increase in concentration.

5.3 Newmarket Till

The deformed and loaded contact between the Lower sediment and the Newmarket Till is shown in Fig. 5, photo 6. Elemental characteristics of the Newmarket Till are very consistent (e.g. Ti, Zn, Zr), however there are three small geochemical discontinuities through out the till, and one distinct change at the top of the borehole. These may mark small shifts in provenance/sedimentation source, possibly indicating the presence of multiple smaller till units (depositional episodes) combining to form the composite Newmarket Till.

Unit 1: 42-36.5 m of massive diamicton. Elemental concentrations for unit 1 are either lower or higher for many elements (e.g. Al, Ca, Rb) than the underlying Lower sediment.

Unit 2: 21.5-36.5 m of massive diamicton with a 38 cm thick zone of no recovery overlain by gravel with one granitic boulder near its base. A decrease in sand content and a corresponding increase in silt content at the contact with overlying sediments of unit 3 is observed. Compared to the underlying sediments of unit 1, Ca and Sr concentrations are slightly higher and K and Si concentrations are slightly lower. This unit shows a slight increase or decrease in concentration for one sample at the contact with overlying unit 3 samples.

Unit 3: 4.5-21.5 m of massive diamicton with a slightly higher clay content, but otherwise very similar to the underlying unit 2 sediments. Units 2 and 3 are very similar in elemental concentrations, they are only separated based on the decrease in sand content and corresponding increase in silt content at the contact, and the general increase in clay content for unit 3.

Unit 4: 0-4.5 m, excluding the uppermost sample that most likely represents a combination of soil forming and weathering processes, these sediments have similar sand, silt, and clay contents to the underlying unit 3 sediments. Total carbon (mainly inorganic) increases from the underlying unit 3 sediments. Granitic cobbles occur throughout the unit. Sediments of unit 4 show a marked increase in Ca and Sr and a decrease in Al, Fe, K, Rb, S, and Si compared to the underlying unit 3 sediments.

6.0 Summary

This study provides new lithological and geochemical observations and data for the Lower sediment and overlying Newmarket Till from the Pickering borehole. These results further characterize surficial sediment aquifers and aquitards across Canada and more specifically in southern Ontario. This study expands the use of pXRF spectrometer to collect meaningful geochemical data that can be used to address both provenance and depositional process.

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