Investigating Physical and Chemical Properties of Sediments in Relation to Spatial Variability Across Lake Louise, Georgia

Author
Amie Leandro

Advisor
Dr. James A. Hyatt

A report submitted to the department of
Environmental Earth Science
in conformity with the EES 480 requirements

Eastern Connecticut State University
83 Windham Street
Willimantic, CT 06226

ABSTRACT

Lake Louise is a coalescent sinkhole lake located in Lowndes County, southern Georgia. Previous studies indicate that construction of a nearby interstate highway in 1957 introduced significant quantities of sediment into the lake, but the characteristics of the resulting silt layer vary with location. This variability may influence chemical concentrations of lake bottom sediments.

This study examines more than 190 samples collected from three sites across the primary inflow basin of the lake at water depths of 6.1, 5.4, and 4.5 m. Analysis of physical characteristics identify four zones within the uppermost ~ 4.5 m of the lake sediment. Basal zone I, at least 1.3 m thick, consists of organic rich gyttja with small increases in moisture content and organic carbon concentrations, decreasing dry bulk densities, and no consistent trend in inorganic carbon contents moving up core. Zone II displays less well defined yet opposite trends of declining moisture content and organic carbon concentrations, slight increasing in dry bulk densities upwards in the core. The most dramatic changes occur in the silty sediments of zone III, which are characterized by a sharp increase in dry bulk densities, by as much as a factor of 15, and sudden decreases in moisture content, organic carbon and inorganic carbon concentrations. Theses trends reverse in the upper half of zone III and continue upwards through zone IV but at a reduced rate.

Correlations between sites indicate that the thickness and concentrations of sediments in these zones change across the lake, most notably in zone III. This zone is thickest (0.09 m) in the deepest part of the basin, decreases to 0.05 m at intermediate depths, and it is difficult to determine thickness near the lake side. Sediment densities and inorganic sediment concentrations in zone III also decrease with water depth by as much as a factor of 60. Comparisons of the spatial variations in physical properties with similar trends in metal concentrations, as determined by aqua regia digestion and ICP-AES, show an overall increase in chemical masses in zone III.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Human alteration of the environment is often recorded in the nature of sediments deposited in lakes. However, sediments entering lakes are not distributed evenly. Consequently, it is important to consider the spatial variability of sedimentary deposits when reconstructing environmental change. This study investigates sediment records of human induced change in Lake Louise, a small research lake in South Georgia that is owned by Valdosta State University (VSU). Research is based upon several sediment cores collected in June 2004 with the assistance of Dr. James A. Hyatt and Todd Ostrowski from Environmental Earth Sciences at ECSU, Dr. Brevik and several students from Valdosta State University.

The primary focus of this study is to define variations in the sedimentary record with depth below the lake bottom and at varying locations across the lake. As such, the specific objectives for this report are to:

1. Define variations in physical properties with depth (moisture content, bulk density, organic carbon and inorganic carbon concentrations);
2. Identify spatial trends across the lake based on physical properties; and
3. Determine if similar cross-lake trends are reflected in chemical analyses of sediment sub samples.

CONTROLS ON SPATIAL VARIABILITY OF SEDIMENTATION IN LAKES

Sediment deposits in lakes are an available record of past events that contain chemical and physical indicators of environments and environmental change. Core analyses from specific sites are typically extrapolated to the entire lake (Smol, 2002). However, sediment deposits in lakes can vary spatially, commonly creating thicker layers in the deeper parts of the lake (Axelsson, 2004; Dearing and Foster, 1993; Meyers and Ishiwatari, 1995; U.S.G.S, 2004). This preferential deposition in deeper basins, or sediment focusing, effects the accumulation rate at a given location due to the combination of processes active in a particular lake basin. As sediments accumulate the bottoms of lakes are leveled. This gradually decreases the holding capacity of lakes and may be of concern for people using lakes. As a result, dredging is sometimes necessary, particularly for reservoirs (Blais and Kalff, 1995; Davis and Ford, 1982; Lehman, 1975).

PROCESSES THAT REDISTRIBUTE SEDIMENTS IN LAKES

Processes that influence the spatial variability of sedimentation include stratification in the water column, river inputs, organic production, wave action, and slope processes. The effectiveness of these processes depends upon sediment characteristics, basin morphology and organic decomposition in a lake.

A stratified lake has warm waters above cold waters. This prevents the mixing of the lake waters which distribute oxygen from the surface to the deeper parts of the lake. Oxygen is used for decomposition at the bottom of the lake and when depleted leads to anoxic conditions. Oxygen poor environments greatly hinder decomposition of organic material. Therefore, apparent accumulation rates in the lower portion of lakes may be greater than in more shallow oxic waters near lake margins. If top waters cool to temperatures less than that occurring in deeper waters, a turn over of water will occur providing a re-suspension of sediment into the water column. The thickness of sediment deposited is related to the amount of water above the location of the deposition because the sediment volume in the water column is distributed equally during overturn. Since there is a larger volume of water above deeper locations in lakes, a larger amount of the sediment will be present and available for deposition. By way of comparison, in shallow areas the water column volume is smaller and less sediment is available for deposition. Thus, more sediment is often deposited in the deeper parts of the lake where the water column is larger than in the shallow portions of the lake with smaller volumes (Hilton, 1985).

As sediments are carried by rivers into low energy lake environments, settling occurs, particularly near the mouth of the river but also continuing out into the lake thereby forming deltas. Coarser textured sediments are typically deposited near the mouth of the river, decreasing in size further into the lake due to the decreasing competency and declining current velocity. Storm events can increase sediment volume entering the lake resulting in depositional events in the stratigraphic record (Hilton et al., 1986).

Organic matter enters lakes from a variety of sources both internal and external to the lake. Rivers provide a large source of organic material by delivering plant and other organic matter from upstream locations. Other inputs include wind transporting matter such as leaf debris and overland flow from surrounding lands washing organic matter into the lake. Within the lake, organic blooms can produce thick accumulation of algae or other materials that may cover the lake's surface, die, and settles to the lake bottom and undergo decomposition. As well organic material along the lake edge may be redistributed to deeper locations in the lake by turbidity currents. Organic blooms and eolian input introduce organic sediments evenly across the lake, but the thickest accumulation will occur in horizontal areas of the lake bed. On slopes accumulation per unit area is reduced resulting in a thinner layer. Bacterial decomposition of sediments reduces accumulation rates. In near surface oxic waters bacterial decomposition of the organics reduces the amount of sediment being deposited. In contrast, bacterial activity is hindered by anoxic conditions which are more common in the deeper portions of lakes (Hilton and et al., 1986; Hilton, 1985).

Wave action produced by wind erodes pre-existing bottom sediments and re-suspend materials. Erosion occurs in shallow lake margins while other processes such as turbidity currents transport the re-suspended sediments to deeper accumulation zones. The amount of wave energy depends upon wind intensity, the duration, and the span of open water in the direction of blowing wind. Waves transfer motion through the water column causing water particles to move along orbital paths. The re-suspension and reworking of the sediment is influenced by the physical properties of the sediment such as grain size and cohesiveness. Less cohesive material require less energy to be re-suspended while more cohesive sediment can resist the erosive forces of the waves. (Håkanson, 1977; Håkanson, 1981; Hilton, 1985).

Slopes in lakes are more of a transportation zone for sediments than an accumulation area. For example, slumping and sliding of material due to slope failure can deliver a great amount of sediment to deeper parts of the lake. Even low slope angles of 4% can deliver sediments by density currents that travel along to the bottom eventually losing competency. Furthermore, sediments are unlikely to accumulate on high angle slopes due to the kinetic energy of turbidity currents overcoming the frictional resistance on the slope. This can result in turbidity currents bypassing steep slopes to deposit sediments in the bottom of the basin (Blais and Kalff, 1995; Håkanson, 1981; Hilton, 1985; Hilton and et al., 1986).

STUDY SITE

Lake Louise, a small (5 ha) blackwater lake in Lowndes County, Georgia, located 12 km south of Valdosta, Georgia has formed into two coalesced sinkholes. The lake contains one in flowing and one out flowing stream, it is surrounded by heavily vegetated swamplands, and the lake is about 130m east of Interstate-75 (I-75). The lake contains two basins with depths of 6.4 and 6.1m (Bearden, 1997; Ekstrom, 1996). Water flowing through the swamplands has a black tea-like color due to acids produced from decaying organic matter. Also the lake is stratified in the summer but may mix intermittently throughout the rest of the year. Steep slopes occur along the sides of the lake basin leading to a relatively uniform lake bottom. Therefore, sediment deposition on the sides is likely controlled by slope processes of sliding and slumping, while deposition on the flat bottom reflects sediment focusing, leveling and filling (Bearden, 1997).

The primary inflow channel at the north end of the lake has carried a large amount of silt into the lake over time particularly following construction of nearby I-75 in 1957 across the stream 130 m east of the lake (Ekstrom, 1996). A silt layer deposited at this time has since become buried by approximately 20 cm of black organic-rich lake sediment referred to as "gyttja." This silty layer is a valuable reference horizon that may be used to analyze patterns of sediment spatial variability within the lake.

Studies by Bearden (1997) and Ekstrom (1996) have previously examined aspects of the near-surface sediments in this lake. Bearden (1997) examined the spatial variability of the highway derived silty layer in the south basin of the lake. He identified qualitative trends of increasing inorganic sediments toward the center of the lake basin associated with the introduction of sediment during highway construction. Ekstrom (1996) found greater inorganic concentrations in the northern basin of the lake presumably due to this basin's proximity to the main inflow channel. Ekstrom (1996) also noted increased clastic sediments associated with highway construction and she reported large quantities of metal were introduced to the lake due to the inflow of highway derived sediments.

RESEARCH METHODS

Sediments were extracted using a piston coring technique at selected locations as measured with a Trimble Geoexplorer GPS (accurate to ± 3 m). Bathymetry along the transect was imaged using Lorance X-10 echo sounder to determine water depths along the profile. Subsamples from sediment cores, either extruded or taken volumetrically with a syringe, were analyzed for organic and inorganic concentrations, dry bulk densities, and moisture content.

Field Methods

A total of 15 core drives were recovered from 3 sites, with composite core depths to 4.5 m below the lake bed. These cores were recovered along a transect crossing the lake from the lake's only inflow channel on the west bank to the east side of the lake (Figure 1). Cores were collected from a platform constructed on two jon boats through water depth of 6.1, 5.4, and 4.5 m. Coring focused on three sites along the transect: (1) near the center of the lake basin (74.7 m) from the west shore, 55 m from the east shore, 6.1 m deep), (2) at a location part way up the basin's side slope (104.7 m from the west shore, 35 m from the east shore, 5.4 m deep), and (3) in shallow water 119.7 m from the west shore, 20 m from the east shore, and 4.5 m deep.

Two coring techniques were used in order to ensure recovery of the sediment water interface, and a sufficient depth of penetration for subsequent analyses. The water interface was recovered using a 7.5 cm diameter plexiglas piston core (clear core) with a rubber stopper to prevent the sediment from washing out upon recovery. These cores were subsequently extruded upward in 1 to 2 cm intervals, double bagged to prevent moisture loss, and transported to ECSU (Figure 2). In addition, a Wright square rod piston corer was used to retrieve several ~1 m long overlapping core drives with a total depth of penetration ~3.4 m. These cores (split core) were extruded horizontally in the field into split shells (Figure 3). The shells were then double wrapped and placed into cold storage prior to transport to ECSU.

Laboratory Methods

Sub-samples from the three clear cores were homogenized in the bags and extruded through a cut corner into two vials, one for chemical analyses and the other for moisture content, bulk density and organic/inorganic determinations. The split shell samples were sampled volumetrically every 10 cm with a 60 cm^3 syringe. Chemistry samples were collected from the surrounding area with HCL washed plastic tools. Cores were logged for Munsell color making note of any silt or notable debris. Moisture content was determined by oven drying samples at 105ºC for 24 hours to determine the percent mass lost. Wet and dry bulk densities were calculated from the wet or dry mass divided by the original wet volume respectively. Organic and inorganic fractions were determined by standard loss of ignition techniques (LOI) with firings at 550ºC for 4 hours for organic carbon LOI, and at 950ºC to infer inorganic carbon LOI %. All data are presented as raw LOI percentages. Selected samples were submitted for multi element scans using partial digestion by aqua regia and inductively coupled plasma-atomic emissions spectra technique. All chemistry analyses were preformed by Chemex Incorporated on dried ground samples.

RESULTS

Analysis of subsamples for clear core and split core at site 1 through site 3 reveal variation in moisture content, dry bulk density, organic carbon by mass LOI at 550°C,

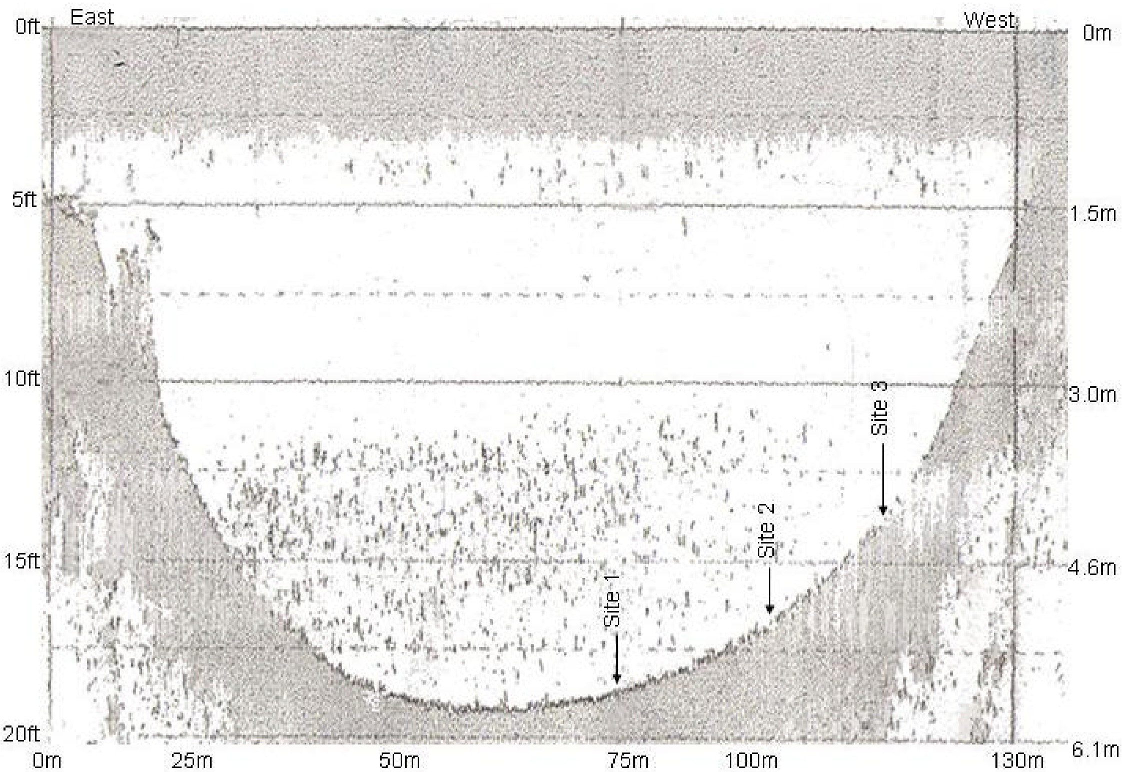

Figure 1. Echo sounding plot along sampling transect. Depths are 0.4m greater than indicated on scale.

and inorganic carbon expressed LOI at 950°C both with depth and across the lake. The following summarizes trends with depth from the lake bottom to ~0.8 m clear core depth, and to ~3.5 to 4.5 m split core depth. In addition, in order to bring core data sets together and consider cross-lake variability, the following compares physical properties for replicate sub-samples from both core sets.

Results presented below refer to four "zones" numbered from bottom of the core upwards. These zones are identified based on qualitative changes in physical properties with depth in each core.

Variations with depth in split core

Figure 4 presents variations in physical properties with depth in split core from approximately 4.5 to 0.2 m depth below the lake bed. It is important to note that the uppermost 0.6 m in these cores overlap with sediments in the clear cores described subsequently. In general two zones are well represented, reflecting different rates of change in physical parameters with depth: Lowermost zone I is characterized by slight increases in moisture and organic carbon, decreasing dry bulk density, and no consistent trend in inorganic carbon moving up core. Zone II displays less well defined yet opposite trends of decreasing moisture and organic carbon, and increasing dry bulk density trend upwards in the core. Zones III and IV are not well sample in these cores.

Figure 2. Vertical extrusion of "clear" core samples in the field.

Figure 3. Horizontal extrusion of "split" core samples using the Wright square rod piston corer.

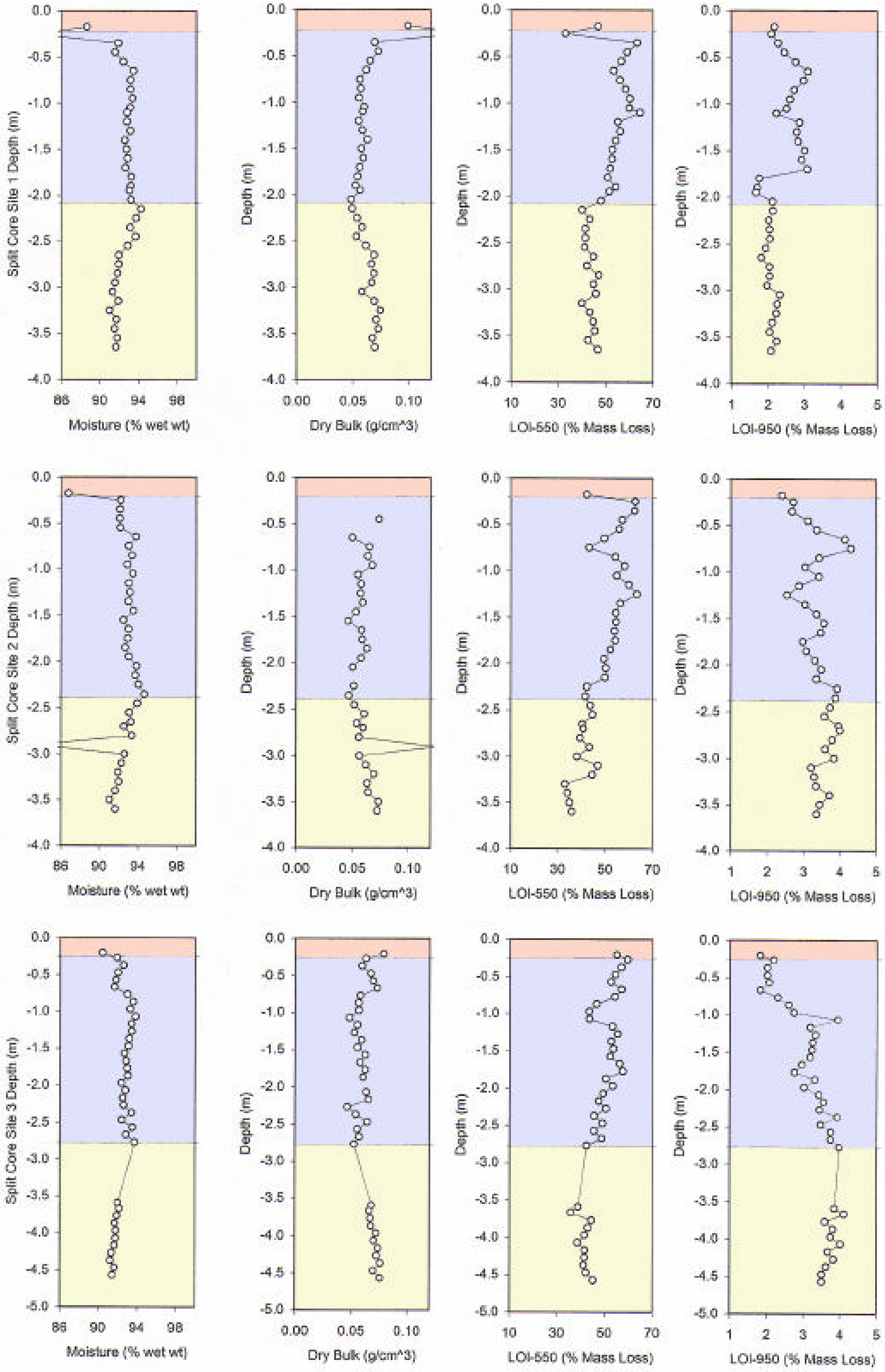

Figure 4. Physical characteristics for split core samples based on volumetric syringe subsamples.

Although subtle changes in physical properties occur for zones I and II, descriptive statistics (Table 1) for these zones do not differ markedly. Mean moisture content for zones I and II differ by less than 2% at all three locations, while standard deviations for zones I and II are also similar, typically ranging from 0.26 to 1.05. Dry bulk density values (means and standard deviations) are similar for zones I and II at all sites. The most obvious difference between zones I and II descriptive statistics occurs for LOI organic carbon. At all three sites zone I mean concentrations vary between 41.30 and 43.39% by dry weight whereas mean values for zone II range from 51.33 to 55.49%. High temperature burn data do not reveal substantial difference between zones I and II.

Variations with depth in clear core

Variations in moisture content, dry bulk density, organic and inorganic carbon with depth in clear core reflect changes in zones II, III, and IV (Figure 5). In general zone II sediments show consistent values with depth for moisture, dry bulk density and organic carbon up to the contact with zone III. The transition to zone III is characterized by a sharp increase in dry bulk density and a sharp decrease in moisture, organic and inorganic content with a rapid decline of the trends up to zone IV. Moisture contents in zone III are lower but most variable at site 1 (with a mean of ~68% and a standard deviation of ~13), increasing slightly at site 2 (76%) and site 3 (89%). The variation also decrease substantially for site 1 to site 3 (Table 1). Interestingly moisture minimum values increase from 47.45% at site 1 to 61.56% at site 2 to 87.64% at site 3. Moisture, organic, and inorganic contents generally increase upward through zone IV while dry bulk density decreases slightly. Average basal zone IV mean moisture increases from 87.60% at site 1 to 91.52% at site 2 to 93.39% at site 3.

Dry bulk densities display inverse trends to that of moisture content. Densities increase dramatically across the zone II/III contact with mean values in zone III of 0.38 at site 1 to 0.27 at site 2 to 0.11 at site 3. Averages decrease upwards in zone IV to 0.13 at site 1 to 0.08 at site 2 to 0.06 at site 3. An unusually high density value of 0.79 g/cm^3 occurs in zone III at site 1.

Organic carbon concentrations in the clear cores decreases very substantially (by up to 35% for mean values) across the Zone II/III contact. Mean organic concentrations in zone III vary from 20.06 at site 1 to 25.01 at site 2 to 41.82 at site 3. A less dramatic change occurs in zone IV with organic concentrations decreasing to 30.67% (site 1), 38.36% (site 2), to 45.80% (site 3). Inorganic carbon concentrations displays similar but muted trends to those seen in organic carbon. In general values decline from zone II to a minimum in zone III, before increasing slightly in zone IV.

Comparing split core and clear core samples

Figure 6 and Table 2 present comparisons between samples from split core and clear core that were collected at similar depths. Individual plots in Figure 6 include values plotted against depth for each core type, with summary mean values and ±1 standard deviation displayed below the plots. Moisture contents (Fig 6a) for samples

Table 1. Descriptive statistics describing variations in physical properties with depth for split and clear core at sites across the lake.

		Moisture			Dry Bulk Density			Organic Carbon			Inorganic Carbon		
		Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Number	Zone 4	10	16	20	10	16	20	10	16	20	10	16	20
	Zone 3	11	4	6	11	4	6	11	4	6	11	4	6
	Zone 2	26	32	33	26	32	32	26	32	33	26	32	33
	Zone 1	17	13	11	17	13	11	17	13	11	17	13	11
Mean	Zone 4	87.59	91.52	93.39	0.13	0.08	0.06	30.67	38.36	45.80	2.31	2.48	2.06
	Zone 3	68.24	76.13	88.98	0.38	0.27	0.11	20.06	25.01	41.82	2.08	1.68	1.90
	Zone 2	92.43	92.88	93.04	0.07	0.06	0.06	55.49	54.71	51.33	2.58	2.73	3.04
	Zone 1	92.27	91.83	91.73	0.06	0.07	0.07	43.39	41.80	41.30	2.10	3.62	3.70
Std	Zone 4	5.00	4.17	2.54	0.06	0.04	0.03	7.32	7.99	4.32	0.12	0.17	0.13
	Zone 3	13.44	9.89	1.12	0.20	0.13	0.01	11.33	10.08	4.08	0.34	0.19	0.11
	Zone 2	1.05	0.76	0.80	0.02	0.02	0.01	4.65	5.88	4.22	0.44	0.77	0.51
	Zone 1	0.92	2.58	0.26	0.01	0.02	0.00	2.21	3.28	2.56	0.13	0.27	0.26
Max	Zone 4	96.64	96.87	96.84	0.19	0.15	0.11	43.57	55.28	51.88	2.60	2.77	2.35
	Zone 3	90.10	88.67	91.24	0.79	0.45	0.13	49.29	41.25	50.30	2.65	1.92	2.02
	Zone 2	96.87	94.64	96.55	0.12	0.09	0.09	64.21	63.92	57.60	3.61	4.30	3.98
	Zone 1	94.29	93.91	92.19	0.07	0.13	0.08	47.18	46.95	45.22	2.33	4.14	4.11
min	Zone 4	82.24	85.23	89.03	0.03	0.03	0.03	22.49	28.47	36.63	2.16	1.98	1.77
	Zone 3	47.45	61.56	87.64	0.09	0.09	0.09	10.55	14.49	39.20	1.44	1.48	1.68
	Zone 2	90.12	90.93	91.53	0.05	0.05	0.03	48.13	41.62	42.48	1.68	1.65	2.22
	Zone 1	91.03	83.38	91.25	0.05	0.05	0.07	40.02	35.57	35.84	1.83	3.21	3.14

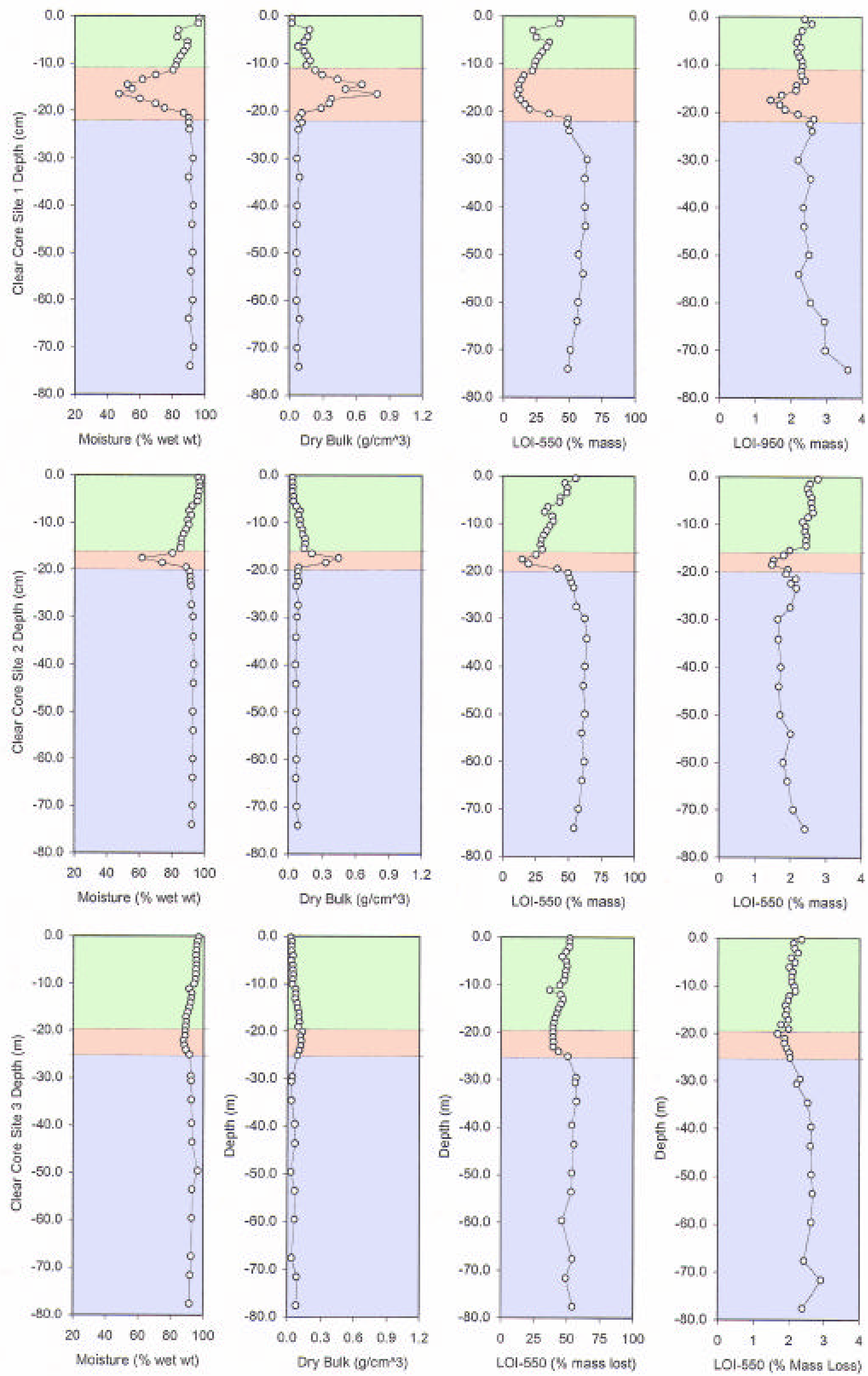

Figure 5. Physical characteristics for clear core samples based on vertically extruded volumetric samples.

from each type of core are very similar at all sites, with mean values differing by less than 1%. In Figure 6b dry bulk density values are also similar although there are fewer data to compare at site 2. Organic LOI-550 (Fig 6c) at all three site are broadly similar with mean ±1 standard deviation ranges overlapping at all three sites. In Figure 6d inorganic concentrations show the poorest agreement between cores with values being similar for the two core types at site 1, split cores having higher values at site 2, and clear cores higher at site 3. Given these discrepancies LOI-950 data are not considered further in subsequent analyses.

Chemical variations with depth

Figure 7 presents plots of variations in bulk density and concentrations for Al, Cr, Cu, Fe, P, Pb, and Zn with depth for all sites. Trends across the lake are shown by comparing the vertically stacked plots for each element. Elemental concentrations in almost all cores are lowest in zone II, increase dramatically in zone III and either continue to increase upward through zone IV (Al, Cr, Fe) or decrease slightly before increasing upward in zone IV (Cu, P, Pb, Zn). Generally, actual concentrations for elements in the same zones are similar and do not change markedly from one site to the next. For example Pb concentrations for all three sites are about 25 ppm in zone III and increase to a concentration of about 75 ppm in zone IV. Except for Al and Cr, concentrations are higher in zone IV than in zone III for all elements, with Al and Cr decreasing in zone IV.

DISCUSSION

Observations presented above indicate a number of important trends with respect to physical characteristics of the cores (moisture, bulk density, and LOI). Variations in physical characteristic define four zones in the sampled sediment. The lower two zones (I and II) are very similar and differ substantially from the shallower zones III and IV. Comparisons of physical parameters for the two core types (split core versus clear core) shows little difference (Figure 6) supporting the combination of these data sets. Combined physical data (Figure 8) for both types of core indicate how properties vary with location across the lake. There is little change in physical characteristics for zones I and II, yet a dramatic increase in zone III is evident.

These changes in zone III are due to the resulting silt deposit caused by highway construction across the lakes inflow stream in 1957. The effects of the deposit on the physical characteristics of the sediment decreases in zone IV. This likely reflects vegetation regrowth after the construction, slowed erosion, and decreased contributions of silty sediment to lake.

Zone III results display the most interesting trends. The base of zone III occurs at progressively greater depths when moving from deeper (site1) toward the shallower (site 3) location across the lake. This trend is counter intuitive because sediment focusing processes commonly result in more deposition at the deep locations in the lake. Therefore, one would expect increased deposition and a greater depth to the base of zone III at site 1 than at the shallower site 3 (lake sides). The observed

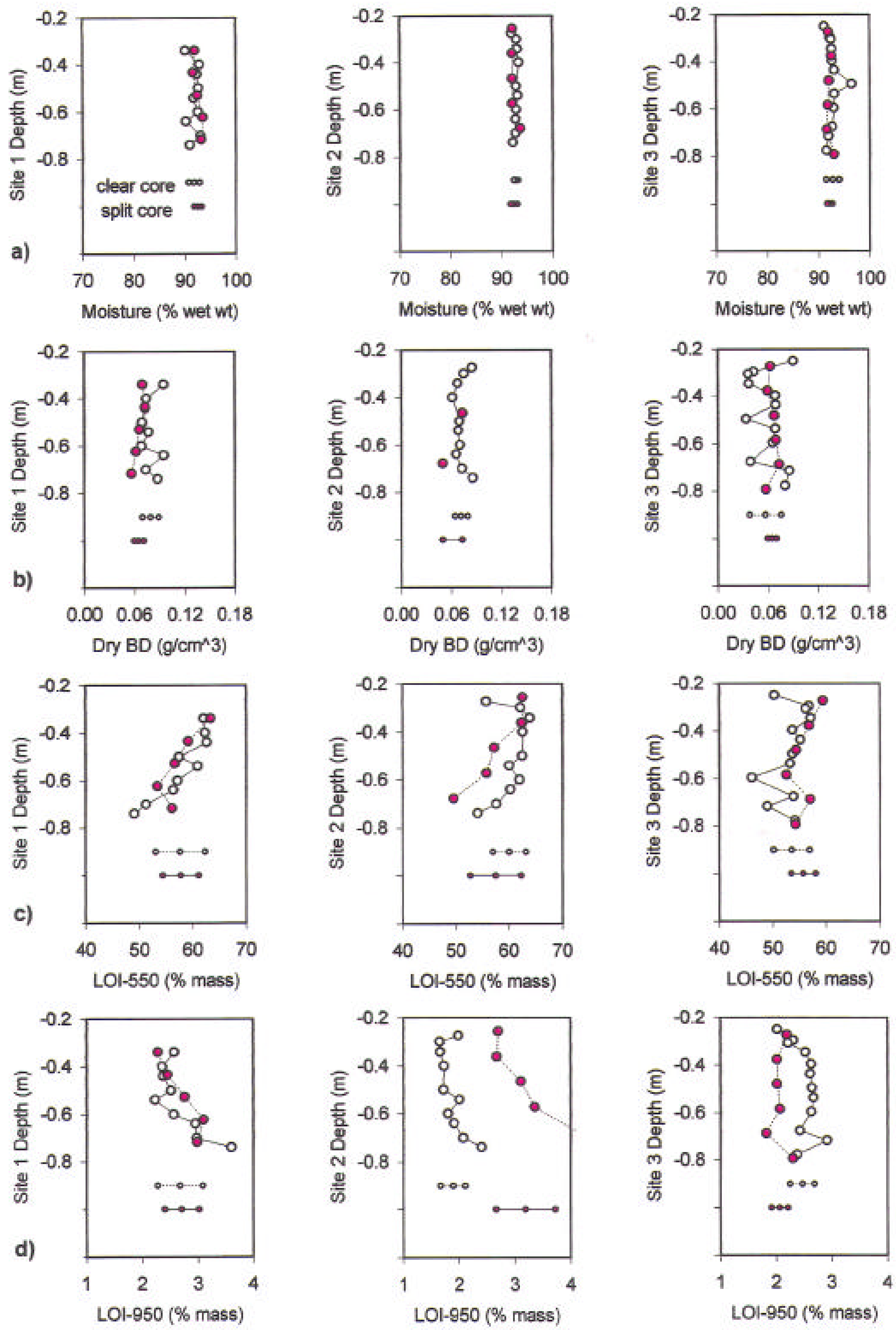

Figure 6. Comparisons of physical properties for split core and clear core subsamples. Site 1 is in the left column, site 2 the center, and site 3 the right column.

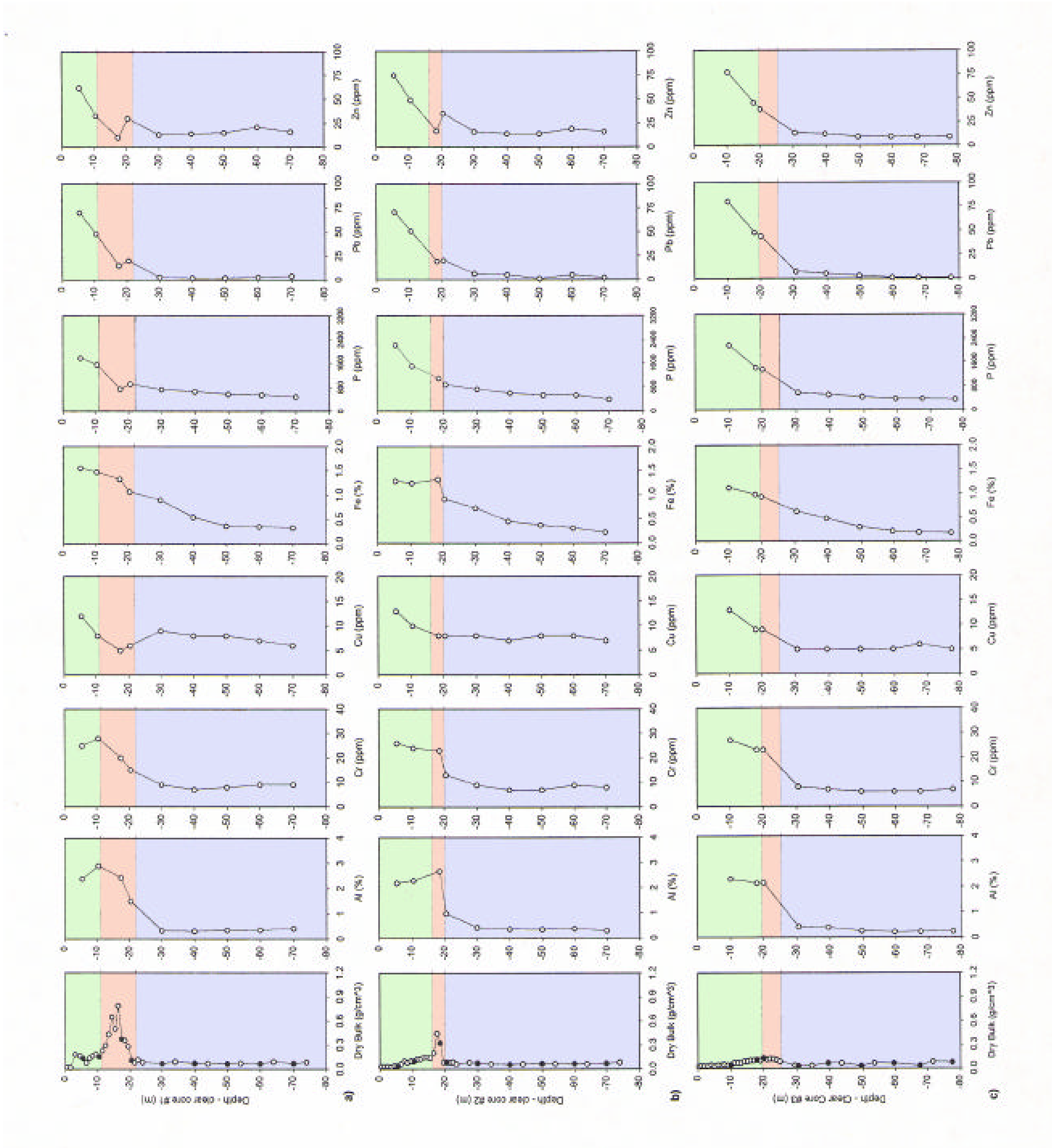

Figure 7. Selected plots depicting variations of bulk sediment elemental concentrations based on aqua regia digestion. Note that concentrations commonly are higher in zone IV (green) than in the zone of silty sediment (zone III, pink).

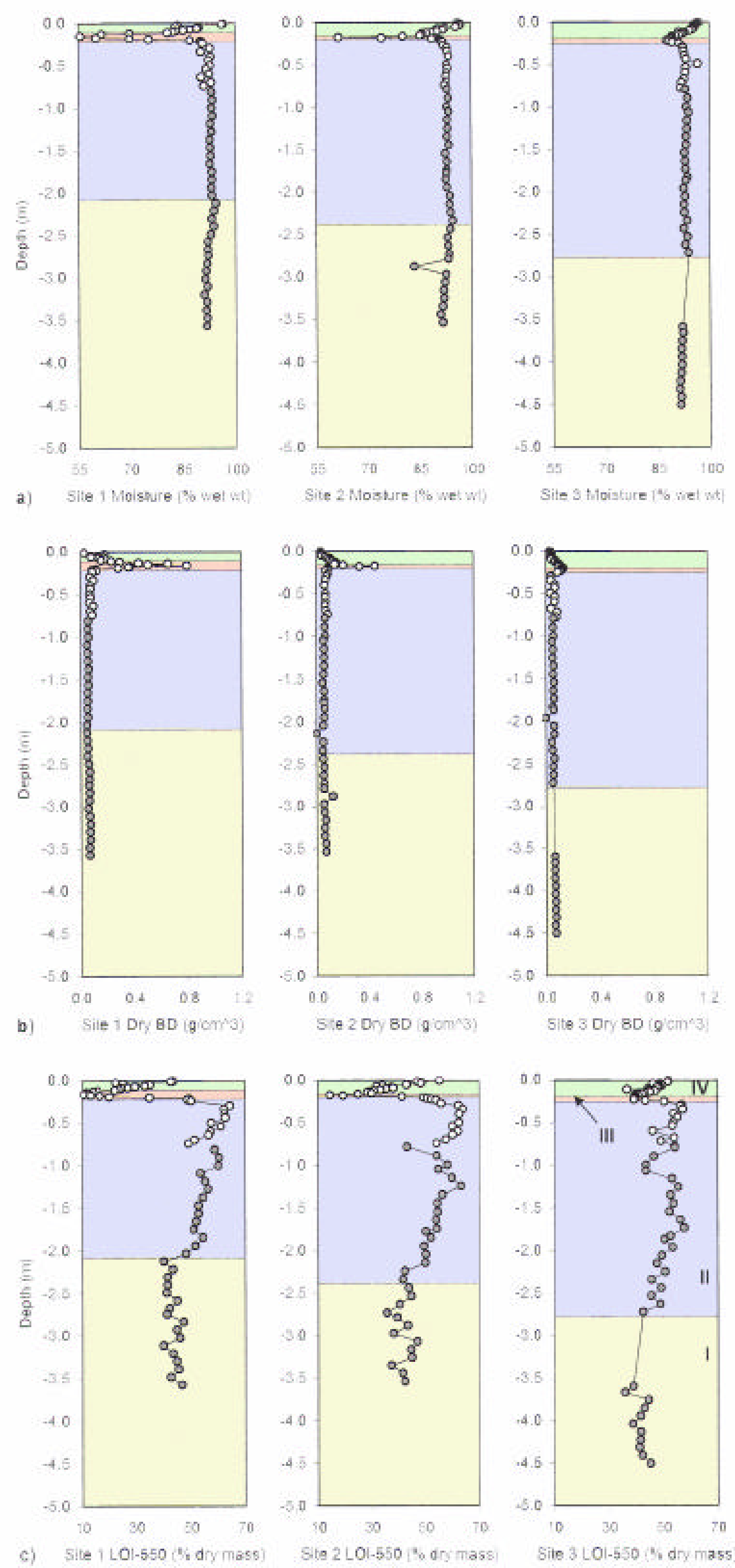

Figure 8. Combined core data sets illustrating spatial changes in physical characteristics across the lake.

Table 2. Comparison of physical property descriptive statistics for split and clear core.

		Moisture (% wet wt)			Dry BD (g/cm^3)		
		Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Clear Core	number	9.00	10.00	12.00	9.00	10.00	9.00
	mean	91.83	92.83	92.76	0.08	0.07	0.06
	stan dev	1.07	0.39	1.27	0.01	0.01	0.02
Split Core	number	5.00	5.00	6.00	5.00	2.00	6.00
	mean	92.54	92.49	92.17	0.07	0.06	0.06
	stan dev	0.71	0.65	0.47	0.01	NA	0.01

		Organic (LOI%)			Inorganic (LOI %)		
		Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Clear Core	number	9.00	10.00	9.00	9.00	10.00	9.00
	mean	57.67	60.11	53.60	2.68	1.90	2.48
	stan dev	4.62	3.08	3.32	0.41	0.22	0.22
Split Core	number	5.00	5.00	6.00	5.00	5.00	6.00
	mean	57.71	57.52	55.76	2.71	3.20	2.07
	stan dev	3.36	4.80	2.27	0.31	0.53	0.15

increase in depth to the base of zone III toward the lake side may reflect increased contributions of leaf litter and large organic fragments from the thick lake side swamp and vegetation cover. This would increase the thickness of the overlying sediment in zone IV resulting in greater depths to the base of zone III. Alternatively, the greater depth to zone III, at least at site 3 (lake side) may be a result of the difficulty in clearly defining where zone III begins. Physical characteristics change gradually across both lower and upper contact of zone III (Figure 5c). No clear jump in moisture content or bulk density is evident, leading to some uncertainly in choosing the depth of contact.

Interestingly, despite the counter intuitive increase in depth to the base of zone III, the thickness of this unit does appear to increase from site 3 to site 1. In Figure 5 the vertical stacking of the three sites show an increasing thickness of zone III from the lake shallows (site 3) to the deeper part of the lake (site1).

The magnitude of moisture content, dry bulk density and organic concentration values in zone III changes substantially from shallow to deep parts of the lake. This trend likely reflects sediment focusing and the influence of deltaic sedimentation from the inflow channel (Figure 1). Influx of silt from highway construction into the lake was focused to the deeper areas, resulting in a highly concentrated silty layer which is thickest at site 1. This silt layer thins toward site 3 causing changes in the physical properties of sediments in zone III. Furthermore, the increasing distance away from the inflow channel when moving from site 1 to site 3, would also contribute to observed trends in zone III. Specifically deltaic sedimentation associated with the inflow channel would decrease from site 1 to site 3.

Chemical trends

It is important to consider whether variations across the lake in physical properties control similar spatial changes in the chemistry of sediments.

Chemical results (Figure 7) indicate a progressive increase in concentrations of all elements upward toward the lake bed from very low and consistent values in zones I and II, which was deposited before the construction of the highway across the lake inflow, through the highway layer (zone III) into recent sediments (zone IV). In order to consider variability in chemical loading across the lake, it is helpful to combine measurement trends in bulk density with chemical concentrations. To do this bulk density values are multiplied by a volume of sediment equivalent to 1 m^2 area of the lake bed and 1 cm thick. The resulting mass of dry sediment is then multiplied by the concentration of extracted chemical element (data in Figure 7). This provides an estimate of the mass (in g or mg depending upon the element) of extractable element for a thickness of 1 cm of sediment at the depth of the sample point (Figure 9). Since the aqua regia digestion used in chemical analyses is fairly strong, but does not completely digest all the minerals, the estimates of mass in Figure 9 should be viewed as likely maximum values available from the sediments to surrounding environments.

Figure 9 presents results of the combined chemical concentrations and bulk density data as variations in mass of specific element per m^2 of lake bed with depth. In connection with previous plots of raw elemental abundance (Figure 7), Figure 9 depicts changes in mass of extractable elements across the lake as vertically stacked plots. Three trends are evident. First, the masses for samples from zones I and II are uniformly low at all sites, while all sites show substantially higher masses in zones III and IV. Increased masses for sites 1 and 2 in zones III and IV are very similar except for Pb and Zn at site 1. However, this similarity may be an artifact of sample selection. Notice that samples in zone III that were submitted for chemical analysis have very similar bulk densities (filled circles in the left-most plot in Figure 9), but that the sample for site 1 did not correspond to the most dense part of zone III. Rather this sample occurs on the limb of the bulk density spike. Therefore, it is likely that site 1 elevated concentrations may underestimate true chemistry concentrations of sediments within zone III.

The second trend in chemical variations is evident when comparing masses (Figure 9) with elemental concentrations (Figure 7). Despite higher absolute concentrations in zone IV, there is more mass of elements associated with zone III. This would indicate the heavy influx of silty sediment during the highway construction contributed to the higher masses of elements in zone III. As vegetation around the construction area recovered and erosion diminished the quantity of silt entering the lake would have declined. However, some highway derived sediments and associated elements would still be introduced to the lake from aerosols and runoff from the highway contributing to higher absolute concentrations of elements in zone IV (Figure 7). Nonetheless, due to the lower density of zone IV sediments the associated mass of elements (Figure 9) decreases into zone IV.

Finally, Pb and Zn masses values for site 1 are not consistent with other trends.

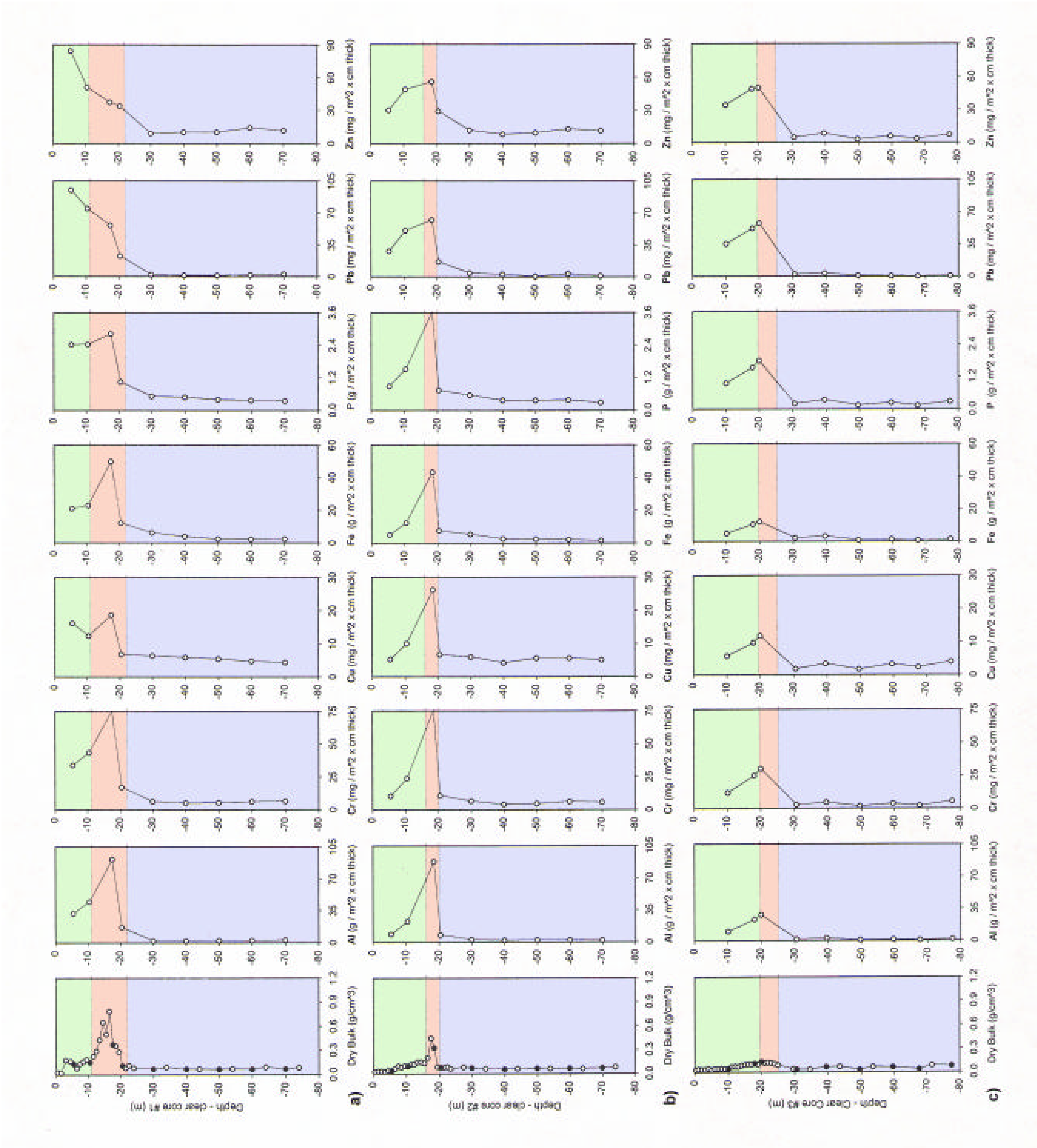

Figure 9. Selected plots depicting variations of bulk sediment elemental mass calculated from concentration data (Figure 7) and bulk densities (left-most plot). Except for Pb and Zn, elemental masses are highest in the silty highway-derived sediment layer.

While other elements decrease in zone IV, Pb and Zn continue to increase through zone III and IV. Furthermore, given that bulk densities are substantially lower in zone IV, the elemental concentration must increase very substantially for these sediments in order to account for increasing masses. This suggests substantial and continuing introduction of Pb and Zn to the lake most likely from aerosols and through stream inputs from the nearby heavily used interstate highway.

SUMMARY

The findings of this study are as follows:

1. Four zones were defined based on physical characteristics, the upper two being related to recent highway construction.
2. Silt is thicker in the deeper part of the lake due to sediment focusing.
3. Split and clear core can confidently be combined to identify trends.
4. Elemental concentrations increase upward though the highway layer and into recent sediments. In contrast, converted masses of extractable elements show a sharp spike in the highway layer (zone III) but are lower in zone IV.
5. Overall, chemical trends (by mass) displays similar spatial variations as displayed by physical properties, except for Pb and Zn. This suggests continued inputs of Pb and Zn to the lake.

ACKNOWLEDGEMENTS

I would like to thank the AAUP Student Scholarship committee supporting some of my travel expenses and ECSU for the use of a university van. I also give my deepest gratitude to the individuals who worked in the field on this project: Dr. James A. Hyatt and Todd Ostrowski (Environmental Earth Science, ECSU), Dr. Eric Brevik and several students from Valdosta State University (Paul Austin, Eason (Scooter) Hines, Angela Wall, James Moors, Katrina Pate, and Joe Hebert. Also, we very much appreciated accommodations provided by the VSU International Program (Tracy Harrington). I would also like to thank those people at Eastern who put in time to help process samples and data (Dr. James A. Hyatt, Shantar Zuidema, and Sara Smith).

REFERENCES

Axelsson, V. 2004. Sediment accumulation and modern sedimentary sequences in coastal bays, sea basins, water reservoirs, and lakes. Retrieved 09-26-04. http://home.swipnet.se/valter/Ri4.htm

Bearden, A. B. 1997. The Spatial Variability of Inorganic Sediments in Lake Louise, Georgia. Unpublished report for Department of Physics, Astronomy and Geology, Valdosta State University.

Blais, J. M., Kalff, J. 1995. The influence of lake morphometry on sediment focusing. Limnology and Oceanography 40:582-588.

Davis, M. B., Ford, M. S. 1982. Sediment focusing in Mirror Lake, New Hampshire. Limnology and Oceanography 27:137-150.

Dearing, J. A., Foster, I. D. L. 1993. Lake Sediments and Geomorphological Processes: Some Thoughts. In Geomorphology and Sedimentology of Lakes and Reservoirs. Ed. J. McManus and R. W. Duck pp.5-14. Chichester: John Wiley & Sons.

Ekstrom, N. F. 1996. Inorganic Sediment and Trace Metal Distribution in Lake Louise, Georgia. Unpublished report for Department of Physics, Astronomy and Geology, Valdosta State University.

Håkanson, L. 1977. Influence of wind, fetch, and water depth on the distribution of sediments in Lake Vanern, Sweden. Canadian Journal of Earth Sciences 14:397-412.

Håkanson, L. 1981. On lake bottom dynamics-the energy-topography factor. Canadian Journal of Earth Sciences 18:899-909.

Hilton, J. A. 1985. A conceptual framework for predicting the occurrence of sediment focusing and sediment redistribution in small lakes. Limnology and Oceanography 30:1131-1143

Hilton, J., Lishman, J. P., Allen, P. V. 1986. The dominant processes of sediment distribution and focusing in a small, eutrophic, monomictic lake. Limnology and Oceanography 31:125-133.

Lehman, J. T. 1975. Reconstructing the Rate of Accumulation of Lake Sediment: The Effect of Sediment Focusing. Quaternary Research 5:541-550.

Meyers, P. A., Ishiwatari, R. 1995. Organic matter Accumulation Records in Lake Sediments. In Physics and Chemistry of Lakes. Ed. A. Lerman, D. Imboden, and J. Gat. pp.279-328. Berlin: Springer-Verlag

Smol, J. P. 2002. Pollution of Lakes and Rivers A Paleoenvironmental Perspective. London: Arnold.

U.S. Department of the Interior, U.S. Geological Survey. Last modified 10-25-04. Reservoir Sediment Studies in Kansas. Retrieved 11-16-04. http://ks.water.usgs.gov/Kansas/studies/ressed/