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The Role of Atmospheric Deposition of Contaminant Metals to the Great Lakes: Deduced from Sediment Cores

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THE ROLE OF ATMOSPHERIC DEPOSITION OF CONTAMINANT METALS TO THE GREAT LAKES: DEDUCED FROM SEDIMENT CORES

By

Adam W. Heft

A THESIS

Submitted to Michigan State University in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Geological Sciences

1993

David T. Long, Advisor

ABSTRACT THE ROLE OF ATMOSPHERIC DEPOSITION OF CONTAMINANT METALS TO THE GREAT LAKES: DEDUCED FROM SEDIMENT CORES

By Adam W. Heft

In recent years, contamination of aqueous environments by atmospheric source pollution has become a major concern. Atmospheric deposition of organic contaminants has been documented to be beyond a doubt the most significant input process to the Great Lakes. It is the purpose of this study to determine if atmospheric deposition is the most significant input process for the trace metals As, Cd, and Pb.

Sediment cores were collected from Lakes Michigan and Ontario. Sediment thus collected was subjected to a total metal extraction using a microwave-nitric acid digestion technique, and analyzed using graphite furnace atomic absorption spectroscopy.

Results of this study indicate that background concentrations for all trace metals are within the range for uncontaminated soils. From ²¹⁰Pb corrected data and comparisons of excess concentrations and atmospheric deposition rates, it was determined that atmospheric deposition is the most significant input process of As, Cd, and Pb to the Great Lakes Region.

This thesis is Dedicated to all those who live in and love the Great Lakes Region.....

ACKNOWLEDGEMENTS

There are many people I would like to acknowledge for their help and/or support of this project. First, I am grateful to the United States Environmental Protection Agency and the Great Lakes Protection Fund for their grants to the Universities of Minnesota and Michigan State which funded and made this study possible. I would like to thank the Captain and crew of the Research Vessel Lake Guardian, from the decks of which the data used in this study were collected. I would also like to thank my thesis advisor, Dave Long, for his guidance in this project, and for his criticisms. I am grateful to the members of my thesis committee, Peggy Ostrom and Graham Larson for their comments, and suggestions regarding this work. I would like to thank the other "lab rats" (Joe McKee, Jane Matty, and Eric Roth) for their help in understanding the instruments and techniques necessary for this study. Thanks as well to Anton Spirenburg, Bill Sitarz, and Jon Kolak for all their help on the early phases of this project. A big thank you to my undergraduate thesis advisor Dave Matty for his encouragement to me to continue my education past my BS--yes, it was worth it. I am grateful to my parents and grandparents for all their support and understanding through the years. Finally, a special thank you to my fiancee Sue Sorensen for her patience and support during all the rough spots in this work.

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I. INTRODUCTION

In recent years the fluxes of trace metals to the natural environment have increased dramatically. This increase has led to an upsurge of interest in atmospheric contamination processes by environmental scientists and governmental authorities alike (Barrie et al., 1987; Tessier and Campbell, 1987). The most dramatic increase in trace metal concentrations was documented to have occurred during the period from 1957-74 (Rybak et al., 1989), although anthropogenic contamination has been significant since 1933 (Mueller et al., 1989). Christensen and Goetz (1987) indicate contamination in Southern Lake Michigan began in 1894. The contamination of air and water by persistent toxic substances is one of the most important environmental issues concerning the Great Lakes region (Arimoto, 1989).

The goal of this study is to evaluate the significance of atmospheric deposition of certain heavy metals to the Great Lakes region. In order to accomplish this, a certain process will be followed to isolate the effects of atmospheric deposition. That process is outlined below. However, some terms must be defined at this time.

First, this study will examine the background (or natural) concentrations of trace metals found in the Great Lakes. The background concentration is the average value of all samples below (inclusive) the background depth. Background depth is the depth in a core where the concentration of a trace metal becomes a relatively constant, minimum concentration (calculated for each of the trace metals separately). The excess concentration is defined as the average value of all samples above the background depth, less the value of the background concentration for a given core. Figure 1 is a graphic representation of these terms. The inventory of a metal is somewhat similar to the excess concentration. Inventory is simply the total amount of



Concentration in µg/g

Figure 1: Diagrammatic representation of terms used in profiles

the metal in the core less the background concentration. It also represents the anthropogenic loading of the metal.

The next step is to use ²¹⁰Pb data to establish a focusing factor. The focusing factor is used to account for variable sedimentation rates. The details of how the focusing factor is established are presented later. By accounting for variable sedimentation rates, data from different parts of the Great Lakes can be compared. This is accomplished by dividing the inventory of the metal in a core by the focusing factor. The corrected data may then be compared. If the results are similar, then atmospheric deposition is the significant process for depositing trace metals into the Great Lakes region. At this time, however, there is ²¹⁰Pb data for only three of the cores. This may not be enough to establish conclusive results, so another method will be used to support the findings of this method.

The supporting method will be a comparison of excess concentrations. By calculating and comparing the excess concentrations of all the cores, regional trends may become apparent. These regional trends will be examined to see if there is any correspondence with the geographic location of the core to the proximity of atmospheric sources.

Finally, the excess concentrations of the trace metals will be compared to atmospheric deposition rates of the metals which were compiled by Eisenreich and Strachan, (1992). If the excess concentrations of the metals show a correspondence to the atmospheric deposition rates, then this will indicate that atmospheric deposition is the most significant depositional process of trace metals into the Great Lakes region.

BACKGROUND

The Great Lakes are a precious natural resource which represent the largest freshwater lake system in the world. For the past 150 years, man's activities have had an ever increasing impact on the quality of the water in the Great Lakes. Anthropogenic activities have disrupted the natural cycles. Indiscriminant use of pesticides and other chemicals, the use of lead as a gasoline

additive, and heavy industrialization of the Great Lakes region have all played a part in the contamination of these lakes. Mining and related activities, waste incineration, fossil fuel combustion, and the automobile industry have been the greatest anthropogenic culprits.

Until the latter portion of this century, the Great Lakes were regarded as being large enough to be unaffected by man's activities. This attitude changed as numerous studies revealed the scope of damage done. Since that time, there have been attempts to stop, mediate, or reverse the effects of contamination to this vast ecosystem.

The Great Lakes region is a heavily industrialized and densely populated area, which contains 20% of the US population and 60% of the Canadian population (Long, 1992). Many of the people living in this area are living directly on the shore of one of the lakes or connecting channels, or only a short distance inland. As a result, these people are easily affected by contaminants released into these waters.

It has been estimated by the US Government Accounting Office that in one year 89,000 pounds of lead, 1,900 pounds of PCBs, and 900 pounds of mercury are discharged <u>legally</u> into the Great Lakes basin (Schoonover, 1992). These estimates do not include illegal discharges such as the 200,000 pounds of inorganic mercury discharged into the St. Clair river during the 1960s and 1970s (Wood, 1971; Hamdy and post, 1985; Annett et al., 1972), agricultural and urban runoff, or atmospheric deposition. Assuming a volume of 2.28x10¹⁶ L for the Great Lakes, legal concentrations in the Great Lakes would be approximately 1.77 parts per billion (ppb) for lead, .003 ppb for PCB's, and .002 ppb for mercury, assuming an even concentration throughout the entire Great Lakes system. All of these values are far below the health guidelines for these contaminants set up by the federal government. In reality, there are certain areas (proximate to discharge points) where the levels are much higher, and other areas which are at lower levels. The amount of contaminants entering the Great Lakes due to these discharges is clearly unable to account for the total concentration levels reported in various areas in the basin. Of the storage capacity of metals in Lake St. Clair, 62% of the 690 metric tons of Cd, and 39% of the 3200 metric tons of Pb are a direct result of anthropogenic activities (Rossmann, 1988). During the time

period 1960-1973, there were government warnings and bans on fish consumption for this region.

Other regions reported similar problems: high mercury levels were also reported in fish and waterfowl in Ball Lake, Ontario (Annett et al., 1975). Johnson (1987) reported that most lakes in Ontario have anthropogenic loadings from 1.8 to 2.6 times the background levels, although Stephenson and Mackie (1988) reported that lakes within 20 km of Sudbury have much higher Cd concentrations than other lakes in central Ontario. Furthermore, the anthropogenic enrichment of As, Cd, and Pb are highest near industrial regions; whereas the enrichment of Hg is more widespread, which may be due to the higher volatility of Hg.

The St. Clair River is just one example of a polluted channel in the Great Lakes region. The St. Mary's River, and the Detroit River are also heavily polluted. The fact that all of the connecting channels of the upper Great Lakes are polluted led the International Joint Commission (IJC) of the U.S. and Canada to designate them (and other areas) as "areas of concern" (Nichols et al., 1991; Marsalek and Ng, 1989).

Calculations show that the 1983 median values for worldwide emissions of trace metals into the atmosphere are as follows: As $18,820 \times 10^3$ kg/yr; Cd $7,570 \times 10^3$ kg/yr; Hg $3,560 \times 10^3$ kg/yr; Pb $332,250 \times 10^3$ kg/yr. The emission of these trace metals into aquatic environments for 1983 was: As 9.4×10^6 kg/yr; Cd 9.4×10^6 kg/yr; Hg 4.6×10^6 kg/yr; Pb 138×10^6 kg/yr (Nriagu and Pacyna, 1988). By preponderance of the evidence from these studies, it can be seen that man is the single most important factor in the biogeochemical cycling of trace metals.

There are both organics and heavy metal contaminants in the Great Lakes. The organic contaminants (pesticides, chlorinated hydrocarbons, etc.) have no natural component in the environment. Because of this fact, it is relatively easy to discern locations where these organic contaminants tend to accumulate. Furthermore, it is also possible to determine which processes have an effect on the organics, and how great that effect is.

Heavy metals, on the other hand, do have a natural component: crustal degassing, rock weathering, and volcanic emission (Glass et al., 1986). Because of these natural processes,

heavy metals are commonly found in the natural environment (Matty, 1992; Edenborn et al., 1986). It is much more difficult to trace heavy metal behavior patterns in the aquatic environment. While there is a paucity of data on background metal levels, some do exist for Hg. According to Fleishcer (1970), most igneous and sedimentary rocks contain less than 200 ppb Hg. Furthermore, background levels of Hg in sediments range from .01-.15 ppm (Jernelov and Asell, 1973) to .25 ppm reported in the Gulf of St. Lawrence (Zingde and Desai, 1981; Lowring and Bewers, 1978). Arsenic concentrations in soils are typically .1-40 mg/kg and in sediments ~18±5 mg/kg (Farmer and Lovell, 1986).

The difficulty in discerning anthropogenic contamination arises from the many different processes interacting on the metals and with each other in the lakes; and the fact that there <u>is</u> a natural background concentration whose magnitude is not always known (Arimoto, 1989). Furthermore, the natural metal concentrations entering the aquatic environment may change with changes in the chemistry of the source region (Prohic and Juracic, 1989).

Part of the concern about environmental contamination stems from the fact that it is not usually known what amounts of the metals enter the Great Lakes due to anthropogenic activities. There are many minable deposits in the Great Lakes region: several gold deposits which have associations with mercury; deposits of zinc with cadmium; lead and arsenic deposits, and extensive deposits of iron, copper, and nickel. These deposits are all to be found within the Great Lakes basin area, and the Canadian shield rocks found therein. Besides these deposits, there are many areas where these metals were brought into the region by way of repeated glacial activity, especially during the Pleistocene.

STATEMENT OF THE PROBLEM

Several metals, such as arsenic, cadmium, and lead, have long been recognized as a human health threat (Taymaz et al., 1984). These are nonessential elements for biological processes (Ozretic et al., 1990; Langston, 1982) and are toxic even in very low concentrations. The presence of these metals in humans and animals has been linked to cardiovascular disease, reproductive impairments, brain damage, and various other problems (Furgesson, 1990; Nriagu, 1988; Long, 1992).

For trace metals to have an impact on aquatic organisms, the metals must be in a form that is biologically available to them (Waldichuk, 1985); only in this form are they toxic (Nelson and Donkin, 1985). In many cases, trace metals are emitted to the environment in a form which is not harmful to organisms. There are many cases where mercury was emitted to the environment as elemental mercury and was transformed to methylmercury (D'Itri, 1992). Methylmercury is the most toxic species of mercury (Senaratne and Dissanayake, 1989; D'Itri, 1992). Mercury metal species often undergo some kind of transformation to a toxic form, caused by either biological (enzymatic) or nonbiological (chemical-physical) agents.

A significant number of people have been affected by these metals, even as far back as Roman times, when trace metal concentrations in the environment were increased four to five times. This increase in available trace metals has even been linked to the fall of the Roman Empire through heavy metal poisoning (Urban et al., 1990). Increases of Pb have been confirmed in remote areas such as the large ice sheets, where only atmospheric deposition can account for the metals present. The Antarctic ice sheet has shown a 5x increase in Pb levels in the last 13,000 years (Boutron and Patterson, 1987). Furthermore, Ng and Patterson (1981) showed a 300x increase in 3,000 year old ice from Greenland.

It can be seen from past studies that the amounts of heavy metal contamination in the environment has been increasing to a dangerous level. These heavy metals are toxic in low concentrations to both humans and other organisms sharing our environment. As more people

become aware of the dangers posed by contaminants, the more necessary it becomes to impose limits on anthropogenic emissions.

Because of the problems caused by contamination, the International Joint Commission (IJC) has targeted the four metals As, Cd, Hg, and Pb; and 10 organic compounds: PCBs, benzo(a)pyrene, PAHs, HCB, mirex, dieldrin, HCHs, DDT, toxaphene, PCDDs and PCDFs, as critical contaminants in the Great Lakes region (Colborne et al., 1990; Eisenreich and Swackhamer, 1990; Eisenreich et al., 1990; Long, 1992). Some of these metals tend to bioaccumulate in fish and other aquatic organisms (this is indisputable for Hg), and, therefore, pose health risks to other organisms besides humans (Apsimon et al., 1990; Lindberg et al., 1987). Fish have been known to easily bioaccumulate metals and pesticides in high concentrations (Thommes et al., 1972; Seagran, 1970) which pose a threat not only to their own health, but to humans and predators such as herons and other birds. Since trace metals are not degradable, the threats they pose do not just go away over time.

It can be demonstrated that some of the contaminants in the Great Lakes are not the direct result of anthropogenic activities in the Great Lakes region. Toxaphene, an organic compound which is on the LJC critical contaminant list, was used only minimally in the Great Lakes Basin, and yet is found in high concentrations in Lake Michigan (D'Itri, 1992; Voldner and Schroeder, 1989). Toxaphene was used extensively in Southern states, and atmospheric wind currents brought it north. Toxaphene was applied extensively to cotton, and was used in the Great Lakes as a rough fish control (Rapaport and Eisenreich, 1986). The atmosphere is conceded to be the major source of organic contamination, at least for the international upper Great Lakes (Strachan, 1985; Swackhamer and Armstrong, 1986; Swackhamer et al., 1988). To a certain degree, this is probably the case for some, or all, of the trace metals that will be dealt with in this study.

Therefore, in order to begin to bring the levels of heavy metals in the lakes to an acceptable level, the background vs. atmospheric inputs and surficial vs. atmospheric inputs, as well as the processes affecting those inputs, must be understood. If, for example, the

background (natural) concentrations are underestimated, legislation might be introduced which would require the metal concentrations to be at a lower level than the background, in effect legislating natural processes, an unsound principle. This study represents a phase of the understanding of trace metal behavior which is necessary to begin to control heavy metal levels in the Great Lakes region.

HYPOTHESIS

The hypothesis that atmospheric deposition is the most important source for the trace metals As, Cd, and Pb in the Great Lakes is the basis of this research. If this hypothesis is correct, then similar atmospheric depositional loadings of metals can be expected for all regions of the Great Lakes. Studies by Eisenreich et al. (1992, 1990) showed this to be the case for selected trace organic compounds.

There are three methods to determine if this hypothesis is correct. First, the atmosphere signal can be determined by backing the atmosphere signal out of the total Great Lakes signal. This is done by examining the trace metal signal in remote lakes and ombrotrophic peat bogs in the Great Lakes region. These locations (by definition) have only atmospheric sources of trace metals. This atmosphere signal can then be subtracted from the total signal in the Great Lakes cores to determine the relative significance of atmospheric deposition. This method is currently being worked on by Bill Sitarz at MSU, and will not be further addressed in this study.

A second method to answer this question is to use ²¹⁰Pb dates of the sediments, and, combined with inventories of the metals, establish a focusing factor. This focusing factor can be used to normalize the data throughout the Great Lakes region to account for things like variable sedimentation rates. The corrected data can be compared using this focusing factor; if all the data are similar, it indicates that atmospheric deposition is the dominant input process to the Great Lakes. If the data are not similar, it means that the study is inconclusive, and that the question

must be confirmed in another manner. This method will be used to a limited extent in this study because not all of the ²¹⁰Pb data is available at this time.

The final method used to answer this question is to compare the excess concentrations of the metals in the sediment profile. These excess concentration values can be used in the same way that ²¹⁰Pb normalized data is compared. This can be used to establish regional patterns of each of the metals, and some information regarding atmospheric depositonal patterns may be derived. This method will be used extensively in this work due to the absence of other data.

ATMOSPHERIC DEPOSITION

The Laurentian Great Lakes are especially sensitive to atmospheric deposition because they have high surface to drainage basin area ratios (figure 2), are near and downwind of urban and industrial centers, and receive a major fraction of their hydrologic input by direct precipitation on the lake surface (Eisenreich et al., 1992). In the past 20 years, numerous studies have shown atmospheric deposition to be a significant source of pollution to the Great Lakes basin. Several studies (Levy and Moxim, 1989; Eadie et al., 1984, Spencer and Sachs, 1970) noted that the background atmosphere chemistry varies seasonally: a late summer contamination increase due to U.S. emissions; and a smaller increase in the spring due to Asian emissions. Remoudake et al., (1991) attributed the variability of atmosphere aerosol concentrations on a daily and seasonal time scale to scavenging by precipitation, and not changes in the source regions.

Many studies have documented that the atmosphere is the dominant input for organic contaminants to the Great Lakes (Kelly et al., 1991; Eisenreich et al., 1986; Evans, 1986; Eisenreich et al., 1984; Murphy et al., 1984; Doskey and Andren, 1981; Eisenreich et al., 1979). Urban et al., (1990) found that wet deposition of lead decreased from 1981 to 1983, and attributed this to decreased use of lead in gasoline. The use of lead as a gasoline additive and exhaust from automobiles has been the major source of lead to the atmosphere (Veron et al., 1987).

Murphy and Rzeszutko (1977) reported PCB concentrations on Beaver Island in northern Lake Michigan to be the same as those in Chicago. This was interpreted to mean that sources to the atmosphere are diffuse and/or residence times in the atmosphere are long. Residence times



Figure 2: Map of Great Lakes Region (after Upchurch, 1972)

for Hg in the atmosphere are about 6 to 90 days (Clarkson et al., 1984). This probably holds true for other trace metals besides Hg. Lake Simcoe, Ontario has an atmosphere input of 77% of the total inputs for Cd (Johnson and Nicholls, 1988). According to Nriagu (1986), atmospheric deposition is responsible for 60% of the Cd and 64% of the Pb in Lake Ontario (Coale and Flegal, 1989).

Atmospheric deposition begins with the generation of trace metals in a form which is conducive to transport by the atmosphere. This can occur two ways. The natural component, which is significant for Hg, but less so for other trace metals, is the result of re-emission of mainly metallic Hg vapor from soil, lakes and oceans (Brosset, 1982). The other way trace metals get into the atmosphere is due to combustion of fossil fuels, smelting or waste incineration which volatilizes the metal (Lyons et al., 1983; Andren and Strand, 1981; Annett et al., 1972). Globally, these anthropogenic processes are significant, as reported values of the release of Hg is at least 3 times higher than the amount released naturally (Annett and D'Itri, 1973).

Once released into the atmosphere, the trace metals are either associated with soot produced in the combustion process, or they exist as a vapor which is often sorbed to other particles in the atmosphere (Arimoto, 1989). Several studies have documented that ~90% of all Hg species emitted to the atmosphere by combustion processes exist as Hg° in the vapor state (Lindberg, 1987; Lindberg, 1980; Johnson and Braman, 1974). Of the metals associated with particulates, the water soluble species are usually the most common form (Lum et al., 1987). If associated with particulates, there is some dependance on wind direction, which is important to the concentration of the trace metals (Brossett, 1982). Sanderson et al., (1985) showed that primary statistical analysis indicates concentrations of the metals are related to intensity and amount of precipitation, but not to wind direction.

It has been shown (Buat-Menard and Duce, 1987), that there is no "normal" background type of aerosol in the atmosphere. The type and size of these particles have considerable variability. The particles in the atmosphere exist in various sizes. The largest size particles (diameter larger than 2-2.5 μ m) are produced by mechanical means, such as weathering of soils, sea spray, pollen and spores, among others. The smallest particles (diameter smaller than .08 μ m) are called aitken nuclei, and are produced by gas-to-particle conversion. These small particles make up most of all particulates in the atmosphere, but have little mass. Mid size particles (diameter .08-2 μ m) are produced by either coagulation of aitken nuclei or by gas-to-particle conversion. The mid size particles represent about 50% of the mass, and most of the surface area, of all atmosphere particulates (Bidleman, 1988). These mid size particles are the most significant phase for atmosphere transport. The size of the mid-size and smaller particles may be due to high temperature processes such as combustion (Jeffries and Snyder, 1981).

Atmospheric deposition can occur at any time after the formation of particulates of vapor in the atmosphere. Edgington and Robbins (1976) found the residence time for Pb in the atmosphere over Lake Michigan was approximately10 hours. The actual deposition process can be wet or dry. Dry deposition entails the settling of particulates out of the atmosphere. The size of the particulates determines the probable distance of travel before deposition occurs. Vapors containing trace metals (or organic contaminants) may react with other contaminants in the atmosphere and become sorbed to particulates or settle out on their own. Most particulates are of a small size, and, therefore, usually travel a long distance before they settle out of the atmosphere. Vapors are conducive to long range transport of the contaminant (especially Hg) and global dispersion. Migon et al., (1991) found that dry deposition accounts for about one third of contaminants deposited from the atmosphere.

Wet deposition is the removal of particulates and vapor by some form of precipitation. The precipitation scavenges, or scrubs, these materials from the atmosphere (Andren and Strand, 1981). This process typically has a greater effect on the larger particulates than on the smaller ones. Wet deposition acts to drastically shorten the residence time of trace metals in the atmosphere, and is the main cause of short range transport of contaminants identified in other studies.

Furthermore, wet deposition is responsible for bringing nearly all of the contaminants deposited atmospherically into the Great Lakes. Andren and Strand (1981) reported an input ratio

of 40:1 of wet to dry deposition for total organic carbon. Lindberg (1987) reported that precipitation scavenging is the major removal process for Hg vapor. The rate of contaminant removal from the atmosphere is ultimately dependent on the rate of pollutant attachment to the falling precipitation particles and to the precipitation flux at the ground (Scott, 1981).

METAL CYCLING

In the past 20 years, there have been an ever increasing number of studies focusing on the effects of contamination in the Great Lakes. Most of these studies are concerned with organic contaminants. There are two reasons for this. First, these contaminants are solely the result of man's activities: there are no natural sources for any of these contaminants. Second, once the contaminants are in the natural environment, it is easier to keep track of them: there are no background concentrations that might mask or confuse the concentrations. In addition, most of the physical properties of the organics must be known before they are allowed to be released into the natural environment. Simulating contaminant behavior by using computer modeling programs makes it easier to predict what will happen to the contaminant. Figure 3 shows a summary of the processes affecting the concentration and distribution of trace metals in aquatic environments.

Metal studies are much more difficult because the physical properties may not be fully understood with regards to how the metal behaves in the environment. Furthermore, the metals have a natural component in the environment, and the "natural" (or background) levels are seldom known. Because of interactions of natural vs. anthropogenic contamination, the physical processes are more complex for metals than for organics. Because of this complexity, an in-depth discussion of all the processes involved in metal cycling is beyond the scope of this study. Therefore, this study will only briefly discuss the processes involved in metal cycling, and how those processes may impact this study.



Figure 3: Diagram showing processes affecting metal cycling (after Matty, 1992)

Once the metals enter the Great Lakes (whether by atmospheric deposition or by riverine input) they are subject to many processes before they become a "permanent" part of the sediment column. To remain consistent with the theory that atmospheric deposition is the most significant source of trace metals to the Great Lakes, these processes will be dealt with beginning at the lake surface and working towards the sediment.

Upon first entering the lake, the contaminants enter what is known as the surface microlayer, or film. Deposition to this layer is by molecular diffusion and/or by particulate settling (Eisenreich, 1987; Armstrong and Elzerman, 1982; Slinn et al., 1978). Despite the fact that these microlayers are transitory, and even though the residence times of trace metals in them may be on the order of minutes (Eisenreich, 1982), they are important. It has been documented that trace metals accumulate to high concentrations in these microlayers. This is due to complexation with organic matter (Eisenreich, 1991; Ridgeway and Price, 1987; Santschi, 1984). Enrichment of trace metals in this layer indicates a significant input of atmospheric aerosols (Elzerman, 1982). Furthermore, metals entering by particulate settling may be released to the water column by partial dissolution of the particulates (Armstrong and Elzerman, 1982). The movement of trace metals into and out of this layer has been of concern in relation to their upward and downward fluxes and possible toxicity to biota (Elzerman, 1982).

Concentration gradients can be affected by several processes operating in the water column. For instance, the magnitude and depth dependence of the diffusion coefficient can have a critical influence on the interpretation of observed profiles with regard to both the rate and location of the chemical reactions supporting concentration gradients (McDuff and Ellis, 1979). When dealing with thin layers (up to a few meters thickness), the timescale for diffusion across the layer is much less than the time for sinking, or advection, out of that layer (Denman and Gargett, 1983; Platt et al., 1982). Whereas for very thick layers, the timescale for diffusion across the layer greatly exceeds the time for sinking out of the layer (Small et al., Lande and Wood, 1987; Takahashi and Honjo, 1983).

Particles (and trace metals) sinking through the water column pass through the epilimnion. This is the portion of the lake warmed by the sun and above the Thermocline. According to Coale and Flegal (1989), the residence times for Cd and Pb are 9 days and 4 days respectively. These short residence times of the dissolved phased reflect rapid scavenging of the trace metals by particulates in the water column. Suspended solids in the water column are important in controlling the water column concentrations of trace metals (Dolan and Bierman, 1982). Humic material, which is one of the dominant forms of organic material has a stronger affinity for Pb than for Cd (Campbell and Evans, 1987). This may account for the difference in residence times. Other factors affecting trace metal removal in the primary sedimentation process include the metal's solubility and the settleability of the insoluble forms (Kempton et al., 1987).

Any free metal ions in the water column can become hydrated, which plays a major role in initiating adsorption to particulates (Jean and Bancroft, 1986). Of the particulates that the metals can adsorb onto or complex with, metallic oxides, organic matter, carbonates and clays are the most important components (Rapin et al., 1983; Forstner, 1982; Jenne, 1973). This sorption and complexation occurs in the water column, and acts to keep the concentration of metals (especially mercury) near background levels, except for near local points of discharge directly into the lake (Bubb et al., 1991a; So, 1980).

Adsorption is recognized as the main control on trace metal behavior (Long, 1991; Honeyman et al., 1988; Santschi, 1984; Eadie et al., 1984; Stumm and Morgan, 1981; and Balistreri et al., 1981). Due to the large number of studies which involve adsorption, it is known what kind of an effect most of the adsorption controls have, but not how they all interact.

The lower the pH, the higher the concentration of trace metals in the water column (Masscheleyn et al., 1991; Johnson, 1991; Lodenius and Autio, 1989; Stephenson and Mackie, 1988; Di Toro et al., 1985). More basic conditions tend to decrease the solubility of trace metals, and force them to become sorbed onto particles in the water column or sediment-water interface. The pH of the water column has been shown to have a diurnal cycle of variability due to effects produced by photosynthesis. Trace metal concentrations, have a similar cycle which lags a few

hours behind the pH cycle; the highest concentrations of As in the water column occurs just after the pH is the lowest (Fuller and Davis, 1989).

The redox conditions (which can be controlled biologically as well as physically) are also important. Under oxidizing conditions, trace metals are not very soluble, and tend to be partitioned with particulates. Under reducing conditions, trace metals are more soluble, and concentrations in the water column increase significantly (Masscheleyn et al., 1991).

The ionic strength of the water also plays a part in trace metal chemistry. Metal-clay sorption is known to decrease significantly as ionic strength increases (Di Toro et al., 1985). This may also be true for other types of substrate materials.

Particle size and composition have an effect on trace metal concentrations. Brook and Moore (1988) reported that concentrations of As, Cd, and Pb in a Montana stream generally increase with decreasing particle size. Metals are usually enriched in the smaller silt/clay fractions of the sediment (Bubb et al., 1991b, 1991c)

Complexing of trace metals is a process that is similar to adsorption, and is also known as scavenging. The difference between adsorption and complexing is that adsorption is a single bonding of the trace metal to another substance, and complexing is a multiple bonding, usually to an organic substance. Most commonly, these organics are humic or fulvic materials (Eisenreich, 1991; Long, 1991; Hirner et al., 1990; Davis, 1984; Frimmel et al., 1984; Elderfield, 1981; Reuter and Perdue, 1977; Andren and Harriss, 1975). This multiple bonding creates a stronger cohesive force than adsorption alone, and, as a result, trace metals are usually partitioned with organic materials and share their fate. Some materials, such as organic matter or iron and manganese oxides, have a scavenging ability far out of proportion to their abundance in the environment (Tessier and Campbell, 1987).

Phases most important in scavenging dissolved metals are fine grained organic matter and Fe/Mn oxides. The fine grained material is selectively removed to the deepest regions of depositional basins by sediment focusing, and the oxides continue to scavenge dissolved metals as they move through the water column (Long, 1989; Santschi, 1984). In one study, iron and

manganese oxides were found to scavenge metals to 50% of the total heavy metal content (Feijtel et al., 1988).

It should be noted, however, that not all metals tend to complex with the same ligands (organics), nor is the degree (strength) of bonding the same. Cd adsorption is not significantly affected by the presence of organic material, due to the weak complex formation with organic ligands (Davis, 1984). Furthermore, the ligand concentration and ligand type will influence the degree and type of complexing taking place (Santschi, 1984).

Complexing can also occur with water itself. Due to the polar nature of the water molecule, bonds can form with either positively or negatively charged species (Long, 1991). Bonding usually occurs with six water molecules. The water molecule can be broken down, and the trace metal may be complexed with five water molecules and one OH⁻. Breaking more water molecules will increase the number of OH⁻, and, therefore, increase the pH of the system.

The water molecule may first be bound to another inorganic substance; so, when trace metals complex with the water molecules, they are bound to an inorganic substance as well. This creates what is called the double layer complex, where H_2O , H_3O^+ , and OH^- can be bound to a solid substance (figure 4). Consequently, both positive and negative species can be bound to the substrate.

The rate of adsorption/complexing is usually rapid, but depends on several factors. Concentrations of the trace metals and ligands, type and size of ligands, and residence times of the trace metals and ligands in each reservoir, temperature, pH, and ionic strength are all important in determining the rate of adsorption (Frimmel et al., 1984; Balistrieri et al., 1980). However, Nyffeler et al. (1986) indicates that uptake of (radioactive) trace metals by suspended particles in natural aquatic systems is often slow, and the time constraints for scavenging are of the same order of magnitude as the residence times of particles in the water column. While there is some variability in the complexation process between the different trace metals and their prefered ligands, the complexation reactions with ligands in solutions and on solid surfaces are essential features of the biogeochemical cycling of trace metals (Comans and Van Dijk, 1988).



Figure 4: Diagrammatic representation of Double Layer complex (after Long, 1990)

Particulates in the water column settle to the sediment, carrying trace metals with them. The nepheloid layer, however, has a tendency to have a much higher density of particulates in it. The nepheloid layer is the region of the water body in which there is a marked increase in the suspended particulate matter. These particulates have been shown to have median diameters 20% smaller than the particulates found in surface waters (Baker et al., 1985), and are composed primarily of silica, calcite and organic matter (Mudroch and Mudroch, 1992). As a result of all of these particulates, there are highly elevated concentrations of trace metals to be found in the nepheloid layer. Sandilands and Mudroch (1983) found that the nepheloid layer in Lake Ontario had Pb concentrations similar to those found in the 0-1 cm layer of the sediments. The nepheloid later is important for accumulating, recycling, and transporting contaminants in Lake Ontario (Mudroch and Mudroch, 1992).

There is a second zone in the water column which has an abnormally high particulate concentration. Located just above the sediment, it is called the benthic nepheloid layer. This layer is also higher in trace metals than the surficial sediments (Cahill and Shimp, 1984).

The action of biota in the lake or sediment is an important but often neglected factor in trace metal behavior (Long, 1991). The fact that there are many ways that biota can effect the environment may be part of the reason for this omission. Microorganisms such as bacteria have evolved enzymes capable of changing the oxidation state of elements (Jackson et al., 1982; Wood, 1973; Jernelov and Assell, 1973; Iverson et al., 1973). Wilhelmy and Flegal (1991) found that high concentrations of trace metals are often associated with high nutrient levels in the water column.

Bioturbation of the sediments can exchange or mix particles in the water (Santschi, 1984). Mixing caused by benthic biota can drastically change the input record of contaminants in sediments. Christensen and Klein (1991) proposed a method for the "unmixing" of the sediment input records for areas where bioturbation is a significant problem. Eadie et al. (1984), Luoma and Davis (1983), and Shafer and Armstrong (1990) recognized the effects of grazing, filter feeding, and fecal pelletization on water chemistry. Biological materials are an important carrier phase for

trace metals because they are rich in organic matter, and allow easy sorption of the metals. The settling of material has been shown to be an important carrier phase for trace metals (Sigg et al., 1987; Landing and Feely, 1982). The effects reported from biological uptake by organisms such as fish may not represent true concentrations of metals in the organism's habitat, but may be due to interactions with the food chain and the environment (Glass, 1973). The uptake of trace metals by biota in the aquatic environment is known to be related to the activity of the free aquo metal ion and may be treated as a series of complexation reactions (Comans and Van Dijk, 1988).

Bioturbation is not the only means by which the lake bottom may be disturbed or reworked. Bottom currents, which can be due to density, poor lake stratification, or temperature differences, can be especially strong during storm events, and have a significant effect on sediment profiles (Bennett, 1987; Flood and Johnson, 1984; Johnson et al., 1984). Furthermore, in places where the lakes are shallow, especially near shipping channels, freighters and other boats may churn up sediments, bringing buried metals back into the system.

The process of resuspension plays an important role in the transfer of particles from the sediment to the water column. Several studies have clearly documented the importance of this process. Bennett (1987) has shown that if there were no resuspension and no source of sediment to Lake Michigan, the lake would be clear of suspended matter in about two months. In reality, there is about two years worth of sediment suspended in the water column. Walsh et al., (1988) found that the total particulate fluxes at the bottom of a lake were greater than those found in the mid-water column. Other studies show that the exponential increase of suspended matter in the water column as the bottom is reached indicates resuspension of bottom sediments (Walsh et al., 1988; Aggett and O'Brien, 1985; Eadie et al., 1984; Chambers and Eadie, 1981; Spencer and Sachs, 1970). Resuspension is affected by stratification of the water column. When there is no stratification, resuspension of particles is most extreme (Aggett and O'Brien, 1985; Eadie et al., 1984).

Because of the processes reworking the sediment, the sediment itself may become a source of contamination to the overlying water (Officer and Lynch, 1989; Salomans et al., 1987).

According to the Great Lakes Water Quality Board, this is occurring in 38 of 42 Great Lakes areas of concern (Theis et al., 1988).

Organic material often tends to coat the surfaces of other inorganic materials such as Fe/Mn oxides and oxyhydroxides (Chen and Deng, 1989; Davis, 1984; Lion et al., 1982). These oxides and oxyhydroxides are thought to play an important role in trace metal cycling in sediments. Burial of sediments containing such oxides and oxyhydroxides lead to reductive dissolution below the redox interface (Belzile et al., 1989; McKee et al., 1989). Little is known about the extent to which organic material covers the surfaces of inorganic material in the natural environment. Davis (1982) illustrated that the amount of organic material adsorbed was influenced by the chemical nature of the surface; so hydrous oxides, which are basic, tend to adsorb greater amounts of natural organic matter than those with acidic surfaces such as silica (Davis, 1984). This means that Fe and Mn oxides are important to the processes controlling adsorption of trace metals (Jackson et al., 1982; Lion et al., 1982). As these oxides usually tend to accumulate at the redox boundary in the sediment, there is often a high concentration of trace metals there as well.

It is also believed that the fate of some trace metals may be determined by processes related to organic matter diagenesis occurring at the sediment-water interface (McKee, 1987; Pedersen et al., 1986; Klinkhammer, 1980).

Trace metals are released from particles in the sediment during burial and early diagenesis. During burial, organic matter decays and the redox state and pH of the sedimentary environment changes. There are several processes that affect particle-bound trace metals in various diagenetic environments in aquatic systems: the formation and reduction of Fe and Mn oxides (Rezabek, 1988; Cornwell, 1986; Laxen and Chandler, 1983; Cerling and Turner, 1982; 1981; Balzer, 1982; Davison et al., 1982; Chapnick et al., 1982; Tipping et al., 1981; Davison, 1979; Davison and Heany, 1978; Anthony, 1977; Robbins and Callender, 1975); the decay of organic matter (So, 1980; Lerman, 1979; Berner, 1972); the reduction of sulfate and the formation of sulfides such as pyrite, galena, and sphalerite (Jean and Bancroft, 1986; Pyzik, 1981;
Jenne, 1973; Berner, 1972, 1967); and the formation and dissolution of carbonates and Fe concretions (Effler, 1984; Treese et al., 1981; Dean and Gorham, 1976). In large lakes, the above processes have a signigicant effect on the remobilization of particle-bound trace metals (Long, 1989; Allan, 1986; Kosov, 1986; Rossmann, 1986; Salomons and Forstner, 1984; Rea et al., 1981; Johnson and Eisenreich, 1979; Sly and Thomas, 1974). The flux of trace metals (especially Hg) from the sediments will be higher if the bottom waters are anoxic (Bothner et al., 1980). The effect of early diagenesis on most heavy metals is unclear, and, in most cases is obscured by the strong anthropogenic signature of the total hydromorphic profile (McKee et al., 1989)

It should be further noted that trace metals are not irreversibly fixed on particles, but can be released in response to changes in the aquatic environment they are part of (Comans and Van Dijk, 1988). Therefore the term "permanent sink" for trace metals is something of a misnomer. The metals will reenter the environment at an accelerated rate if changes in conditions in the environment occur, but, regardless, will eventually reenter the environment. The residence time for mercury in sediments is on the order of millions of years (Clarkson et al., 1984), and the other trace metals may have similar residence times.

III. METHODS

SAMPLING

Collection of the sediment cores used in this study was done during September of 1991, and in August of 1992. Both trips involved the use of the USEPA Research Vessel Lake Guardian. Sediment cores were collected in Lakes Michigan and Ontario in several different locations (figures 5 and 6). A total of 15 cores were collected for this study; 8 from Lake Michigan, and 7 from Lake Ontario. Most of these cores are located within or on the edges of depositional basins in these lakes. The specific site locations and descriptions of the cores are given in tables A1-A15 of Appendix A.

A stainless steel box coring device (30cm x 30cm x 70cm) was lowered from the Research Vessel Lake Guardian to the sediment and retrieved. This device was lowered by cable to the lake bottom, slowly enough so that the sediment was not disturbed by this action: evidenced by the lack of suspended matter in the water above the sediment, and the presence of "fluff" found on the sediment surface of two cores. Fluff is the material often found at the sediment-water interface. It is typically very difficult to collect and easily disturbed, and appears as a nebulous, fluffy material. Subcores of this sediment block were then taken. Five 3" PVC core tubes were inserted into the sediment under vacuum to avoid compaction of the sediment. The cores were inserted about 5 cm away from the sides of the box core to avoid the disruption of the sediment caused by the box coring device. Once all core tubes were inserted into the box core, the bottom was opened, and rubber stoppers were inserted into the bottom of the core tubes. The top of the core tubes were sealed with polyethylene caps to prevent contamination of the sediment core.



Figure 5: Lake Michigan sampling locations (after Eisenreich et al., 1990)





Immediately upon removal from the box core, the tubes were taken to the onboard lab for processing of the core. The sediment in the tubes was sectioned using a hydraulic extrusion device. The tubes were double stoppered on the bottom and placed on the extruder. This device forces the sediment up the tube using water pressure. The double stopper prevents water from coming in contact with the sediment at the bottom of the core. The upper 20 cm of the core was sectioned into 1 cm increments, while the remainder of the core was sectioned into 2 cm increments. Most of the cores were sectioned under air, but two of the master station samples were sectioned under a N₂ atmosphere in a glove bag to help ensure contamination was minimal, and also to prevent oxidation of the sediment. The sediment in contact with the sides of the core tube was scraped away using a teflon spatula to remove any sediment smearing along the edge of the tube. At no time during the collection or sectioning process did the cores come into contact with metal of any kind. The increments were then placed into individual polyethylene bottles (acid washed and rinsed thoroughly prior to sampling) and refrigerated to 4°C until they were homogenized, at which time they were frozen.

During the extrusion of core EPA#LG1, it was noticed that partway through the sectioning process numerous small vesicles appeared in the sediment column. It was thought that this was due to a pressure release phenomena which caused pockets of gas (produced by decaying organic matter) to expand. A study by Robbins (1980) experienced the same phenomena. His explanation was that the expansion was due to expansion of the cores and/or gas pockets as a result of a high rate of sedimentation. Both explanations are viable, and are quite similar. Furthermore, EPA#LG1 is located in a depositional basin of Lake Ontario, and can be expected to have a high sedimentation rate.

CLEAN PROCEDURES

Care was taken at all phases of this study to avoid contamination of the samples. With the exception of the sample collection, all phases of this study were conducted in a clean laborotory. This lab was supplied with filtered air (slight positive pressure) and sealed against the entry of dust or other contaminants from the outside. All materials used in the processing of the samples were washed with 10% analytical grade HCl and rinsed with distilled, deionized water (DDW) prior to use. Sample bottles were precleaned in this acid by soaking ~24 hours, followed by a rinse in DDW, a 24 hour soak in DDW, 4 additional rinses in DDW, and drying in a clean hood supplied with filtered air from a class 100 filter. The reaction vessels used in digestion of the samples were cleaned with the same instra-grade HNO_3 used in the digestion step. The filters and syringes used in the leaching procedure were cleaned in the same manner as the sample bottles. All samples and equipment used in this study were handled only with the use of sterile, latex examination type gloves.

CHEMICAL EXTRACTION

A leaching procedure was performed on the sediment in order to remove the trace metals from the particulate (hydromorphic) phase (Eisenreich et al., 1990). The hydromorphic fraction is the portion from which the metals are easily removed (Long, 1991). This chemical extraction gives a total metal concentration of the sediment. For this study, 15M Instra grade HNO₃ was used to digest the sediment. This extraction was done using the microwave-nitric acid technique developed by Hewitt and Reynolds (1990). The microwave apparatus used for the digestion is the CEM MDS-81D with pressure controller. The sediment core to be extracted was allowed to thaw at room temperature overnight. The sediment was oven dried at 50°C for 24 hours before digestion. Exactly 0.50g of the dried sediment was placed into the reaction vessel, and 10.0ml of HNO₃ was carefully dispensed into the vessel. There were 11 samples and 1 blank (HNO₃)

digested at one time. One of the samples was connected to the pressure controlling device, and the pressure was regulated at 150 psig. Each digestion lasted 15 minutes, was run at 100% power, and was allowed to cool in the reaction vessels until the pressure in the vessels returned to zero.

Upon removal from the reaction vessel, the leachate was diluted with 90.0ml of distilled, deionized water (DDW), and filtered using 0.45µm acid washed nucleopore filters. Two 5ml aliquots of the leachate were used to condition the filters and syringes, and were then discarded. The remainder of the leachate was filtered into prewashed polyethylene bottles and stored at room temperature until analysis. 30ml of each sample were placed into two polyethylene bottles: one bottle for analysis of As, Cd, and Pb; the other bottle for Hg. The bottle containing the aliquot for Hg analysis had an additive of 300uL of a gold chloride solution to prevent sorption of Hg onto the walls of the sample bottle.

Analysis of the leachate from this process was made using the Perkin Elmer 5100 PC atomic absorption spectrophotometer graphite furnace to determine total concentrations of the trace metals As, Cd, and Pb. The sample was injected into the furnace chamber by an automatic pipeting arm. The pipet arm collected 20μ I of matrix modifier, 10μ I of diluent, and 10μ I of sample (in that order) and injected it onto a L'vov platform within the furnace chamber. For Cd and Pb, the matrix modifier consists of a 1:1 mix of two solutions: 4g of (NH₄)H₂PO₄ in 100ml of DDW, and 2g of Mg(NO₃)₂ in 100ml of DDW. For As, the matrix modifier was 0.2g of Ni(NO₃)₂ in 100ml of DDW.

The furnace chamber and the L'vov platform consist of analytically pure graphite, and were changed as needed to prevent contamination from either part wearing out. The purpose of the L'vov platform was to allow a more uniform atomization of the sample, which results in more reproduceable results. For each sample that was analyzed, three replicates of the analysis was done to be sure of precise results.

QUALITY ASSURANCE PROCEDURE

At the beginning of this study, the entire analytical procedure was performed on NBS standard material # 2704 (Buffalo River sediment) for each of the trace metals. The specifications for this standard material in ug/g are: As, $23.4\pm.8$; Cd, $3.45\pm.22$; and Pb, 161 ± 17 . The results of the analysis of the standard material by the techniques mentioned here, showed that the concentrations of each of the three trace metals fall well within the reported tolerance values for this material. For this reason, it is believed that the addition of H_2O_2 to the sediment during the digestive procedure (as was the case in previous studies at MSU) is an unnecessary, step which has the potential to introduce some contamination. Furthermore, during method development at the beginning of this study, a sample was digested once with HNO₃ and H_2O_2 , and once with HNO₃ alone. These two methods of digestion showed no appreciable difference in concentration for any of the three trace metals discussed in this study.

Other factors are included in the Q.A. procedures besides the use of the standard reference material. As mentioned previously, three replicates of each analysis for every sample was made. The relative standard deviation (RSD) was required to be less than 15% for the replicates of the same sample, or else the sample was reanalyzed. If the RSD value was still in excess of 15% after the second analysis, the sample was flagged as bad. If more than 5% of the samples within a core were flagged, the entire core was to be reanalyzed.

In addition, for every 20 samples analyzed, one sample was subsplit 3 times for 3 separate analyses. The RSD value of the subsplits was required to be less than 20%. This provided a check on the analytical and laboratory procedures. The standard reference material was also reanalyzed every 20 samples for additional quality control. Results of the Q.A. checks are shown in tables A2-1 through A2-4 of Appendix B.

IV. RESULTS

The results of this study are presented in two forms. The actual concentration values for the various metals are reported in table form in Appendix C. The core profiles showing a plot of concentration vs. depth are presented in this chapter by element. In addition to the concentration profiles, a statistical analysis was done to compare the maximum, minimum, and excess concentrations of each metal, both within in the core, and among the cores. The excess concentration calculation was made in order to identify the anthropogenic input to the sediments of the Great Lakes, since the information needed to calculate focusing factors is not yet available for most of the cores.

ARSENIC

The profiles showing the concentrations of arsenic in the cores of this study are shown in figures 7-10. It can be seen that the highest concentration of As is typically in the upper portion of the core. There are, however, exceptions: cores EPA#19 (LM), EPA#27, EPA#41b, EPA#19 (LO), EPA#64a, and EPA#LG1. These cores have high concentrations of As in near surface sediments, but have higher concentrations at depth. EPA#19 (LM), EPA#19 (LO), and EPA#64a, for instance, have very high As concentrations in a single sample. These peaks are the result of early diagenesis taking place in the sediments, and correspond to the presence of an active redox horizon (see description of core profiles in Appendix A). EPA#11 shows several small peaks at depth; these correspond to remnant (non-active) redox horizons.

The As profiles appear to be generally ragged, with spikes and antispikes throughout. In addition, the background concentrations are fairly difficult to establish. For EPA#41b, it is



Figure 7: EPA#s: 11, 18, 19, and 23 As profiles



Figure 8: EPA#s: 27, 34, 40, and 41b As profiles



Figure 9: EPA#s: 19, 25a, 40a, and 64a As profiles







impossible to establish a background concentration due to the shape of the profile. This core was from a nondepositional area, being composed almost entirely of sand with slight amounts of silt and organic matter mixed in. By comparing this profile to those from other locations, it can be seen that all concentrations in EPA#41b correspond to typical background.

Table 1 is a summary of minimum, maximum, and excess concentrations of As from this study. A statistical analysis of the values for the minimum and maximum was done for purposes of comparison of cores in this study, as well as to compare with data from other studies. From this table it can be seen that As concentrations range from a minimum of $3.1 \,\mu g/g$ in EPA#41b to a maximum of 221.8 $\mu g/g$ in EPA#LG2. The mean value for As in this study was $12.4 \,\mu g/g$. The excess concentration of As has considerable variation: from a low of $1.5 \,\mu g/g$ in EPA#27, to a high of 54.1 $\mu g/g$ in EPA#19 (LO). Excess concentration for EPA#41b was not calculated because all concentration values for this core were consistent with the background concentrations of all other profiles, and, furthermore, the shape of this profile does not lend itself to this calculation.

Core	Minimum (µg/g)	Maximum (µg/g)	Excess (µg/g)
EPA#11	2.1	14.0	7.2
EPA#18	3.0	38.5	4.8
EPA#19 (LM)	1.3	67.3	4.5
EPA#23	2.7	8.8	2.6
EPA#27	1.8	5.4	1.5
EPA#34	3.5	14.7	6.4
EPA#40	2.2	22.5	2.9
EPA#41b	2.2	5.2	n.c.
EPA#19 (LO)	2.5	512.4	54.1
EPA#25a	6.4	29.2	12.3
EPA#40a	4.9	29.8	10.8
EPA#64a	2.9	180.9	15.4
EPA#LG1	7.7	34.4	11.9
EPA#LG2	1.7	30.0	10.9
EPA#55	6.8	53.9	12.6
Mean	3.4	69.8	11.3
Std. Dev.	2.0	129.8	13.1

Table 1: Minimum, maximum, and excess As concentrations

n.c.: Not Calculated

CADMIUM

The profiles showing the concentrations of cadmium in the cores of this study are shown in figures 11-14. It can be seen that the highest concentration of Cd is typically in the uppermost portion of the core. EPA#34 is the only exception to this, and does not correspond to any visible redox boundary. With the exceptions of EPA#23, and EPA#41b (these cores are composed almost completely of glacial clay), the profiles appear smooth. The other profiles show "classical" peaks at the top portion of the core. Background concentrations are for the most part constant, and the depth where the profile achieves background levels are easily determined.

In the case of all cores except EPA#23, EPA#27, EPA#34, and EPA#41b (which may all be erosional sites), the concentration trend in the profiles are decreasing to the present day from a maximum concentration level. According to ²¹⁰Pb dating, the peak concentration for Cd on cores EPA#18 and EPA#19 (LO) was achieved in the mid 1950s (figure 15).

Table 2 is a summary of minimum, maximum, and excess concentrations of Cd from this study. A statistical analysis of the values for the minimum and maximum was done for purposed of comparison of cores in this study, as well as to compare with data from other studies. From this table it can be seen that Cd concentrations range from a minimum of .03 μ g/g in EPA#LG2, to a maximum of 6.14 μ g/g in EPA#LG1. The mean value for Cd in this study was .94 μ g/g. The excess concentration shows some variability, but not as much as did As. Cd excess ranges from a low of .23 μ g/g in EPA#27 to a high of 2.3 μ g/g in EPA#55. Excess concentration was not calculated for EPA#41b as mentioned above.



Figure 11: EPA#'s: 11, 18, 19, and 23 Cd profiles



Figure 12: EPA#'s: 27,34,40, and 41b Cd profiles



Figure 13: EPA#'s: 19, 25a, 40a and 64a Cd profiles



Figure 14: EPA#s: LG1, LG2 and 55 Cd profiles



Figure 15: EPA#11, EPA#18, and EPA#19 (O) Cd profiles showing ²¹⁰Pb dates

Core	Minimum (µg/g)	Maximum (µg/g)	Excess (µg/g)
EPA#11	0.11	2.00	1.24
EPA#18	0.25	2.64	1.20
EPA#19 (LM)	0.06	1.49	0.88
EPA#23	0.09	0.83	0.37
EPA#27	0.10	0.54	0.23
EPA#34	0.10	2.66	0.76
EPA#40	0.09	2.27	1.16
EPA#41b	0.06	0.27	n.c.
EPA#19 (LO)	0.20	3.78	2.21
EPA#25a	0.30	4.18	1.79
EPA#40a	0.18	3.42	1.58
EPA#64a	0.13	3.87	1.62
EPA#LG1	0.21	6.14	2.11
EPA#LG2	0.03	3.68	1.70
EPA#55	0.19	4.48	2.30
Mean	0.14	2.82	1.37
Std. Dev.	0.078	1.630	0.7

Table 2: Minimum, maximum, and excess Cd concentrations

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n.c.: Not Calculated

LEAD

The profiles showing the concentrations of lead in the cores of this study are shown in figures 16-18. Once again, it can be seen that the highest concentrations of Pb is typically in the upper portion of the core. EPA#55 is the only exception to this, and the sample in the lower portion of that core with high Pb concentrations is suspected to be anomalous. All core profiles are fairly smooth, with the same "classical" peaks in the upper portion of the cores. Background concentrations are fairly constant, and the depth where the profile achieves background levels are easily determined.

As was the case for Cd, for all cores except in the possible erosional sites EPA#23, EPA#27, EPA#34, andEPA#41b, the concentration trend in the profiles are decreasing to the present day from a maximum concentration level. The position of the maximum concentrations overlap the Cd peaks exactly, and correspond to the mid 1950s (figure 19).

Table 3 is a summary of minimum, maximum, and excess concentrations of Pb from this study. A statistical analysis of the values for the minimum and maximum was done for purposes of comparison of cores in this study, as well as to compare with data from other studies. From this table, it can be seen that Pb concentrations range from a minimum of $3.1 \,\mu$ g/g in EPA#41b, to a maximum of 221.8 μ g/g in EPA#LG2. The mean value for Pb in this study was 48.3 μ g/g. Excess concentration varies considerably: from a low of 17.4 μ g/g in EPA#23, to a high of 108.3 μ g/g in EPA#19 (LM). Once again, the excess concentration was not calculated for EPA#41b.



Figure 16: EPA#s: 11, 18, 19, and 23 Pb profiles



Figure 17: EPA#s: 27, 34, 40, and 41b Pb profiles



Figure 18: EPA#'s: 19, 25a, 40a, and 64a Pb profiles





Figure 19: EPA#'s: LG1, LG2, and 55 Pb profiles



Figure 20: EPA#11, EPA#18, and EPA#19 (O) Pb profiles showing ²¹⁰Pb dates

Core	Minimum (µg/g)	Maximum (µg/g)	Excess (µg/g)
EPA#11	20.4	158.0	86.3
EPA#18	8.2	158.4	76.9
EPA#19 (LM)	6.2	189.4	108.3
EPA#23	10.0	92.0	37.5
EPA#27	4.6	44.2	17.4
EPA#34	4.8	115.8	80.4
EPA#40	4.2	122.8	56.5
EPA#41b	3.1	19.8	n.c.
EPA#19 (LO)	8.0	166.8	92.5
EPA#25a	12.6	157.8	70.0
EPA#40a	11.4	176.8	79.2
EPA#64a	9.2	182.0	85.5
EPA#LG1	16.6	181.4	78.8
EPA#LG2	7.0	221.8	106.5
EPA#55	11.2	216.2	50.4
Mean	9.2	146.9	73.3
Std. Dev.	4.8	58.3	25.4

Table 3: Minimum, maximum, and excess Pb concentrations

n.c.: Not Calculated

V. DISCUSSION

GENERAL OBSERVATIONS

Most of the profiles of the cores from this study show similar patterns of concentration for the metals. The upper portion of the core has (in most cases) the peak of maximum concentration. There are two causes of these concentration patterns. The high concentrations may be due to diagenetic remobilization under reducing conditions, followed by readsorption on oxides in aerobic layers (Farmer and Lovell, 1986). The other way metals accumulate in near surface sediments is from anthropogenic influence (Prohic and Juracic, 1989). There is a way to determine which process is controlling metal concentrations in most cases. When the high concentrations are present in a narrow spike (one sample), (such as EPA#19 (LO), sample 9, As profile), diagenetic remobilization is the controlling factor. In the case of elevated concentrations in several proximate samples (EPA#40a, samples 1-17, Cd profile), anthropogenic contamination is the primary culprit.

Not all profiles from this study show nice peaks of metal concentration. Profiles EPA#23, EPA#27, and EPA#41b show concentrations at maximum in the uppermost sample. It is quite likely that these sites are all erosional, or at the very least, nondepositional. There is evidence to support this: these are the four shortest profiles from the study. The reason for this is that the sediment at these locations was not conducive to coring: EPA#27 and EPA#34 had a high sand content (a material not generally found in depositional basins); EPA#23 and EPA#41b were almost completely composed of red glacial clay. Another piece of evidence suggesting an erosional site is the location from which the cores were collected. All four of these cores come

from the central part of Lake Michigan, which happens to be between the northern and southern depositional basins of the lake.

A comparison of the data from this study and from the literature was made as an additional method to see if concentration values were reasonable. Table 4 is a summary of data from the literature on the concentrations of As, Cd, and Pb in the sediments of the Great Lakes. With the exception of the highly polluted sediments of Toronto Harbor, the concentrations for background, peak, and the range of values in various studies are compatible with those from this study.

BACKGROUND CONCENTRATIONS

As mentioned previously, the background concentration is defined as the mean concentration of the samples located below the background depth. The data which compose figure 21 come from table 5, which is a comparison with a study of uncontaminated soils done by Connor and Shackette (1975). The mean background concentration was computed for purposes of comparison with data from the literature. As can be seen, the range of background concentrations for each As, Cd, and Pb is less than the range of the concentration values for the uncontaminated soil study. In addition, the mean of the background concentrations for this study is less than the mean value in the soil study for each of the trace metals. Cd is an exception; there is no mean value reported in the soil study. The fact that the background levels for this study are lower than uncontaminated soils is an important one; it indicates that sampling and analytical techniques used in this study do not introduce contamination to the samples.

By comparing the background concentrations, some regional trends appear (figures 22-24). The Pb concentrations have the least amount of variation: that is, the cores from the same regional areas (basins) are similar. The profiles from Lake Ontario show higher concentrations than those from Lake Michigan. Furthermore, profiles from the southern basin of Lake Michigan

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Reference	As	cq	Ρb	Comments
Cahil and Shimp, 1984	.8-153	.5-2.5	1.0-153	Surface sediment concs.
Parker et al., 1982		.5-2.3		Lake Michigan concs.
Kemp et al., 1978			55-165	Peak concentrations
Rossman, 1986			10/160	Background/Peak concs.
Robbins, 1980		1.4/3.85	20/160	Background/Peak concs.
Crowder et al., 1989	1.0-50		2.0-200	Concentration range
Munawar and Thomas, 1989			37-1008	Toronto Harbor (polluted)
Mueller, 1989			ω	Background (Louisiana
Mudroch, 1983			205	stream) Peak

CORE	As	Cd	Pb
EPA#11	4.2	0.16	22.8
EPA#18	7.6	0.41	11.1
EPA#19 (LM)	7.8	0.17	12.4
EPA#23	3.3	0.12	11.0
EPA#27	3.5	0.18	10.5
EPA#34	5.2	0.36	8.2
EPA#40	4.4	0.15	8.0
EPA#41b	n.c.	n.c.	n.c.
EPA#19 (LO)	11.1	0.26	22.2
EPA#25a	8.0	0.32	15.7
EPA#40a	6.7	0.23	15.4
EPA#64a	3.0	0.24	15.2
EPA#LG1	8.3	0.23	19.6
EPA#LG2	6.7	0.17	20.6
EPA#55	7.8	0.36	8.1
Mean	6.3	0.24	14.3
SOILS			
high	13.0	<1	31.0
low	5.5		2.6

Table 5: Background concentrations of sediments and soils (all units in μ g/g)

n.c.: not calculated



Figure 21: EPA#s: Comparison of background concentrations of sediments and uncontaminated soils (from Connor and Shackette

have higher concentrations than the mid-lake locations, which have slightly higher concentrations than the northern basin.

The Cd profiles show similar profiles to those of Pb. Profiles from Lake Ontario are generally higher than Lake Michigan. The basins of Lake Michigan have slightly different trends than Pb. The southern and mid-lake profiles have similar concentrations; these are higher than the concentrations found in the northern basin.

The As profiles show similar trends. Lake Ontario background concentrations are greater than those from Lake Michigan. Profiles from the southern basin appear to have generally higher As concentrations than either the north basin or the mid-lake profiles (which are at about the same levels).

By comparing the profiles of each As, Cd, and Pb for the same site, several things become evident. Figure 25 shows the profiles of As, Cd, and Pb for EPA#25a. First, the maximum concentration (peak) occur at the same depth for both Cd and Pb. The maximum concentration for As occurs at a shallower depth than the Cd or Pb. The shape of the Cd and Pb profiles are both smooth, but As is rather jagged. The last thing that can be noticed is that the background depth for Cd and Pb occur at the same depth. The background for the As profile occurs at a shallower depth. This same phenomena can be observed in many of the profiles from this study.

From the comparison of these profiles it can be seen that Cd and Pb appear to behave in a similar fashion in the sediments of the Great Lakes. Arsenic on the other hand, seems to behave differently. The cause of the difference between As and the Cd/Pb profiles is the effect of early diagenesis. Because of early diagenesis, there are limitations which must be kept in mind when interpreting the type of profiles (concentration vs. depth) presented in this study.

Organic matter present in the sediments decays. Any metals bound to this organic matter are then released to the sediment-pore water system. In addition, the decay of organic matter lowers the pe or redox potential of the sediment-pore water system. The lowered pe causes Fe and Mn oxides present in the sediments to dissolve. Any metals bound to these oxides are



Figure 22: EPA#s: Background concentrations of As from Lakes Michigan and Ontario












released to the pore water. The metals thus released to the pore water are free to migrate upward in the sediment-pore water system. Eventually the metals reach a point where the sediment-pore water system is oxic, and the metals are readsorbed to the sediments. This process causes remobilization of the metals, and alters the appearance of the profile. As is much more susceptible to this process than Cd or Pb, and, as a result, the shape and conformation of the As profile is different from that of the Cd and Pb. Furthermore, not all of the metals which accumulate in the uppermost portion of the profile are due to the anthropogenic influence.

For example, there are several profiles which contain redox layers. Figures 26-33 show the effects of early diagenesis on the metal concentrations of the profiles of EPA#11, EPA#19 (M), EPA#27, EPA#34, EPA#40, EPA#41b, EPA#19 (O), and EPA#64a respectively. EPA#11 had 5 Fe/Mn oxide layers (see core EPA#11 description, Appendix A). All of the concentration peaks located below the background depth correspond to the presence of an Fe/Mn redox layer. It should be noted that the lowermost redox layer is currently active; the other layers are nonactive, older layers. Furthermore, the samples between the redox layers have lower concentrations of As; these are for the most part nearly the same concentration. All of the other profiles have only one redox layer, and this layer corresponds to a high concentration of As. This is the case for all profiles except EPA#34. In this profile, the redox layer is located below the higher excess concentration of the profile. In addition, this profile's redox layer may just be beginning to form, so As concentrations may not have been able to accumulate to higher levels.

SEDIMENT FOCUSING AND 210Pb DATING

One method of determining whether atmospheric deposition is the significant input process for contaminants (trace metals) to the Great Lakes, is by applying a focusing factor to the inventory of metals in the sediments. This is done by computing the inventory of metals in the sediment, and dividing by the focusing factor. The focusing factor accounts for differential sedimentation rates between sampling locations. Once the focusing factor is established, the



Figure 26: EPA#11 profile showing the correspondance of redox zones and background concentration peaks















inventory of metals in the sediment at different sites within both the same lake and within the entire Great Lakes basin can be compared.

There are two commonly used methods of ²¹⁰Pb dating. The first is the constant initial concentration (CIS) model. In this model, the rates of mass sedimentation and unsupported ²¹⁰Pb supply are proportional to one another such that the ²¹⁰Pb concentration always has a constant value at the top of the sediment core. The other model, the constant rate of supply (CRS) has a basic assumption that the net supply of unsupported ²¹⁰Pb is constant despite variations in the mass sedimentation rate (Hermanson and Christensen, 1991).

²¹⁰Pb dating does have a problem however. An underlying assumption common to all ²¹⁰Pb dating models is that once in the sediment, the ²¹⁰Pb remains there. In reality, there is at least some postdepositional mobility which may result in dating errors (Benoit and Hemond, 1991; Schell, 1986). Other assumptions include: a constant ²¹⁰Pb flux to the sediment-water interface, and the sedimentation rate is constant (Robbins and Edgington, 1975). Although this problem with establishing an absolute date on sediments does exist, it does not undermine the validity of this study. The dates used to establish the focusing factor are not altered enough to make any significant difference in the calculation. The entire process of calculating focusing factors is described below.

Sediment focusing is defined as movement of sediment toward deeper parts of a lake, usually resulting from periodic turbulence such as overturn (Likens and Davis, 1975). Other significant processes include slumping and sliding of material on slopes, and current erosion/redeposition (Hilton et al., 1986). The higher sedimentation rate means higher loadings of metals in the depositional basin(s) of the lake. This must be accounted for in order to determine the atmospheric signal. ²¹⁰Pb dating is then used to determine sedimentation rates at the sampling sites.

The first step in establishing a focusing factor is to determine the porosity of the core. This is done by weighing the sediment while wet, and again when dry. By using the calculation from Hermanson and Christensen (1991), porosity is established. The calculation is:

$Ø = 1/(1 + (Md/(2.45 \cdot W)))$

where \emptyset is porosity, Md is the mass of sediment (dry), and W is the mass of water lost. Using 1- the porosity and assuming the bulk density of 2.45g/cm³, the (cumulative) dry weight of the sediment (g/cm²) can be calculated.

Once the dry weight of sediment is calculated, and using 210 Pb information (the unsupported activities, and the age dates of the sediments), other calculations can be made. The sediment accumulation rates (g/cm² yr) are simply the dry mass of sediment divided by the age of the sample. The cumulative unsupported 210 Pb (inventory) is necessary to calculate the focusing factor. This is calculated as follows:

$$CU = \Sigma (CDM)(UA)$$

where CU is the inventory in pCi/cm², CDM is the cumulative dry mass of sediment in g/cm², and UA is the unsupported activity in pCi/g.

Using the cumulative unsupported ²¹⁰Pb (CU), and assuming an atmospheric rate of 15.5 pCi/cm² (Eisenreich, 1992 personal communication), the focusing factor (FF) can be calculated as follows:

FF = (CU) / 15.5

The focusing factor is used to normalize the data. This is done by dividing the inventory by the focusing factor. The data may then be compared to determine the significance of atmospheric deposition.

The inventory of the metals in the sediment is calculated as follows:

$I = \sum ((MC-BC)(BD)(1-\emptyset)(T))$

where I is the inventory in μ g/cm², MC is the metal concentration in μ g/g, BC is the concentration of metals in the background, BD is the bulk density (2.45 g/cm³), Ø is porosity, and T is the thickness of the sediment interval. Results of the inventory calculation for the sites with ²¹⁰Pb data are shown below:

Uncorrected Inventories:

Site #	As	Cd	Pb
EPA#11	27.6	4.60	318.5
EPA#18	27.2	9.09	543.4
EPA#19 (O)	197.1	6.53	263.7

For the three cores which have ²¹⁰Pb data at this time, the calculated focusing factors were: EPA#11 FF=1.99, EPA#18 FF=2.43, and EPA#19 (O) FF=1.07. All of the calculations needed to determine the normalized data (inventory) are shown in Appendix D. These focusing factors were applied to the inventories of each of the trace metals and the result was compared. Results for the three sites for the three metals are shown below:

Corrected Inventories:

Site #	As	Cd	Pb
EPA#11	13.3	2.21	152.9
EPA#18	10.4	3.48	207.6
EPA#19 (O)	171.1	5.67	228.9

It can be seen from the data presented above that the focusing factor corrected inventories for the three metals are similar. Site EPA#19 (O) (As data) is the only corrected inventory which is

radically different than the others. This is because of the redox zone within the background depth which has a high concentration of As in it. The Cd and Pb data show some slight variation, but are still reasonably similar. If there were more data points to work with, it would be easier to determine with a greater degree of certanty that the data are truely similar.

Because there are only 3 profiles that have can be compared in this way due to the lack of ²¹⁰Pb data, another method must be used to confirm the tentative results seen here. This method is a comparison of the excess concentrations and the atmospheric deposition rates of the metals over the Great Lakes.

EXCESS CONCENTRATIONS

The excess concentration is defined as the mean concentration of the samples above the background depth less the background concentration. Figures 34-36 are comparisons of excess concentration for As, Cd, and Pb respectively. It can be seen that for each of the metals As, Cd, and Pb the excess concentrations are generally greater in Lake Ontario than in Lake Michigan. The excess of EPA#19 (O) for As (and to a much lesser amount Pb) is greater than that of the other Lake Ontario cores. This may be because EPA#19 (O) is located near the mouth of the Niagara River, which is highly polluted. The Lake Ontario excess concentrations are calculated to determine the anthropogenic signal, the fact that the Lake Ontario cores all have similar values indicates that the process acting to disperse the anthropogenic fraction is acting over the entire lake. Furthermore, the fact that EPA#19 (O) is higher than the other profiles of Lake Ontario (overprinted due to a local source) indicates that the process acting on the anthropogenic fraction is not riverine transport.

Lake Michigan profiles also show some variation. EPA#11 through EPA#23 are from the southern basin of the lake, and are reasonably similar in excess concentration for all metals.



Figure 34: Comparison of As excess concentrations



Figure 35: Comparison of Cd excess concentrations



Figure 36: Comparison of Pb excess concentrations

EPA#23 has lower concentrations for all metals; this may be due to the fact that the material making up the bulk of the core is glacial clay, and/or that this site may be erosional.

The southern basin has higher concentrations than either the mid-lake or northern basin regions. For Cd and Pb, the northern basin has higher concentrations than As; for the mid-lake region the reverse is true. For Lake Michigan, the process acting to distribute the anthropogenic **signal appears to operate on a basin-wide scale**, but not over the entire lake.

Based on these observations, it is suspected that the process controlling distribution of the anthropogenic signal in the Great Lakes region is atmospheric deposition. Data from a workshop held at the Canada center for Inland waters (Eisenreich and Strachan, 1992) indicate that the atmospheric deposition rates of As, Cd, and Pb are:

Lake	As	Cd	Pb
Mi chigan	215 <i>µ</i> g/m ² yr	153 <i>µg/</i> m ² yr	1747 µg/m ² yr
O Intari o	235 µg/m ² yr	167 µg/m ² yr	1907 <i>µ</i> g/m ² yr

These values are, unfortunately, the only ones in effect for the respective lakes, and not Subdivided by basin. Some tentative conclusions can be reached based on these numbers. By Comparing the atmospheric deposition rates to the excess concentrations, it can be seen that there is a general match. Values are highest for Lake Ontario, and lower for Lake Michigan. While the trends cannot be applied to basins within the lakes, it does seem that atmospheric deposition is the significant input process of As, Cd, and Pb to the Great Lakes.

A further piece of evidence for atmospheric deposition being the most significant input Drocess is the orientation of Lakes Michigan and Ontario. In Lake Ontario, concentrations of all trace metals were nearly the same, while in Lake Michigan, the concentrations of the metals varied by basin. Considering that the predominant wind direction is west to east (with some north/south variation), the excess concentration trends make sense. Lake Ontario has its long axis oriented subparallel to wind direction, so concentrations should be similar throughout. Lake Michigan has its long axis oriented perpendicular to wind direction, so excess concentrations would depend on point sources upwind of the sampling sites. This is borne out by the fact that the highest excess concentrations are found in the cores from the southern basin; the southern end of Lake Michigan is more highly industrialized than the northern or mid-lake regions.

It can be seen that the ²¹⁰Pb focusing corrected data and the comparison of excess concentrations of metals with the atmospheric deposition rates both show that atmospheric deposition of the metals As, Cd, and Pb is the dominant input process to the Great Lakes region. When more ²¹⁰Pb data becomes available, it is believed that the conclusions reached in this study will be suported.

VI. CONCLUSIONS

From comparisons of the trace metal concentrations in the 15 cores collected in Lakes Michigan and Ontario with data from the literature, several conclusions can be drawn. First, the background concentrations of all 3 trace metals are equivalent to concentrations found in uncontaminated soils. This is important to note, because it means that sediments from background horizons are uncontaminated beyond natural levels, and that the process of core collection, extraction, and analysis does not introduce any trace metal contamination to the sediments. In addition, the background depths for 3 cores were established to correspond to the early 1800s by use of ²¹⁰Pb dating: the time period when the Great Lakes region was becoming heavily industrialized. This date (1820s-1840s) appears to be regionally the same, as one dated core was from Lake Ontario, and the other two were from Lake Michigan.

There are differences in the calculated metal calculations. The background concentrations of all three metals have variations on a regional scale. Lake Ontario has higher background concentrations than Lake Michigan. This could be due to differences in rock type: Lake Michigan is accumulating sediments derived from glacial drift, that were eroded from sedimentary rock, while Lake Ontario is accumulating sedimentary tocks. There is variation in the basins of Lake Michigan as well. Generally, the southern basin has higher concentrations of trace metals than the northern or mid-lake areas.

Excess concentrations vary regionally as well. Lake Ontario has higher concentrations of all 3 trace metals than Lake Michigan. Excess concentrations in Lake Ontario are consistent throughout the lake except where overprinted by influx of the Niagara River. Lake Michigan excess concentrations vary from north to south, with highest concentrations in the south. High

concentrations are also found in Green Bay, but appear to be confined to the southern part of the bay. The regional gradients are believed to be the result of the orientations of the two lakes with respect to predominant wind direction. Additionally, the excess and measured atmospheric concentrations of the trace metals over Lakes Michigan and Ontario show the same trends: higher over Lake Ontario than Lake Michigan.

By applying a focusing factor to profiles EPA#11, EPA#18, and EPA#19 (O), it can be seen that the normalized data are similar. The exception to this is the As data from EPA#19 (O), which is caused by the effects of a redox zone in the background area of the profile. This is further confirmation that the effects of diagenesis in the sediments have an effect on certain rnetals, in this case As. Since the data are similar (inasmuch as 3 data points for each of the metals can be called similar) for Cd and Pb (and 2 for As) it can be concluded that atmospheric deposition is indeed the dominant input process of the trace metals As, Cd, and Pb to the Great Lakes region.

APPENDICES

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TABLE A1-1:

LAKE MICHIGAN, Depth 430'

CORE 1991 BC-1 EPA 11

Lat: 42° 22' 36"N Long: 86° 59' 05"W

1 0-1 1 Dark grey soupy material 2 1-2 1 Dark grey soupy material 3 2:3 1 Dark grey, less soupy 4 3-4 1 Dark grey, sold material 6 5-6 1 Upper portion dark grey, lower 2 om kgrey, sold material 2 om light red color, possible worn burrows in section 7 6-7 1 Light grey, with tan mottling, some dark blebs of material (carbon) 8 7-8 1 More rigid, slightly more tan coloration and mottling-possible Fe oxides 9 8-9 1 Upper portion firm, lower portion soupy, same coloration 10 9-10 1 Sand present in this layer, same coloration 11 10-11 1 Higher sand content, possible Fe oxides 12 11-12 1 Light tan upper portion, Redox bands begin (littled), yellow redox crust -cements the sediment, 1 cm thick, remainder of section is light tan material also remainder of section is light tan material also remainder of section is light tan material dos remainder of section is light tan material also remainder of section is light tan material alsos remainder of section is light tan mat	SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION	_
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3 2-3 1 Dark grey, lamost sold material 4 3-4 1 Dark grey, lamost sold material 5 4-5 1 Dark grey, solid material 6 5-6 1 Upper portion dark grey, lower 2 might red color, possible worn burrows in section 2.3 might red color, possible worn burrows in section 7 6-7 1 Light grey, with ten mottling, some dark blebs of material (carbon) 8 7-8 1 More rigid, slightly more tan coloration and mottling- possible Fe oxides 9 8-9 1 Upper portion firm, lower portion soupy, same coloration 10 9-10 1 Sand present in this layer, same color 11 10-11 1 Higher sand content, possible Fe oxides 12 11-12 1 Light tan upper portion, Redox bands begin (titled), yellow redox crust at base of section 13 12-12.5 .5 Yellow redox crustcements the sediment, 1 cm thick, remainder of section is light tan material, as in 13, light tan material as iso remainder of section 15 13.5-14.5 1 Light tan material with dark specks (carbon?), redox material (vivanite?) 16 14.5-15 .5 Fedox crusts (2) aach .1 cm thick Fe/Mn oxides, remainder of section 17 15-15.5 .5 Tar and grey	2	1-2	1	Dark grey soupy material	
4 3-4 1 Dark grey, almost sold material 5 4-5 1 Dark grey, sold material 6 5-6 1 Upper portion dark grey, lower .2 cm light red color, possible worm burrows in section .2 cm light red color, possible worm burrows in section 7 6-7 1 Light grey, with tan mottling, some dark blebs of material (carbon) 8 7-8 1 More rigid, slightly more tan coloration and mottling-possible Fe oxides 9 8-9 1 Upper portion firm, lower portion soupy, same coloration 10 9-10 1 Sand present in this layer, same color color 11 10-11 1 Higher sand content, possible Fe oxides 12 11-12 1 Light tan upper portion, Redox bands begin (titted), yellow redox crust at base of section 13 12-12.5 .5 Yellow redox crust-cements the sediment, 1 cm thick, remainder of section is light tan material also remainder of section is light tan material with dark specks (carbon?), redox material at base with green material (wivanite?) 16 14.5-15 .5 Tean and grey motting material (wivanite?) 16 14.5-15 .5 Tean and grey motting material (wivanite?) 18	3	2-3	1	Dark grey, less soupy	
54-51Dark grey, solid material65-61Upper portion dark grey, lower .2 cm light red color, possible worm burrows in section76-71Light grey, with tan mottling, some dark bles of material (carbon)87-81More rigid, slightly more tan coloration and mottling- possible Fe oxides98-91Upper portion firm, lower portion109-101Sand present in this layer, same color1110-111Higher sand content, possible Fe oxides1211-121Light tan upper portion, Redox bands begin (tilted), yellow redox crust at base of section1312-12.5.5Yellow redox crust at base of section1412.5-13.51More redox material, as in 13, light tan material, firm tan material, as in 13, light tan material, as in 14, light tan material, as in 13, light tan material, as in 13, light tan material, as in 13, light tan material with dark specks (carbon?), redox material at base with green material at tan and grey mottling material very dry1614.5-15.5Tan and grey mottling material very dry1815.5-16.51Some redox, no sand midle of section, dark tan bebs 2 mm across2017.5-18.51Thicker redox layer, pockets in middle of section, dark tan bebs 2 mm across	4	3-4	1	Dark grey, almost solid material	
6 5-6 1 Upper portion dark grey, lower 2 cm light red color, possible worm burrows in section 7 6-7 1 Light grey, with tan mottling, some dark blebs of material (carbon) 8 7-8 1 More rigid, slightly more tan coloration and mottling possible Fe oxides 9 8-9 1 Upper portion firm, lower portion 10 9-10 1 Sand present in this layer, same color 11 10-11 1 Higher sand content, possible Fe oxides 12 11-12 1 Light tan upper portion, Redox bands begin (titled), yellow redox crust at base of section 13 12-12.5 .5 Yellow redox crust-cements the sediment, 1 cm thick, remainder of section is light tan material, fim 14 12.5-13.5 1 More regid, sonth dark specks (carbor)?, redox material at base with green material (vivanile?) 16 14.5-15 .5 Tean and grey motting material (vivanile?) 16 14.5-15 .5 Tan and grey motting material very dry 18 15.5-16.5 1 Some redox, no sand 19 16.5-17.5 1 Thicker redox layer near bottom of section 20 17.5-18.5 1 <td< td=""><td>5</td><td>4-5</td><td>1</td><td>Dark grey, solid material</td><td></td></td<>	5	4-5	1	Dark grey, solid material	
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20 17.5-18.5 1 Section middle of section, dark tan blebs 2 mm across	19	16.5-17.5	1	Redox layer near bottom of	
20 17.5-18.5 1 Thicker redox layer, pockets in middle of section, dark tan blebs 2 mm across				section	
middle of section, dark tan blebs 2 mm across	20	17.5-18.5	1	Thicker redox layer, pockets in	
blebs 2 mm across				middle of section, dark tan	
				blebs 2 mm across	

21	18.5-20.5	2	Mottling disappears through section
22	20.5-22.5	2	Redox layer .75 cm from section top, some mottling, remainder is tan
23	22.5-24.5	2	Redox layer, no mottling, tan with some grey material, <i>Current active redox layer</i> (color change)
24	24.5-26.5	2	Light grey, several black layers, much more soupy (anoxic layers)
25	26.5-28.5	2	Same as 24, slightly more black material

TABLE_A1-2:

LAKE MICHIGAN, Depth 495'

<u>CORE 1991 BC-2 EPA 18</u>

Lat: 42° 44' 44"N Long: 87° 00'10"

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Grey soupy material, worm
2	1-2	1	Grey soupy material, worm
3	2-3	1	Grey material, less soupy, worm
4	3-4	1	burrows Grey material, less soupy, worm
-			burrows
5	4-5	1	Grey material, almost firm, worm burrows
6	5-6	1	Grey material, firm
7	6-7.5	1.5	Grey material, firm
8	7.5-8.5	1	Grev material, firm
9	8.5-9.5	1	Grev material, firm
10	9.5-10.5	1	Grev material, firm
11	10.5-11.5	1	Slightly lighter grey material,
12	11 5-12 5	1	Mottled grey and tan some
12	11.5-12.5	I	zones of block material
			ZUNES UN DIACK Material,
10	10 E 10 E	4	Some as 10
13	12.5-13.5		Same as 12 Zanas of day dock motorial
14	13.5-14.5	1	Zones of dry dank material
			(carbon?), some mottling, gritty
15	14.5-15.5	1	Less black material, sand
16	15.5-16.5	1	Mostly grey, black almost gone,
47		4	no sand
17	16.5-17.5	1	A few dark streaks in the light grey material
18	17.5-18.5	1	Same as 17, mostly firm
19	18.5-19.5	1	No dark streaks, same as 18
20	19.5-20.5	1	Dark band at base, remainder is grey/tan material
21	20.5-21.5	1	Dark grev material, some sand
22	21.5-22.5	1	Same as 21
23	22.5-23.5	1	Dark material abundant, same as
24	23 5-24 5	1	Same as 23
25	24 5-25 5	1	Same as 23
26	25 5-27 5	2	Same as 23
27	27 5-29 5	2	Some slight mottling, dark
27	27.3-29.5	2	bands at base
SKIP	29.5-31.5	2	Material discarded, same as 27
28	31.5-33.5	2	More soupy, less dark material, mostly light grey with some mottling
29	33.5-35.5	2	Same as 28
SKIP	35.5-37.5	2	Material discarded, same as 29

30	37.5-39.5	2	No dark streaks, all grey material
31	39.5-41.5	2	Mostly very dark material, remainder is light grey
SKIP	41.5-43.5	2	Material discarded, same as 31
32	43.5-45.5	2	Very dark material
SKIP	45.5-47.5	2	Material discarded, same as 32
33	47.5-49.5	2	Very dark material with some tan layers, bottom of core touches stopper

TABLE A1-3:

LAKE MICHIGAN, Depth 310'

CORE 1991 BC-3 EPA 19

<u>Lat:</u> 42[°] 44' 00"N <u>Long:</u> 86[°] 35' 00"W

1 0-1 1 Grey soupy material 2 1-2 1 Grey soupy material 3 2-3 1 Grey soupy material, more firm 4 3-4 1 Grey soupy material, almost firm 5 4-5 1 Dark grey material, almost firm 6 5-6 1 Dark grey material, almost firm 7 6-7 1 Light grey and tan material, almost firm 8 7-8 1 Same as 7 9 8-9 1 Same as 7 9 8-9 1 Light tan with increasing light 11 10-11 1 Light tan material with sand 12 11-12 1 Tan material with sand 13 12-13 1 Dark er and more grey, more rust spots, some other light mottling 15 14-15 1 Dark tan color deepens to base of sample 16 15-16 1 Redox zone: dark tan band .4 cm thick, dark grey band .2 cm thick, solid crust 17 16-17 1 Dry tan crust at top, grey watery material below (.6 cm) 18 17-18 1
2 1-2 1 Grey soupy material 3 2-3 1 Grey soupy material, more firm 4 3-4 1 Grey soupy material, almost firm 5 4-5 1 Dark grey material, almost firm 6 5-6 1 Dark grey to tan material, almost firm 7 6-7 1 Light grey and tan material, almost firm 8 7-8 1 Same as 7 9 8-9 1 Same as 7 10 9-10 1 Light tan with increasing light material, some sand present 11 10-11 1 Light tan material with sand 12 11-12 1 Tan material with rust brown spots (Fe minerals?) 13 12-13 1 Dark er and more grey, more rust spots, some other light mottling 15 14-15 1 Dark tan color deepens to base of sample 16 15-16 1 Redox zone: dark tan band .4 cm thick, sust brown band .4 cm thick.solid crust 17 16-17 1 Dry tan crust at top, grey watery material below (.6 cm) <
3 2-3 1 Grey soupy material, more firm 4 3-4 1 Grey soupy material, more firm 5 4-5 1 Dark grey soupy material, almost firm 6 5-6 1 Dark grey material, almost firm 7 6-7 1 Light grey and tan material, firm 8 7-8 1 Same as 7 9 8-9 1 Same as 7 9 8-9 1 Same as 7 10 9-10 1 Light tan with increasing light material, some sand present 11 10-11 1 Light tan material with rust brown spots (Fe minerals?) 13 12-13 1 Darker and more grey, more rust spots, some other light mottling 15 14-15 1 Dark tan color deepens to base of sample 16 15-16 1 Redox zone: dark tan band .4 cm thick, dark grey band .2 cm thick, solid crust 17 16-17 1 Dry tan crust at top, grey watery material below (.6 cm) 18 17-18 1 Grey creamy textured material 19 18-17-18 1 Grey creamy textured material
43-41Grey soupy material, more firm54-51Dark grey material, almost firm65-61Dark grey material, almost firm76-71Light grey and tan material, almost76-71Light grey and tan material, firm87-81Same as 798-91Same as 7 with mottling109-101Light tan with increasing light material, some sand present1110-111Light tan material with sand1211-121Tan material with rust brown spots (Fe minerals?)1312-131Darker and more grey, more rust spots1413-141Same as 13, fewer rust spots, some other light mottling1514-151Dark grey band .4 cm thick, dark grey band .2 cm thick, lark grey band .4 cm thick, ust brown band .4 cm thick, ust brown band .4 cm thick corust at top, grey watery material below (.6 cm)1817-181Grey creamy textured material Same as 19
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98-91Same as 7 with mottling109-101Light tan with increasing light material, some sand present1110-111Light tan material with sand1211-121Tan material with rust brown spots (Fe minerals?)1312-131Darker and more grey, more rust spots1413-141Same as 13, fewer rust spots, some other light mottling1514-151Dark tan color deepens to base of sample1615-161Redox zone: dark tan band .4 cm thick, dark grey band .2 cm thick, rust brown band .4 cm thick-solid crust1716-171Dry tan crust at top, grey watery material below (.6 cm)1817-181Grey creamy textured material1918-191Same as 19
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1312-131Same as 13, fewer rust spots, spots1413-141Same as 13, fewer rust spots, some other light mottling1514-151Dark tan color deepens to base of sample1615-161Redox zone: dark tan band .4 cm thick, dark grey band .2 cm thick, rust brown band .4 cm thick-solid crust1716-171Dry tan crust at top, grey watery material below (.6 cm)1817-181Grey creamy textured material Same as 18
1312-131Darker and more grey, more rust spots1413-141Same as 13, fewer rust spots, some other light mottling1514-151Dark tan color deepens to base of sample1615-161Redox zone: dark tan band .4 cm thick, dark grey band .2 cm thick, rust brown band .4 cm thick-solid crust1716-171Dry tan crust at top, grey watery material below (.6 cm)1817-181Grey creamy textured material1918-191Same as 18
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1716-171cm thick-solid crust1817-181Dry tan crust at top, grey watery material below (.6 cm)1918-191Grey creamy textured material
1716-171Dry tan crust at top, grey watery material below (.6 cm)1817-181Grey creamy textured material1918-191Same as 18
1817-181material below (.6 cm)1918-191Grey creamy textured material
1817-181Grey creamy textured material1918-191Same as 18
19 18-19 1 Same as 18
Calle as to
20 19-20 1 Same as 18 with dark spots of
organic material present
21 20-22 2 Dark grey sandy material with
black streaks at base of
section
22 22-24 2 Same as 21, with a .3 cm band of
black, rigid organic material
23 24-26 2 Lighter grey creamy texture with
some dark spots
24 26-28 2 Same as 23 with sand and gravel
up to 1 mm in size
25 28-30 2 Darker grey than 24, sand and
gravel up to 1.5 mm in size

TABLE A1-4:

LAKE MICHIGAN, Depth 310'

CORE 1991 BC-4 EPA 23

Lat: 43° 08' 07"N Long: 87° 00' 06"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Grey soupy material, some worm burrows
2	1-2	1	Grey soupy material, more firm
3	2-3	1	Grey material, base of section is red clay, mostly firm
4	3-4	1	Little grey material on surface, remainder is red clay (glacial?)
5	4-5	1	Uniform red clay material
6	5-7	2	Uniform red clay material
SKIP	7-9	2	Material discarded, same as 6
7	9-11	2	Red clay with some grey/black mottling
SKIP	11-13	2	Material discarded, same as 7
8	13-15	2	Same as 7, no mottling
SKIP	15-17	2	Material discarded, same as 7
9	17-19	2	Red clay
SKIP	19-21	2	Material discarded, same as 9
10	21-23	2	Red clay
SKIP	23-25	2	Material discarded, same as 9
11	25-27	2	Red clay
SKIP	27-29	2	Material discarded, same as 9
12	29-31	2	Red clay

TABLE A1-5:

LAKE MICHIGAN, Depth 354'

CORE 1991 BC-5 EPA 27

Lat: 43° 36' 00"N Long: 86° 55' 00"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Light grey porous material, coarse sand and gravel
			mixed with fine grained
			material, soupy
2	1-2	1	Darker grey, very sandy, much
			more firm, base of section is
			dark tan color
3	2-3	1	Dark grey and tan material, finer
			grained, some spots of
			reddish material about sand
			sized (Fe/Mn oxide?)
4	3-4	1	Dark tan material, very gritty with
_			same reddish material as in 3
5	4-5	1	Same as 4, less reddish material
6	5-6	1	Same as 5, reddish material
			nearly absent, some gravel
7	07		present
<i>/</i>	6-7	1	Some grey blotches, same as 6
o	/-8	1	Grey mottling in dark tan
			material, lots of gravel, large
			dark grey/black spot 2 mm in
٩	9-0	1	
JO	0-9	1	Same as 8
11	10-11	1	Same as 9
12	11-12	1	Same as 8
13	12-13	1	Lighter tan material at base of
	12 10	I I	section some big chunks of
			aravel
14	13-14	1	l ight tan clay material more
••		·	aravel
15	14-15	1	Some gravel less firm light tan
		·	clay (red)
16	15-17	2	Drver same as 15
17	17-19	2	Same as 16 some white
		-	blotches
18	19-21	2	White blotches larger, more
-		_	extensive (redox zones)
19	21-23	2	Same as 18, some small gravel
20	23-25	2	Same as 19

TABLE A1-6:

LAKE MICHIGAN, Depth 490'

CORE 1991 BC-6 EPA 34

Lat: 44° 05' 31"N Long: 86° 46' 26"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Dark grey material, worm
			burrows
2	1-2	1	Dark grey material, more firm
3	2-3	1	Pudding-like dark grey material,
			some sand present
4	3-4	1	Same as 3, lower .2 cm
			becomes tanned and sandy
5	4-5	1	Same as 4, firmer medium tan
			redox layer towards base of
_			section
6	5-6	1	Same as 5, firmer band with
_			coarse sand (storm event)
7	6-7	1	Same as 6, grit layer laterally
•			discontinuous
8	7-8	1	Same as 7, coarse grit patches
9	8-9	1	Same as 8
10	9 -10	1	Same as 9, with grey patches
			and pockets of sand
11	10-11	1	Becomes less gritty towards
40		4	base of section, same as 10
12	11-12	1	Much less grifty, same tan
10	40.40	4	
13	12-13		Same as 12 Some as 10, much drive then
14	13-14	1	Same as 13, much dher than
15	14 15	4	BOUVE Some as 14 dries and lighter
15	14-15	I	Same as 14, oner and ligner,
16	15-16	1	Same as 15 but darker tan
17	16-17	1	Same as 16
SKIP	17-19	' 2	Material discarded same as 17
18	10-21	2	Same as 17
10	13-21	2	

TABLE A1-7:

LAKE MICHIGAN, Depth 525'

CORE 1991 BC-7 EPA 40

Lat: 44° 45' 36"N Long: 86° 58' 00"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Grey soupy material
2	1-2	1	Grey soupy material with dark
			patches
3	2-3	1	Same as 2, firmer
4	3-4	1	Dark grey mud wet but firm
5	4-5	1	Same as 4
6	5-6	1	Slightly darker than 5, still wet
7	6-7	1	Black mud with lighter patches
8	7-8	1	Black mud, darkens in color to
			bottom
9	8-9	1	Black mud, some white patches
			and some sand towards
			base of section
10	9 -10	1	Very black mud becomes dark
			grey at bottom of section
11	10-11	1	Black/dark grey material mix
12	11-12	1	Same as 11, black material
			disappears
13	12-13	1	Black and grey clay material
14	13-14	1	Same as 13, grey component is
			whiter in color and slightly
			more abundant than the
			black material
15	14-15	1	Two layers of black material in
			the grey matrix .2 cm thick
			appears to be charcoal or
			other organic material
16	15-16	1	Dark tan material with black
			patches, black disappears at
			base of section
17	16-17	1	Dark tan material with a few dark
			patches on top, black
			increases to about 90% at
			base of section
18	17-18	1	Dark tan and black material
19	18-19	1	Same as 18, large chunks of
			black material increasing
			towards base of section and
			a bit more dry
20	19-20	1	Black material with some tan
			patches, material is
•	00.04	4	Decoming more dry
21	20-21	1	LOIS OF DIACK IN GARK TAN MATRIX,
			some sand or grit at base of
			Section

TABLE A1-7 (continued):

22	21-22	1	Dark tan/grayish, some black fragments, sand, dark at base with lighter tan patches, some chunks of black stuff
23	22-23	1	Much drier, a few large chunks of black material, still gritty, light tan material replaces black at base of section
24	23-24	1	Light tan clay with some spots of black material at top, no more grit
25	24-25	1	Mostly light tan with some dark tan material
26	25-26	1	More light tan material, increase in dark tan, material is drier
27	26-27	1	Light and dark tan material
20	21-28	I	is wetter
29	28-30	2	Partly wet, partly dry, wet
			material is very gritty, two
			rust brown crusts (redox?),
			one at base of section,
			bottom
30	30-32	2	Wet and dry areas alternate with
			grit present in the wet areas
31	32-34	2	Mostly light tan material, upper layer is dark tan with pockets of water and coarse particles (sand and shells), mottling of light tan with grey, more wet material, light material predominates at base of section
32	34-36	2	Very moist light tan creamy material, gets black towards
0.0	00.00	0	the base of the section
33	30-38	2	Same as 32, black increases to hase
34	38-40	2	Black matrix with light tan
			spotting, some black
		•	chunks, somewhat drier
35	40-42	2	I hin black layer through light tan
26	12-11	2	material, inclined at 15°
30	72-77	2	dry and firm (charcoal)
37	44-46	2	Light tan material with some black spots
38	46-48	2	Same as 36
39	48-50	2	Same as 38
40	50-52	2	Same as 38, stopper in section

.

TABLE A1-8:

LAKE MICHIGAN, Depth 575'

CORE 1991 BC-8 EPA 41b

Lat: 44° 42' 36"N Long: 86° 30' 20"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Grey soupy material
2	1-2	1	Dark grey material grades into dark tan, section is firm with sandy patches
3	2-3	1	Grayish in color, more coarse sand
4	3-4	1	Very coarse, patches of rust brown (Fe oxides?)
5	4-5	1	Med. tan color, very coarse sand, some shells in mid section
6	5-6	1	Very coarse dark tan material
7	6-7	1	Tan patches, less coarse material with shells
8	7-8	1	Some coarse patches, lighter in color with shells, some grey patches
9	8-9	1	Light tan clay at top, bottom is coarse with shells
10	9-10	1	Lighter color, less coarse with
SKIP	10-12	2	Material discarded
11	12-14	2	Dark sandy clay, coarser layer with shells

TABLE A1-9:

LAKE ONTARIO, Depth 345'

CORE 1991 BC-9 EPA 19

Lat: 43° 30' 00"N Long: 79° 25' 00"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Tan soupy material, worm
			burrows
2	1-2	1	Tan soupy material
3	2-3	1	Tan material, less soupy
4	3-4	1	Tan material grades into grey
			material, almost firm
5	4-5	1	Grev material, slightly watery
6	5-6	1	Grev color darkens to base
-	•••	·	some sand
7	6-7	1	Grev material with dark spot
	• ·	·	grades into tan material
			slightly gritty
8	7.7 5	5	Tan material grades into grev
Ğ	7 5-8	.5	Dry redox boundary (orange)
10	8-Q	1	Grev material with some redox
	0-3	•	chunks
11	9-10	1	Grav material with some black
	3-10	I	chey material with Some Diack
12	10-11	1	Spois Darker grov material with day
12	10-11	I	block on oto
10	11 10	4	Diack spois Deductions with deducerate
13	11-12	I	Dark grey with dark spots,
			snades to lighter grey with
	10.10		dark black spots
14	12-13		Same as 13, dry at base
15	13-14	1	Mostly dark material mixed with
4.0			light grey material
16	14-15	1	Same as 15
17	15-16	1	Same as 16, pockets of water in
			light grey material
18	16-17	1	Same as 17
19	17-18	1	Same as 17
20	18-19	1	Light grey shades into dark grey
_			material
21	19-20	1	Same as 17
22	20-22	2	Dark grey grades into watery
			light grey material
23	22-24	2	Same as 22
24	24-26	2	Tan to dark tan in color
25	26-28	2	Tan and dark tan material
26	28-30	2	Same as 25
27	30-32	2	Same as 25
SKIP	32-34	2	Material discarded, same as 27
28	34-36	2	Same as 25
29	36-38	2	Same as 25
30	38-40	2	Same as 25
TABLE A1-10:

LAKE ONTARIO, Depth 394'

CORE 1991 BC-10 EPA 25a

Lat: 43° 30' 00"N Long: 79° 05' 00"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Tan, very soupy material, worm
			burrows
2	1-2	1	Tan material, less soupy
3	2-3	1	Same as 2
4	3-4	1	Lighter tan material, almost firm
5	4-5	1	Same as 4
6	5-6	1	Very dark grey material
7	6-7	1	Same as 6, but darker color
8	7-8	1	Same as 7, with darker spots
9	8-9	1	Same as 8
10	9-10	1	Same as 8, darker color, more black material
11	10-11	1	Lighter color, more dark spots
12	11-12	1	Same as 11, but very dry
13	12-13	1	Same as 12
14	13-14	1	More dark material at base
15	14-15	1	Very dark material at base
16	15-16	1	Very dark throughout section,
			lots of dark grey material at
			base
17	16-17	1	Lighter color, with more grey material
18	17-18	1	Same as 17
19	18-19	1	Mostly light tan with some black
			material, very creamy
20	19-20	1	Gets darker at base of section
21	20-22	2	Light colored and firm, changes
			to darker colored and wet at base
22	22-24	2	Light and dark material mixed, very wet
23	24-26	2	Same as 22, darker at base
24	26-28	2	Same as 22, darker throughout section
25	28-30	2	Same as 22
26	30-32	2	Same as 22
27	32-34	2	Same as 22
28	34-36	2	Same as 22 darker color
29	36-38	2	Same as 28
30	38-40	2	Same as 28
		-	

TABLE A1-11:

LAKE ONTARIO, Depth, 621'

CORE 1991 BC-11 EPA 40a

Lat: 43° 37' 00"N Long: 78° 05' 00"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Tan fluff, some spots of black
			material
2	1-2	1	Same as 1, Some grey spots
3	2-3	1	Tan with grey spots, almost firm
4	3-4	1	Greenish tan material, very
			soupy, black and grey spots
			at base of section
5	4-5	1	Grey colored material, some
			chunks of black material,
_			almost firm
6	5-6	1	Same as 5, darker towards base,
_			and black stuff gets coarser
7	6-7	1	Grey darkens, black chunks get
-			larger
8	7-8	1	Dark grey with tan mottling, color
			darkens towards base with
-			black chunks
9	8-9	1	Mostly tan with black mottling
			(chunks)
10	9-10	1	Very dark grey to black material
11	10-11	1	Same as 10, black chunks and
			grey mottling are present
12	11-12	1	Fewer black chunks, tan with
			black mottling at base of
40	10.10		section
13	12-13	1	Same as 12
14	13-14	1	Dark grey color turns to light
			grey at base, becomes
1 5	44.45	4	creamy texture
15	14-15	1	Lighter color tan/grey, small
16	15 10	4	black chunks
10	12-16	1	Grey color with black spots
			increasing to the base of
17	16 17	4	section
17	10-17	1	Grey/tan material darkens
			towards base of section,
10	17 10	4	Decomes firm
10	10 10	1	Uniform black material
13	10-19	I	Same as 18, becomes lighter to
20	10-20	4	Dase Dort growten with the standard
20	19-20	I	Dark grey/tan with black chunks
21	20-21	1	within light tan patches
<u> </u>	20-21	•	grou at have of eastion
22	21-22	1	yrey at base of section Modium ton becomes lighter
tin ta	£1-22	•	towarde base with lighter
			iowalus base with lighter
			parches

TABLE A1-11 (continued):

23	22-23	1	Light tan at top with black layer .1 mm thick, tan becomes dark to base
24	23-24	1	Light/dark tan mixture with black mottling at top, becomes light tan at base, two thick black layers in section
25	24-25	1	Light tan with a black layer, darkens to dark tan color at base
26	25-26	1	Same as 25, more black material, more wet
27	26-27	1	Same as 26
28	27-28	1	Mixture of light and dark tan material
29	28-29	1	Same as 28
SKIP	29-30	1	Material discarded
30	30-31	1	Creamy light and dark tan material
SKIP	31-32	1	Material discarded
31	32-33	1	Light tan changes to dark tan at
			base, some kind of grass
			like material
SKIP	33-34	1	Material discarded
32	34-35	1	Light tan material with black spots
SKIP	35-36	1	Material discarded
33	36-37	1	Light tan material, black specks and a black patch
SKIP	37-38	1	Material discarded
34	38-39	1	Mostly light grey, some light tan with dark specks and some
			grit
SKIP	39-40	1	Materials discarded
35	40-41	1	Mixture of dark tan and light grey with some black spots
SKIP	41-42	1	Material discarded
36	42-43	1	Mostly dark tan material with some light tan material
SKIP	43-44	1	Material discarded
37	40-44	1	Very dark arey with a lighter layer
07		·	layer in the middle of the
SKIP	45-46	1	Material discarded
38	46-47	1	Light tan turns dark grey then
		·	back to light tan at base of section
SKIP	47-48	1	Material discarded
39	48-49	1	Dark grey material with tan
SKIP	49-50	1	Material discarded
40	50-51	1	Same as 39 dark natches and
		•	light mottling
SKIP	51-53	2	Material discarded
41	53-55	2	Same as 40

TABLE A1-12:

LAKE ONTARIO, Depth, 550'

CORE 1991 BC-12 EPA 64a

Lat: 43° 35' 00"N Long: 77° 07' 00"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Tan soupy material
2	1-2	1	Darker tan soupy material, more
			firm
3	2-3	1	Same as 2
4	3-4	1	Grey material with some tan
			mixed in, almost firm, worm
			burrows
5	4-5	1	Grey darkens to base, some tan
			mottling, few worm burrows
6	5-6	1	Tan mottling in grey upper part,
			black material in darker grey
			at base
7	6-7	1	Grey to dark grey material with
			black mottling
8	7-8	1	Same as 8
9	8-9	1	Same as 8
10	9-10	1	Same as 8, more black material
11	10-11	1	Same as 10, some light grey
			material
12	11-12	1	Same as 11, much drier,
			becomes wetter at base and
			color lightens
13	12-13	1	Same as 12, pockets of water
			and much more black
			material at base
14	13-14	1	Same as 13
15	14-15	1	Light grey mixed with dark grey
			and black spots
16	15-16	1	Same as 15
17	16-17	1	Same as 15, very light grey
			material also
18	17-18	1	Light and dark material mixed
19	18-19	1	Very light grey with black or dark
			grey spots in lower half of
			section
20	19-20	1	Same as 19
21	20-21	1	Same as 19, drier
22	21-21.75	.75	Same as 21
23	21.75-22	.25	Redox zone, orange crust with
			dark material mixed in
24	22-23	1	Very light grey material, wetter,
			not quite the same material
			as above redox
25	23-24	1	Same as 24, some pink material
• -		4	('?)
26	24-25	1	Same as 25
27	25-26	1	I an grey and blue grey mix, tan
•••	AA AT	4	grey material is wetter
28	26-27	1	Same as 2/

TABLE A1-12 (continued):

29	27-28	1	Mostly tan grey material, wet
30	28-29	1	.25 cm black material
31	29-30	1	Same as 30
SKIP	30-31	1	Material discarded
32	31-32	1	Same as 30
SKIP	32-33	1	Material discarded
33	33-34	1	Turns dark at base of section, light grey and black becomes light grey
SKIP	34-35	1	Material discarded
34	35-36	1	Mostly light tan with black specks
SKIP	36-37	1	Material discarded
35	37-38	1	Mostly light grey with black material at base of section
SKIP	38-39	1	Material discarded
36	39-40	1	Lots of black material and some pockets of water in the grey material
SKIP	40-41	1	Material discarded
37	41-42	1	Upper part of section is light grey with black specks, turns black at base
SKIP	42-43	1	Material discarded
38	43-44	1	Mixture of light grey and predominantly black material
SKIP	44-45	1	Material discarded
39	45-46	1	Same as 38, slightly lighter color

TABLE A1-13:

LAKE ONTARIO, Depth, 696'

CORE 1992 BC-13 EPA LG1

Lat: 43° 34' 30"N Long: 76° 41' 00"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Tan fluffy soup, color darkens below
2	1-2	1	Darker tan soupy material, some black organic material, medium gray at base of
3	2-3	1	Dark gray to light tan color, still
4	3-4	1	Equal amounts of light tan, medium gray, and dark gray material, some organic stuff present, slightly less source
5	4-5	1	Light gray tan color, nearly firm, some tan mottling, organics
6	5-6	1	Dark gray, almost firm with some tan spots, lots of organic material at base of section, also two layers of organic material about midsection, 1mm thick
7	6-7	1	Mostly medium gray matter with spots of black organic material, base of section is dark gray to black in color
8	7-8	1	Light and dark gray material, tan pockets at base with a blob of black organic material towards the center
9	8-9	1	Dark gray to black material, organic material is common
10	9-10	1	Tan to dark gray; big pocket of black organic material in section, small black flecks throughout section
11	10-11	1	Dark tan grades to dark gray at base, organics prevalent, these have hair-like fibers in pockets
12	11-12	1	Dark gray and black grades to tan at base, black organic flecs in section; slightly more dark gray than tan material is present
13	12-13	1	Dark gray with tan mottling and black clots
14	13-14	1	Dark gray creamy material with black clots about 1mm in diameter

TABLE A1-13 (continued):

15	14-15	1	Same as 14
16	15-16	1	Medium to dark gray material
			with black clots; reddish
17	16 17	4	worm noted in section
17	16-17	1	Medium to dark gray with clots;
			and dray streaks black layer
			1mm thick halfway through
			section
18	17-18	1	Medium gray material with black
			streaks
19	18-19	1	Medium to dark gray and black,
			grades to dark gray at base
20	19-20	1	Dark gray and tan with black
			clots, grades to tan material
21	20-22	2	al Dase Dark gray grades to tan at base
22	20-22	2	Dark gray with pockets of black
		-	organic laver is 2mm thick
			halfway through section
23	24-25	1	Creamy tan to gray with a pocket
			of black material; clayey
			base, vesiculation of
			remaining core length noted
24	25-26	1	at this time Medium gray to tan color with
27	25-20	1	black material present only
			in the tan, fibrous material in
			dark organic material
25	26-27	1	Medium gray with some tan and
			black
26	27-28	1	Same as 25
27	28-29	1	Same as 25, tan content higher
20	29-30	I	disappears
29	30-31	1	Black material gone, grav and
		·	tan material present, 70%
			gray
30	31-32	1	Dark gray and tan as above with
01/10			black material
SKIP	32-33	1	Material Discarded
31	33-34	I	more soupy, light gray with tan
			5mm diameter
SKIP	34-35	1	Material Discarded
32	35-36	1	Light gray with black clots, some
			water
SKIP	36-37	1	Material Discarded
33	37-38	1	Same as 32
SKIP	38-39	1	Material Discarded
SKIP	<u>40-41</u>	1	Jame as J2 Material Discarded
35	41-42	1	Same as 32
SKIP	42-44	2	Material Discarded
36	44-46	2	Same as 32

TABLE A1-13 (continued):

Material Discarded Same as 32

SKIP	46-50	4
37	50-52	2

REMAINDER OF CORE DISCARDED

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TABLE A1-14:

LAKE ONTARIO, Depth, 610'

CORE 1992 BC-14 EPA LG2

Lat: 43° 35' 45"N Long: 76° 37' 15"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Dark tan fluffy material
2	1-2	1	Very soupy light tan material
3	2-3	1	Same as 2, slightly less soupy
4	3-4	1	Slightly more gray, still tan color,
			grades to dark gray at base
			of section, some black clots
			present at base of section
5	4-5	1	Slightly darker gray material
6	5-6	1	Very dark gray, base is darker,
			some black clots present
7	6-7	1	Almost black color, very watery,
			lots of organics with some
			light gray mottling
8	7-8	1	Slightly lighter gray color with
_			lots of water, same as 7
9	8-9	1	Same as 7, more medium gray
			color
10	9-10	1	Same as 7, with black spots
11	10-11	1	Dark gray material, some
			medium tan is present,
			section is getting to be tirm,
			less of the medium tan
10	11 10	4	matenal than above
12	11-12	1	Same as 11 loss water
13	12-13	1	Same as 11, less water
14	13-14	1	Same as 11, sediment nimer
15	14-15	1	Same as 11
17	16-17	1	Same as 11
18	17-18	1	Same as 11 grades to lighter
.0	17-10	•	drav
19	18-19	1	Same as 11 more water
20	19-20	1	Same as 11
21	20-21	1	Light gray material firmer than
		•	before black organic flecs
			present
22	21-22	1	Light gray to dark gray color
23	22-23	1	Contrasting light and dark grav
			colors about 5mm in
			thickness
24	23-24	1	Watery layer, mostly light tan,
			fewer of the black chunks
25	24-25	1	Dark material, layers 5mm thick,
			wet in between light tan
26	25-26	1	Light gray material
27	26-27	1	Same as 26, chunky black
			material present (organics)
28	27-28	1	Same as 26
29	28-29	1	Same as 26

TABLE A1-14 (continued):

30	29-30	1	Same as 26
SKIP	30-31	1	Material Discarded
31	31-32	1	Same as 26, more watery
SKIP	32-33	1	Material Discarded
32	33-34	1	Same as 31
SKIP	34-35	1	Material Discarded
33	35-36	1	Lighter gray and less watery than 31
SKIP	36-37	1	Material Discarded
34	37-38	1	Same as 33, more black chunks, slight banding of the light and dark layers
SKIP	38-39	1	Material Discarded
35	39-40	1	Same as 34
SKIP	40-41	1	Material Discarded
36	41-42	1	Same as 34
SKIP	42-43	1	Material Discarded
37	43-44	1	Same as 34

•

TABLE A1-15:

LAKE ONTARIO, Depth, 666'

CORE 1992 BC-15 EPA 55

Lat: 43° 26' 36"N Long: 77° 26' 18"W

SAMPLE #	DEPTH (cm)	THICKNESS (cm)	DESCRIPTION
1	0-1	1	Dark tan fluffy material, shrimp
			swimming in sediment
2	1-2	1	Very soupy dark tan material
3	2-3	1	Dark tan/light gray material
4	3-4	1	Slightly darker gray material
	• •	·	some organic flecs dark
			material increases to hase of
			section almost firm
5	4-5	1	Medium gray with bigher black
J	40	•	organic content bottom
			darker grav almost firm no
			black matorial at base
6	5-6	1	Modium grou with ton mottling
0	5-6	I	Medium gray with tan mottling,
			some clots of organic
7	6 7	4	
1	6-7	ł	Dark gray with tan mottling,
			some organics which
•	7.0		increase to base
8	/-8	1	Same as 7
9	8-9	1	Tan material increases, black
			and tan material increases
			toward bottom, large clot of
_			black material at base
10	9-10	1	Medium to dark gray with a lot of
			organic material mixed in
11	10-11	1	Dark gray with chunks of black
			organics and tan mottling
12	11-12	1	Medium gray with black chunks
13	12-13	1	Same as 12
14	13-14	1	Even mix of medium and dark
			gray material with some
			organics
15	14-15	1	Dark gray with light to medium
			gray mottling and some
			organics, more tan material
			near base of section
16	15-16	1	Same as 15
17	16-17	1	Dark gray grades to medium gray
		·	with some black chunks
18	17-18	1	Medium gray with light gray
		·	mottling a large black chunk
			at base of section
19	18-19	1	Color lightens slightly and
	10 15	I	organia material diconnears
			to base of contion
20	10-20	1	Nodium grow with block obunko
20	13-20	'	Niculum yray will Diack Chunks,
			a Dialth layer Zmm UNCK
			musection

TABLE A1-15 (continued):

21	20-21	1	Light gray with tan and dark gray mottling, black chunks
22	21-22	1	Light to medium gray, few organics
23	22-23	1	Medium gray with light gray mottling
24	23-24	1	Light gray with medium gray mottling_some organics
25	24-25	1	Same as 24
26	25-26	1	Medium to dark gray, few organics
27	26-27	1	Same as 26
28	27-28	1	Medium gray with tan mottling
29	28-29	1	Same as 28, more organics
30	29-30	1	Light gray with medium gray mottling
31	30-31	1	Same as 30, more organics
SKIP	31-32	1	Material Discarded
32	32-33	1	Light gray with dark gray
			mottling, some organics,
			base is light gray with no
			organics present
SKIP	33-34	1	Material Discarded
33	34-35	1	Dark tan with medium gray
			mottling at top, base has
			medium gray with Dark tan mottling
SKIP	35-36	1	Material Discarded
34	36-37	1	Same as 33
SKIP	37-38	1	Material Discarded
35	38-39	1	Dark tan to light gray with
01/10			organics
SKIP	39-40	1	Material Discarded
36	40-41	1	Medium gray with light gray
			mottling near top grading to
			mostly dark gray hear the
	44.40		Dottom of the section
SKIP	41-42	1	Material Discarded
37 67/10	42-43	1	Same as so
3NIP 20	43-44	1	light grow to modium grow mix
30	44-40	1	arading to medium gray mix
			base of section
SKIP	45-46	1	Material Discarded
30	46-47	1	Medium to dark aray grading to
55	-01	I	light gray with medium gray
			mottling no organics
SKIP	47-48	1	Material Discarded
40	48-49	1	Medium gray with tan mottling
		·	dark gray at the base 2
			lavers of dark material 1mm
			thick midway through
			section

Sample	Run 1	Run 2	Run 3	Mean	Std. Dev.	RSD%
BC1-18	2.1	2.8	2.5	2.5	0.351	14.24
BC2-18	12.0	13.0	12.5	12.5	0.500	4.00
BC2-32	3.6	3.5	3.4	3.5	0.100	2.86
BC5-17	3.6	3.8	2.8	3.4	0.529	15.56
BC6-18	3.5	4.2	4.4	4.0	0.473	11.72
BC7-23	7.1	9.3	8.7	8.4	1.137	13.59
BC7-38	2.2	2.2	2.1	2.2	0.058	2.66
BC8-10	5.2	5.0	4.8	5.0	0.200	4.00
BC9-23	7.9	9.6	9.7	9.1	1.012	11.16
BC9-30	8.5	10.4	10.5	9.8	1.127	11.50
BC10-16	8.5	11.0	10.7	10.1	1.365	13.56
BC10-30	8.1	11.5	11.6	10.4	1.992	19.15
BC11-20	5.9	6.6	7.2	6.6	0.651	9.91
BC11-41	6.6	7.4	7.7	7.2	0.569	7.86
BC12-19	6.1	5.9	5.3	5.8	0.416	7.22
BC12-38	6.5	9.0	9.0	8.1	1.443	17.67
BC13-22	23.0	27.4	29.4	26.6	3.274	12.31
BC13-37	8.3	10.0	10.1	9.5	1.012	10.69
BC14-20	10.4	10.6	10.3	10.4	0.153	1.46
BC14-37	4.8	5.2	5.0	5.0	0.200	4.00
BC15-20	8.7	9.3	8.5	8.8	0.416	4.71
BC15-40	8.5	8.5	8.1	8.4	0.231	2.76

Table A2-1: QA Checks: As replicate results

Sample	Run 1	Run 2	Run 3	Mean	Std. Dev.	RSD%
BC1-18	0.20	0.17	0.17	0.18	0.017	11.47
BC2-18	0.26	0.37	0.33	0.32	0.056	17.40
BC2-32	0.35	0.38	0.39	0.37	0.021	5.58
BC5-17	0.12	0.13	0.10	0.12	0.015	13.09
BC6-18	0.18	0.21	0.18	0.19	0.017	9.12
BC7-23	0.17	0.22	0.20	0.20	0.025	12.80
BC7-38	0.32	0.30	0.32	0.31	0.012	3.69
BC8-10	0.15	0.13	0.15	0.14	0.012	8.06
BC9-23	0.26	0.32	0.33	0.31	0.042	12.48
BC9-30	0.25	0.34	0.34	0.31	0.052	16.76
BC10-16	0.44	0.46	0.48	0.46	0.020	4.35
BC10-30	0.33	0.35	0.33	0.34	0.012	3.43
BC11-20	0.72	0.59	0.59	0.63	0.075	11.85
BC11-41	0.51	0.57	0.54	0.54	0.030	5.56
BC12-19	0.20	0.23	0.26	0.23	0.030	13.04
BC12-38	0.28	0.38	0.37	0.34	0.055	16.04
BC13-22	1.43	1.51	1.49	1.48	0.042	2.82
BC13-37	0.21	0.28	0.31	0.27	0.051	19.24
BC14-20	0.28	0.27	0.28	0.28	0.006	2.09
BC14-37	0.44	0.35	0.36	0.38	0.049	12.87
BC15-20	0.21	0.22	0.23	0.22	0.010	4.54
BC15-40	0.41	0.32	0.38	0.37	0.046	12.39

Table A2-2: QA Checks: Cd replicate results

Sample	Run 1	Run 2	Run 3	Mean	Std. Dev.	RSD%
BC1-18	5.3	7.1	7.5	6.6	1.172	17.67
BC2-18	5.3	6.1	5.7	5.7	0.400	7.02
BC2-32	3.6	3.6	4.4	3.9	0.462	11.95
BC5-17	7.2	9.2	8.2	8.2	1.000	12.20
BC6-18	4.4	4.4	4.5	4.4	0.058	1.30
BC7-23	3.9	4.0	4.4	4.1	0.265	6.45
BC7-38	4.4	4.7	4.9	4.7	0.252	5.39
BC8-10	8.2	8.8	8.3	8.4	0.321	3.81
BC9-23	11.7	9.4	9.5	10.2	1.300	12.75
BC9-30	10.3	9.6	10.1	10.0	0.361	3.61
BC10-16	21.5	19.7	21.1	20.8	0.945	4.55
BC10-30	9.5	9.7	10.3	9.8	0.416	4.23
BC11-20	12.8	15.9	14.8	14.5	1.572	10.84
BC11-41	7.3	8.0	7.9	7.7	0.379	4.90
BC12-19	9.5	9.1	9.5	9.4	0.231	2.47
BC12-38	8.9	8.4	8.9	8.7	0.289	3.31
BC13-22	43.2	41.1	41.8	42.0	1.069	2.54
BC13-37	8.3	7.1	6.6	7.3	0.874	11.91
BC14-20	40.2	38.0	39.0	39.1	1.102	2.82
BC14-37	8.2	8.6	8.8	8.5	0.306	3.58
BC15-20	10.7	11.0	8.6	10.1	1.308	12.95
BC15-40	7.0	5. 9	7.4	6.8	0.777	11.48

Table A2-3: QA Checks: Pb replicate results

Table	A2-4:	QA	Checks:	SRM	results

Sample	As	Cd	Рb
CDM 2	10 5	2 66	A 9 C
SKM-S	19.3	2.00	40.0 176 0
SRM-4	10.7	2.34	1/0.0
SKM-D	19.5	3.39	144.0
SKM-12	20.1	2.42	157.0
SKM-13	18.7	3.69	158.4
SRM-14	20.1	2.68	215.0
SRM-A	17.9	2.92	183.0
SRM-B	17.9	2.60	162.0
SRM-C	18.9	2.98	158.0
SRM-D	18.9	1.74	95.2
SRM-E	19.3	2.82	172.0
SRM-F	19.4	3.20	105.0
SRM-G	18.7	3.10	93.8
SRM-H	19.3	3.16	176.4
SRM-I	19.0	3.22	176.0
SRM-J	19.0	3.06	179.6
SRM-K	18.7	2.72	93.6
SRM-L	17.9	2.96	101.8
SRM-M	17.5	3.34	95.2
SRM-N	19.1	3.52	96.8
SRM-O	19.6	3.22	93.4
SRM-P	19.0	3.02	96.2
		0.VL	JU.L
Mean	18.9	2.97	132.3
Specifications:	23.4±.4	3.45±.22	161±17

Table A3-1:	EPA#11	trace	metal	and	porosity	data

Sample #	Depth (cm)	As (µg∕g)	Cd (µg/g)	Pb (µg∕g)	Porosity (%)
	0.1.0	12.50	1.01	140.00	04.50
1	0-1.0	12.50	1.81	140.80	84.56
2	1.0-2.0	12.80	1.89	152.00	82.39
3	2.0-3.0	12.50	2.00	151.20	82.20
4	3.0-4.0	14.00	1.96	158.00	79.49
5	4.0-5.0	11.80	1.90	145.20	79.21
6	5.0-6.0	9.70	1.05	62.80	77.78
7	6.0-7.0	13.70	0.38	37.20	77.20
8	7.0-8.0	4.00	0.21	26.00	73.63
9	8.0-9.0	3.30	0.32	24.80	73.34
10	9.0-10.0	2.30	0.28	25.60	73.04
11	10.0-11.0	2.30	0.20	22.80	66.29
12	11.0-12.0	3.00	0.19	27.60	67.48
13	12.0-12.5	6.50	0.16	24.40	68.43
14	12.5-13.5	5.80	0.17	22.80	64.90
15	13.5-14.5	3.30	0.16	22.40	61.40
16	14.5-15.0	7.20	0.20	22.40	64.03
17	15.0-15.5	4.10	0.16	20.40	66.47
18	15.5-16.5	2.10	0.20	21.20	65.80
19	16.5-17.5	3.90	0.16	20.80	65.57
20	17.5-18.5	4.60	0.14	20.40	63.60
21	18.5-20.5	4.90	0.12	22.00	64.87
22	20.5-22.5	5.00	0.11	21.60	66.66
23	22 5-24 5	7 10	0.13	21.60	66 66
24	24 5-26 5	2 70	0.15	24 40	65 76
25	26.5-28.5	3.70	0.13	23.20	64.41

Table A3-2:	EPA#18	trace	metal	and	porosity	data
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Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	13.4	1.96	130.0	86.19
2	1.0-2.0	15.4	2.24	139.2	84.32
3	2.0-3.0	14.7	2.26	145.8	83.46
4	3.0-4.0	22.3	2.14	148.6	83.37
5	4.0-5.0	38.5	2.26	152.2	84.04
6	5.0-6.0	10.5	2.64	158.4	82.35
7	6.0-7.5	7.5	2.59	116.8	81.92
8	7.5-8.5	7.7	2.26	101.2	80.84
9	8.5-9.5	8.3	2.56	86.0	78.99
10	9.5-10.5	6.6	1.77	78.2	77.68
11	10.5-11.5	6.6	1.38	53.6	77.80
12	11.5-12.5	4.9	0.46	26.8	77.21
13	12.5-13.5	4.2	0.32	19.4	76.44
14	13.5-14.5	3.9	0.25	19.0	77.46
15	14.5-15.5	5.3	0.27	19.4	77.39
16	15.5-16.5	8.0	0.30	14.0	75.65
17	16.5-17.5	8.4	0.27	11.2	74.30
18	17.5-18.5	12.0	0.26	11.0	75.16
19	18.5-19.5	5.7	0.41	12.8	75.97
20	19.5-20.5	7.7	0.30	12.4	73.64
21	20.5-21.5	12.0	0.32	11.6	75.10
22	21.5-22.5	3.5	0.30	10.8	76.16
23	22.5-23.5	3.8	0.31	11.0	76.28
24	23.5-24.5	3.0	0.30	11.4	74.79
25	24.5-25.5	3.2	0.30	11.4	76.42
26	25.5-27.5	6.8	0.37	11.8	76.27
27	27.5-29.5	11.0	1.35	13.4	75.78
28	31.5-33.5	6.7	0.35	14.0	74.99
29	33.5-35.5	14.5	0.42	13.0	76.61
30	37.5-39.5	8.3	0.41	12.4	74.43
31	39.5-41.5	16.3	0.41	10.4	74.89
32	43.5-45.5	3.6	0.35	9.2	75.76
33	47.5-49.5	5.1	0.33	8.2	75.63

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	19.0	1.33	177.2	84.82
2	1.0-2.0	17.6	1.46	189.4	83.26
3	2.0-3.0	17.8	1.49	176.8	90.87
4	3.0-4.0	15.7	1.38	161.8	74.83
5	4.0-5.0	10.6	1.36	152.2	76.89
6	5.0-6.0	10.7	0.80	76.2	75.51
7	6.0-7.0	4.5	0.51	26.6	67.59
8	7.0-8.0	1.8	0.09	6.2	57.85
9	8.0-9.0	1.3	0.10	6.2	59.29
10	9.0-10.0	6.0	0.07	6.2	62.41
11	10.0-11.0	7.1	0.06	6.2	60.89
12	11.0-12.0	6.7	0.24	10.4	64.08
13	12.0-13.0	7.0	0.14	13.2	68.52
14	13.0-14.0	7.5	0.11	12.8	65.27
15	14.0-15.0	8.3	0.16	15.4	69.96
16	15.0-16.0	67.3	0.35	12.6	69.94
17	16.0-17.0	7.5	0.08	16.8	71.39
18	17.0-18.0	2.4	0.23	14.8	66.36
19	18.0-19.0	2.4	0.22	12.2	65.21
20	19.0-20.0	8.5	0.13	13.8	64.98
21	20.0-22.0	32.7	0.17	13.8	66.68
22	22.0-24.0	26.1	0.22	14.2	68.24
23	24.0-26.0	17.2	0.20	14.6	68.17
24	26.0-28.0	14.3	0.20	14.2	65.57
25	28.0-30.0	8.3	0.17	14.6	67.33

 Table A3-3:
 EPA#19 (M) trace metal and porosity data

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	8.8	0.83	92.0	85.08
2	1.0-2.0	7.9	0.57	64.0	76.20
3	2.0-3.0	4.1	0.37	27.0	53.91
4	3.0-4.0	3.1	0.18	11.4	74.25
5	4.0-5.0	3.5	0.09	10.0	74.09
6	5.0-7.0	3.5	0.09	10.0	74.13
7	9.0-11.0	3.6	0.12	10.8	72.54
8	13.0-15.0	3.5	0.11	10.0	74.42
9	17.0-19.0	2.7	0.15	11.8	40.99
10	21.0-23.0	3.3	0.12	12.6	73.39
11	25.0-27.0	3.1	0.12	11.4	73.40
12	29.0-31.0	3.5	0.12	11.4	72.58

 Table A3-4:
 EPA#23 trace metal and porosity data

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Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	5.0	0.54	44.2	59.60
2	1.0-2.0	4.4	0.50	31.6	44.90
3	2.0-3.0	5.4	0.19	7.8	60.06
4	3.0-4.0	4.4	0.14	5.0	56.08
5	4.0-5.0	5.0	0.49	6.8	56.74
6	5.0-6.0	4.1	0.18	6.0	52.10
7	6.0-7.0	3.7	0.21	6.0	54.15
8	7.0-8.0	1.8	0.10	4.6	47.86
9	8.0-9.0	2.7	0.15	6.0	44.76
10	9.0-10.0	3.4	0.13	6.6	56.18
11	10.0-11.0	3.0	0.13	12.2	59.45
12	11.0-12.0	2.6	0.17	10.4	54.18
13	12.0-13.0	2.8	0.25	10.8	49.80
14	13.0-14.0	2.9	0.15	12.4	50.36
15	14.0-15.0	5.0	0.10	15.4	52.83
16	15.0-17.0	5.0	0.28	15.0	53.29
17	17.0-19.0	3.6	0.12	14.4	52.91
18	19.0-21.0	2.9	0.11	13.4	54.41
19	21.0-23.0	3.6	0.17	13.4	47.42
20	23.0-25.0	3.2	0.10	13.8	55.37

 Table A3-5:
 EPA#27 trace metal and porosity data

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	14.7	1.52	115.8	87.48
2	1.0-2.0	14.2	1.41	113.0	84.12
3	2.0-3.0	10.5	0.95	80.2	79.39
4	3.0-4.0	7.1	0.58	45.4	70.21
5	4.0-5.0	5.5	0.25	6.4	64.88
6	5.0-6.0	4.9	0.13	5.0	63.64
7	6.0-7.0	4.2	0.10	4.8	62.19
8	7.0-8.0	4.9	0.10	5.0	62.46
9	8.0-9.0	5.0	0.16	8.6	66.35
10	9.0-10.0	5.2	0.11	6.6	60.91
11	10.0-11.0	5.3	0.15	8.8	66.06
12	11.0-12.0	6.4	0.16	12.0	73.20
13	12.0-13.0	6.2	0.17	10.8	71.12
14	13.0-14.0	5.6	2.66	10.2	68.06
15	14.0-15.0	5.6	0.32	10.0	67.55
16	15.0-16.0	5.3	0.21	8.8	67.35
17	16.0-17.0	5.4	0.24	8.4	65.38
18	19.0-21.0	3.5	0.18	7.4	64.33

 Table A3-6:
 EPA#34 trace metal and porosity data

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	22.5	1.91	107.2	85.54
2	1.0-2.0	16.7	1.93	106.0	85.62
3	2.0-3.0	11.2	1.97	108.4 ·	83.83
4	3.0-4.0	10.1	2.02	117.4	84.01
5	4.0-5.0	9.1	1.96	122.8	82.93
6	5.0-6.0	8.2	2.27	102.6	82.03
7	6.0-7.0	7.1	2.23	96.2	82.02
8	7.0-8.0	5.8	1.99	85.4	81.03
9	8.0-9.0	6.3	1.68	70.2	81.70
10	9.0-10.0	6.4	1.75	73.0	80.79
11	10.0-11.0	5.9	1.65	67.4	80.89
12	11.0-12.0	5.7	1.61	60.4	81.49
13	12.0-13.0	5.4	1.36	53.6	81.65
14	13.0-14.0	4.4	1.15	52.6	80.42
15	14.0-15.0	3.7	0.59	34.8	79.43
16	15.0-16.0	3.4	0.39	23.8	79.76
17	16.0-17.0	3.8	0.26	19.2	79.90
18	17.0-18.0	3.7	0.26	20.2	79.92
19	18.0-19.0	3.9	0.24	13.4	79.33
20	19.0-20.0	3.1	0.22	11.6	77.59
21	20.0-21.0	6.0	0.22	12.4	75.71
22	21.0-22.0	7.6	0.19	7.8	73.63
23	22.0-23.0	7.1	0.17	7.8	71.34
24	23.0-24.0	3.6	0.15	9.0	58.54
25	24.0-25.0	3.4	0.18	11.0	68.38
26	25.0-26.0	3.3	0.16	9.8	69.33
27	26.0-27.0	2.4	0.14	10.4	68.81
28	27.0-28.0	2.3	0.09	10.8	68.31
29	28.0-30.0	13.7	0.16	7.8	70.18
30	30.0-32.0	10.6	0.20	9.4	67.32
31	32.0-34.0	11.0	0.27	8.0	70.24
32	34.0-36.0	2.7	0.14	8.4	68.94
33	36.0-38.0	2.8	0.19	7.6	68.01
34	38.0-40.0	2.5	0.12	9.0	70.75
35	40.0-42.0	2.3	0.20	7.8	69.10
36	42.0-44.0	2.4	0.12	6.8	69.57
37	44.0-46.0	2.5	0.11	6.4	69.47
38	46.0-48.0	2.2	0.12	4.4	67.13
39	48.0-50.0	2.3	0.11	5.2	70.22
40	50.0-52.0	2.5	0.12	4.2	69.33

 Table A3-7:
 EPA#40 trace metal and porosity data

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)	_
1	0-1.0	2.5	0.27	19.8	59.71	
2	1.0-2.0	3.9	0.26	16.4	58.50	
3	2.0-3.0	2.9	0.09	4.2	57.49	
4	3.0-4.0	2.8	0.11	4.2	49.75	
5	4.0-5.0	2.5	0.06	3.1	52.27	
6	5.0-6.0	2.2	0.06	4.8	51.79	
7	6.0-7.0	3.8	0.09	8.6	63.15	
8	7.0-8.0	3.7	0.14	8.6	61.79	
9	8.0-9.0	3.9	0.18	9.2	59.11	
10	9.0-10.0	5.2	0.15	8.2	59.89	
11	12.0-14.0	5.0	0.17	8.2	62.61	

 Table A3-8:
 EPA#41b
 trace
 metal
 and
 porosity
 data

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	21.1	2.62	109.6	89.39
2	1.0-2.0	23.3	2.86	130.8	87.78
3	2.0-3.0	36.3	2.84	141.6	87.76
4	3.0-4.0	11.8	3.28	151.6	87.74
5	4.0-5.0	18.2	3.78	166.8	86.26
6	5.0-6.0	21.2	3.35	152.0	83.29
7	6.0-7.0	28.2	1.98	86.0	79.62
8	7.0-7.5	88.6	0.87	22.8	79.61
9	7.5-8.0	512.4	0.66	8.0	79.67
10	8.0-9.0	13.9	0.20	14.8	78.76
11	9.0-10.0	2.5	0.33	18.8	77.41
12	10.0-11.0	6.3	0.27	19.6	78.25
13	11.0-12.0	18.6	0.37	19.6	77.62
14	12.0-13.0	41.7	0.26	22.8	77.26
15	13.0-14.0	27.2	0.25	24.8	78.37
16	14.0-15.0	4.4	0.25	20.8	77.76
17	15.0-16.0	4.8	0.27	22.0	77.84
18	16.0-17.0	3.9	0.25	21.2	77.03
19	17.0-18.0	5.5	0.20	19.6	77.60
20	18.0-19.0	4.7	0.25	20.4	77.89
21	19.0-20.0	7.4	0.24	23.2	76.54
22	20.0-22.0	7.5	0.25	22.4	76.36
23	22.0-24.0	7.9	0.26	20.0	77.87
24	24.0-26.0	13.5	0.25	22.0	78.03
25	26.0-28.0	12.9	0.29	24.0	76.07
26	28.0-30.0	7.6	0.25	22.4	76.56
27	30.0-32.0	8.0	0.25	24.8	76.21
28	34.0-36.0	7.9	0.27	24.8	76.88
29	36.0-38.0	7.9	0.26	27.2	77.36
30	38.0-40.0	8.5	0.25	25.6	77.80

 Table A3-9:
 EPA#19 (O) trace metal and porosity data

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity
					(%)
1	0-1.0	21.4	2.33	88.0	89.04
2	1.0-2.0	27.1	2.17	95.2	86.97
3	2.0-3.0	29.2	2.39	103.2	85.83
4	3.0-4.0	20.5	2.77	140.2	84.66
5	4.0-5.0	14.9	3.87	157.8	85.21
6	5.0-6.0	24.4	4.18	157.0	84.98
7	6.0-7.0	24.5	3.98	132.8	85.30
8	7.0-7.5	21.7	2.93	102.6	83.55
9	7.5-8.0	18.5	2.03	93.8	81.70
10	8.0-9.0	22.1	1.98	80.8	80.18
11	9.0-10.0	15.9	1.55	64.2	77.96
12	10.0-11.0	14.1	1.18	51.4	79.11
13	11.0-12.0	9.7	1.04	28.2	78.11
14	12.0-13.0	7.8	0.59	30.4	79.26
15	13.0-14.0	8.6	0.48	24.8	78.19
16	14.0-15.0	8.5	0.44	19.8	78.10
17	15.0-16.0	7.7	0.38	16.0	80.31
18	16.0-17.0	7.7	0.32	14.4	78.57
19	17.0-18.0	7.0	0.32	13.8	77.83
20	18.0-19.0	6.8	0.32	12.6	77.23
21	19.0-20.0	8.1	0.33	16.8	78.01
22	20.0-22.0	6.4	0.33	16.6	77.14
23	22.0-24.0	8.5	0.31	15.8	77.74
24	24.0-26.0	8.7	0.31	17.0	78.25
25	26.0-28.0	8.9	0.34	16.4	77.51
26	28.0-30.0	9.2	0.30	16.2	77.64
27	30.0-32.0	7.8	0.36	16.0	77.57
28	34.0-36.0	7.8	0.32	15.8	76.20
29	36.0-38.0	8.0	0.32	16.8	77.08
30	38.0-40.0	8.1	0.33	n.a	78.06

 Table A3-10:
 EPA#25a trace metal and porosity data

Table A3-11: EPA#40a trace metal an	nd porosity data
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Sample #	Depth (cm)	As (µg∕g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	26.3	1.80	54.8	92.27
2	1.0-2.0	29.3	2.30	86.0	89.51
3	2.0-3.0	14.2	2.21	93.4	87.76
4	3.0-4.0	15.9	2.64	123.4	86.94
5	4.0-5.0	14.0	2.83	146.6	88.02
6	5.0-6.0	22.0	3.15	161.4	88.90
7	6.0-7.0	19.5	3.30	176.8	86.71
8	7.0-8.0	17.5	3.42	162.6	88.28
9	8.0-9.0	16.5	3.09	153.8	86.69
10	9.0-10.0	16.9	2.62	145.6	86.60
11	10.0-11.0	22.4	2.05	126.6	84.35
12	11.0-12.0	21.2	1.88	113.8	81.89
13	12.0-13.0	12.8	1.54	87.8	82.69
14	13.0-14.0	9.2	1.34	68.2	98.41
15	14.0-15.0	10.4	1.22	73.0	81.19
16	15.0-16.0	10.9	0.84	59.2	81.26
17	16.0-17.0	8.2	0.52	42.0	82.55
18	17.0-18.0	7.7	0.41	35.2	81.44
19	18.0-19.0	7.1	0.31	30.4	83.20
20	19.0-20.0	5.9	0.27	25.6	82.33
21	20.0-21.0	7.4	0.22	20.2	81.80
22	21.0-22.0	6.7	0.23	18.6	81.88
23	22.0-23.0	8.0	0.22	18.8	81.68
24	23.0-24.0	8.4	0.22	18.6	81.99
25	24.0-25.0	6.0	0.21	17.2	82.72
26	25.0-26.0	n.a.	n.a.	n.a .	82.74
27	26.0-27.0	n.a.	n.a.	n.a.	82.39
28	27.0-28.0	6.9	0.24	16.0	81.06
29	28.0-29.0	6.7	0.24	17.8	82.63
30	30.0-31.0	6.7	0.27	16.6	83.15
31	32.0-33.0	6.9	0.26	16.0	82.30
32	34.0-35.0	7.8	0.25	15.6	81.20
33	36.0-37.0	7.2	0.26	15.8	81.77
34	38.0-39.0	5.6	0.23	11.4	82.11
35	40.0-41.0	6.6	0.24	12.0	81.92
36	42.0-43.0	5.8	0.20	13.8	81.96
37	44.0-45.0	5.4	0.24	13.4	82.07
38	46.0-47.0	5.5	0.22	13.6	82.24
39	48.0-49.0	4.9	0.18	14.2	80.95
40	50.0-51.0	5.8	0.29	14.0	81.10
41	53.0-55.0	6.6	0.22	14.6	80.51

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	29.7	2.11	97.2	93.23
2	1.0-2.0	32.9	2.27	103.2	90.27
3	2.0-3.0	41.1	2.56	111.6	89.15
4	3.0-4.0	23.4	2.55	129.2	91.12
5	4.0-5.0	14.1	3.68	170.8	89.97
6	5.0-6.0	19.4	3.87	182.0	89.44
7	6.0-7.0	16.8	2.96	118.0	87.55
8	7.0-8.0	14.6	2.19	124.0	85.86
9	8.0-9.0	16.6	1.96	114.4	83.32
10	9.0-10.0	14.9	1.67	98.4	83.96
11	10.0-11.0	14.4	1.25	84.4	82.60
12	11.0-12.0	13.5	0.77	70.0	82.08
13	12.0-13.0	9.7	0.71	60.4	82.71
14	13.0-14.0	7.9	0.57	48.4	80.93
15	14.0-15.0	6.9	0.38	38.0	80.56
16	15.0-16.0	5.5	0.28	16.4	79.81
17	16.0-17.0	5.3	0.25	16.0	80.46
18	17.0-18.0	4.4	0.24	12.0	81.02
19	18.0-19.0	3.8	0.20	10.4	79.87
20	19.0-20.0	4.8	0.22	10.4	82.48
21	20.0-21.0	4.9	0.19	9.2	76.18
22	21.0-21.75	12.4	0.24	16.0	74.73
23	21.75-22.0	180.9	0.22	10.0	76.06
24	22.0-23.0	13.2	0.14	15.6	75.16
25	23.0-24.0	3.9	0.19	15.6	74.72
26	24.0-25.0	4.7	0.34	18.8	74.10
27	25.0-26.0	6.1	0.29	15.2	73.95
28	26.0-27.0	2.9	0.16	13.2	71.22
29	27.0-28.0	3.0	0.27	16.4	73.70
30	28.0-29.0	3.1	0.24	16.4	75.37
31	29.0-30.0	3.5	0.13	17.2	75.58
32	31.0-32.0	9.5	0.39	18.0	72.96
33	33.0-34.0	22.2	0.35	17.8	74.10
34	35.0-36.0	41.2	0.21	17.4	75.51
35	37.0-38.0	12.6	0.20	17.2	74.39
36	39.0-40.0	6.5	0.32	16.6	74.05
37	41.0-42.0	3.7	0.22	16.8	77.34
38	43.0-44.0	6.5	0.28	17.0	76.64
39	45.0-46.0	6.5	0.24	17.2	74.67

 Table A3-12:
 EPA#64a
 trace
 metal
 and
 porosity
 data

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	20.9	2.21	45.8	98.02
2	1.0-2.0	31.7	2.17	56.0	91.38
3	2.0-3.0	13.0	2.55	75.6	90.17
4	3.0-4.0	12.6	2.61	93.0	88.73
5	4.0-5.0	11.8	3.54	109.4	88.02
6	5.0-6.0	14.9	3.57	150.2	87.16
7	6.0-7.0	17.6	4.02	159.6	87.17
8	7.0-8.0	19.3	4.22	166.4	87.16
9	8.0-9.0	24.1	4.11	169.6	88.51
10	9.0-10.0	34.2	4.17	181.4	89.23
11	10.0-11.0	31.7	3.45	147.4	89.65
12	11.0-12.0	34.4	3.01	146.8	90.15
13	12.0-13.0	22.4	2.97	140.0	84.45
14	13.0-14.0	20.7	6.14	143.2	85.47
15	14.0-15.0	18.0	2.57	126.6	85.03
16	15.0-16.0	17.3	2.28	108.2	83.91
17	16.0-17.0	16.5	1.97	104.4	84.14
18	17.0-18.0	15.2	1.59	90.8	83.55
19	18.0-19.0	16.3	1.54	94.6	82.65
20	19.0-20.0	17.5	1.48	82.8	84.79
21	20.0-22.0	18.2	1.47	82.8	83.72
22	22.0-24.0	23.0	1.43	86.4	81.19
23	24.0-25.0	16.0	0.99	68.0	81.44
24	25.0-26.0	20.2	1.02	66.2	83.65
25	26.0-27.0	21.3	1.04	66.6	83.22
26	27.0-28.0	20.8	0.98	62.0	83.49
27	28.0-29.0	22.4	0.91	61.4	81.49
28	29.0-30.0	22.8	0.88	60.8	82.68
29	30.0-31.0	23.3	1.12	65.0	82.32
30	31.0-32.0	21.0	0.91	56.4	83.99
31	33.0-34.0	18.6	0.75	47.2	83.24
32	35.0-36.0	9.2	0.25	20.6	82.16
33	37.0-38.0	9.3	0.21	24.4	76.98
34	39.0-40.0	7.8	0.22	20.6	80.94
35	41.0-42.0	8.4	0.23	18.4	81.01
36	44.0-46.0	7.7	0.26	17.8	81.42
37	50.0-52.0	8.3	0.21	16.6	80.58

 Table A3-13:
 EPA#LG1 trace metal and porosity data

 Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	27.6	1.79	82.4	92.66
2	1.0-2.0	30.0	1.71	84.8	89.73
3	2.0-3.0	14.5	2.06	109.8	87.12
4	3.0-4.0	11.8	2.52	148.2	83.09
5	4.0-5.0	15.5	3.02	186.2	85.81
6	5.0-6.0	20.7	3.27	207.4	87.54
7	6.0-7.0	25.5	3.68	221.8	87.02
8	7.0-8.0	24.1	3.22	197.8	86.42
9	8.0-9.0	20.9	2.52	177.2	83.98
10	9.0-10.0	17.1	2.47	129.6	80.26
11	10.0-11.0	14.6	1.78	133.0	81.08
12	11.0-12.0	14.8	1.38	113.2	82.57
13	12.0-13.0	13.3	1.14	97.8	80.68
14	13.0-14.0	11.3	0.94	93.0	80.08
15	14.0-15.0	11.4	0.84	87.8	80.13
16	15.0-16.0	12.4	0.70	97.2	79.00
17	16.0-17.0	13.1	0.58	68.8	81.23
18	17.0-18.0	9.9	0.39	51.2	77.98
19	18.0-19.0	9.7	0.25	35.6	79.48
20	19.0-20.0	5.2	0.28	40.2	79.42
21	20.0-21.0	7.7	0.21	32.0	79.81
22	21.0-22.0	8.6	0.21	29.0	81.49
23	22.0-23.0	1.9	0.23	30.4	79.70
24	23.0-24.0	1.7	0.17	27.0	81.76
25	24.0-25.0	7.2	0.21	25.8	85.99
26	25.0-26.0	3.7	0.23	26.4	78.43
27	26.0-27.0	3.0	0.17	24.2	78.46
28	27.0-28.0	9.8	0.22	22.4	79.48
29	28.0-29.0	9.2	0.20	22.2	78.06
30	29.0-30.0	9.5	0.19	20.0	77.98
31	31.0-32.0	8.9	0.27	7.6	77.93
32	33.0-34.0	7.4	0.04	8.2	77.25
33	35.0-36.0	6.5	0.11	8.0	77.13
34	37.0-38.0	6.2	0.03	8.8	76.65
35	39.0-40.0	7.3	0.05	7.0	76.88
36	41.0-42.0	6.3	0.04	7.8	77.99
37	43.0-44.0	4.8	0.04	8.2	78.43

 Table A3-14:
 EPA#LG2 trace metal and porosity data

Sample #	Depth (cm)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	Porosity (%)
1	0-1.0	17.9	1.03	23.4	95.50
2	1.0-2.0	53.9	2.30	47.3	89.07
3	2.0-3.0	16.4	3.20	60.0	85.17
4	3.0-4.0	14.8	2.83	66.4	83.81
5	4.0-5.0	15.3	3.87	81.2	86.14
6	5.0-6.0	18.0	4.17	94.7	85.46
7	6.0-7.0	21.8	4.48	102.8	85.52
8	7.0-8.0	25. 9	4.03	100.5	85.93
9	8.0-9.0	21.9	3.42	82.9	85.14
10	9.0-10.0	28.2	2.90	80.6	84.14
11	10.0-11.0	23.5	2.74	69.4	81.93
12	11.0-12.0	19.9	2.00	57.1	82.07
13	12.0-13.0	12.5	1.03	30.1	80.70
14	13.0-14.0	12.7	1.07	38.6	81.04
15	14.0-15.0	13.5	0.69	26.1	80.90
16	15.0-16.0	10.3	0.42	19.6	81.07
17	16.0-17.0	8.0	0.31	14.6	81.80
18	17.0-18.0	8.1	0.23	12.1	83.26
19	18.0-19.0	8.1	0.25	11.5	82.50
20	19.0-20.0	8.7	0.21	10.7	83.05
21	20.0-21.0	8.7	0.25	10.7	91.24
22	21.0-22.0	7.9	0.24	10.4	89.88
23	22.0-23.0	7.5	0.27	9.1	81.47
24	23.0-24.0	7.9	0.24	8.8	81.08
25	24.0-25.0	7.6	0.29	8.6	77.58
26	25.0-26.0	7.2	0.23	6.3	80.03
27	26.0-27.0	8.2	0.25	7.6	81.80
28	27.0-28.0	7.3	0.25	7.6	80.84
29	28.0-29.0	7.8	0.73	6.8	78.88
30	29.0-30.0	7.4	0.57	6.7	79.61
31	30.0-31.0	7.3	0.69	5.7	82.07
32	32.0-33.0	6.8	0.75	6.4	80.08
33	34.0-35.0	7.5	0.25	5.6	81.71
34	36.0-37.0	7.9	0.25	7.8	79.63
35	38.0-39.0	7.1	0.28	108.1	/ 8.4/
36	40.0-41.0	9.0	0.25	1.6	82.00
3/	42.0-43.0	7.8 7 5	0.22	7.b 7.0	79.54
38	44.0-45.0	7.5	0.35	۲.۵ ۲.۵	/8.9/
39	46.0-47.0	8.Z	1.03	b.J	81.29
40	48.0-49.0	Ø.5	0.19	7.0	78.50

 Table A3-15:
 EPA#55 trace metal and porosity data

127	7
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Table A3-16: Normalized data for As (EPA#18/EPA#19 (O))

В	С	-	2
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B C - 9	
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Depth (cm)	Cons		BC-9
0	Concentration 5.4	Depth (cm)	Concentration
1	5.4	0	10.2
2	0.2	1	19.2
3	5.9	2	21.2
4	0.9	3	33.0
5	15.4	4	10.7
6	4.2	5	16.5
7.5	3.0	6	19.3
8.5	3.1	7	25.6
9.5	3.3	7 5	80.5
10 5	2.6	8	465.8
11 5	2.6	0	12.6
12 5	2.0	10	2.3
12.5	1.7	10	5.7
13.5	1.6	12	16.9
14.5	2.1	12	37.9
15.5	3.2	13	24.7
10.5	3.4	14	4.0
17.5	4.8	15	4.4
10.5	2.3	10	3.5
19.5	3.1	17	5.0
20.5	4.8	18	4.3
21.5	1.4	19	6.7
22.5	1.5	20	6.8
23.5	1.2	22	7.2
24.5	1.3	24	12.3
25.5	2.7	26	11.7
27.5	4.4	28	6.9
31.5	27	30	7.3
33.5	5.8	34	7.2
37.5	3.3	36	7.2
39.5	6 5	38	7.7
43.5	1 4		- • •
47.5	2.0		

Depth (cm)	Concentration	Depth (cm)	Concentration
0	0.78	0	2.38
1	0.90	1	2.60
2	0.90	2	2.58
3	0.86	3	2.98
4	0.90	4	3.44
5	1.06	5	3.05
6	1.04	6	1.80
7.5	0.90	7	0.79
8.5	1.02	7.5	0.60
9.5	0.71	8	0.18
10.5	0.55	9	0.30
11.5	0.18	10	0.25
12.5	0.13	11	0.34
13.5	0.10	12	0.24
14.5	0.11	13	0.23
15.5	0.12	14	0.23
16.5	0.11	15	0.25
17.5	0.10	16	0.23
18.5	0.16	17	0.18
19.5	0.12	18	0.23
20.5	0.13	19	0.22
21.5	0.12	20	0.23
22.5	0.12	22	0.24
23.5	0.12	24	0.23
24.5	0.12	26	0.26
25.5	0.15	28	0.23
27.5	0.54	30	0.23
31.5	0.14	34	0.25
33.5	0.17	36	0.24
37.5	0.16	38	0.23
39.5	0.16		
43.5	0.14		
47.5	0.13		

Depth (cm)	Concentration	Depth (cm)	Concentration
0	52.0		99.6
1	55.7	1	118.9
2	58.3	2	128.7
3	59.4	3	137.8
4	60.9	4	151.6
5	63.4	5	138.2
6	46.7	6	78.2
7.5	40.5	7	20.7
8.5	34.4	7.5	7.3
9 .5	31.3	8	13.5
10.5	21.4	9	17.1
11.5	10.7	10	17.8
12.5	7.8	11	17.8
13.5	7.6	12	20.7
14.5	7.8	13	22.5
15.5	5.6	14	18.9
16.5	4.5	15	20.0
17.5	4.4	16	19.3
18.5	5.1	17	17.8
19.5	5.0	18	18.5
20.5	4.6	19	21.1
21.5	4.3	20	20.4
22.5	4.4	22	18.2
23.5	4.6	24	20.0
24.5	4.6	26	21.8
25.5	4.7	28	20.4
27.5	5.4	30	22.5
31.5	5.6	34	22.5
33.5	5.2	36	24.7
37.5	5.0	38	23.3
39.5	4.2		
43.5	3.7		
47.5	3.3		

Table A3-16:	Normalized	data	for	Pb	(EPA#18/EPA#19	(0))

BC-9

BC-2

APPENDIX D

The data and calculations presented in this section are a direct result of information provided by Eisenreich et al., 1991, 1992. The calculations leading up to the establishment of the focusing factors are presented in the discussion section, and are not repeated here. These calculations are for the final step in determining the focusing factor, and for establishing and normalizing the data for each metal.

Site EPA#11: Cumulative unsupported ²¹⁰Pb= 30.988 30.988 / 15.5 =1.99 (focusing factor)

Site EPA#18: Cumulative unsupported ²¹⁰Pb= 37.7311 37.7311 / 15.5 = 2.43 (focusing factor)

Site EPA#19 (O): Cumulative unsupported ²¹⁰Pb= 16.5721 16.5721 / 15.5 = 1.07 (focusing factor)

Inventories are calculated for each metal for each profile. It is the sum of the corrected metal concentrations above the background depth less the background concentration. The results of this calculation is shown below for each of the metals for each of the profiles, and the actual calculation and data are on the succeeding pages.

Site #	As	Cd	Pb
EPA#11	27.6	4.60	318.5
EPA#18	27.2	9.09	543.4
EPA#19 (O)	197.1	6.53	263.7

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The calculation to establish an inventory of metals in the sediment is:

$I = \sum ((MC-BC)(BD)(1-\emptyset)(T))$

where I is the inventory in μ g/cm², **MC** is the metal concentration in μ g/g, **BC** is the background concentration, **BD** is the bulk density (2.45 g/cm²), Ø is the porosity of the sediment, and **T** is the thickness of the sediment interval in cm. The data used in the calculation is shown below.

Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	12.5	8.3	0.8456	0.1544	1cm	3.1397
2	12.8	8.6	0.8239	0.1761	1cm	3.7104
3	12.5	8.3	0.822	0.178	1cm	3.6196
4	14	9.8	0.7949	0.2051	1cm	4.9245
5	11.8	7.6	0.7921	0.2079	1cm	3.8711
6	9.7	5.5	0.7778	0.2222	1cm	2.9941
7	13.7	9.5	0.772	0.228	1cm	5.3067
					Inventory:	27.6

EPA#11 As:

EPA	11	Cd:
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Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	1.81	1.65	0.8456	0.1544	1cm	0.6242
2	1.89	1.73	0.8239	0.1761	1cm	0.7464
3	2.00	1.84	0.8220	0.1780	1cm	0.8024
4	1.96	1.80	0.7949	0.2051	1cm	0.9045
5	1.90	1.74	0.7921	0.2079	1cm	0.8863
6	1.05	0.89	0.7778	0.2222	1cm	0.4845
7	0.38	0.22	0.7720	0.2280	1cm	0.1229
8	0.21	0.05	0.7363	0.2637	1cm	0.0323
					Inventory:	4.60
EPA#11 Pb:

Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	140.8	118.0	0.8456	0.1544	1cm	44.637
2	152.0	129.2	0.8239	0.1761	1cm	55.7427
3	151.2	128.4	0.8220	0.1780	1cm	55.9952
4	158.0	135.2	0.7949	0.2051	1cm	67.9373
5	145.2	122.4	0.7921	0.2079	1cm	62.3451
6	62.8	40.0	0.7778	0.2222	1cm	21.7756
7	37.2	14.4	0.7720	0.2280	1cm	8.0438
8	26.0	3.2	0.7363	0.2637	1cm	2.0674
					Inventory:	318.5

EPA#18 As:

Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	13.4	5.8	0.8619	0.1381	1cm	1.9624
2	15.4	7.8	0.8432	0.1568	1cm	2.9964
3	14.7	7.1	0.8346	0.1654	1cm	2.8771
4	22.3	14.7	0.8337	0.1663	1cm	5.9893
5	38.5	30.9	0.8404	0.1596	1cm	12.0825
6	10.5	2.9	0.8235	0.1765	1cm	1.2540
					Inventory:	27.2

EPA#18 Cd:

Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	1.96	1.55	0.8619	0.1381	1cm	0.5244
2	2.24	1.83	0.8432	0.1568	1cm	0.7030
3	2.26	1.85	0.8346	0.1654	1cm	0.7497
4	2.14	1.73	0.8337	0.1663	1cm	0.7049
5	2.26	1.85	0.8404	0.1596	1cm	0.7234
6	2.64	2.23	0.8235	0.1765	1cm	0.9643
7	2.59	2.18	0.8192	0.1808	1.5cm	1.4485
8	2.26	1.85	0.8084	0.1916	1cm	0.8684
9	2.56	2.15	0.7899	0.2101	1cm	1.1067
10	1.77	1.36	0.7768	0.2232	1cm	0.7437
11	1.38	0.97	0.7780	0.2220	1cm	0.5276
12	0.46	0.05	0.7721	0.2279	1cm	0.0279

Inventory: 9.09

EPA#18 Pb:

Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	130.0	118.9	0.8619	0.1381	1cm	40.2292
2	139.2	128.1	0.8432	0.1568	1cm	49.2109
3	145.8	134.7	0.8346	0.1654	1cm	54.5845
4	148.6	137.5	0.8337	0.1663	1cm	56.0223
5	152.2	141.1	0.8404	0.1596	1cm	55.1729
6	158.4	147.3	0.8235	0.1765	1cm	63.6962
7	116.8	105.7	0.8192	0.1808	1.5cm	70.2313
8	101.2	90.1	0.8084	0.1916	1cm	42.2947
9	86.0	74.9	0.7899	0.2101	1cm	38.5544
10	78.2	67.1	0.7768	0.2232	1cm	36.6930
11	53.6	42.5	0.7780	0.2220	1cm	23.1158
12	26.8	15.7	0.7721	0.2279	1cm	8.7662
13	19.4	8.3	0.7644	0.2356	1cm	4.7909
					Inventory:	543.4

EPA#19 (O) As:

Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	21.1	10.0	0.8939	0.1061	1cm	2.5995
2	23.3	12.2	0.8778	0.1222	1cm	3.6526
3	36.3	25.2	0.8776	0.1224	1cm	7.5570
4	11.8	0.7	0.8774	0.1226	1cm	0.2103
5	18.2	7.1	0.8626	0.1374	1cm	2.3901
6	21.2	10.1	0.8329	0.1671	1cm	4.1349
7	28.2	17.1	0.7962	0.2038	1cm	8.5382
8	88.6	77.5	0.7961	0.2039	.5cm	19.3576
9	512.4	501.3	0.7967	0.2033	.5cm	124.8450
10	13.9	2.8	0.7876	0.2124	1cm	1.4571
11	2.5	-8.6	0.7741	0.2259	1cm	-4.7597
12	6.3	-4.8	0.7825	0.2175	1cm	-2.5578
13	18.6	7.5	0.7762	0.2238	1cm	4.1123
14	41.7	30.6	0.7726	0.2274	1cm	17.0482
15	27.2	16.1	0.7837	0.2163	1cm	8.5320

Inventory: 197.1

Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	2.62	2.36	0.8939	0.1061	1cm	0.6135
2	2.86	2.60	0.8778	0.1222	1cm	0.7784
3	2.84	2.58	0.8776	0.1224	1cm	0.7737
4	3.28	3.02	0.8774	0.1226	1cm	0.9071
5	3.78	3.52	0.8626	0.1374	1cm	1.1849
6	3.35	3.09	0.8329	0.1671	1cm	1.2650
7	1.98	1.72	0.7962	0.2038	1cm	0.8588
8	0.87	0.61	0.7961	0.2039	.5cm	0.1524
					Inventory:	6.53

EPA#19 (O) Cd:

EPA#19 (O) Pb:

Sample	Conc.	Corr. Conc.	Ø	1 - Ø	thickness	µg/cm2
1	109.6	87.4	0.8939	0.1061	1cm	22.7192
2	130.8	108.6	0.8778	0.1222	1cm	32.5138
3	141.6	119.4	0.8776	0.1224	1cm	35.8057
4	151.6	129.4	0.8774	0.1226	1cm	38.8679
5	166.8	144.6	0.8626	0.1374	1cm	48.6767
6	152.0	129.8	0.8329	0.1671	1cm	53.1395
7	86.0	63.8	0.7962	0.2038	1cm	31.8560
8	22.8	0.6	0.7961	0.2039	.5cm	0.1499
					inventory:	263.7

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