Physical and Geochemical Sedimentary Records of Environmental Change in the ECSU Arboretum.

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Abstract

This study examines physical and geochemical characteristics of sediment cores collected from the ECSU Arboretum. The Arboretum is an important resource to the ECSU community and is greatly affected by the highly developed land that borders it. Records of this development are reflected in the Arboretums sedimentary column. In particular, I examine two sediment cores that were taken from an undisturbed site and a site known to have been disturbed by previous hydrologic sampling.

Three distinct sedimentary units occur in both cores. Lowermost Unit I consists of fine to coarse grain sands with some large clasts and low chemical and organic contents. This unit is interpreted to be glacio-fluvial in origin. Unit II contains fine grain muds, terrestrial root remains, and small twigs with higher chemical and organic carbon concentrations. All of which indicate that this unit is a buried soil horizon. Unit III is an organic rich muddy deposit with elevated elemental concentrations. These sediments were deposited in standing water after the Arboretum pond was constructed. All elemental concentrations are enriched in Unit III. Howerver, after normalizing for organic content and clastic sediments the number of enriched elements in Unit III decreases drastically.

Physical and geochemical characteristics of the undisturbed and disturbed cores were examined to determine whether previous hydrologic sampling activities compromise the use of sediments in the pond for reconstructing past environments. T-tests comparison of means show that 9 of 19 elements differ significantly at the $p<0.05$ level which suggests that based on average composition most elements do not differ significantly. However, physical and chemical properties of the sediments have changed through time, reflecting major changes in depositional environments. Further detailed comparisons of chemical profiles from core s2003-01 (undisturbed) and 2003-03 (disturbed site) indicate that the later is much more irregular and contains higher concentrations than core 2003-01. This suggests that disturbed sites are unsuitable for detailed core studies.

Normalized chemical profiles indicate that only Pb, Be, Cu, and S have been significantly enriched in the Arboretum sediments (Unit III). These changes are likely the result of increased runoff and deposition of contaminated sediments associated with construction adjacent to the Arboretum site.

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Introduction

Lakes act as catchments receiving runoff from the surrounding land. Physical materials, chemicals, and pollutants fixed onto sediments may also be transported into lakes by runoff. As well, lakes undergo internal physical, biological and chemical changes that also influence the quality of water in the lake. These are preserved within lake bottom sediments, thereby creating a sedimentary timeline of changes that have occurred in and near the lake. As a result, lake sediments can be used to interpret environmental change.

Land use plays an important role in conditioning lakes and lake sediments. For example, Field et. al. (1996) reports that agricultural, urban, and forested land uses have differing effects on the quality of water in lakes. Fertilizer and wastewater from agricultural and urban areas supply different amounts and types of nutrients and mineral constituents to lakes. Thus, a change from forested to urban land use can be seen in the sediment profile (Thomas, 1988). The chemical and physical characteristics of sediments in lakes also differ for water bodies influenced by these land uses. As such, past environmental changes can be interpreted by examining sedimentary records in lakes.

The ECSU Arboretum (Figure 1) is an important resource for Eastern Connecticut State University. It acts as a place of recreation and as a natural laboratory for faculty and students. Furthermore, land within and adjacent to the Arboretum has been significantly altered by people. For example, residential expansion is ongoing beside the Arboretum, and Highway 6 abuts the northern edge of the Arboretum (Eastern Connecticut Environmental Review Team, 1998). The Arboretum is directly affected by development in these areas receiving runoff that may contain chemicals, sewage, or other emissions. In addition, recent construction of a parking garage on campus has greatly changed the surrounding topography disturbing the land and likely increasing the amount of eroded sediment entering the Arboretum. As such, it is both prudent to document the changes, and important to consider whether sediment within the Arboretum contain evidence of these and other environmental changes near the campus of ECSU.

This study investigates the physical and geochemical sedimentary records of environmental change in the ECSU Arboretum. The specific purposes of my research are:

1) To analyze and describe physical and geochemical characteristics of two sediment cores collected from the Arboretum pond.
2) To determine whether the physical and geochemical characteristics of sediments entering the Arboretum have changed through time.
3) To determine whether there are differences in these properties at undisturbed and disturbed sampling locations in the Arboretum, and
4) To consider whether such changes are related to human actions within or near the Arboretum.

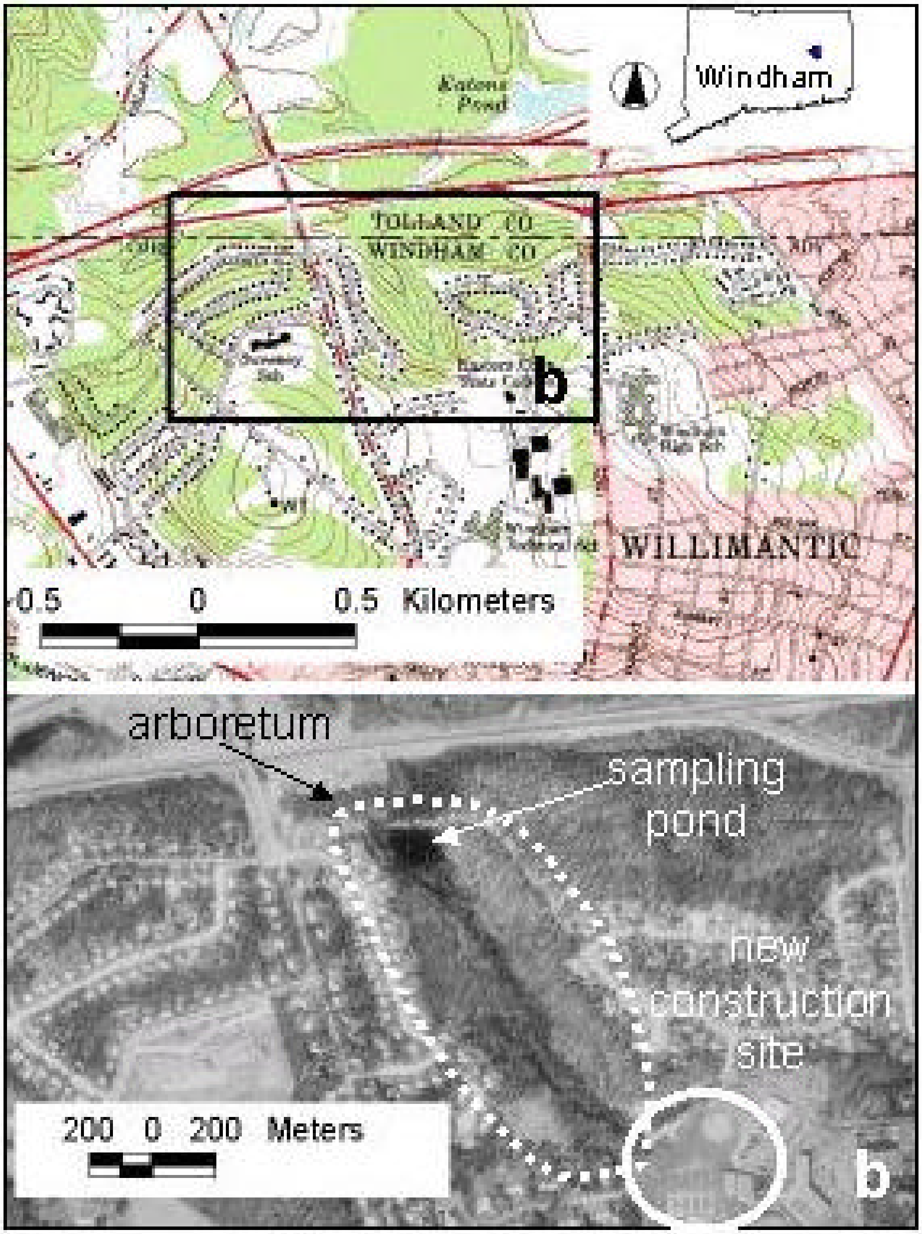


Figure 1: Site location map showing a section of USGS 1:24000 Willimantic map showing a) topography and b) aerial photography of ECSU Arboretum, sampling pond, and new construction site. Figure provided by J.A. Hyatt.

The Importance of Sediment Chemistry Analysis

Histories of environmental change preserved in lake sediments reflect direct changes by external factors (e.g. weathering and erosion) as well as changes that occur within the lake in response to external change (e.g. eutrophication) (Thomas, 1998).

Lake sediments record environmental change that is reflected in the chemical makeup of the sediments. As land use changes the availability of chemical constituents change. For example, Connecticut experienced a decline in agricultural land use between 1934 to 1990, an increase in urban land, and relatively little change in forested land (Field, et. al., 1996). Impervious surfaces and residential housing increased erosion and nutrient loading rates to many lakes. Sewage, lawn fertilizers, phosphate-containing laundry detergents, and pet wastes from urban and residential areas have also added Phosphorus (P) and Nitrogen (N) to lakes throughout Connecticut's human history (Field, et. al., 1996). In general, enhanced weathering and erosion increases the mass transport of raw soils and increases sodium (Na), potassium (K), and magnesium (Mg) levels in lake sediments (Thomas, 1988). Salting residential roads in winter leads to high concentrations of Na and chlorine (Cl), and lead (Pb) from gasoline.

Topography, Vegetation, Geology and Hydrology of the ECSU Arboretum

The ECSU Arboretum, located on the north end of the Eastern Connecticut State University campus, occupies approximately 6 acres and includes a stream corridor, valley side slopes and a pond (Ecosystem Consulting Service, Inc., 1994). The Arboretum property is approximately 549 meters long and 46 meters wide with the stream averaging 1.5 meters wide and 0.9 meters deep during bank full conditions. The stream receives storm water from a 1.5 meter culvert that drains almost one half of the ECSU main campus and additional storm water runoff from the end of Pigeon Road (Figure 2). Groundwater seeps at the south end of the wetland also provide a water source to the stream (Ecosystem Consulting Service, Inc., 1994). The arboretum consists of woodland, swamp, and marsh with two and four-tenths hectares identified as wetland (Carlson, 1999).

The wetland portion of the Arboretum is divided into four classes: Deciduous Wooded Swamp, Shrub Swamp, Deep Marsh, and Shallow Marsh (Ecosystem Consulting Service, Inc., 1994). The Deciduous Wooded Swamp is located at the southern section of the wetland beginning at the culvert and extending north approximately 305 meters. The Shrub Swamp begins about 305 meters from the culvert and continues on 457 meters from the culvert. The Deep Marsh begins 457 meters from the culvert and is surrounded by strips of Deciduous Wooded Swamp, Shrub Swamp, and Shallow Swamp.

The surficial geology at the Arboretum consists of four units, glacial till occurs adjacent to the western end of the Arboretum, while stratified drift paralleling the eastern edge of the till deposit and also underlies the eastern portion of the Arboretum. A second stratified drift morphosequence occupies much of the central portion of the Arboretum with swamp deposits underlying the northern end of the Arboretum including the pond cored in this study.

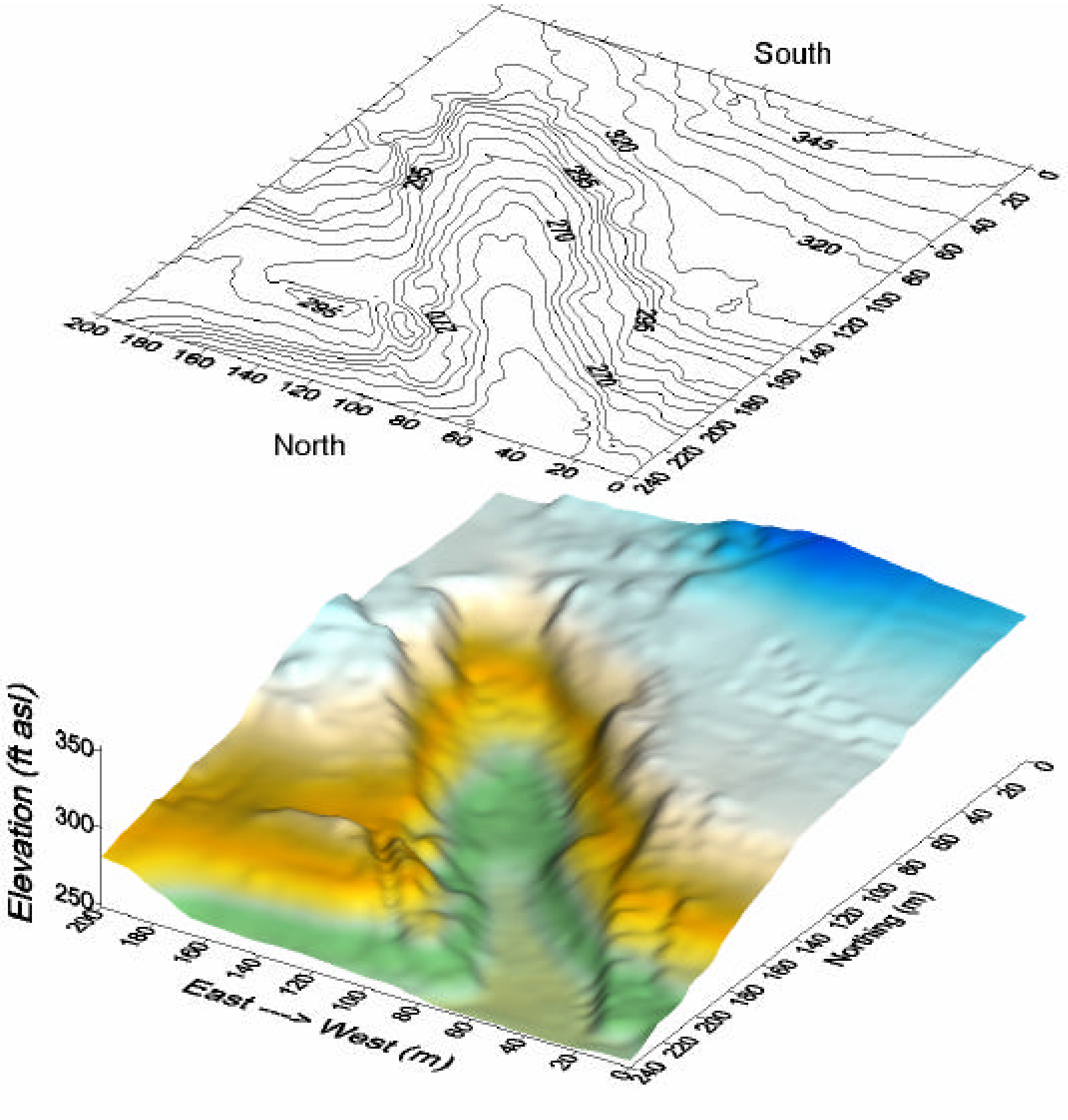


Figure 2: Topography map of ECSU Arboretum and digital elevation model showing the Arboretum stream corridor.

Hydrologic characteristics of the Arboretum have been described by Carlson (1999) and examined by Applied Hydrogeochemistry classes in 1996 and 1997. Three water types were distinguished including A, B, and C with groundwater dominating the chemistry of the pond. Water discharging from the storm drain system differs from downstream samples, seeps and the monitoring well. However, downstream water chemistry is quite similar to the monitoring well located adjacent to the pond. Water chemistry from red-stained groundwater seeps differs from downstream and monitoring well samples. Manganese and iron precipitates, which are not common in this area of Connecticut, likely explain the red deposits around these seeps. The source of these precipitations maybe artificial till used to construct the campus parking lot located up-gradient from the arboretum (Carlson, 1999).

Campus and residential construction has influenced the Arboretums' development. The construction of Resident Villages A and B and the recent construction of the campus parking garage introduced artificial materials to the area and changed local drainage patterns. Surrounding residential developments have also introduced foreign material and affected drainage. This development makes the area vulnerable to sewage spills and human impact.

Methods

Field Methods

Three sediment cores, ranging in length from 0.22 m (Core 2003-02), 0.75 m (Core 2003-03) and 0.89 m (Core 2003-01) were collected by percussion coring techniques using three inch PVC pipe from the ECSU Arboretum on February 16, 2003 (Figure 3). The sites were chosen in order to sample sediments from sites that were thought to be undisturbed (Cores 2003-01 and 2003-02) and sites that were disturbed (Core 2003-03) by other scientific studies (Carlson, 1999). Cores 2003-01, 2003-02, and 2003-03 were retrieved from depths of 0.24 m, 0.29 m, and 0.25 m respectively. The depth to the sediment water interface was measured using a weighted disk and tape measure at sites 2003-01, 2003-02 and by direct measurement with tape measure at site 2003-03. All cores were extracted using a tripod and winch setup (Figure 4) and cut to length in the field and transported to ECSU for cold room storage, sampling and analysis in the laboratory.

Laboratory Methods

Sediment cores were split lengthwise taking care to minimize contamination from the saw, and designated as a sampling half and a photographic half. Detailed descriptions of the stratigraphy were prepared with focus on contact zones, facies changes, munsell color, texture, and special features. All core log descriptions are provided in Appendix A.

Sample halves were sub-sampled with the intent to capture physical and chemical changes occurring down the core. All cores were sampled at 1 – 2 cm intervals through the uppermost facies, sub-samples collected from facies present lower in the core were removed above and below contacts and at points of interest or 5 cm intervals.

Sub samples were placed in pyrex containers and analyzed to determine moisture, organic, and inorganic content. Moisture content was calculated by determining the percent mass lost at 105° C for 24 hours. Samples were ground using a mortar and pestle and organic and inorganic content was calculated by determining the percent mass lost upon ashing at 550° C and 950° C for 4 hours.

Sub samples were also collected for chemical analysis. These samples were dried for 24 hours at 100° C and were desegregated using a glass-stirring rod. A total of 59 samples were submitted to Chemex Inc. for multi-element bulk sediment analysis using an aqua-rejia digestion and inductively coupled plasma - atomic emission spectrum equipment. Results of the analysis are provided in Appendix B.

Inductively Coupled Plasma - Atomic Emission Spectroscopy (ICP-AES) is a technique used to measure the concentration of chemical elements in complex systems (Manning, 1997). Emission spectroscopy uses emitted light, absorbed light, or scattered light to interpret concentrations of specific elements.

In Analytical Atomic emission spectroscopy involves: atom formation and excitation and emission. During atom formation an element that is bound to a specific matrix must be separated from the matrix so its atomic emission spectra can be measured. From this the atoms total concentration is determined. In the excitation stage there must be enough available energy to move an electron from its' ground state into an excited state. In its' excited state the atom emits light that is characteristic of that element. The Inductively Coupled Plasma serves as the reservoir for emission spectroscopy (Manning, 1997).

To perform ICP-AES the sample must first be prepared by undergoing treatment with acids, heating and microwave digestion. The sample must then be converted from liquid to aerosol. Any remaining solids or liquids must be dried to remove any remaining water and converted to gases. Once the sample is in the gas phase its bonds are broken so that only atoms are present. During this step the plasma temperature and an inert chemical environment are crucial. The atoms are then excited so they emit light of a characteristic wavelength. Finally, a grating disperses light and allows it to be measured and quantified (Manning, 1997).

Results

Two cores were collected from ECSU's Arboretum pond (Figure 3) from an undisturbed site (Core 2003-01) and a disturbed site (Core 2003-03) in water depths of 0.24 m and 0.25 m respectively.

Visual and Textural Characteristics of Sediment Cores

Core 2003-01 (0.89 m), collected at the undisturbed site, includes three sedimentary units identified by visible changes in color, texture, and organic content (Figure 5). Unit I, >60 cm thick, consists of fine to coarse grain sands in two sub-units. The lower, at depths greater than 55 cm, consists of a mixture of fine to medium grain sand that generally fines up. The lower portion (Unit IA) also includes two silty zones that display slight stratification at 72-76 cm and 79-83 cm. The color of the lower portion of the unit changes with depth from olive gray to olive (5Y 4/2 – 5Y 5/3) in the silty sections to light yellowish brown to dark grayish brown (2.5Y 6/3 – 2.5Y 4/2) in the sandy sections. The upper portion (Unit IB) consists of 25 cm of massive coarse-grained sand that fines upward and has a uniform olive gray color (5Y 5/2) throughout.

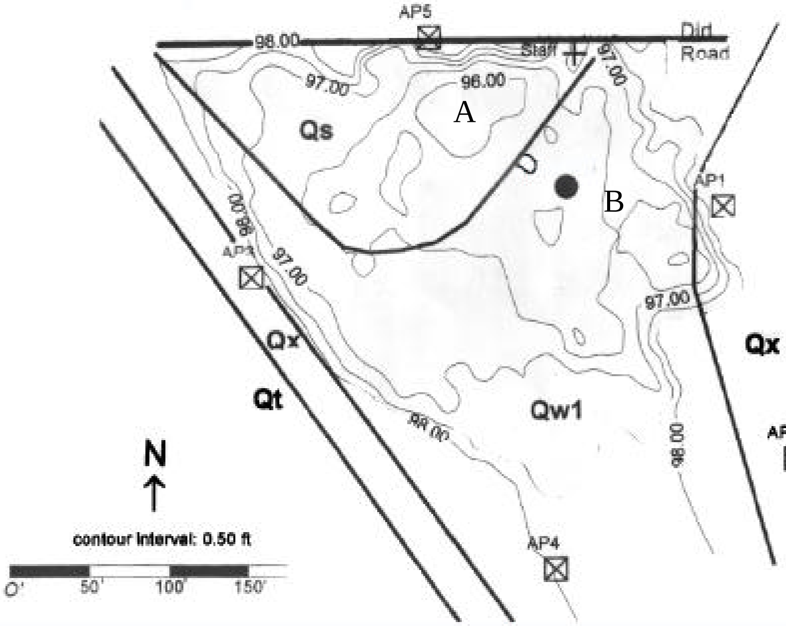


Figure 3: Detailed map of the Arboretum showing the locations of core samples.
A - location of core 2003-01 (undisturbed)
B - location of core 2003-03 (disturbed) between monitoring well and station AP1

Figure 4: Photograph of coring apparatus including a) assembling the coring tripod and b) removing core through the platform.

Several large clasts, up to 0.5 – 2 cm across, occur within these sediments. Unit II, approximately 9 cm thick, has a gradational lower contact and contains terrestrial root remains

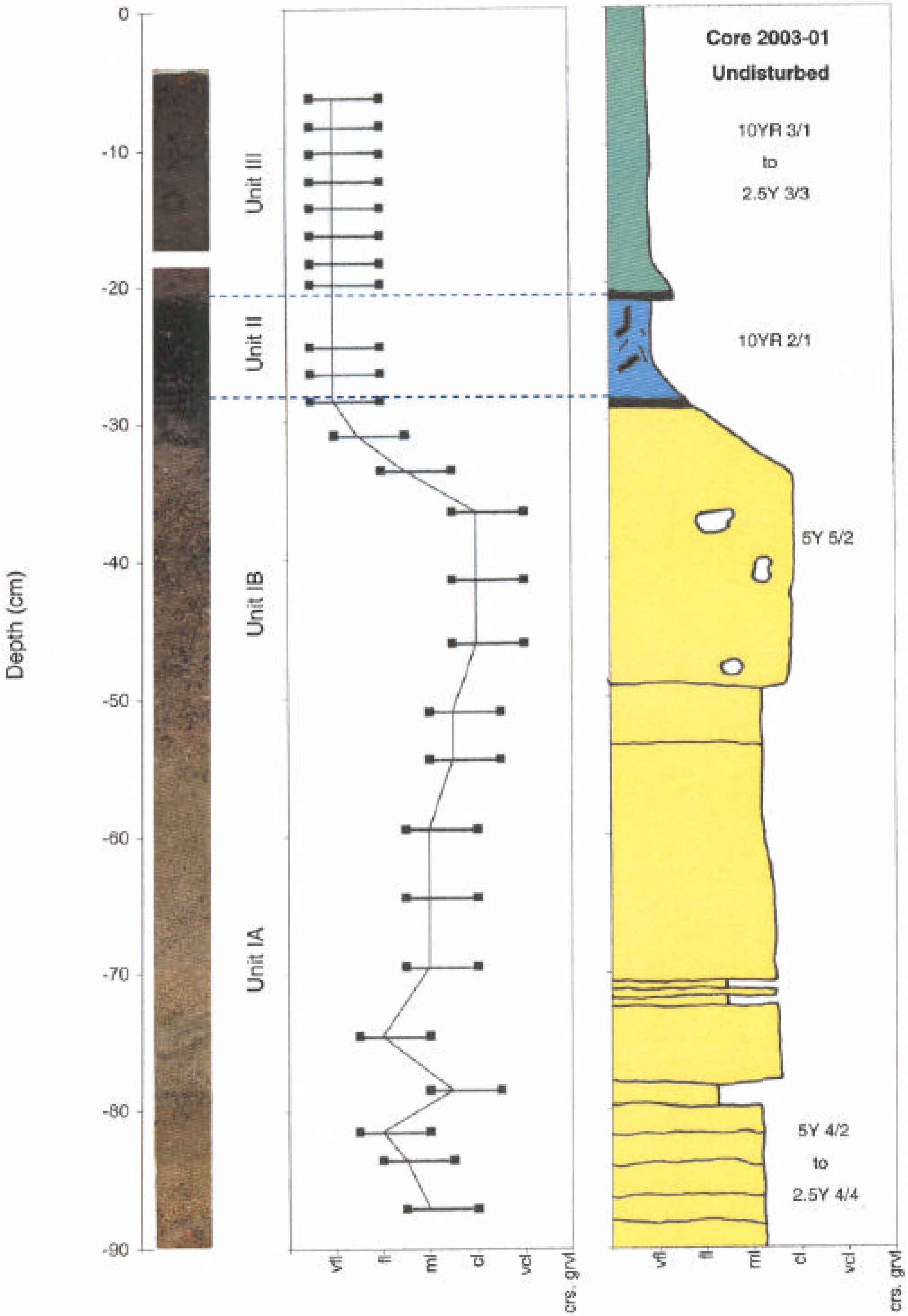


Figure 5: Photography log, visible texture mode (line) and range (bars) and graphic log for core 2003-01.

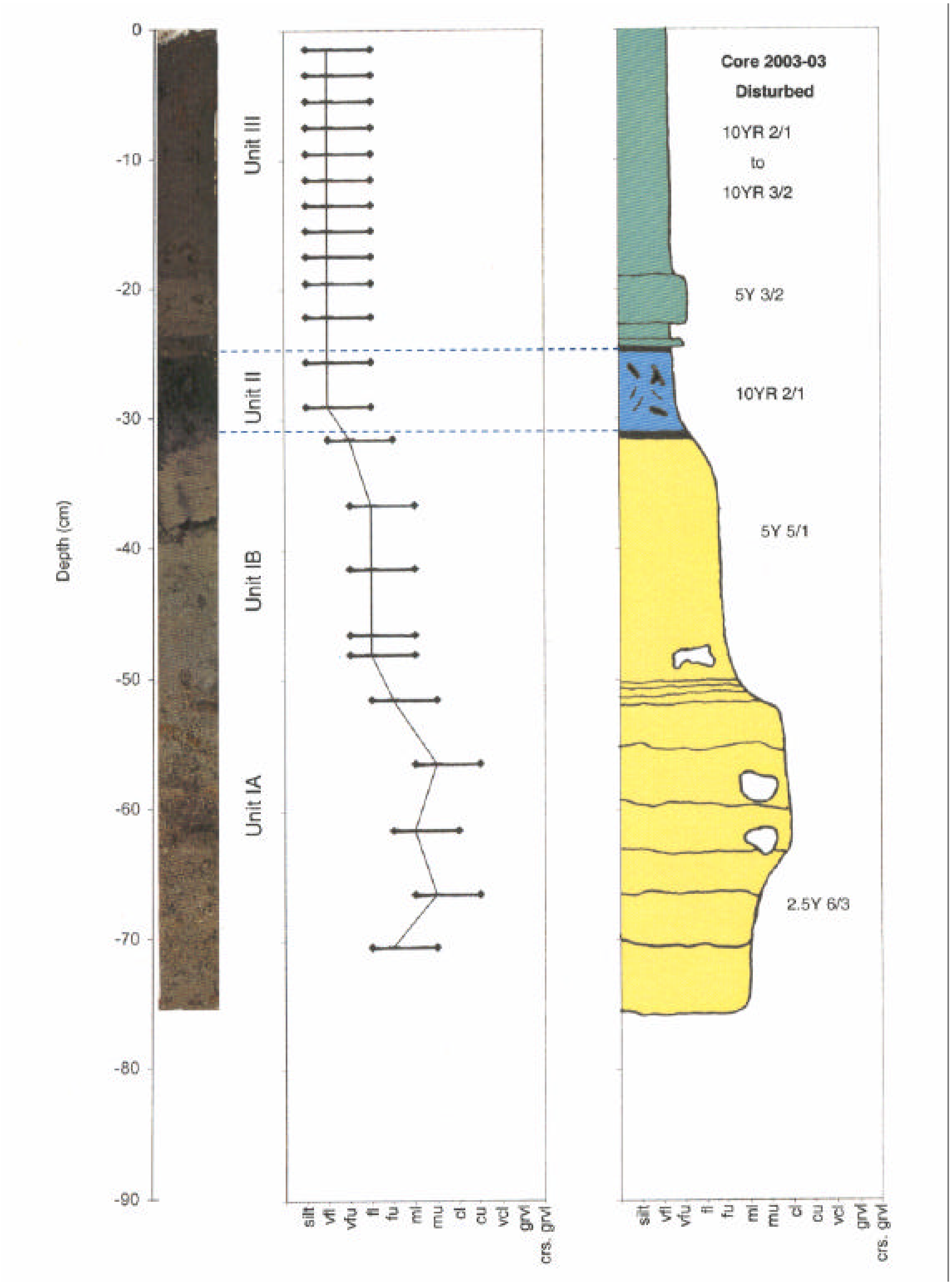


Figure 6: Photographic log, visible texture mode (line) and range (bars) and graphic log for core 2003-03.

and mud. Stringy root fragments and twigs are found throughout and there is no evidence of bedding. Unit II has a consistent black color (10YR 2/1) throughout the layer. Unit III, 16 cm thick, is separated from Unit II by an abrupt contact and is silty in its' lower portion becoming more fine grained and organic-rich upwards. The unit is compact all the way through and ranges in color from dark olive brown (2.5Y 3/3) at the bottom to very dark gray (10YR 3/1) at the top. Partially decayed wood fragments occur at the top of the unit and some small stringy root fragments are dispersed throughout.

Core 2003-03 (0.75 m) was collected at a disturbed site and is also divided into three sedimentary units that are similar to that observed in core 2003-01 (Figure 6). Unit I is >35 cm thick and can be divided into upper and lower sections. The lower section (Unit IA) is a massive coarse-grained sand. Large clasts ranging in size from 1-4 cm in diameter are dispersed through the section with a concentration at a depth of 58-62 cm. A light yellowish brown (2.5Y 6/3) remains consistent through the section. There is no evidence of stratification in the section and no presence of organics. The upper section of the unit occurs between depths of 32 cm to 52 cm. The upper section consists of fine silty/sand that fines upward. The gray color (5Y 5/1) is constant through the section. A small, mostly decomposed twig fragment present at depth 40 cm and a small break in the core due to drying occurs at 38 cm. Unit II, 8 cm thick, is separated from Unit I by an irregular contact. The composition of Unit II consists of mud; stringy root fragments and small twigs (0.5 – 1.5 cm diameter). Unit II is a black color (10YR 2/1). Unit III is 25 cm thick and is separated from Unit II by an abrupt contact but contains a slight mixing of units. The lower portion of the unit between depths of 19 cm to 25 cm is made of compact silt of color dark olive gray (5Y 3/2). Above 19 cm the unit is composed of a fine-grained organic rich gyttja that varies in color from black (10YR 2/1) to very dark grayish brown (10YR 3/2) with depth. The unit is uniformly spongy and contains small, stringy root debris.

Physical Characteristics of Sediment Cores

Both cores were analyzed for variations with depth in moisture content (% wet weight), organic and inorganic carbon (% dry weight), and magnetic susceptibility (CGS) (Figure 7). Both cores displayed similar trends in moisture content and organic and inorganic carbon. Moisture content values are approximately the same through unit I of both cores (Table 1). Core 2003-01 values average near 10 percent and Core 2003-03 values average around 15 percent and increase near Unit II. Both cores have their peak values in Unit II with Core 2003-01 reaching 80 percent and Core 2003-03 being 75 percent. Moisture content decreases at the base of Unit III but increases as you near the top of the core.

Organic and inorganic carbon values exhibit similar trends. Unit I values for organic carbon remain near 1 % increasing in Unit II. Core 2003-01 has a maximum value of 58 % and core 2003-03 has a maximum of 35 % in Unit II. Values decrease at the bottom of Unit III but increase near the top of the core. Values for inorganic carbon are similar between cores. Values for both cores are below 1 % through Unit I and start to increase into Unit II. Both cores peak in Unit III at approximately 2.25 %.

Magnetic Susceptibility is different in both cores. Core 2003-01 has a spike value in unit I at 60 cm depth, most likely due to a metal fragment. Other than this peak, values remain below

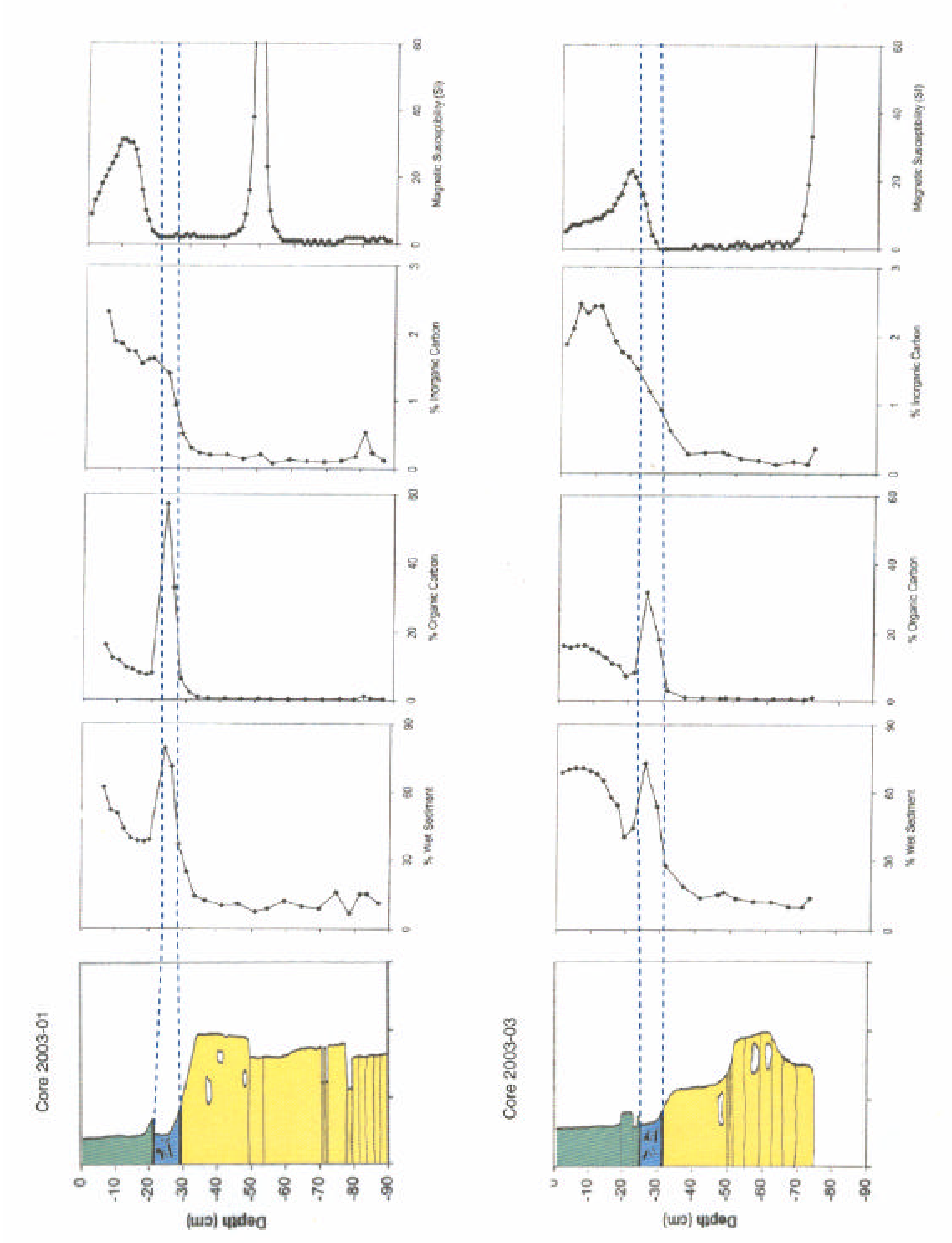


Figure 7: Physical properties including moisture content (% wet sediment) organic matter concentration (% dry mass), inorganic matter concentration (% dry mass) and magnetic susceptibility (CGS $\times 10^{-6}$ g/cm^3) for cores 2003-01 and 2003-03.

Table 1: Summary statistics for physical properties from core 2003-01 and 2003-03.

Core 2003-01 - Undisturbed

	Moisture	Organic Carbon	Inorganic Carbon
Unit III:			
Mean	50.019	16.144	1.555
Std	14.830	15.518	0.482
Unit II:			
Avg	19.454	1.615	0.278
Unit I:			
Mean	11.265	0.402	0.187
Std	2.913	0.231	0.112

Core 2003-03 - Disturbed

	Moisture	Organic Carbon	Inorganic Carbon
Unit III:			
Mean	61.896	12.992	2.065
Std	11.153	3.374	0.334
Unit II:			
Avg	63.455	25.029	1.060
Unit I:			
Mean	15.290	0.905	0.277
Std	4.945	0.731	0.139

10 in Units I and II increasing in Unit III where the highest values occur. In core 2003-03 there is a spike at the very bottom of the core possibly due to a small amount of metal from the core catcher. Above this values decrease to near zero through the rest of Unit I. In Unit II values rise and peak around 22 before decreasing upward through Unit III.

Chemical Characteristics of Sediment Cores

Results of the chemical analysis illustrate similar trends in both cores (Figures 8 and 9; Table 2). Unit I in both cores has the lowest concentrations. However, there is some variation within the cores. For example, in Core 2003-01 there is an increased concentration for most elements near 80 cm depth. Concentrations increase for most elements within Unit II. However, a few element concentrations do decrease initially in Unit II (Mg, Ti) but rise again at shallower depths in the core. Concentrations in Unit III are generally the highest. Although, within Unit III the concentrations may increase or decrease for specific elements.

Element concentrations were also compared between Units I and III to define enrichment ratios (Table 3). Enrichment ratios express the degree to which recently deposited sediments in Unit III have either increased (i.e. enriched) or decreased (i.e. depleted) as compared with elements associated with deposition before human influence (i.e. Unit I). As such, enrichment ratios allow the determination of the effects of land use change on nutrient levels and allow us to speculate on past environments.

When calculating enrichment ratios it is important to keep in mind that the presence of organic matter increases element concentrations by providing a location for the element to attach and remain in the sediments. Thus, enriched ratios based on raw concentration values, as given in Table 1, tend to overestimate enrichment because Unit III sediments have higher concentrations of organic matter. In addition to organic mater, the presence of fine-grained inorganic sediments may also influence the bulk chemistry of sediments, particularly if present in high concentrations. Unit III also has a higher concentration of fine-grained silt and clay (Figures 5 and 6). Thus, it is also helpful to normalize for the fine-grained clastic components. One approach to doing this is to divide raw concentration values by the concentration of Al, which tends to reflect the amount of clay minerals present (because clay minerals are alumino-silicates). In summary, Table 3 presents enrichment ratios based on the raw concentration values as well as normalized values against organic matter and Aluminum (Al). By factoring the organic matter out of the concentrations it is possible to compare Units I and III without the bias of differing organic matter concentrations. Aluminum normalization acts in a similar manner. Much of the regional geology and sediments are made of alumino-silicates whose chemical structure skews concentration measurements.

The enrichment ratios based on raw concentrations and normalized by organic matter and Al are given in Table 3. Enriched ratios for raw concentration data indicate that all elements are enriched in Unit III. This suggests that element concentration levels increased following construction of the Arboretum. Normalized enrichment ratios are less dramatic. In Core 2003-01 only lead (Pb) truly stands out, although manganese (Mn), sulfur (S) and beryllium (Be) may also be enriched. Enrichment values are slightly higher in Core 2003-03 with Be, copper (Cu), Mn, Pb, S and zinc (Zn) possibly being enriched. Normalizing against organic matter decreases enrichment ratios even further. Organic normalized data for Core 2003-01 indicates that only Pb has been enriched, while in Core 2003-03 only Be, Cu, Pb and S show elevated enrichment ratios.

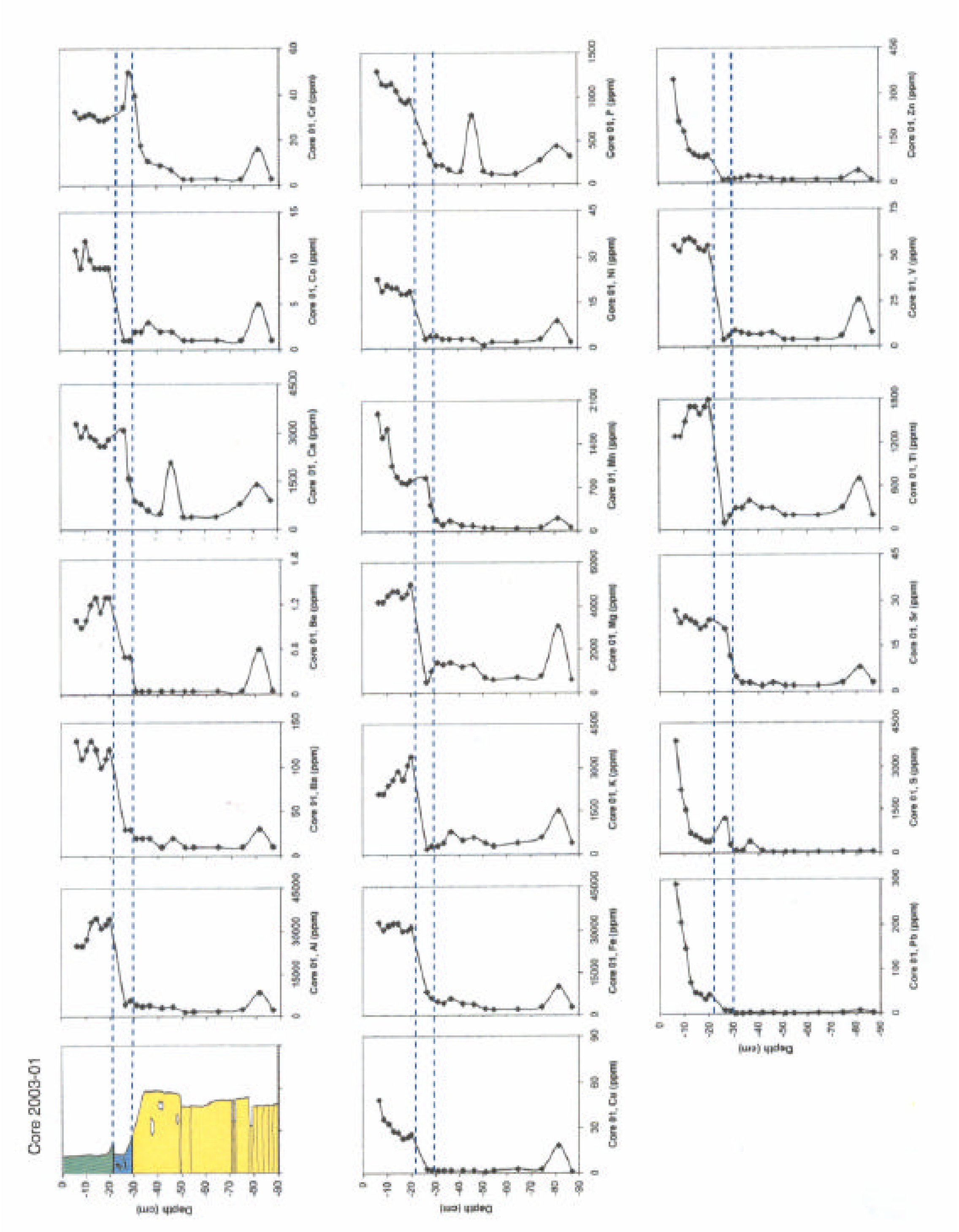


Figure 8: Profiles of chemical concentrations with depth for core 2003-01. Dashed lines identify boundaries between Units 1, 2, and 3. See text for discussion.

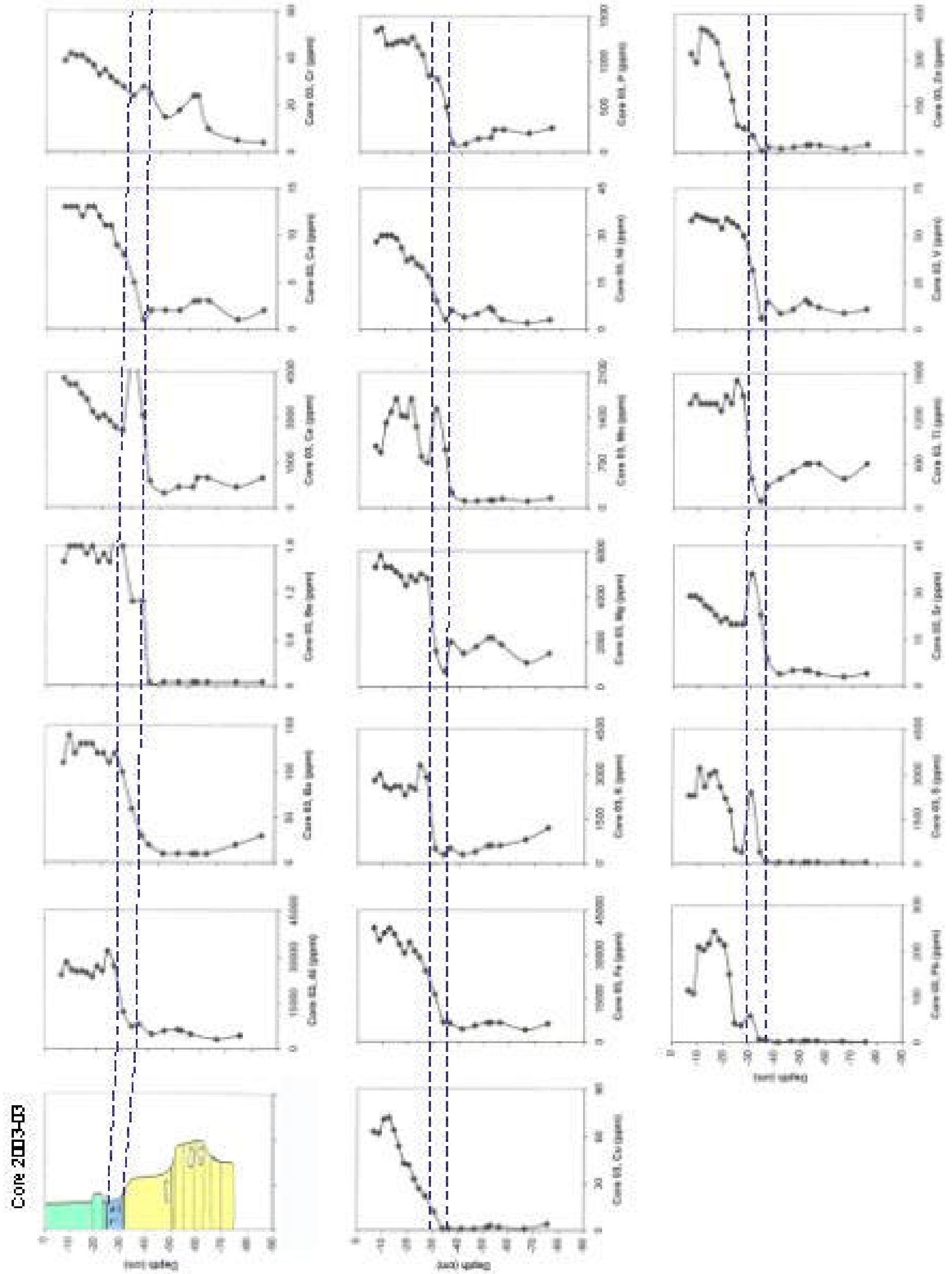
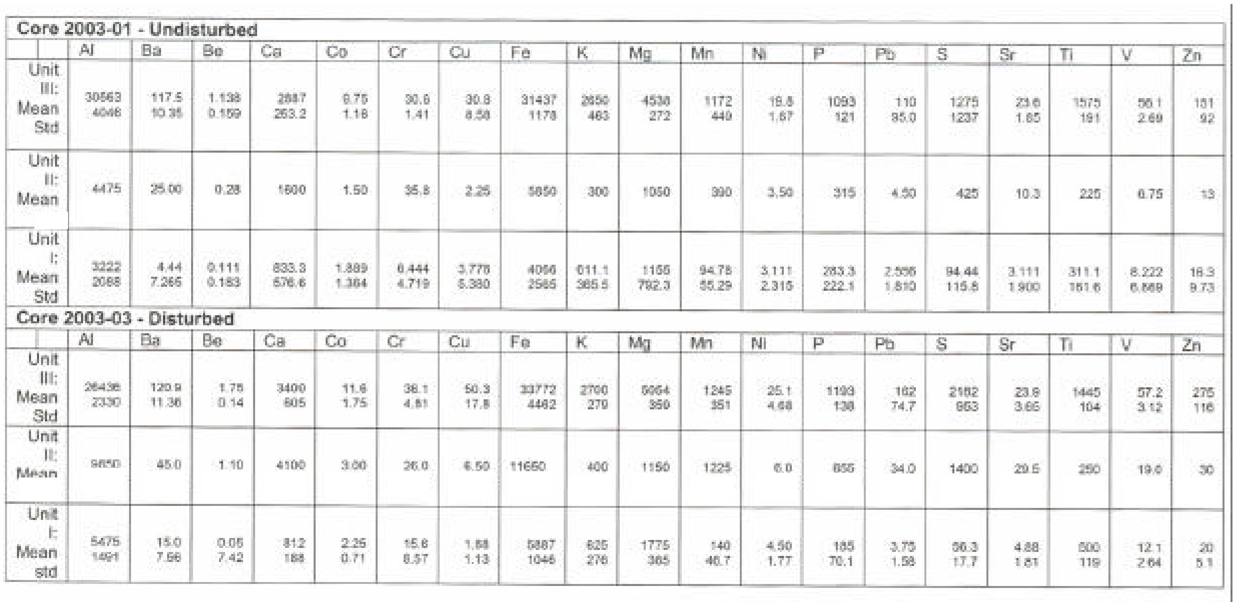


Figure 9: Profiles of chemical concentrations with depth for core 2003-03. Dashed lines identify boundaries between Units 1, 2, and 3. See text for discussion.

Table 2: Mean values and standard deviation of chemical data for Cores 2003-01 (undisturbed) and Core 2003-01 (disturbed). For Core 2003-01 n_{III}=8, n_{II}=2, n_I=12, and for Core 2003-03 n_{III}=11, n_{II}=2, n_I=8.



Core 2003-01 - Undisturbed

	Al	Ba	Be	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	S	Sr	Ti	V	Zn
Unit III: Mean Std	30563 4046	117.5 10.35	1.138 0.159	2887 253.2	8.75 1.16	30.6 1.41	30.8 8.58	31437 1178	2850 463	4538 272	1172 449	18.8 1.67	1093 121	110 85.0	1275 1237	23.6 1.85	1575 191	56.1 2.69	151 92
Unit II: Mean	4475	25.00	0.28	1600	1.50	35.8	2.25	5850	300	1050	390	3.50	315	4.50	425	10.3	225	6.75	13
Unit I: Mean Std	3222 2088	4.44 7.265	0.111 0.183	833.3 576.6	1.889 1.364	6.444 4.719	3.778 5.380	4056 2565	611.1 365.5	1156 792.3	94.78 55.29	3.111 2.315	283.3 222.1	2.556 1.810	94.44 115.8	3.111 1.900	311.1 161.6	8.222 6.869	18.3 9.73

Core 2003-03 - Disturbed

	Al	Ba	Be	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	S	Sr	Ti	V	Zn
Unit III: Mean Std	26436 2330	120.9 11.36	1.75 0.14	3400 605	11.6 1.75	38.1 4.81	50.3 17.8	33772 4462	2700 279	6964 369	1245 351	25.1 4.68	1193 138	182 74.7	2182 863	23.9 3.66	1445 104	57.2 3.12	275 116
Unit II: Mean	9850	45.0	1.10	4100	3.00	26.0	6.50	11650	400	1150	1225	6.0	855	34.0	1400	29.5	250	19.0	30
Unit I: Mean std	5475 1491	15.0 7.56	0.05 7.42	812 188	2.25 0.71	15.6 8.57	1.88 1.13	5887 1046	625 276	1775 385	140 46.7	4.50 1.77	185 70.1	3.75 1.58	56.3 17.7	4.88 1.81	500 119	12.1 2.64	20 5.1

Table 3: Mean element enrichment ratios for comparison of Units III and I and Units II and I of Core 2003-01 (Und.) and 2003-03 (Dist.)

Enrichment Ratios

Core 2003-01																			
Unit III to I	Al	Ba	Be	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	S	Sr	Ti	V	Zn
Raw Conc’s	9.49	8.13	10.23	3.47	5.16	4.75	8.14	7.73	4.33	3.92	12.37	6.35	3.86	43.19	13.50	7.59	5.06	6.83	9.30
Norm – Al	1	0.82	1.39	0.35	0.57	0.53	1.07	0.83	0.44	0.42	1.35	0.70	0.39	5.15	1.50	0.78	0.51	0.76	1.04
Norm -OC	0.46	0.36	0.64	0.15	0.25	0.24	0.42	0.37	0.21	0.19	0.53	0.30	0.16	1.69	0.49	0.34	0.24	0.34	0.38
Unit II to I																			
Raw Conc’s	1.39	1.73	2.48	1.92	0.79	5.55	0.60	1.44	0.49	0.91	4.11	1.13	1.11	1.76	4.50	3.29	0.72	0.82	0.80
Norm – Al	1	1.17	2.12	1.29	0.63	4.08	0.52	1.04	0.36	0.69	2.83	0.84	0.75	1.21	3.02	2.20	0.52	0.65	0.58
Norm -OC	0.25	0.28	0.23	0.21	0.21	0.87	0.12	0.23	0.12	0.23	0.34	0.21	0.15	0.13	0.28	0.29	0.18	0.20	0.18

Core 2003-03																			
Unit III to I	Al	Ba	Be	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	S	Sr	Ti	V	Zn
Raw Conc’s	4.83	8.06	35.09	4.18	5.17	2.31	26.81	5.74	4.32	2.85	8.92	5.58	6.45	43.10	38.79	4.90	2.89	4.72	13.77
Norm – Al	1	1.50	6.80	0.83	1.07	0.51	5.26	1.16	0.79	0.58	1.84	1.19	1.21	9.23	8.04	1.04	0.56	0.96	2.79
Norm -OC	0.32	0.43	2.11	0.23	0.30	0.16	1.26	0.33	0.23	0.18	0.54	0.35	0.34	2.67	2.22	0.32	0.17	0.29	0.70
Unit II to I																			
Raw Conc’s	1.80	3.00	22.00	5.05	1.33	1.66	3.47	1.98	0.64	0.65	8.77	1.33	3.54	9.07	24.89	6.05	0.50	1.57	1.50
Norm – Al	1	1.46	12.17	2.65	0.65	1.07	1.51	1.01	0.32	0.34	4.75	0.71	1.77	4.37	11.82	3.42	0.24	0.75	0.67
Norm -OC	0.06	0.08	0.68	0.14	0.03	0.06	0.07	0.05	0.02	0.02	0.27	0.04	0.09	0.25	0.67	0.20	0.01	0.04	0.03

Discussion

Sediment cores collected from the Arboretum Pond were analyzed for physical and geochemical properties in order to address three primary questions:

1) Have the physical and geochemical characteristics of these sediments changed through time?
2) Do these properties differ at the disturbed and undisturbed locations, and
3) Do the sedimentary records provide evidence of human induced change in or near the Arboretum?

Physical and Chemical Characteristics and Their Change Through Time

Analysis of the physical and chemical characteristics of the Arboretum cores, as described above, indicates that recent sediments (Unit III) have much higher organic contents, are finer grained, and have elevated elemental concentrations. However, when normalized for organic content and for clastic sediments, by dividing for Al, not all elements are enriched in the recently deposited sediments (Unit III). Table 3 shows that when considering both Al normalized and organic carbon normalized data in core 2003-01 only Pb is enriched. Similarly, in core 2003-03 only Be, Cu, Pb and S are enriched for both normalized parameters.

Physical properties of the sediments have changed through time, reflecting major changes in depositional environments. In both cores Unit I is composed of coarse-grained sediments that have low organic matter contents. These sediments likely have a glacio-fluvial origin. Unit II in both cores consists of dispersed terrestrial rootlets with higher organic contents including several twigs. There is no stratification in Unit II suggesting that it was not laid down by water. Unit II therefore is interpreted as a soil horizon that formed on the underlying glacio-fluvial sediments. Unit III, as detailed above, has much higher fine-grained content and organic concentration. This indicates deposition within standing water that would have existed once the Arboretum was dammed. It is interesting to note that there is a high concentration of silt at the bottom of Unit III in both cores. This likely reflects an initial introduction of sediments to the newly formed basin at a time when construction activities would have increased erosion and the amount of sediments entering the drainage basin.

Chemical concentrations have also varied through time, largely reflecting change in the physical character of Units I, II, and III. Elemental concentrations remain low through Unit I due to a low concentration of organic matter (Table 2) and because of the dominance of inorganic mineral constituents. Raw concentrations begin to increase through Unit II and into Unit III. Much of this increase can be attributed to the high organic content and fine grain sediment present in Unit III (Table 3).

It is also useful to compare variations in element concentrations with depth in cores 2003-

01 and 2003-03 for those elements enriched in Unit III, see Figure 10. For both cores, chemical profiles display changes related to sedimentary units previously. In fact, Units I and II are very similar in both cores. Only Unit III differs suggesting that disturbances caused by hydrologic sampling did not extend into Unit II or Unit I, probably because Unit III is softer and more easily disturbed. Within Unit III differences between the cores are evident near the sediment water interface, where disturbed concentrations decrease. Also, the disturbed profile has more irregularities with depth, than do profiles from the undisturbed site. Thus, it is not wise to seek high resolution cores from disturbed sites.

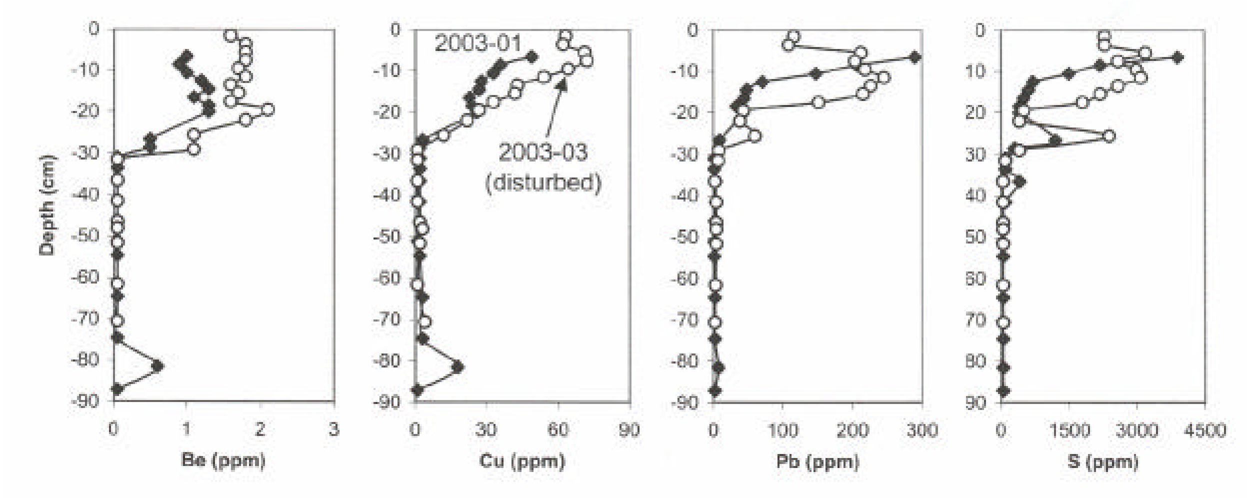


Figure 10: Comparison graphs of enriched elements, after normalizing, for both cores. The black diamonds represent core 2003-01 (undisturbed site) and the empty circles represent core 2003-03 (disturbed site).

Differences Between Undisturbed and Disturbed Sites.

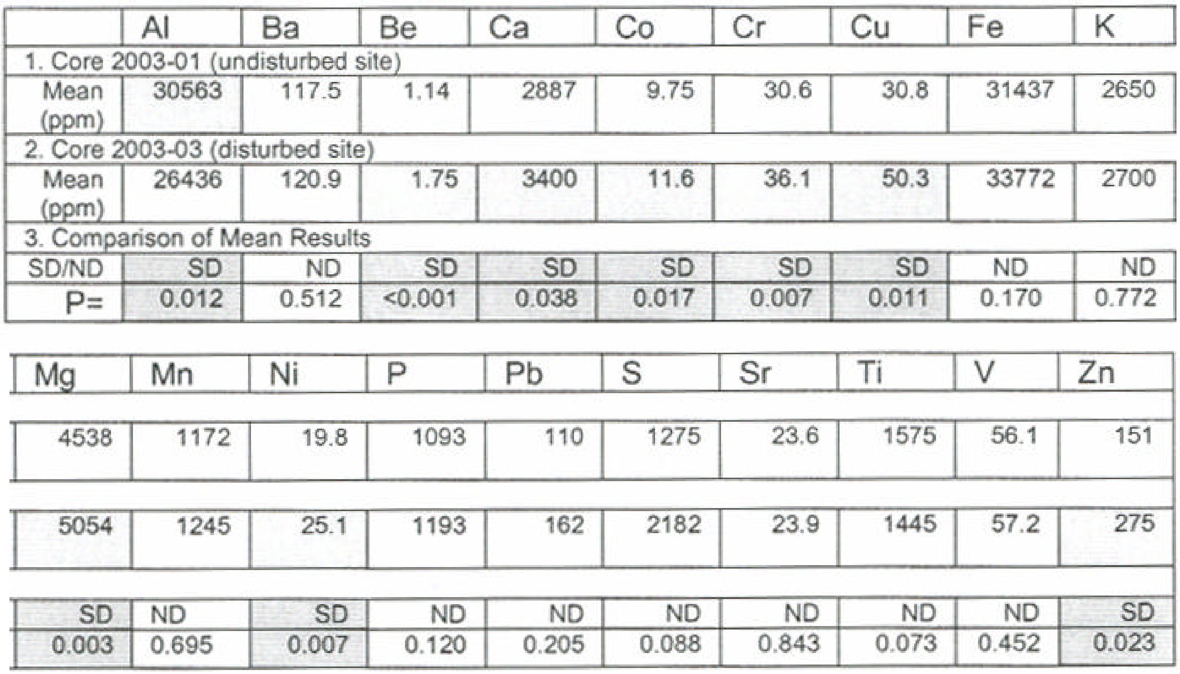
Cores were specifically collected to determine whether disturbances caused by hydrologic sampling were linked to disruptions in the sedimentary records. The degree of disturbance may be evaluated by comparing: 1) mean concentrations for Unit III in cores 2003-01 and 2003-03 and 2) by comparing element profiles, focusing on those elements that are enriched in Unit III.

Mean concentrations for all samples are presented in Table 2, while Table 4 presents the results of t-tests comparisons of means. Table 4 shows that 9 of the 19 elements differ significantly at the $p<0.05$ level with Unit III of core 2003-03 (disturbed) having the highest concentration values. For some elements there is a clear difference in concentrations but overall most elements do not differ significantly.

Sediment Profile Difference and Human Activity.

Only certain elements are enriched when normalized for aluminum and organic matter. Of all the elements Pb, Cu and perhaps S are most likely related with human activity. Hydrologic studies by Carlson (1999) revealed elevated concentrations of iron and manganese in the water column. However, sedimentary records do not indicate substantial enrichment in these elements, when normalized by Al or organic matter.

Table 4: Comparison of means for Unit III of core 2003-01 (undisturbed) and 2003-03 (disturbed). Shaded cells indicate elements which differ significantly between the two cores.



	Al	Ba	Be	Ca	Co	Cr	Cu	Fe	K
1. Core 2003-01 (undisturbed site)									
Mean (ppm)	30563	117.5	1.14	2887	9.75	30.6	30.8	31437	2650
2. Core 2003-03 (disturbed site)									
Mean (ppm)	26436	120.9	1.75	3400	11.6	36.1	50.3	33772	2700
3. Comparison of Mean Results									
SD/ND	SD	ND	SD	SD	SD	SD	SD	ND	ND
P=	0.012	0.512	<0.001	0.038	0.017	0.007	0.011	0.170	0.772

	Mg	Mn	Ni	P	Pb	S	Sr	Ti	V	Zn
1. Core 2003-01 (undisturbed site)										
Mean (ppm)	4538	1172	19.8	1093	110	1275	23.6	1575	56.1	151
2. Core 2003-03 (disturbed site)										
Mean (ppm)	5054	1245	25.1	1193	162	2182	23.9	1445	57.2	275
3. Comparison of Mean Results										
SD/ND	SD	ND	SD	ND	ND	ND	ND	ND	ND	SD
P=	0.003	0.695	0.007	0.120	0.205	0.088	0.843	0.073	0.452	0.023

Summary

The most important findings from this study are:

1) Three sedimentary units are preserved in both the disturbed and undisturbed cores.
2) Basal Unit I is coarse-grained, organic poor and is interpreted as glacio-fluvial sands. Unit II has high organic contents and no stratification and is interpreted to be a submerged soil horizon. Unit III has high concentrations of fine-grained sediments and organic matter and was deposited in the Arboretum pond.
3) All raw element concentrations are substantially enriched in Unit III, although much of this may be due to higher organic content and fine-grained sediments.
4) The chemistry of the cores shows enriched levels of Be, Cu, Pb, and S in Unit III, when normalized for Al and organic matter, with the highest concentrations found in core 2003-03 (disturbed).
5) The chemical profile of core 2003-03, the disturbed site, is much more irregular and has higher concentrations than core 2003-01, suggesting that disturbed sites are unsuitable for detailed core studies.
6) Pb has been enriched more than any other element, when normalized for Al and organic matter. This most likely reflects the introduction of Pb from runoff and sediment inputs two the Arboretum in relation to past construction activities.

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