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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 numerous studies on the glacial sediments of southern Ontario (Fig. 1). Much of the work carried out by the GSC and others is referenced in a field trip guidebook examining the extent, architecture, sedimentary facies and origin of buried valleys within the Oak Ridges Moraine (ORM) (Sharpe et al., 2013).

Although much work has involved sequence stratigraphy and basin analyses of sediments within this region, there is a paucity of information on the regional geochemistry of these sediments. Results from such studies are helpful for defining chemical and related mineralogical variations within sediments which contributes to information collected by other means such as sediment description, grain size data, downhole geophysical, and stratigraphic correlations. Geochemical data also provides information on sediment provenance, as well as an opportunity to establish a chemostratigraphic framework that complements other stratigraphic correlation techniques, for example, lithostratigraphy and biostratigraphy.

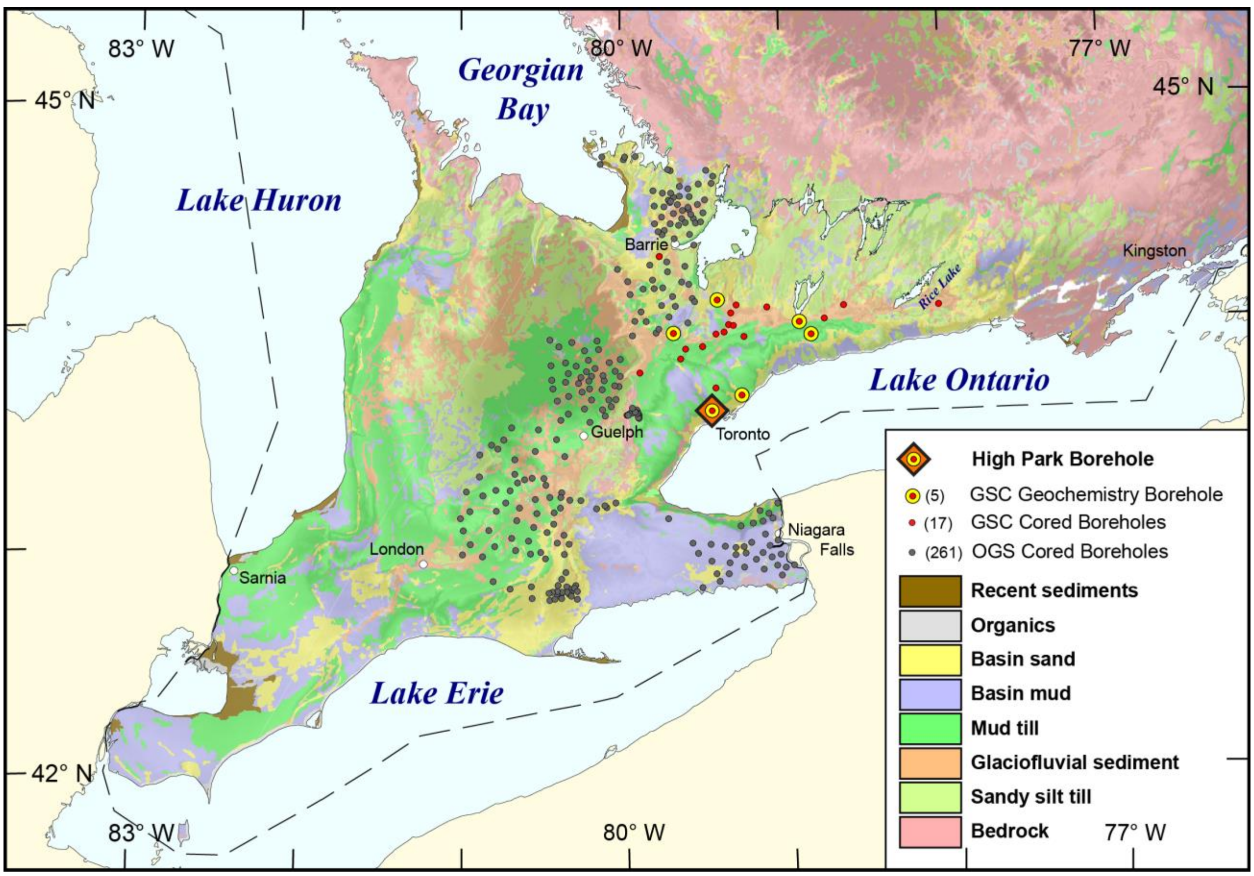

Figure 1: Location of the High Park borehole with simplified regional geology of soutwestern Ontario. Note the distribution of OGS and GS startigraphic boreholes with continuous core descriptions. Geology simplified from Barnett et al. (1991).

For groundwater studies, the collection of sediment geochemistry data is often beyond the scope and budget of many programs, and is generally not included as a part of routine data collection. Portable X-ray fluorescent (pXRF) spectrometry has proven to be a successful tool to characterize the chemostratigraphy of glacially derived sediments (e.g. Crow et al., 2012; Knight et al., 2015a), and to improve the interpretation of downhole geophysics, micropaleontology results, and pore water geochemistry (Medioli et al., 2012). Data collected from this method has now become a routine part of borehole studies within the Groundwater Geoscience Program at the GSC. The method is best suited to unconsolidated or crushed bedrock detritus and reworked surficial sediments that are <0.063 mm (silt and clay) in size (Plourde et al., 2012, Knight et al., 2012). The resulting data sets provide fundamental information used to define chemical and mineralogical variations within aquifers and aquitards. Data collected by pXRF and sedimentological information have been collected for a number of borehole cores in the Greater Toronto Area (GTA) (Coffin, et al., in press a, b; Knight et al., 2015a, Knight et al., in press, a, b, c, d, e; Popovic, el al., in press).

The objective of this Open File is to release the analyses of 58 samples from a 43.8 m borehole drilled in High Park, Ontario, and associated QA-QC data collected using a pXRF spectrometer.

2.0 Study area and geological setting

The borehole is located at easting 624104 and northing 4834313 (UTM NAD 83 - Zone 17) and ~ 89.5 m a.s.l. near Ridout & Howard Ponds, at the curve in Spring Road, in the northeast corner of High Park Toronto (Fig. 1, 2). The site is in a low area and the surface geology has been obscured by anthropogenic activity. Type sections for sediments likely occurring in High Park are located 20 km east-northeast and < 9 km northeast at the Scarborough Bluffs and the Don Valley. At Woodbridge, ~16 km to the northwest (e.g., White, 1975; Karrow et al., 2001), a type section for sub-Newmarket Till is identified. Using downhole geophysical logs, Eyles et al. (1985) extrapolated the Scarborough stratigraphy northward beyond Woodbridge to Alliston based on matching of gamma and conductivity signals of stratigraphic units. This regional stratigraphic correlation has been supported by core collected by both the GSC (Logan et al., 2008) and the OGS (Bajc et al., 2015). Units identified from the Scarborough Bluffs that may be correlative for the High Park core include Scarborough Formation, Pottery Road Formation, Sunnybrook Till, Thorncliffe Formation, the Seminary Till, and the Meadowcliffe Till (Fig. 3).

Surficial geological mapping of the High Park area is presented in three publications (Sharpe, 1980; Sharpe et al., 1997; OGS, 2010). All three present the geology in a similar fashion with slightly different map extents of units in the area. The study area is south of the Lake Iroquois shoreline, an erosional bluff, which is located over 4 km to the north. Approximately 4.1 km to the northeast, Newmarket Till is mapped north of the Lake Iroquois shoreline, whereas Halton Till is mapped approximately 6 km to the northwest (Fig. 2). Both Sharpe et al. (1997) and OGS (2010) map the area of the park as older till units, and stratified deposits (Fig. 2). Sharpe (1980) maps the area east of Grenadier Pond as Lake Iroquois littoral sand with older tills mapped further to the east and west of Grenadier Pond to the Humber River as undifferentiated deep water lacustrine – glaciolacustrine deposits correlative to Thorncliffe, Scarborough and Don formations (unit 2, Fig. 2).

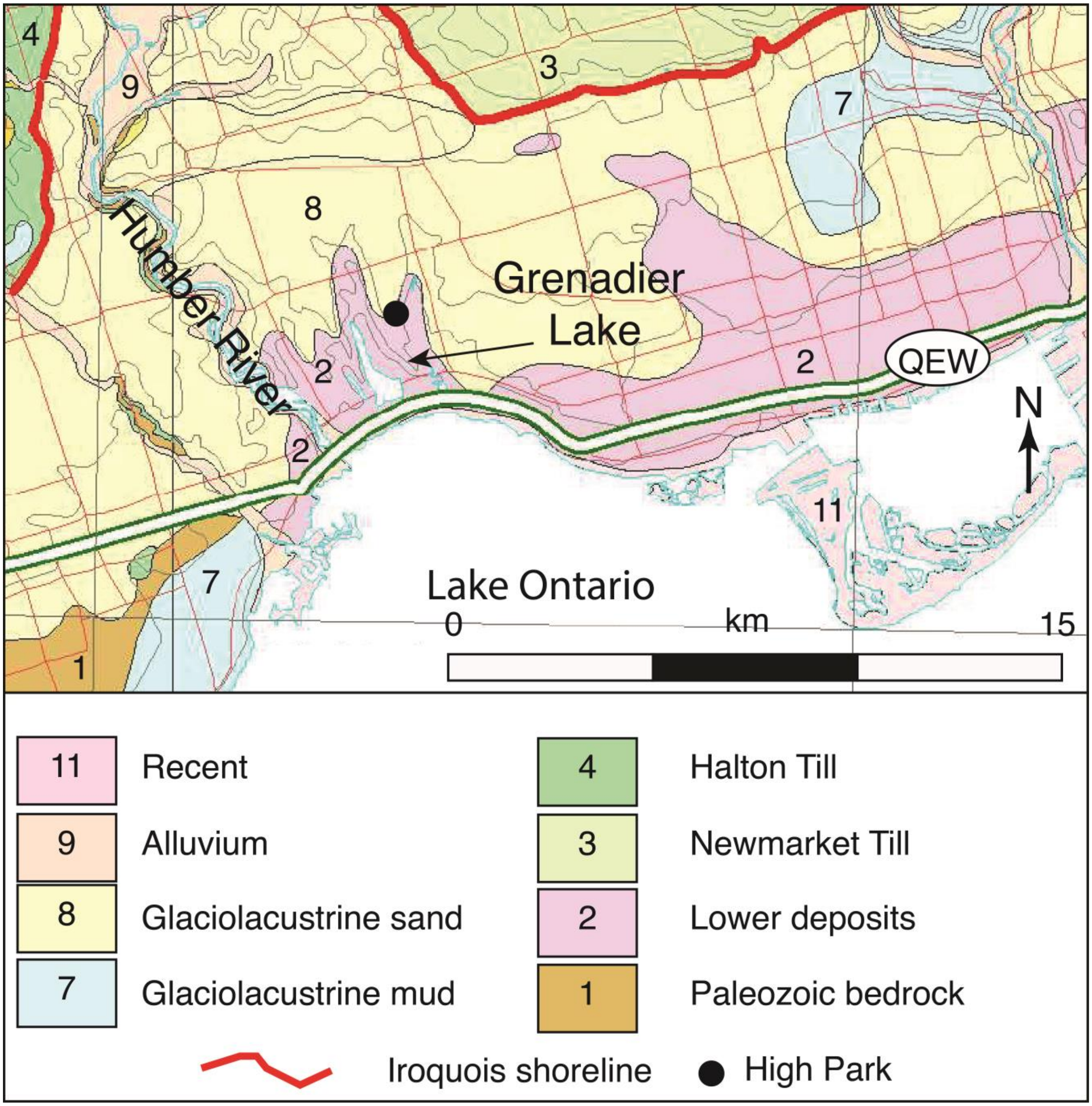

Figure 2: Geological setting of High Park and core site northeast of Grenadier Pond. Note Newmarket Till to northeast and Halton Till to northwest truncated by Iroquois shoreline (red line). In the High Park area undifferentiated older tills (Sunnybrook, Meadowcliffe) and sand gravel (Thorncliffe, Scarborough and Don formations) are mapped as unit 2. Geology from Sharpe et al. (1997).

At the Scarborough Bluffs type section, the Scarborough Formation consists of a lower clay unit of ~20 m thickness overlain by an upper sand unit, averaging 15 m in thickness (Karrow, 1967). The basal clay member consists of rhythmically-bedded, stratified clay and silt to massive sandy silt beds 1- 2 meters thick with irregularly-bedded silt and sand. Disseminated fine organic detritus is present along with occasional larger pieces of wood a few centimetres long which occur more commonly upward. The clays are dark grey in color when wet, but dry to a light creamy grey, having a brownish appearance when compared to glacial varved clays, which in comparison appear almost blue-grey. The sand member is interbedded with silt near the base, and coarsens upward from fine to coarse sand. Crossbedding is common in the sands with deformation structures attributed to underwater slumping during sedimentation (Karrow, 1967).

The Pottery Road Formation consists of cross-bedded gravel and sand facies filling channels eroded up to 40 m into the Scarborough Formation (Karrow, 1976). The gravels commonly contain armoured mud balls interpreted to be prodelta Scarborough Formation sediments (Eyles, 1987). The Pottery Road Formation contains fresh water molluscs and bones of bison, bear, and moose or elk (Churcher and Karrow, 1977).

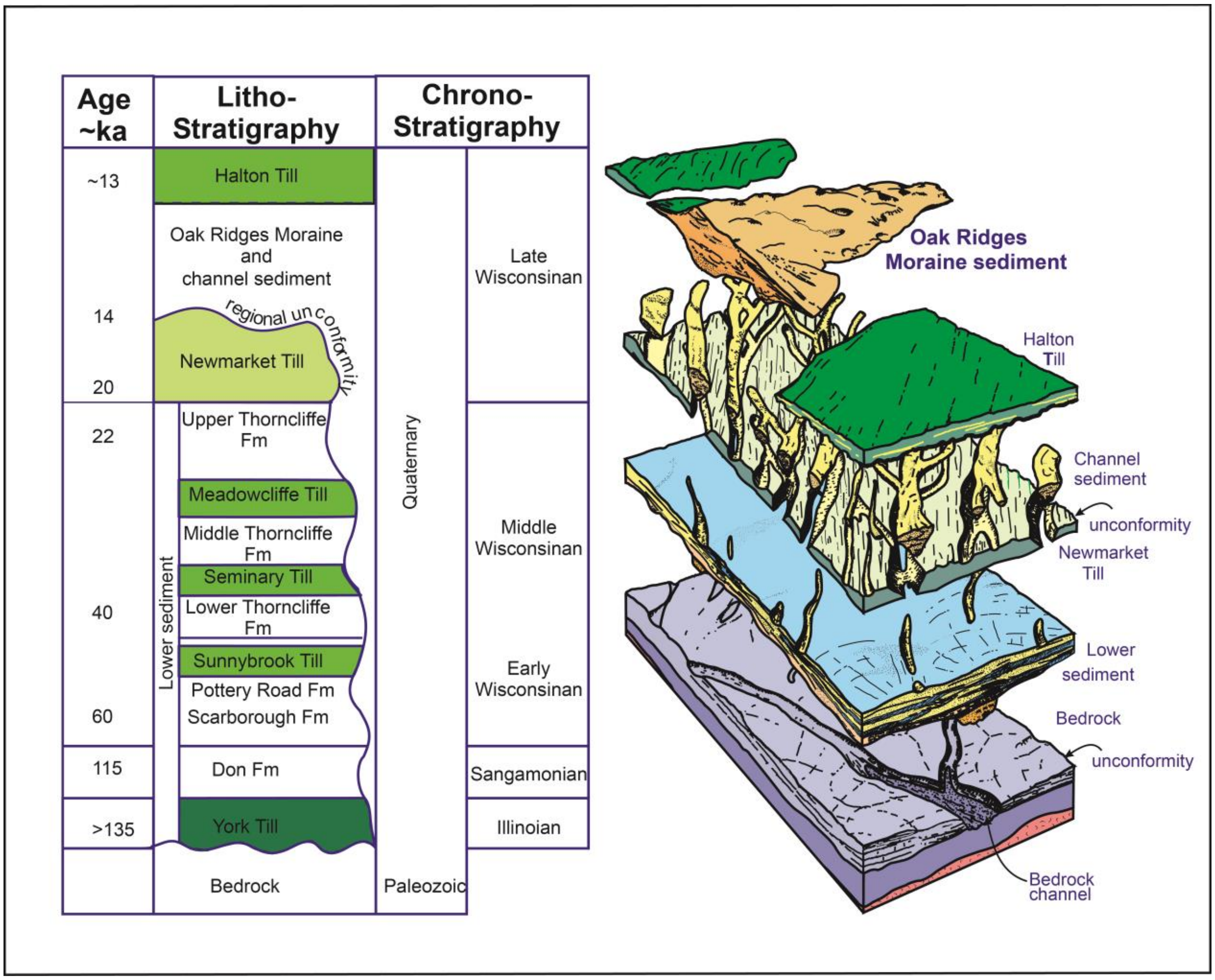

Figure 3: Stratigraphy of the Greater Toronto Area. Modified from Sharpe et al. (2002). Key till units highlighted in green.

Sunnybrook Till overlies and drapes the Scarborough Formation with the basal contact typically being interbedded, conformable, and in many places, loaded. Reworked diamict balls and thin irregular mud bands are observed as much as 5 m below the top of the Scarborough Formation sands. Hicock and Dremanis (1989) describe the Sunnybrook Till as consisting of three stratigraphic units: i) lower interbedded mud and sand up to 1 m thick, ii) a dominantly massive middle diamicton; and an upper stratified to massive mud. Units i and ii are several metres thick. The lowest unit comprises interbedded mud and sorted sediment that is load-casted, faulted, and folded (Hicock and Dremanis, 1989; Eyles and Eyles, 1983). Unit ii consists of a silty till to silty clay till with low pebble content (Karrow, 1967). Glacially faceted and striated boulders are extremely rare (Eyles et al., 2005). The Sunnybrook Till becomes increasingly stratified and grades up into a thick basin fill of thin bedded rhythmites of silt and clay with ice-rafted diamict and stones. These sediments are overlain by thick-bedded graded silty sands (Sr— Fl) in which ice-rafted debris is absent. Unit iii is considered to be the Bloor Member of the Lower Thorncliffe Formation (Karrow, 1967).

The Thorncliffe Formation (Fig. 3) overlies the Sunnybrook Till and consists of three units (Lower, Middle, and Upper) separated by the Seminary Till, and the Meadowcliffe Till. The Lower Thorncliffe Formation is composed of single and multiple graded silt laminations with clay caps (Eyles and Clarke 1988), which are well-exposed at the Don brickyard where the sediments are referred to as, the Bloor Member (Karrow, 1967). The tops of the silt layers are bioturbated by mm diameter horizontal burrows (Eyles and Clarke 1988). Graded discrete silts were probably deposited by weak quasi-continuous density underflows, or turbidity currents with the clay cap representing later pelagic sedimentation.

The Seminary Till is up to 7 m thick and thins inland away from the Lake Ontario bluffs (Karrow, 1967). It consists of a variety of sediment facies including a massive facies, a current reworked facies and resedimented facies with intercalated silt-clast breccias. Rhythmically laminated silty clays within the unit are common. Locally interbedded stratified sandy diamicts, discrete gravel, and rippled sand units are present (Eyles and Eyles, 1983).

The Meadowcliffe Till is up to 12 m thick in shoreline sections, and 22 m thick inland. It consists of a vertical succession which transitions from deformed laminated muds (varves) with load structures, into underlying sand, passing upward to massive diamicton, with few oversized clasts, and thin-bedded rhythmically laminated silty clays that pass up into massive diamict (Karrow, 1967, Eyles and Eyles, 1983). The Meadowcliffe Till is the most fine grained (54 % clay from 9 samples) of the three till units and the massive glaciolacustrine diamict has only minor evidence of resedimented and current-reworked components (Karrow, 1967; Eyles and Eyles, 1983).

3.0 Sample collection, processing and analytical methods

The borehole was drilled between July 9th to 31st 2003 by All Terrain Drilling using a mud rotary/wireline system and completed below 36.9 m by air rotary to bedrock at 43.8 m. Core collected from 0 to 12.5 m had a diameter of ~13 cm and from 12.5 m to 36.9 m a PQ diameter of ~8.5 cm. The change in drill core diameter corresponds to the base of a gravel interval intercepted from 12.2 - 12.5 m. The hole was terminated when artesian flow was encountered.

Artesian flow rose to approximately 20 m above the ground surface and flowed up to 1,800 litres per minute before slowing down to 55 litres per minute after a few days (http://www.highparknature.org/wiki/wiki.php?n=Explore.LaurentianRiver). Borehole core was collected in 10 ft runs with the sediment cores placed in five foot PVC tubes and sealed with tape. The PVC tubes were transported, and stored at the GSC core storage facility at Tunney's Pasture in Ottawa. The core was logged and photographed in 44 cm segments, (generally 5 images per 1.5 m run). Grain size analysis was completed on 27 samples (Appendix A). In the winter of 2015, 58 samples were collected for pXRF analysis. After the analysis, the core was discarded as part of a life cycle management plan of the collection.

Prior to pXRF analyses the sediment was disaggregated and sieved to <63 µm (silt + clay) at the GSC Sedimentology Laboratories in Ottawa. The processed samples were placed in 23 mm diameter plastic vials, to an approximate height of 30 mm, to obtain infinite thickness, and sealed with 4 µm 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 analysis, mounted to a test stand (Fig. 4).

Figure 4. Example of pXRF spectrometer mounted in a test stand with microcomputer for analysis of processed sediment samples.

For pXRF spectrometry, samples were analyzed in Soil Mode which uses Compton normalization that is recommended for elements expected to occur with < 1% concentration. In order to honor the protocol used for previous borehole studies (Knight et al., 2015a; Knight et al., 2012, Plourde et al., 2012), a dwell time of 60 seconds was used for each filter (Main, Low, and High) for a total of 180 seconds per analysis.

The pXRF data are interpreted using single element trends from the base to the top of the borehole. Of the elements detected 18 (As, Ba, Ca, Cr, Cu, Fe, K, Mn, Ni, Rb, S, Sr, Th, Ti, U, V, Zn, and Zr) were suitable for interpretation. The X-ray energy intensities and filter used to determine elemental concentrations in Soil Mode are listed in Table 1. Results are presented in Appendix A and displayed graphically in Appendix B.

Table 1: X-ray energy intensities used to determine elemental concentrations in Soil Mode, as provided by Thermo Scientific (2015).

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
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
U	$L\alpha_1$	13.61	13.48	13.90	Main
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 Teflon blank and a SiO_2 blank were analysed to determine the cleanliness of the pXRF window and sample stand environment. After approximately 10 analyses the operating environment (test stand) was purged with compressed air and wiped clean. Commonly the Teflon blank returns values in the 10's of ppm Ti and may return trace amounts of Mo. The Chemplex Prolene thin-film that separates all samples, except the Teflon blank from the spectrometer, may contain trace amounts of Ca, P, Fe, Zn, Cu, Zr, Ti and Al. Calcium and Fe returned values 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 with the standard reference materials and SiO_2 blank be replaced on a regular basis to avoid contamination. 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 documented in 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 Till-1 (Table 2), Till-4 (Table 3), and TCA 8010 (Table 4). The error column 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. As an example, Cs values obtained from Till-1 have an error of 4654% with a recommended value of 1 ppm and a pXRF mean value from 9 analyses of 48 ppm. Similarly, U values obtained from Till-4 have an error of 159%. These values are consistent with those reported in Knight et al. (2015a) for a borehole located near Aurora, Ontario. Although care must be taken when interpreting data with a high error, it may useful to plot these elements to see if their relative changes in chemostratigraphy correlate with those of other more reliable elements. Since chemostratigraphy utilizes the relative changes in concentration, high precision in returned values is more important than accuracy. It is also important to note that the 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.

Table 2. Summary statistics for SRM Till-1 by pXRF spectrometry for the High Park borehole

	Recommended Value (ppm)	Count	Mean (ppm)	%error	Std Dev (ppm)	%RSD	Minimum (ppm)	Maximum (ppm)
As	18	9	17	-4.4	1.3	7.43	15	20
Ba	702	9	869	23.9	17.63	2.03	834	890
Ca	19440	9	17246	-11.3	139.69	0.81	16943	17428
Co	18	2	146	712.2	31.57	21.59	124	169
Cr	65	9	33	-49.3	5.30	16.08	26	43
Cs	1	9	48	4653.7	3.02	6.35	45	55
Cu	47	9	56	19.3	4.19	7.48	50	63
Fe	48100	9	40998	-14.8	197.13	0.48	40623	41241
K	18429	9	15359	-16.7	215.25	1.40	15031	15785
Mn	1420	9	1367	-3.7	22.76	1.66	1343	1402
Mo	2	4	4.2	107.8	0.96	23.15	3.2	5.5
Ni	24	9	82	241.6	10.69	13.03	59	94
Pb	22	9	13	-42.0	1.17	9.19	11	15
Rb	44	9	40	-8.8	0.92	2.29	38	41
S	< 500	2	444	-11.2	121.29	27.30	327	593
Sr	291	9	271	-7.0	2.33	0.86	266	274
Th	5.6	8	3.9	-30.7	0.88	22.77	2.8	5.2
Ti	5990	9	5377	-10.2	40.57	0.75	5332	5434
U	2.2	8	5.8	164.1	1.04	17.82	4.7	7.3
V	99	9	157	58.4	10.86	6.92	142	176
Zn	98	9	89	-9.1	2.48	2.79	85	93
Zr	502	9	550	9.6	8.93	1.62	536	561

Table 3. Summary statistics of SRM Till-4 by pXRF spectrometry for the High Park borehole

	Recommended Value (ppm)	Count	Mean (ppm)	%error	Std Dev (ppm)	%RSD	Minimum (ppm)	Maximum (ppm)
As	111	9	103	-7.3	2.0	1.90	100	106
Ba	395	9	463	17.3	22	4.74	424	495
Ca	8934	9	8042	-10.0	153	1.91	7769	8298
Cr	53	9	26	-51.1	5.4	20.89	20	35
Cs	12	9	24	98.5	3.4	14.15	16	28
Cu	237	9	217	-8.6	3.4	1.57	213	224
Fe	39700	9	33148	-16.5	132	0.40	32938	33342
K	26980	9	23859	-11.6	201	0.84	23581	24150
Mn	490	9	459	-6.4	29	6.36	424	516
Mo	17	9	57	232.2	7.2	12.78	50	69
Ni	50	9	43	-15.0	2.3	5.33	40	47
Pb	161	9	152	-5.5	1.6	1.08	150	154
Rb	800	9	697	-12.9	133	19.06	410	827
S	109	9	106	-3.3	1.3	1.26	103	107
Sr	17.4	9	42	143.4	1.9	4.41	39	45
Th	4840	9	4669	-3.5	61	1.31	4555	4739
Ti	5	9	13	159.1	3.7	28.69	6	17
U	67	9	128	90.4	8.3	6.54	115	141
V	204	9	179	-12.5	7.5	4.21	163	188
W	70	9	66	-5.6	4.4	6.72	60	74
Zn	385	9	433	12.4	9.3	2.15	421	450
Zr	111	9	103	-7.3	2.0	1.90	100	106

Table 4. Summary statistics of SRM TCA 8010 by pXRF spectrometry for the High Park borehole

	Recommended Value (ppm)	Count	Mean (ppm)	%error	Std Dev (ppm)	%RSD	Minimum (ppm)	Maximum (ppm)
As	5.5	9	6	15.9	1.2	18.09	5	8
Ba	549	9	728	32.5	16.8	2.31	704	752
Ca	15509	9	14188	-8.5	142	1.00	13956	14441
Co	8	2	72	804.4	3.2	4.46	70	75
Cr	48	9	20	-58.9	5.6	28.36	10	26
Cs	1	9	56	5542	2.1	3.67	52	59
Cu	28	9	31	12.1	3.6	11.53	27	37
Fe	20290	9	14010	-31.0	164	1.17	13787	14216
K	19094	9	15978	-16.3	220	1.38	15718	16303
Mn	310	9	313	0.9	11.4	3.65	288	323
Ni	17	9	70	313	10.1	14.38	54	88
Rb	54	9	49	-9.1	1.0	2.04	47	50
Sr	310	9	267	-14.0	2.8	1.06	262	270
Th	5	9	4	-16.3	0.7	17.51	3	5
Ti	2578	9	2460	-4.6	60	2.43	2381	2535
U	1	7	7	598	1.5	21.41	6	9
V	49	9	71	45.7	6.6	9.27	57	79
Zn	32	9	32	1.0	2.5	7.76	29	37
Zr	272	9	304	11.8	13.7	4.51	287	324

3.2 Limits of Detection

Thermo Scientific provides a list of the sensitivity (limit of detection) for the pXRF analysis of each element. 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. Surprisingly for some elements (e.g. As Cr, Ni, and Th) the pXRF returned analyses lower than the recommended LOD. When this occurred, the point was plotted on the chemostratigraphy graph using the returned number however an arrow and title (LOD) was placed on the x-axis depicting the recommended LOD value. Elements detected by each filter and the corresponding lower limits of detection are listed in Table 5.

Table 5. Elements detected in the High Park borehole with corresponding detection limits for the pXRF using two matrix configurations and the filters used to detect these elements, provided by Thermo Scientific.

Element	Matrix		Filter
	SiO_2	SiO_2 + Fe +Ca	
As	4	7	Main
Ba	35	45	High
Ca	40	N/A	Low
Cr	10	22	Low
Cu	10	13	Low
Fe	25	N/A	Main
K	45	150	Low
Mn	35	50	Main
Ni	25	30	Main
Rb	3	3	Main
S	75	275	Low
Sr	3	3	Low
Th	4	4	Main
Ti	20	60	Low
U	5	4	Main
V	10	25	Low
Zn	7	10	Main
Zr	3	4	Main

4.0 Results and Surficial chemostratigraphy

4.1 Borehole Sedimentology and Stratigraphy

The 43.8 m deep borehole terminated in bedrock of the Paleozoic Georgian Bay Formation (S. Davies, pers. com.). For 8 m above bedrock, the drilling intercepted coarse sand and gravel however no core was recovered across this interval. Six principal sedimentary facies are described in Table 6 for the 36.9 m of core recovered. The core recovery rate was approximately 85 %. In at least two locations core recovery in diamicton successions was lost due to disruption caused by the presence of carbonate boulders. From the base of the core to a depth of 29.5 m the sediment generally fines upward with diminishing sand and increasing laminated mud, intraformational breccias, and diamicton (Figs. 5 and 6; Table 6). The contact with underlying gravel was not recovered. The diamicton beds are sharp based with carbonate gravel content and clast sizes that can be > 5 cm (Fig. 5).

From 29.5 m to ~ 3.25 m is a succession dominated by clay silt diamicton (clsiDm) with minor sand and silt (Fl) interbeds. The diamicton consists both of homogenized laminated sediment with only minor remnant lamination or textural contrasts (Dms) and massive diamicton with abundant sand and granules and a few percent pebbles (Dmm). Above 3.25 m the core consists of a succession of weathered organic rich sediment suggestive of anthropogenic modification and soil processes, this near surface unit also includes recent fill.

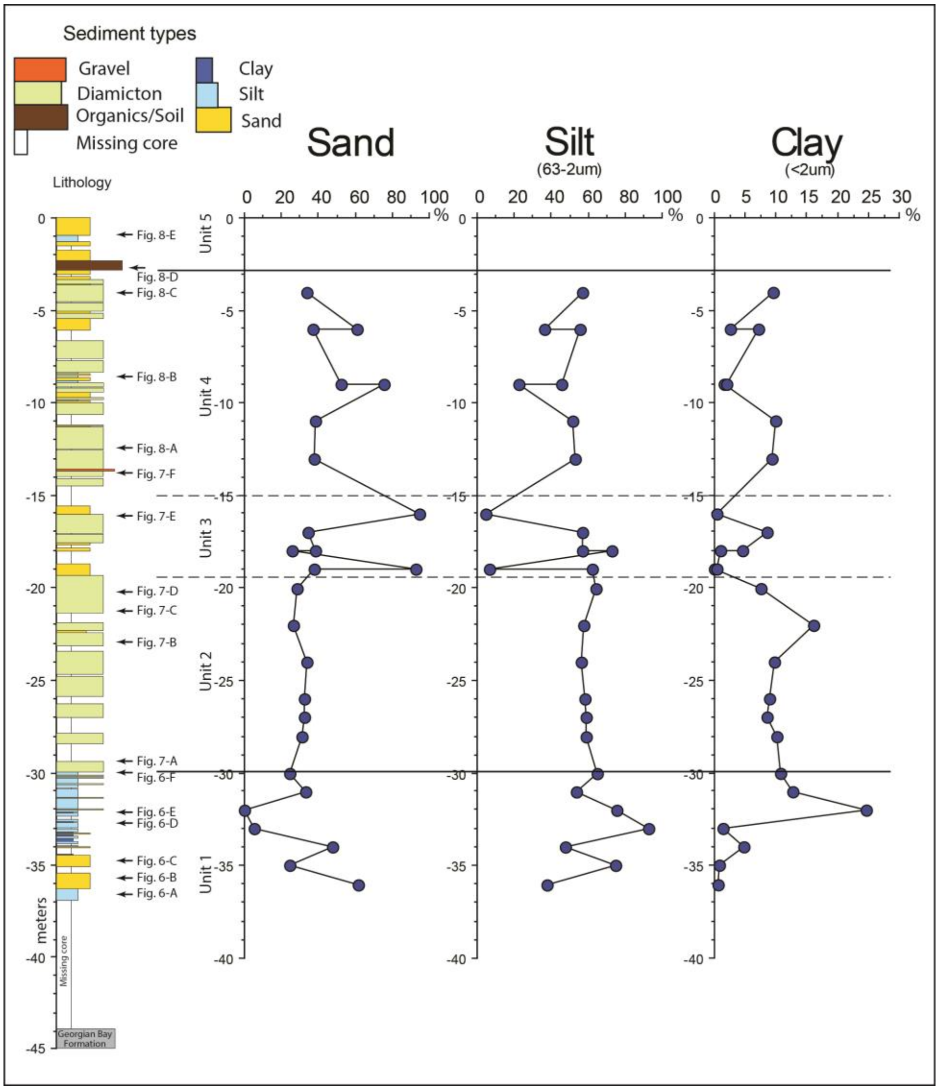

Figure 5. Sediment log for High Park core and grain-size results aggregated to sand-silt-clay. Complete grain size results are available in Appendix A. Stratigraphic location of photographs in Fig. 6, 7, and 8.

Table 6. Sedimentary Facies for High Park borehole. Unit subdivisions are based on pXRF chemostratigraphy depicted in figure 5 and Appendix B. Modified from Miall (1978) and Eyles and Eyles (1983)

Code	Facies	% units 2 to 4/ unit1	Description	Figure
Dmm	Diamicton, massive	62.18 / 5.5	4 to 150 cm thick, sharp, gradational, clay silt, minor fine sand silt, massive, coarse sand and gravel fraction. occasional boulders	7
Dms	Diamicton, stratified	21.82 / 0.65	10 to 101 cm thick, gradational, clay silt, laminations of silt, minor sand stringers, disrupted mud laminae, silt flames, coarse sand, granules, pebbles	7
G	Gravel	3.8/ 0	Sand and gravel No recovery	
S	Sand,	11.35 / 20.05	2 to 63 cm thick, gradational, sharp, deformed, fine to medium, laminated, bedded, massive, dewatered, loose, non cohesive,	6a, b; 7b; 8a
Fb	Mud, breccia	0 / 6.54	2 to 10 cm thick, sharp erosional based, mottled mud matric, clay, silt intraclasts, mining of intraclasts from substrate, three styles i) near equidimensional 3-4 mm intraclasts of silt, ii) larger intraclasts of clay and silt that are equal to or greater than the core diameter, iii) have small granule size carbonate rock fragments	6c, e, f
Fd	Mud, deformed	0 / 14.32	4 to 38 cm thick beds, gradational, abrupt, clay, silt, trace sand as sub mm laminae, dewatering structures, folds, micro faults, massive and laminated intraclasts,	6a
Fl	Mud, laminated	0.8 / 14.87	2 to 48 cm thick, sharp, clay, silt predominantly, trace sand as sub mm laminae, blebs fine sand, graded laminae and beds, internal scour surfaces, inclined – horizontal laminations	6, 8b
Fm	Mud, massive	0 / 11.07	2.5 to 14 cm thick beds, gradational basal contact from Fl, massive to laminated, minor sub mm laminae of silt, wispy, horizontal sub mm lamina of silt, disrupted by horizontal and sub-vertical sills and dykes	6

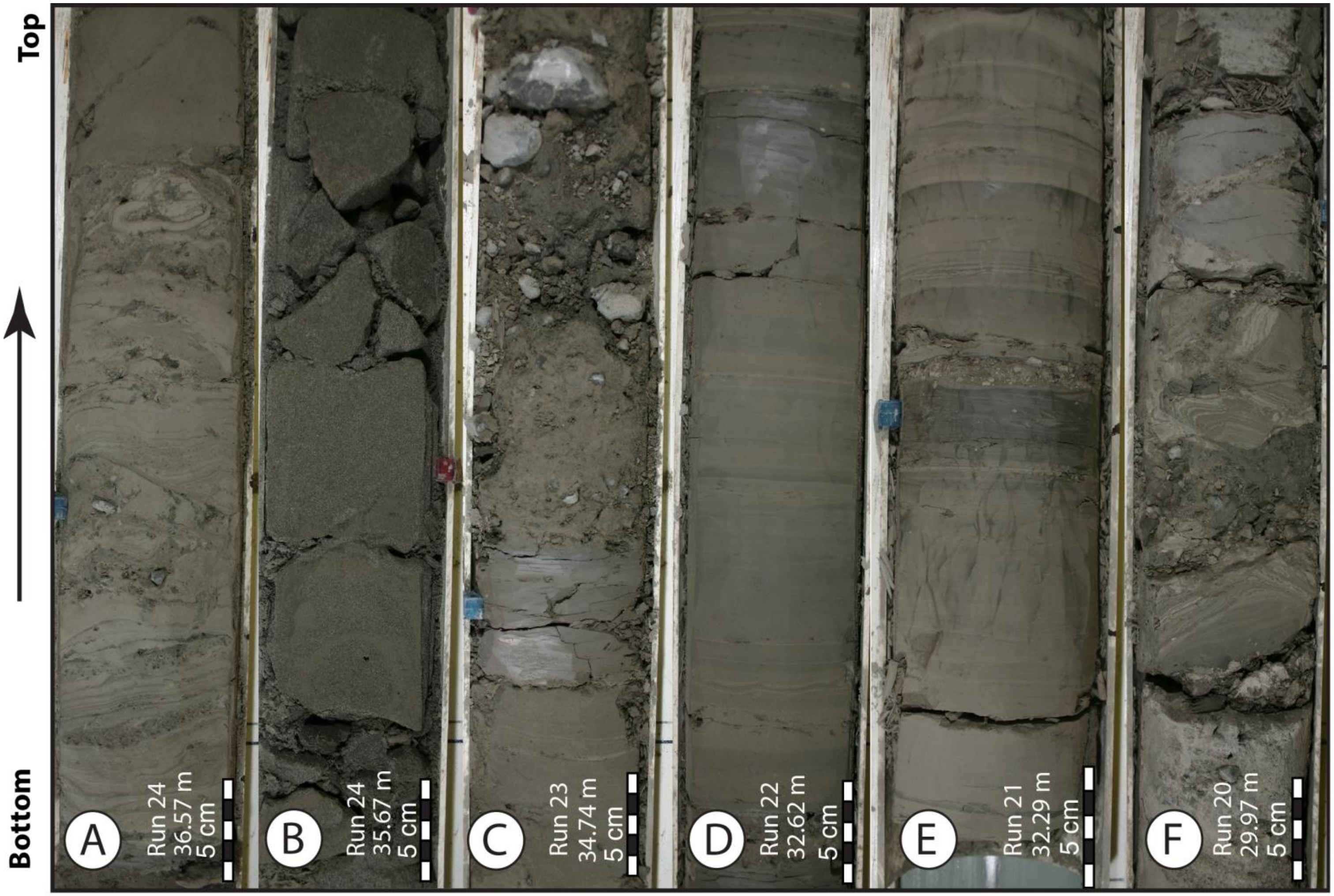

Figure 6. Illustrative images of sediment facies in pXRF unit 1. Numbers to the right of the letters indicate the midpoint depth of the image in the borehole in metres. A) Silty sand B) Medium grained sand C) Fine sand, mud and silty diamicton with carbonate clasts D) Laminated mud with a 5 cm clay rich horizon E) Micro laminated mud with an intra-formational breccia unit. F) Brecciated mud unit.

Figure 7. Illustrative images of sediment facies of pXRF units 2, 3 and 4. Numbers to the right of the letters indicate the midpoint depth of the image in the borehole in metres. A) Very dense clay silt till with carbonate granules and infrequent pebbles. B) Diamicton with interbed of dark medium grained sand. C) Dense clay silt matrix diamicton with carbonate granules. D) Muddy diamicton with fine sand interbed. E) Dense clay silt till with carbonate gravel clasts and infrequent shale pebbles. F) Silt rich diamicton above muds with abundant carbonate gravel.

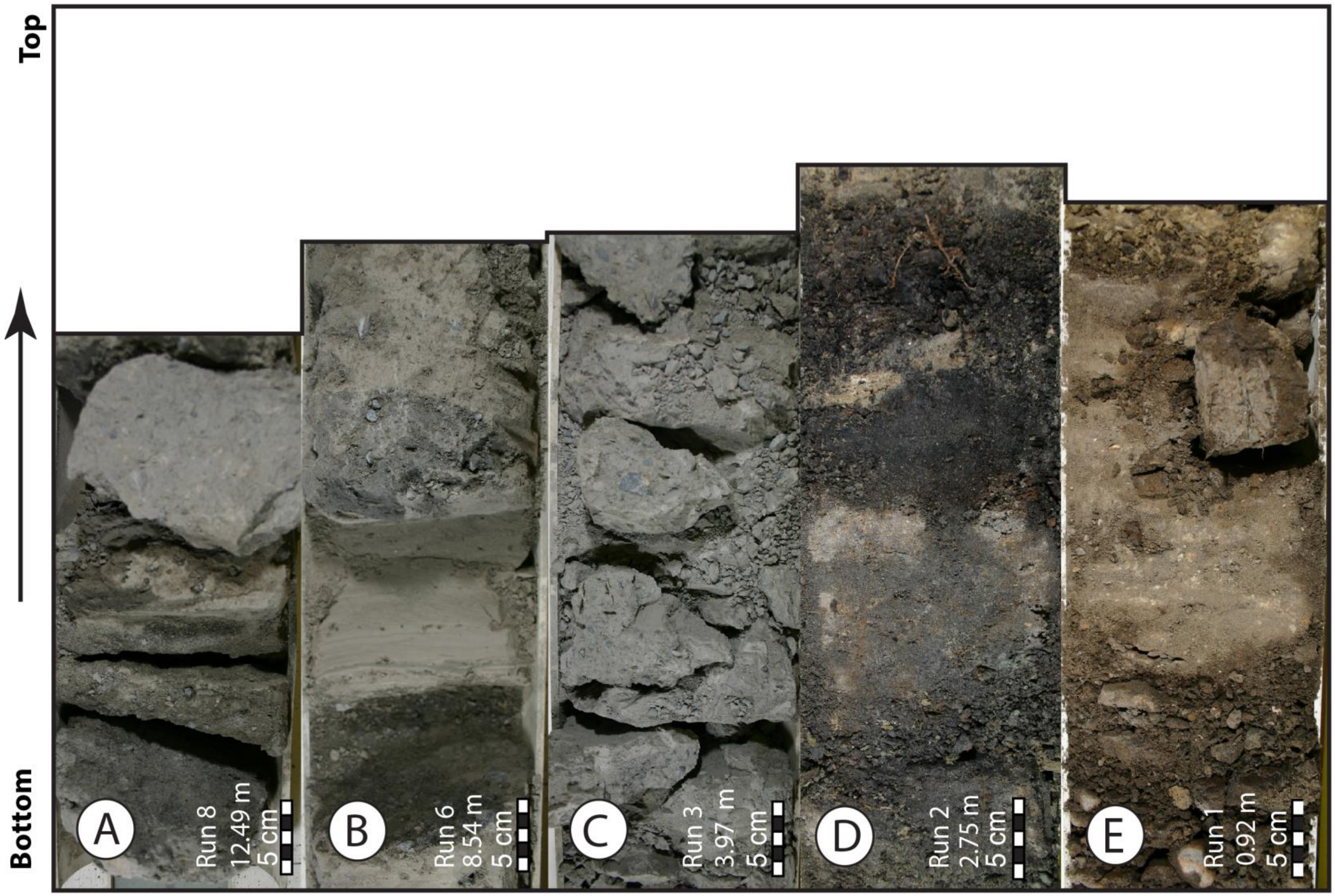

Figure 8. Illustrative images of pXRF units 4 and 5. Numbers to the right of the letters indicate the midpoint depth of the image in the borehole in metres. A) Cemented medium to coarse sand. B) Laminated silts within a muddy diamicton with carbonate granules. C) Fissile, dense diamicton with carbonate granules. D) Organic rich horizon that is partial soil and fill. E) Organic rich horizon within the disturbed park soil profile.

4.2 pXRF Results

Elemental concentrations as determined by pXRF spectrometry are listed in Appendix A. Individual element concentration data are plotted with respect to depth in Appendix B. The relationship between pXRF data and traditional laboratory methods for unconsolidated surficial sediments within this portion of southern Ontario are discussed in Knight et al. (2015a) and Knight et al. (in press a, b, c, d).

Chemostratigraphy of the High Park borehole was divided into 5 units although, as stated above, no marker horizons were encountered in the recovered core. The base of the borehole is represented by clay, silt, and sand horizons although the borehole did intersect bedrock at 43.8 meters in depth.

Unit 1   37.0-29.9 m (clay, silt, sand)
This 7 m thick unit consists predominantly of clay and silt with two sand horizons near the base (Fig. 6 A-F). The uppermost contact is placed at the transition from silt to the overlying unit 2 diamicton. Thirteen samples were collected for pXRF analyses (15-HPK-001 to 15-HPK-013). For most elements the unit 1 sediments are geochemically similar to the overlying unit 2 diamictons. This is similar to the Aurora borehole where the elemental concentrations for the Newmarket Till are similar to the overlying clay/silt rhythmites. Unit 1 can be differentiated from Unit 2 by a change in concentration of Ba, Ca, and S. The sand horizon from a depth of 36.5 – 34.4 m is recorded by a marked increase in S concentration.

Unit 2   29.9-19.7 m (diamicton, minor sand)
This 10.2 m thick succession consists of diamicton and one minor sand horizon (Fig. 7 A-D). A total of 4 meters of core was not recovered from this unit. Twelve samples were collected for pXRF analyses (15-HPK-014 to 15-HPK-025). This unit is differentiated from unit 1 and unit 3 predominantly on the changes in sediment from clay, silt, and sand to diamicton. The chemostratigraphy plots in Appendix B display little change in concentration between this unit and the underlying unit 1 elemental concentrations. Contrary to this Barium displays a marked increase compared to the underlying unit 1 sediments, while Ca displays a high degree of variability compared to both the underlying and overlying sediments. The thin sand horizon at a depth of 22.5 meters is reflected in a spiked increase in Cr, Cu, and S concentrations and minor decreases in Th, Ti, and U concentrations.

Unit 3   19.7-15.0 m (diamicton, sand)
This unit is approximately 4.2 m thick and consists of diamicton with interbedded sands (Fig. 7-E). Approximately 1.5 meters of core was not recovered. Eight samples were collected for pXRF analyses (15-HPK-026 to 15-HPK-033). Although this unit is not clearly defined (dashed line on chemostratigraphic graphs Appendix B) it is differentiated from underlying and overlying sediments based on changes in Ba and Ca. Two spikes in concentration for Fe and S at a depth of 16 m and 18.9 m correspond to sand horizons within the unit. For the lowermost sand horizon at a depth of 18.9 m there is a significant spike in the concentration for Zr. For the sand horizon at a depth of 16 m there is also a spike in concentration for Ba, Ti and V, with a decrease in concentration for Ca, however there is no increase in the concentration of Zr. Based on these changes it is likely the two sand horizons have come from different source areas.

Unit 4   15.0-2.8 m (diamicton, minor silt and sand)
This unit is approximately 12.2 m thick with 2 m of unrecovered sediment. Nineteen samples were collected for pXRF analyses (15-HPK-026 to 15-HPK-033). The unit consists of diamicton with minor sand and silt horizons (Fig 7-F, 8 A-C). The lowermost 4 m displays very consistent concentrations for most elements (e.g. Ca, Fe, K, Rb, Sr, Ti). The variability in concentrations for the remaining portion of the unit reflects diamicton interbedded with sand and silt horizons.

Unit 5   2.8-0.0 m (organics, soil, sand with minor silt and clay)
The basal portion of unit 5 consists of 0.5 metres of soil and organic matter overlain by interbedded sand, silt, and clay (Fig. 8 D-E). Six samples were collected for pXRF analyses (15-HPK-053 to 15-HPK-058).The contact between unit 4 and unit 5 is clearly defined in the change in concentration of K between the two units. Other than Cr, K, and Rb, the geochemical signature of these sediments is highly variable. The lowermost sand horizon displays a sharp increase in the concentration of Zn and Zr. Based on the chaotic nature of the geochemical signature and the basal soil/organic horizon it is suspected that the sediments above the organics have been emplaced by anthropogenic activity (i.e. pushed in over top of the soil)

5.0 Summary

Based on the geographic location of the borehole beneath the Lake Iroquois shoreline, and the extent of mapped lower sediment (stratified and /or tills; Sharpe et al., 2002), the cored sediment is assigned to lower sediment package. There is, however, some ambiguity in the correlation of the diamicton which may also be correlated with either Halton or Newmarket Till.

Geochemistry data does not exists for the units in the area (Don Brick Yard, Scarborough Bluffs), and thus cannot be used to support a stratigraphic correlation using the pXRF results.   Based on descriptions of stratigraphy from the area (e.g., Karrow, 1976; Eyles, 1987), the basal gravels in the High Park core could be correlative with the Pottery Road Formation, however, an absence of core and descriptive information for the basal gravels makes this assignment tentative. Older lower deposits (York Till and Don Formation) have been eroded as Paleozoic bedrock of the Georgian Bay Formation was encountered at the base of the borehole (Davis, unpublished).

Based on sedimentary facies, and absence of detrital organics the basal muds to 29.5 m depth are likely Lower Thorncliffe Formation. The overlying diamicton unit is characterized by evidence of slumping/deformation, and homogenization of previously stratified mud suggestive of debris flows and dewatering remobilization (Fig. 6f). Integrating with the surface mapping would support a correlation of the overlying diamicton with Seminary Till or Meadowcliffe Till. It should be noted that research carried out by Karrow (1967), in the Scarborough area, was unable to trace the Seminary Till inland whereas the Meadowcliffe Till was mapped with a thickness of up to 22 m. Meadowcliffe Till, however, has an average clay content of 54% (Karrow, 1967), whereas grain size analysis from diamicton core samples have an average clay content of 10%. Based on the unit thickness, clast content, and sedimentary facies Halton Till is an alternative possibility, however, as the borehole is below the

Iroquois shoreline and Halton Till has not been mapped across this area this is a secondary option (e.g., Sharpe and Russell, in press). A third option is correlation with Newmarket Till, however, the complete absence of Pre-Cambrian clasts, and lack of high sediment density makes this a less likely correlation (e.g. Boyce and Eyles, 2001; Sharpe and Russell, in press).

Based on the trends in chemostratigraphy for Cr, Cu, Mn, Sr, Zn, and Zr there is little change in provenance between the diamicton, sand and silt deposited in the High Park area. In unit 3 there are two spikes in the sand content that is also reflected in a spike in S concentration and for the lowermost sand spike an increase in Zr concentration. The uppermost sand and S spike does not display a similar increase in Zr concentration suggesting that the sands for each spike have a different provenance. In unit 5 there is also a spike in Zr concentrations related to a sand horizon but no similar spike in S concentrations. Sand horizons in this borehole seem to be derived from several variable provenances. For unit 1, and the lower portion of unit 2, the sand, silt, and clay have similar elemental concentrations to diamicton suggesting either the same source area, or that the sand silt and clay of unit 1 was incorporated into the diamicton of unit 2. Without diagnostic marker horizons chemostratigraphy is unable to support the assignment of definitive stratigraphic units.

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