Characterization of Heavy Metal Contamination in
Two Lateral Lakes of the Lower Coeur d'Alene River Valley,
Northern Idaho

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

The lower Coeur d'Alene River valley in Northern Idaho has received heavy metal contamination from over a century of upstream mining activity. Medicine and Thompson Lakes are two of the 11 lateral lakes of the Coeur d'Alene River that lie on the flood plain. In their bottom sediments is preserved a stratigraphic record of upstream mining operations. A freeze box, designed by a Quaternary geologist in Finland, was used to sample the lake bottom sediments. This method preserves the vertical stratigraphy. As little as 10 cm and up to 52 cm of undisturbed tailing sediments with "varve-like" features was recovered. Geochemical analyses of these sediments show maximum concentrations of 49 ppm Ag, 427 ppm As, 68 ppm Cd, 341 ppm Cu, 10.9% Fe, 1.8 ppm Hg, 1.1% Mn, 1.8% Pb, 48 ppm Sb and 1.1% Zn. ^{137}Cs was used to establish the depositional chronology of the lake bottom sediments. Fourteen centimeters of sediment were deposited between 1951 and 1964, and 10-12 cm from 1964 to 1992. Particle size distribution and analysis found that the fractions containing the highest Cd, Cu, Pb and Zn concentrations are the least abundant in the samples. The most abundant size fraction has some of the lowest heavy metal concentrations. This study shows that the contamination in the lakes is restricted to the shallow sub-bottom and that heavy metal concentrations drop to background levels within a few meters of depth.

ACKNOWLEDGEMENTS

DEDICATION

This thesis is dedicated to my family. Without their encouragement, understanding and support (spiritual as well as financial), none of this would have been possible.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The lateral lakes of the Coeur d'Alene River lie within the flood plain of the Coeur d'Alene River. The lakes are remnants of the once larger Glacial Lake Columbia I, which extended from lake Coeur d'Alene to near Kellogg, Idaho (Waitt and Thorson, 1983). The bottom sediments have preserved the history of the lakes which can be interpreted through the study of the stratigraphy. Previous studies by Bender (1991), Horowitz and others (1995) and preliminary results of this study indicated heavy metal contamination in the sediments of all of the lateral lakes as well as Lake Coeur d'Alene. Contaminated sediments were also visually identified along the banks of the Coeur d'Alene River (Hoffmann and others, 1992).

The Coeur d'Alene mining district was established in 1884 with the discovery of gold. It has since yielded extensive quantities of lead (Pb), zinc (Zn), silver (Ag), copper (Cu) and antimony (Sb), making it one of the richest districts in the world. These deposits brought great prosperity to the area through the smelting and mining industries. Between 1884 and 1991 silver production yielded over 1 billion troy ounces, copper totaled 187,815 tons, lead totaled 8,014,041 tons, zinc totaled 3,243,269 tons and gold totaled 518,552 troy ounces. Since 1884 the district has yielded over $5.2 billion in precious metals (Springer, 1993).

These industries also appear to have had a dramatic impact upon the environment. The Coeur d'Alene mining district has been a factor in many disputes concerning the multiple usage of the Coeur d'Alene River

valley. As early as 1911, public concern was being voiced over the pollution of water supplies in the valley due to the dumping of tailings into the Coeur d'Alene River. This concern was also expressed with regard to the effects of the mine wastes on the fish and waterfowl of the region (Chupp, 1956). In the 1920's, farmers along the Coeur d'Alene River were attempting to sue the mining companies for loss of livestock that grazed in the area and degradation of their cropland with "leaded soil". The suits alleged that the waste produced by the companies was being transported downstream and onto the flood plains during flooding (Ellis, 1932). A soil survey conducted by Lewis and Denecke in 1923 reported the collection of a sediment sample containing 2.86% (28,600 ppm) Pb. Thus the farmers' allegations seem to have been substantiated.

Prior to 1968, the mill tailings were discarded directly into the South Fork of the Coeur d'Alene River. An average of 2217 tons per day of mine slimes were being discarded into the South Fork of the Coeur d'Alene River in 1964 (Maxfield and Wai, 1971). As a result, much of the flood plain, including the 11 lateral lakes of the Coeur d'Alene River and numerous sloughs, served as natural settling ponds. By 1968, the mining companies had constructed settling ponds in order to reduce the amount of waste introduced into the river. However, applicable laws continued to allow substantial quantities of waste to be discharged into the Coeur d'Alene River.

The consequences of these recovery and disposal techniques were elevated levels of Ag, As, Cd, Cu, Fe, Hg, Mn, Pb, Sb and Zn in the dissolved and suspended load of the Coeur d'Alene River. Much of these sediments were deposited in the lateral lakes.

In 1985, twenty-one square miles of the district were designated as the Bunker Hill Superfund Site by the U. S. Environmental Protection Agency. This was due to elevated lead levels found in the blood of children living in the area. The seven-mile by three-mile rectangular Superfund Site is situated East-West along the river and includes the communities of Kellogg, Smelterville and Pinehurst.

Through the course of this study it was thought useful to find time-stratigraphic indicators. These could then be used to determine sedimentation rates within the lakes, as well as the time period of greatest contamination. One useful technique for this was through the measuring the activity of ^{137}Cs. Studies of ^{137}Cs have been performed world-wide with similar results. ^{137}Cesium is a by-product of above-ground nuclear testing. ^{137}Cesium fallout began in early 1951, with Operation Ranger at the Nevada Nuclear Test Site, and reached a maximum in 1963-64 (Pennington and others; 1973; Krey and others, 1990).

Today, contaminated sediments can be easily recognized along the river (Plate 1-1) and the channels leading to the lateral lakes. Annual to semi-annual flooding events, livestock usage and motor boat wakes continue to erode these contaminated sediments and redeposit them further downstream. These contaminated sediments eventually move into Lake Coeur d'Alene and may exit to the Spokane River and further downstream into the Columbia River.

Also of interest is whether the heavy metal ions are being transported into the aquifers which are recharged by these surface waters. The most notable of these aquifers is the Rathdrum Prarie/Spokane valley aquifer, a "sole source" aquifer for the city of

Plate 1-1: Mine tailings deposits along the banks of the Coeur d'Alene River.

Spokane, which receives 30% of its recharge from Lake Coeur d'Alene and the Spokane River (Wyman, 1994).

Geographic Setting

Thompson and Medicine Lakes are two of the 11 lateral lakes located on the flood plain of the Coeur d'Alene River (Figure 1-1). They are approximately three and eleven miles, respectively, east of the mouth of the Coeur d'Alene River.

The Coeur d'Alene mining district of Northern Idaho is located approximately 75 miles east of Spokane, Washington along the South Fork of the Coeur d'Alene River. The district extends for approximately 20 miles from Pinehurst to Wallace, Idaho. Thirty miles downstream, the main stem of the Coeur d'Alene River drains into Lake Coeur d'Alene near Harrison, Idaho.

Mining History

The Coeur d'Alene mining district has been active for over a century. It has been one of the richest deposits of lead, zinc and silver in the world, and produces approximately 20% of the United States' newly mined silver (Springer, 1993). The impact of this mining activity upon the environment has been of much interest for more than 70 years.

Milling in the area began in 1884, by 1925, the 360 acre smelting complex was distributed among six communities in the river valley. The complex consisted of a lead smelter, electrolytic zinc plant, phosphoric acid plant, fertilizer plant, sulfuric acid plant, cadmium plant, the Central Impoundment Area (CIA), assorted waste piles and water treatment facilities.
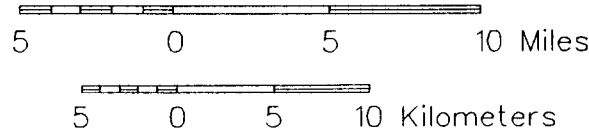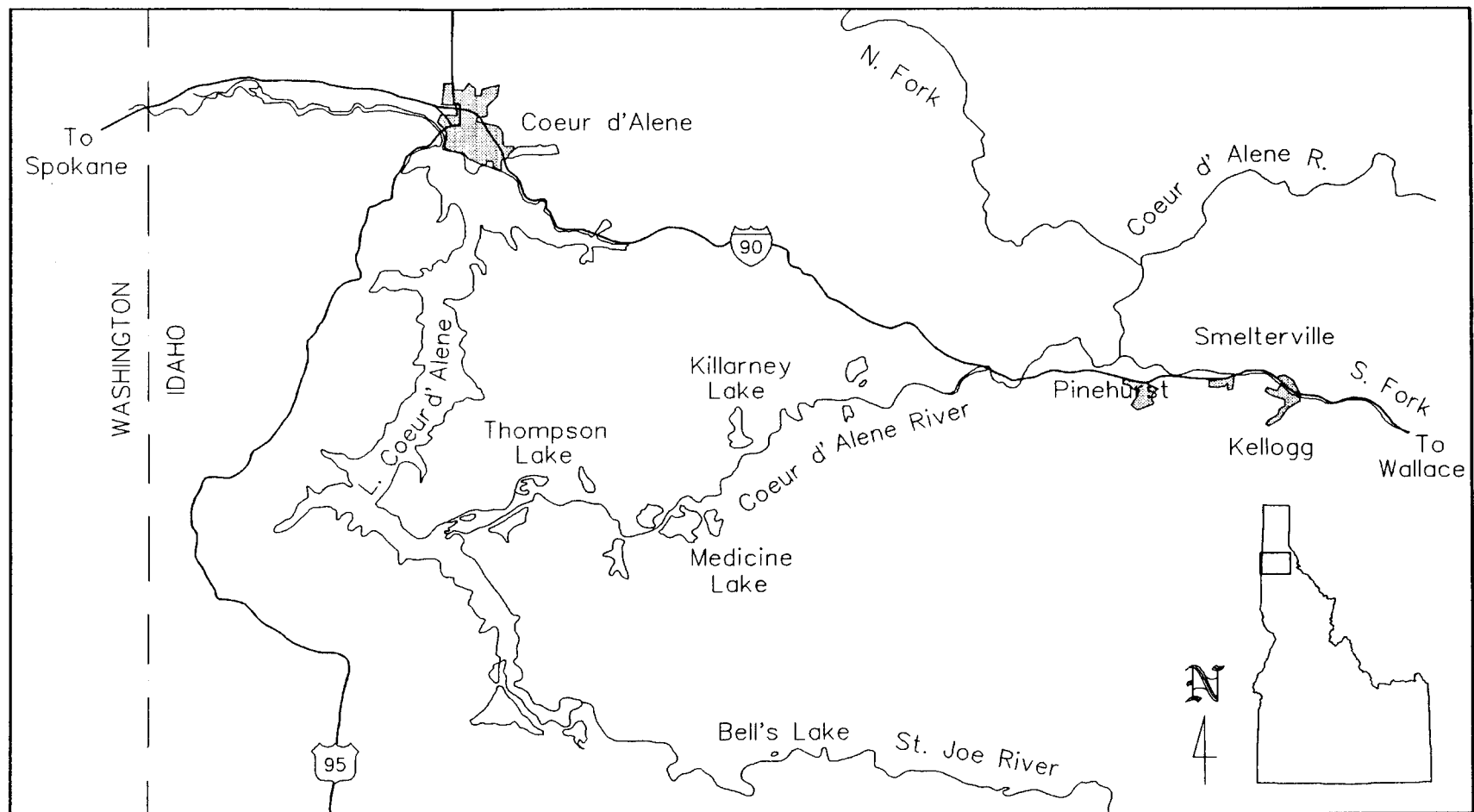
Figure 1-1: Location map of the Coeur d'Alene River area.

Prior to 1930, jigging operations were used for ore recovery. This process resulted in the down-river deposition of sediments with inflated levels of lead, zinc and cadmium. By the early 1930s, this practice was replaced by more efficient floatation recovery methods (Johnson and others, 1976).

Prior to 1968, the use of settling ponds was not implemented in the mining techniques. Consequently, the mine tailings from this era were dumped directly into the South Fork of the Coeur d'Alene River. The inception of settling ponds in 1968 greatly reduced the amount of new sediment introduced into the river (Mink and others, 1973). However, prior to the use of settling ponds, a vast amount of tailings had already been introduced into the river system (Keely and others, 1976). The consequence was unacceptably high levels of lead, zinc and other base metals in the sediments of the Coeur d'Alene River, the lateral lakes and Lake Coeur d'Alene.

Purpose of the Study

The premise of my thesis is that the sediments of Medicine and Thompson Lakes, like the other lateral lakes of the Coeur d'Alene River, contain a record of local mining activities, and that recurrent flooding events in the valley have continually deposited contaminated sediment throughout the river system.

This study was designed to determine the concentrations and vertical distribution of Ag, As, Cd, Cu, Fe, Hg, Mn, Pb, Sb and Zn in the bottom sediments of Medicine Lake and Thompson Lake. A further aim was to correlate these findings with previous work by Bender (1991) on

Killarney Lake. Additionally, contamination within certain particle size categories was evaluated. Possible remediation techniques were also evaluated because remediation may be vital to the continued recreational and economic use of the Coeur d'Alene River system.

Study Area

Some reasons for the selection of Medicine Lake and Thompson Lake for this study are:

1. Investigations dating back over 60 years have found contamination in each of these lakes (Ellis, 1932).

2. Both are located on the flood plain of the Coeur d'Alene River and are directly connected to the river by small dredged channels.

3. Thompson Lake appears to be a meander scar (oxbow) lake, whereas Medicine Lake appears to be controlled by the underlying bedrock topography, therefore giving two different geomorphic settings.

4. Thompson Lake lies approximately seven miles downstream of Medicine Lake. Therefore, a comparison of the two lakes may give an indication of temporal and spatial differences in the distribution of heavy metal laden sediments.

Bells Lake, located in the St. Joe River system, was used as a control lake for the following reasons:

1. The St. Joe River system is located in a similar geographic and geologic setting, but has not been subjected to mining activity (Rabe and Flaherty, 1974).

2. Bells Lake is subject to high-water events similar to those of

Thompson and Medicine Lakes.

3. Bells Lake has been used as a control lake in earlier studies by Rabe and Bauer (1977) and Bender (1991), thus allowing for comparisons with these studies.

CHAPTER II
GEOLOGY

Geologic History

The Coeur d'Alene River is one of the major drainages of the western Bitterroot Range in the Northern Rocky Mountains. The entire river valley is underlain by the Prichard and Burke members of the Precambrian Belt Supergroup (Griggs, 1973), composed predominantly of argillites and quartzites that locally contain minor dolomite and limestone lenses. These metasediments commonly occur in thicknesses exceeding 6-10 km within the Coeur d'Alene valley (Constantopoulos, 1989).

The major structural feature of the region, the Osburn fault, shows approximately 26 km of right-lateral offset (Constantopoulos, 1989). As a result of extensive folding and faulting, most of the bedded rocks show dip angles greater than 45°, with some being overturned (Hobbs and others, 1965).

Mink and others (1973) stated "... the Osburn Fault produced a structural deformation in the sediments into which the metalliferous ores were deposited by thermal solutions emanating from igneous bodies intruded about Cretaceous time." However, galena, sphalerite, tetrahedrite and chalcopyrite, the main ore minerals of the district, have been age dated at 825 Ma. The mineralization must have occurred in post-folding structures, and the mineralization in the district appears to have been the result of remobilization of minerals from the underlying Proterozoic sediments (Constantopoulos, 1989).

Inconsistencies exist in the interpretation of the age relationships of

mineralization in the area. Hayden (1992) found that Cretaceous aged Gem Stocks in the area intruded into and deformed the ore-bearing veins. He also found that age dates of sericite in the veins varied from 77.5 Ma to over 800 Ma. At the Sunshine Mine, uranite veins have been age dated at 1,200 Ma and are found to cut folded belt rocks as well as ore veins (Hayden, 1992).

The underlying sediments may have been the subject of an initial period of Proterozoic mineralization about 1,400 Ma. These units were buried and subjected to a second phase of mineralization which remobilized and removed the ore minerals and deposited them in the overlying Proterozoic rocks during the Goat River orogeny, approximately 850 Ma (Hayden, 1992).

Within the study area, the Belt Supergroup rocks were locally covered by flows of the Miocene Columbia River Basalt Group. These outpourings extended to an elevation of approximately 2900 ft. The furthest extent of the basalt in the Coeur d'Alene River valley is seen as a small outcrop approximately 1 mile west of Killarney Lake (Griggs, 1976).

Quaternary Geology

Five Laurentide glacial stages have been identified in Central North America during the Pleistocene (Frye and Willman, 1960). Regional correlation of these glaciations have been the subject of many studies. Individual valley glaciers have been widespread throughout the Rocky Mountains with local ice caps existing at a number of locations (Richmond and others, 1965).

Historically, the major advances of the Cordilleran ice-sheet of

Western North America have been correlated with the advances of the Laurentide ice-sheet as well as smaller Alpine Glaciers (Richmond and others, 1965). However, the Late Pleistocene glaciers of western North America varied considerably in size and climatic environment and therefore in activity. Recent studies have concluded that the alpine glaciers of the northwest reached their maximum positions about 18,000 to 22,000 years ago. They had, in fact, greatly diminished by the time the Cordilleran ice-sheet was at its maximum stand, 11,000 to 17,500 years ago (Waitt and Thorson, 1983).

Locally, it was believed that the Pend Oreille Lobe of the Cordilleran ice-sheet had extended down the Rathdrum Valley to a point southeast of Spokane, Washington. This impounded a huge volume of water in the Coeur d'Alene River valley, which extended to near Wallace, Idaho (Richmond and others, 1965). Later field investigations have found that the apparent glacially deposited gravels of this lobe were actually jökulhloup deposits formed from the catastrophic discharges of Glacial Lake Missoula. It is now believed that Richmond's Glacial Lake Coeur d'Alene was actually an extension of Glacial Lake Columbia I (Waitt and Thorson, 1983). The approximate altitude of the lake surface at this time was about 2400 ft, compared to 2125 ft at the present time. Today, the elevation of the lake surface is regulated by the Post Falls dam, which lies below Lake Coeur d'Alene on the Spokane River (Bender, 1991). The occurrence of erratics in the Coeur d'Alene River valley at elevations of up to 2665 ft is also the apparent result of the jökulhloups (Richmond and others, 1965).

CHAPTER III

PREVIOUS INVESTIGATIONS

In 1932, Ellis investigated the effects of mining in the Coeur d'Alene district on the biota of the South Fork and main stem of the Coeur d'Alene River. He stated that

> "...no fish were found in the Coeur d'Alene River from its mouth near Harrison ... to a point above Wallace, that is, a 50 mile portion of the Coeur d'Alene River ... was without a fish fauna as far as could be determined.... (Neither) phytoplankton nor zooplankton were found in the waters of the main stream of that portion of the Coeur d'Alene River carrying mine wastes."

Ellis (1932) also found that the *copepod* counts showed Medicine Lake to be fair to good with regards to plankton fauna, whereas in Thompson Lake he found the total amount of plankton to be negligible as a source of fish food and "... in most of the tests ... no plankton of any sort was found."

Ellis (1932) also found a representative bottom fauna was observed in Medicine Lake, whereas fewer individuals were noted than in the other lateral lakes. However, the bottom fauna of Thompson Lake, even near the more favorable areas, yielded only a few blood-worms.

Ellis (1932) also noted that upstream of the polluted portions of the South Fork and in the tributaries, a rich bottom fauna was found. He also noted that "all types of bottom aquatic life expected in clear, cold stream water were found in quantity."

Maxfield and others (1971) studied 107 core samples taken from the delta area of the Coeur d'Alene River and 20 core samples from the lateral lakes of the Coeur d'Alene River. About eight samples were

analyzed from each bomb core sample for Ag, Cd, Cu, Mn, Pb, Sb and Zn. The sediments consisted of laminated fine silt and sand and were found to have elevated heavy metal concentrations, which varied with depth and the nature of the sediments. However, concentrations of heavy metals were found to be relatively consistent in the top layer of the samples. The heavy metal values for these samples are seen in Table 3-1.

	range*	peak*
Ag	6-15	40
Cd	16-75	250
Cu	90-150	>250
Mn	6200-12,500	>14,000
Pb	3000-6300	>8750
Sb	270-900	>1000
Zn	3200-4700	>17,000

Table 3-1:   Range and peak values from the upper 3 cm of sediment taken from the delta area of the Coeur d'Alene River (After Maxfield and others, 1971).
*All values are in ppm.

Overall peaks in heavy metal concentrations were found in different layers as a function of depth, but only a slight decrease was found to occur with increasing distance from the mouth of the river.

This study also addresses the possibility of the incorporation of heavy metals into the biota found at the mouth of the Coeur d'Alene River. Table 3-2 shows the ranges of Cd, Cu, Pb and Zn in 18 plant samples.

Cd	4-30 ppm
Cu	7-70 ppm
Pb	30-200 ppm
Zn	300-892 ppm

Table 3-2: Range of heavy metal
concentrations in plant samples.

One of three bullfrogs caught in the delta area was also found to
have elevated Cd, Pb and Zn levels in the tissue (Table 3-3). The other
two frogs showed "no appreciable amount of metal in their organs"
(Maxfield and others, 1971).

	Cd*	Pb*	Zn*
muscle	3	149	103
liver	11.7	600	334
kidney	113	1600	1190

Table 3-3: Heavy metal concentrations in tissue from a
bullfrog (After Maxfield and others, 1971).
*Concentrations in ppm.

The mobilization of metals in water was also a focus of this study.
These laboratory results found that at natural pH levels, Zn and minor
amounts of Mn were able to go into solution culminating in saturation
concentrations of about 1.8 ppm. Zn concentrations of 1.0 to 2.5 ppm
had been reported in various samples taken from the Coeur d'Alene
River (Maxfield and others, 1971).

Williams and Wallace (1973) studied seven mines in the Coeur
d'Alene Mining District as well as various other locations within the
district. They evaluated the efficiency by which tailings ponds removed
heavy metal ions from concentrator and mine effluents. They identified

the occurrence of heavy metal ions near the abandoned tailings deposits and observed the impact of heavy metal ions with regard to the degradation of local and regional surface and groundwater resources.

In 1974, Bauer studied the concentration and distribution of Pb, Zn, Cu, Cd, Cs and Sb in the water and sediments (Table 3-4) of the lateral lakes as well as in the fauna of the Lower Coeur d'Alene River valley. Bottom sediments were collected with an Eckman dredge, the top 2 to 3 cm of which was sampled.

Analysis of sediment samples taken from two locations in Medicine Lake and Thompson Lake yielded the following results:

	Cd*	Cu*	Pb*	Zn*
Medicine Lake	30	79	3000	2550
	44	87	2650	2950
Thompson Lake	23	82	3700	3000
	31	52	2600	2900

Table 3-4: Concentrations of metals in the sediments from Medicine and Thompson Lakes. The first value is from samples taken near the inlet from the Coeur d'Alene River (After Bauer, 1974). *Values are in mg/kg (ppm)

The average concentrations of Zn in the muscle tissues of the five fish species ranged from 19.5 to 67.6 ppm, while the average concentrations of Zn in the liver tissue was significantly higher, ranging from 107 to 147 ppm. Average Cu concentrations in the muscle tissues of each species ranged from 0.87 to 2.2 ppm and ranged from 8.8 to 41.3 ppm in liver tissue.

The Zn and Cu levels measured in the livers of Yellow Perch were consistent from lake to lake and were significantly higher than in fish from a control lake. Bauer (1974) also noted that there appeared to be

a correlation between metal concentrations and the tropic level with increasing concentrations in the lower tropic levels and highest concentrations of Zn in the muscle and liver tissue of Brown Bullheads.

In the analysis of the lake water, Bauer (1974) found that the dissolved metals were below "toxic levels" in open water during low water periods as well as during flood events. Zn concentrations ranged from 0.04 mg/l (ppm) in open water, to 0.41 ppm near the inlet of Thompson Lake. Concentrations of 0.05 to 0.06 ppm were recorded in Medicine Lake. A concentration of 1.1 ppm was recorded in a water sample taken directly from the Coeur d'Alene River.

Bauer's (1974) conclusions stated that "heavy metals in the sediment appear to be immobile and have little effect on biota of the lakes. (The fact that) no excessive levels of heavy metals were found in fish, shows that fish are not accumulating contaminants from the lakes."

Ioannou (1979) studied the bedload and stream discharge of the Coeur d'Alene River. He found that mill waste was probably the largest component of the sediment load. The suspended sediments were found to contain elevated concentrations of Zn and Pb. He also proposed several reclamation alternatives for controlling the continuous contamination from the tailings piles.

Neufield (1987) investigated heavy metal contamination within the Coeur d'Alene River Wildlife Management Area (WMA), with particular reference to swan mortality rates in the area. Through the course of his study, he found that the recent sediments being reworked and redeposited throughout the valley contain an average of 2,500 ppm Pb, with the highest concentrations (11,000 ppm Pb) occurring nearer the Coeur d'Alene River. This supported Krieger's 1982 investigation as

well as surveys conducted by Rabe and Bauer (1977) and Rabe and Flaherty (1974).

Bender (1991) studied the sediments deposited in Killarney Lake. High concentrations of heavy metals were found in the upper 59 cm of sediments at the center of the lake. Concentrations of up to 37,400 ppm (3.74%) Pb and 32,850 ppm (3.28%) Zn were found in these sediments. However, the majority of the contamination appeared to be confined to the metal bearing silt (tailings) and was found to be minimal in the natural organic silts which underlie the tailings.

In addition to these investigations, extensive bibliographies have been compiled by Wai and others (1985), Savage (1986) and Standish and Sprenke (1994) concerning environmental studies within the Coeur d'Alene River system.

Despite the hundreds of investigations, either completed or in progress, mining wastes are still legally discharged into the Coeur d'Alene River system. The EPA restrictions still allow mine operators to discharge nearly 11,000 pounds of Pb annually (Neufeld, 1987). In addition to this, non point sources of contamination must also be considered, such as windblown soils and erosion of existing tailings. In 1986, the EPA measured as much as 20 pounds of Pb per day (Bender, 1991) being carried in the suspended load of the river.

CHAPTER IV
SAMPLING TECHNIQUES

Field Techniques

The sampling procedure was carried out during the winter of 1991 when the lake surface was frozen. This provided a large working area and stability when the sampling box and sample were raised to the surface. Figures 4-1 and 4-2 show the sample locations in Medicine Lake and Thompson Lake.

All Thompson Lake samples, along with samples M-91-A and M-91-B were taken in January and February of 1991. Sample M-92-Cs was taken in July of 1992. This sample was split for Atomic Adsorption and ^{137}Cs work.

Quaternary geologists have been interested in the study of lake bottom sediments for decades. This is because the continuous, undisturbed nature of the sediments allows them to be used as an accurate continuous record of the recent geological history of an area. Scientists are able to extract data from the sediments dating back tens of thousands of years and are able to correlate local, regional and global events (Sugden and John, 1985).

Sampling was executed with the use of Huttenen-style freeze boxes (Plate 4-1). The freeze box was originally designed by European quaternary geologists to take in-situ samples of lake sediments for varve studies, which require undisturbed samples (Huttenen and Merilainen, 1978). This investigation also required a stratigraphically undisturbed sample and this freeze box method was ideal. The freeze box is a hollow stainless steel box which is beveled on one side at the bottom enabling the sediments on the opposite side to remain
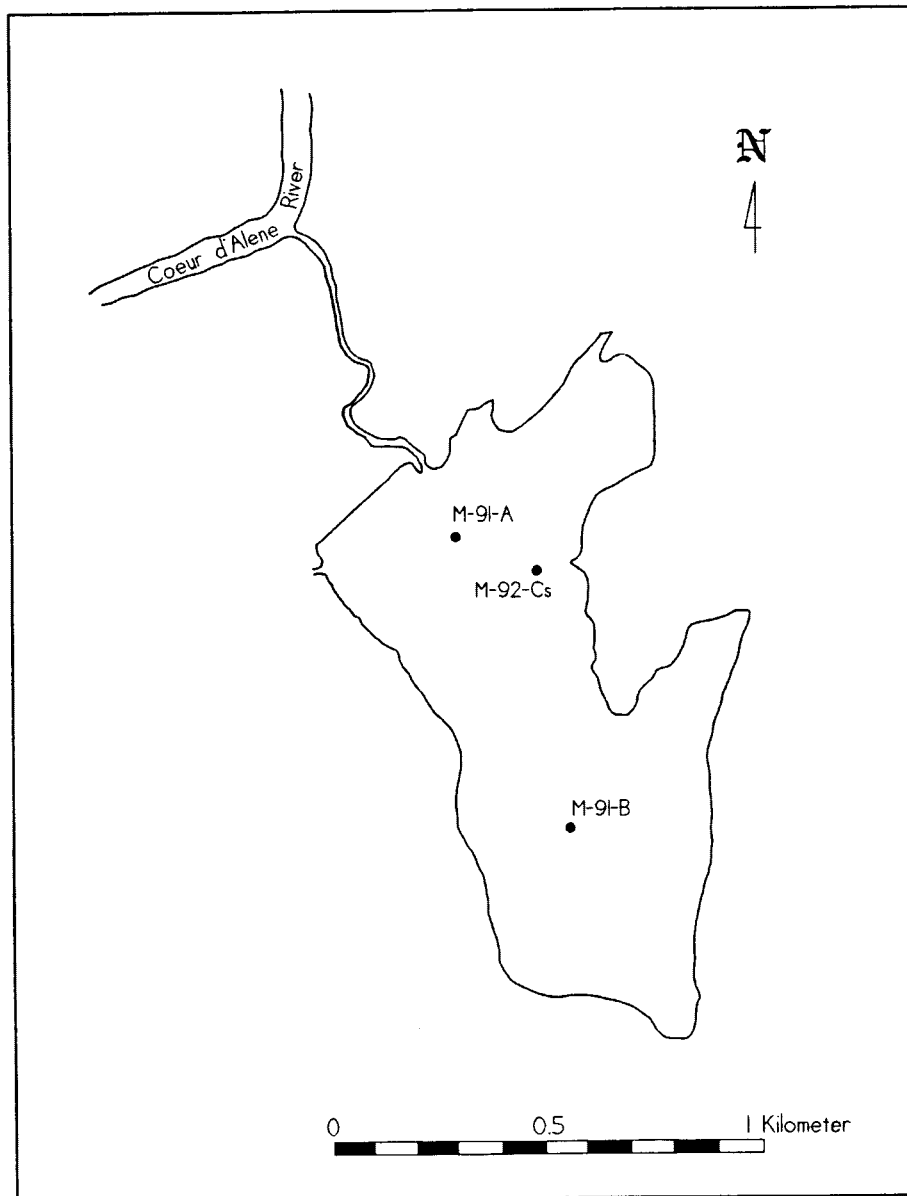
Figure 4-1: Map of Medicine Lake showing
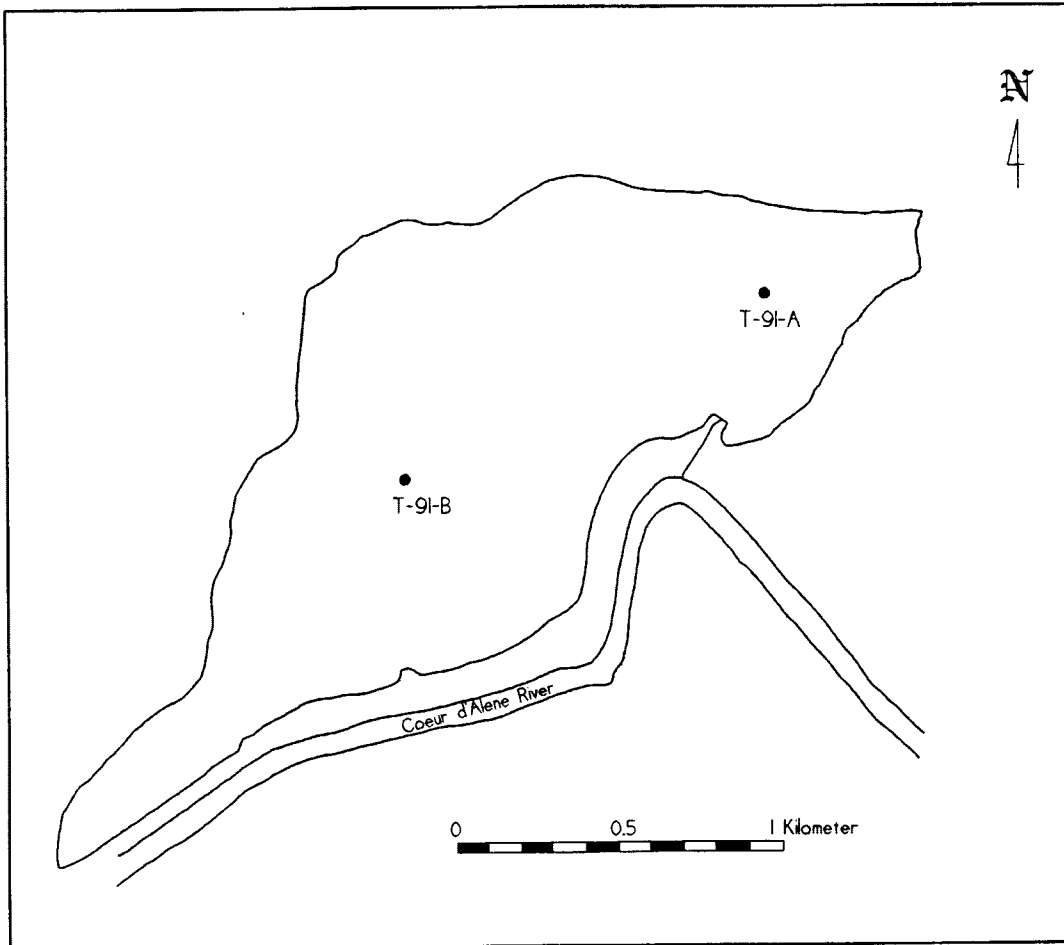sample locations.

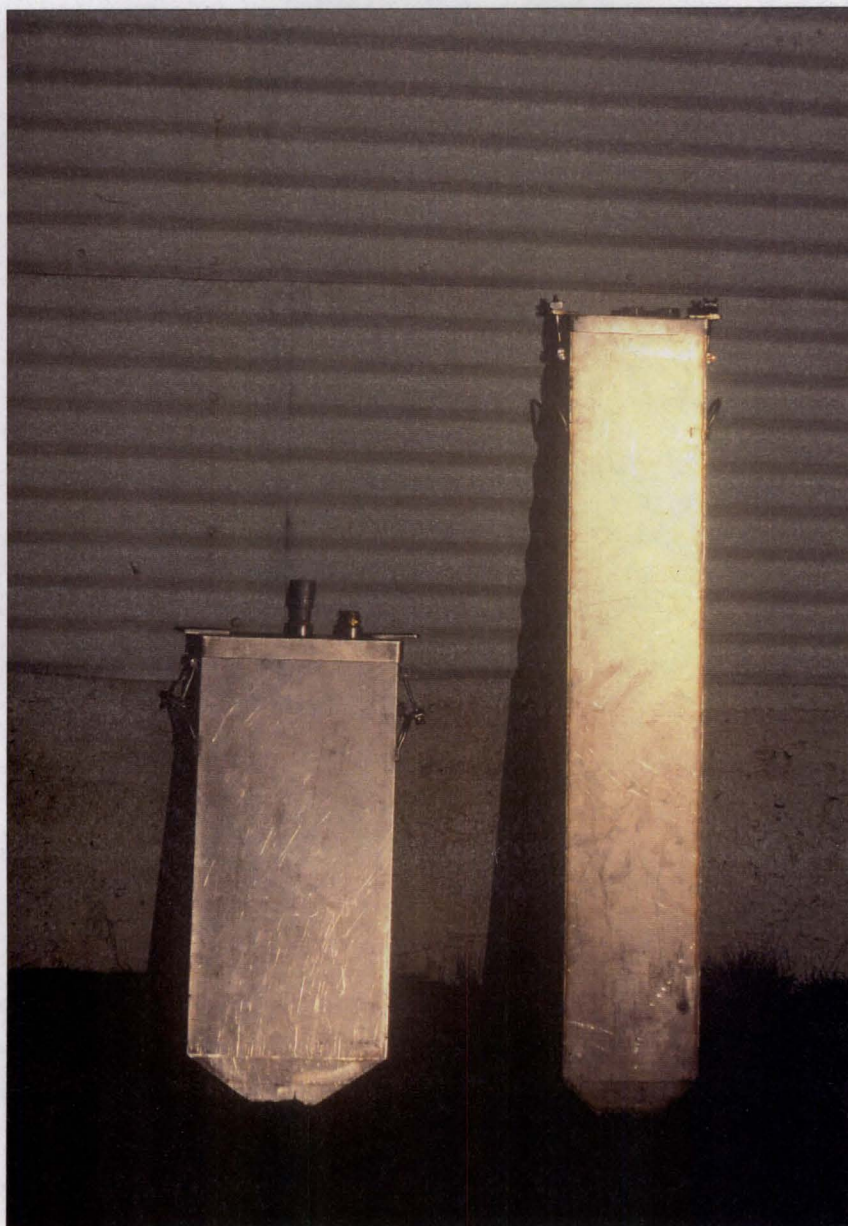Figure 4-2: Map of Thompson Lake showing sample locations.

Plate 4-1: Freeze boxes used in lake bottom sediment sampling.

undisturbed as the box is lowered into position.

Before sampling, a hole was cut in the ice and the depth of water at the site was measured using a fishing line and a large sinker. The freeze box was then filled with dry ice and ethyl alcohol, and the cover was then secured. A steel pipe of greater length than the depth of the water was screwed into the top of the box, and ropes were secured to the box handles. The box was then lowered to the bottom of the lake and pushed into the lake bottom sediments so that the length of pipe below the ice was equal to the depth of water measured. The entire apparatus was then immobilized by securing it at the ice surface and was left undisturbed for approximately 30 minutes. Through the use of the attached ropes and the steel pipe, the box was pulled out of the sediments and lifted to the surface. After the box and sample were retrieved, the sample was removed by emptying the alcohol and filling the box with water. This caused the sample to thaw slightly at the box/sample interface, which allowed the sample to be removed quite easily. The result was a frozen, intact and stratigraphically undisturbed sample measuring approximately 2cm thick x 55cm long x 25cm wide. Each sample was placed in a marked plastic bag, sealed and stored in a cooler until it could be transferred to a freezer. Thus, the sample remained frozen until sub-sampling could be completed.

Sample Locations and Descriptions

The sample locations at Medicine Lake are shown in Figure 4-1. Sample M-91-A (Plate 4-2) was taken in 3.1 meters of water. The upper 10 cm is predominately dark brown to black organic silt and sand with local occurrences of light gray metal bearing silt. The interval
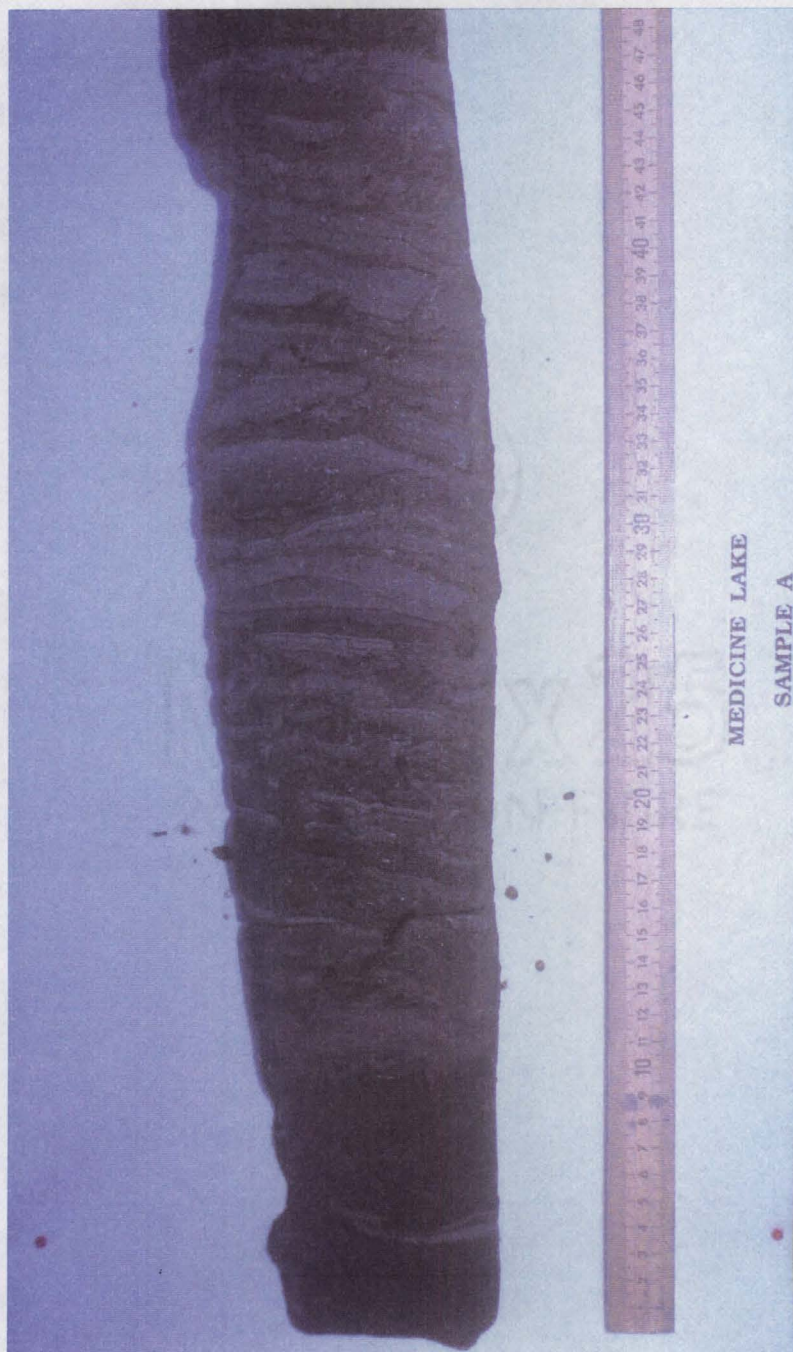
Plate 4-2: Sample M-91-A.

from 10 to 47 cm consists of interbedded light gray metal bearing silt and dark gray to black organic material. The interval from 47 to 54 cm consists of predominately dark brown organic silt with common laminations of light gray metal bearing silt.

Sample M-91-B (Plate 4-3) was taken in 4.7 meters of water. The upper 27 cm consist of dark brown organic silt with abundant laminae and lenses of light gray metal bearing silt. The interval from 27 to 51 cm consists of dark brown organic material.

The upper 10 cm of sample M-92-Cs (Plate 4-4) consist of fresh, dark brown organic material. Below 10 cm the sample consists of interbedded light gray metal bearing silt and dark gray to brown organic material.

Figure 4-2 shows the sample locations at Thompson Lake. Sample T-91-A (Plate 4-5) was taken in 5.8 meters of water. The upper 10 cm is predominately dark brown organic material with abundant lenses of light gray metal bearing silt. The remaining 38 cm consist of interbedded light gray metal bearing silt and dark brown organic material.

Sample T-91-B (Plate 4-6), taken in 1 meter of water, consists entirely of dark brown to black organic material with no occurrences of metal bearing material.

The occurrences of varve-like laminations are typical of the heavy metal laden sediments in the lateral lakes. The dark laminations in the sediment represent autochthonous organic material from the lake. The light laminations and lenses represent allochthonous silt and clay sized mine tailings deposited during flood events.
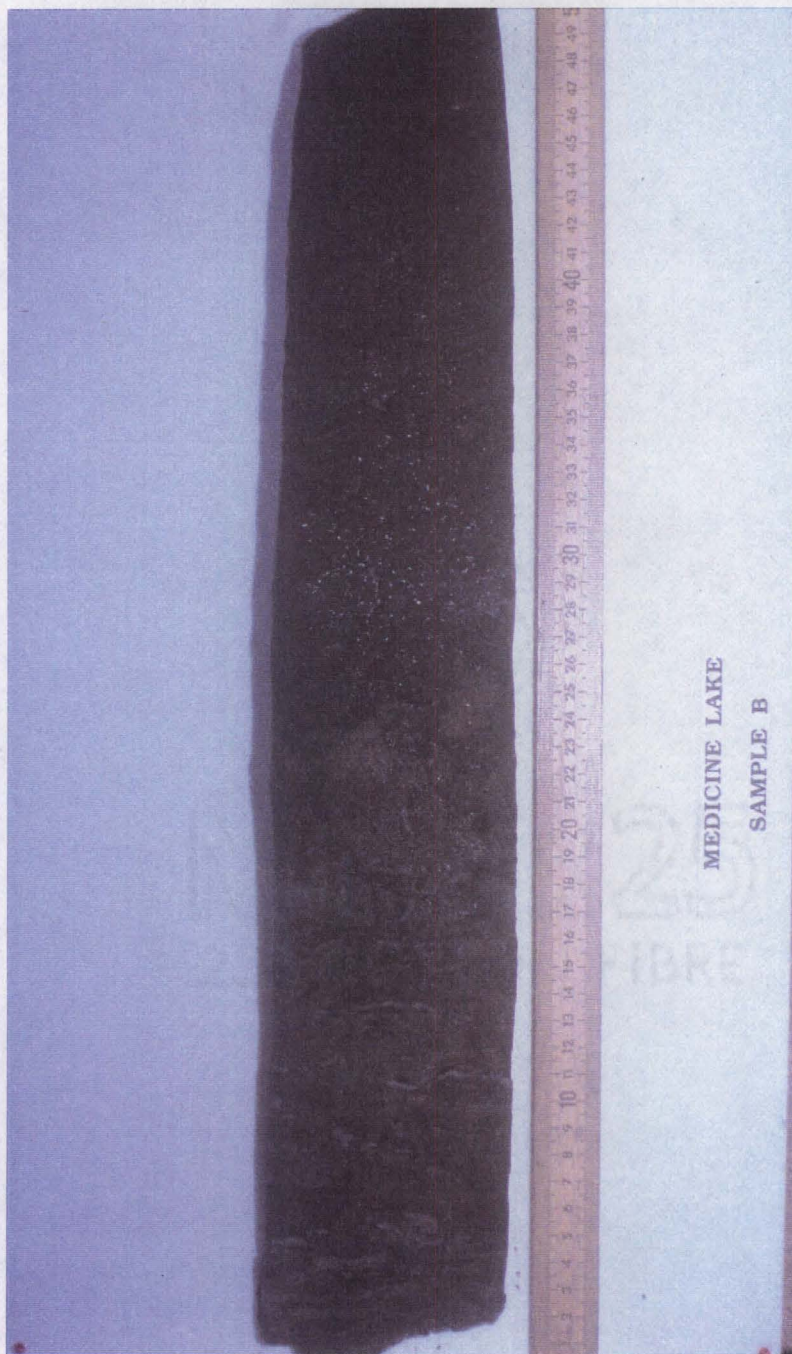
MEDICINE LAKE
SAMPLE B

Plate 4-3: Sample M-91-B.

Plate 4-4: Sample M-92-Cs.

THOMPSON LAKE
SAMPLE A

Plate 4-5: Sample T-91-A.

THOMPSON LAKE
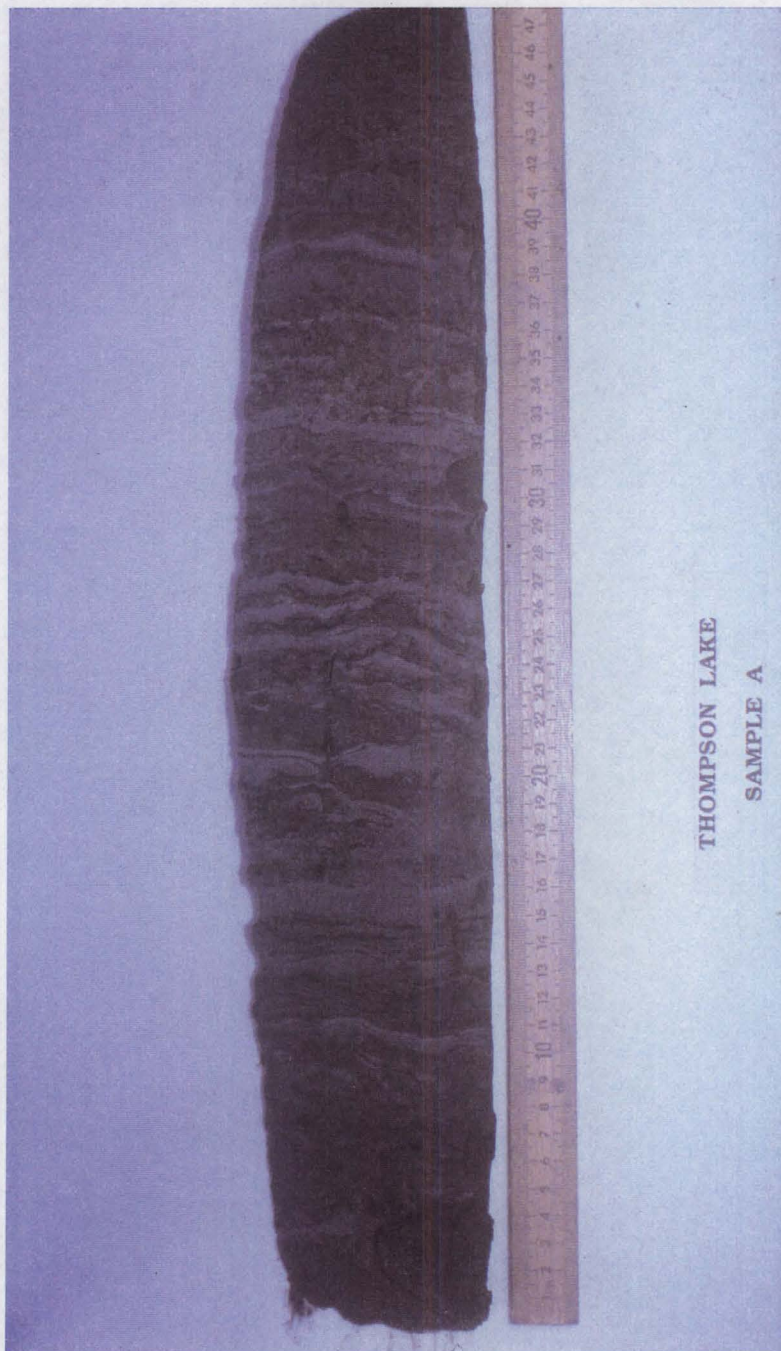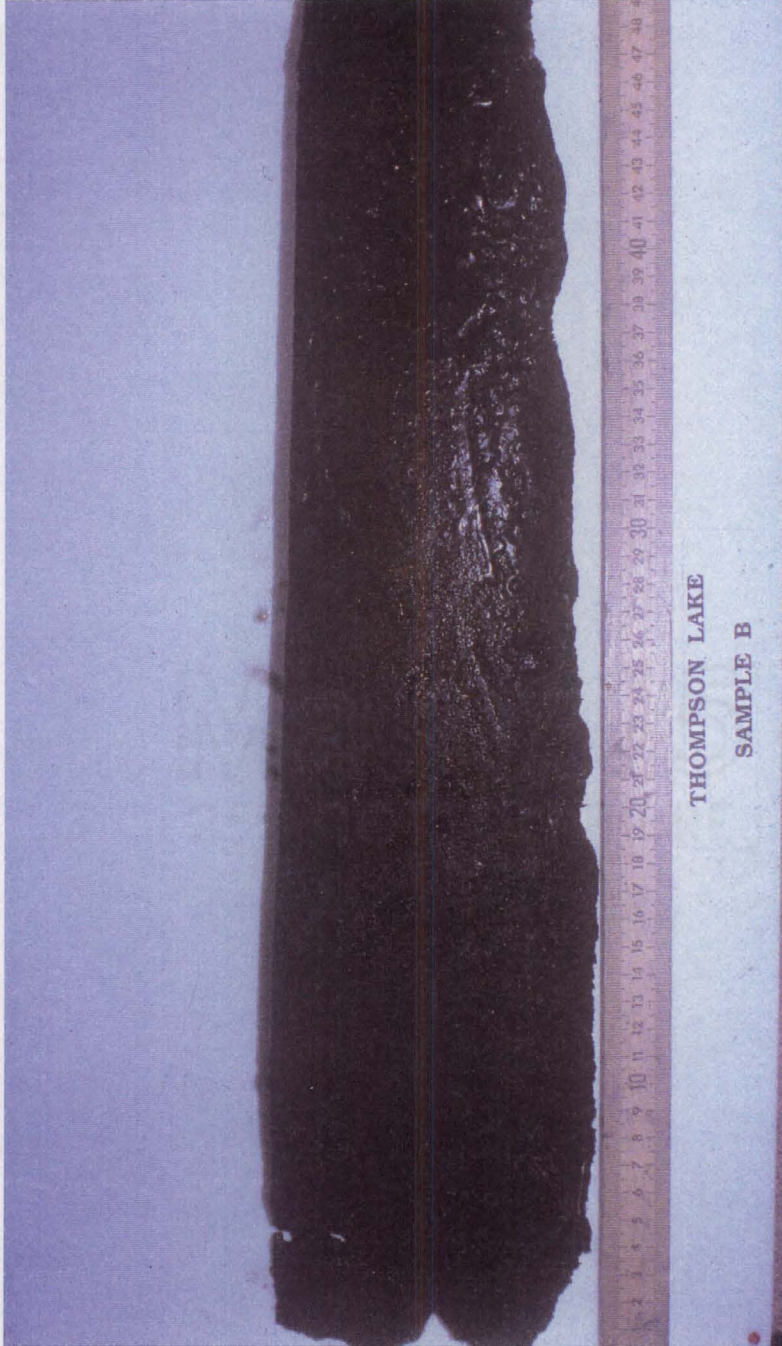
SAMPLE B

Plate 4-6: Sample T-91-B.

Laboratory Techniques

The sub-sampling of Medicine and Thompson Lake samples was completed in the spring and summer of 1991. Initially, each frozen bulk sample was cut down to about a 10 cm width with a band saw. The excess sample was then returned to the freezer for archiving. These samples were then cut at 2 cm intervals throughout the entire length of the sample. These sub-samples were then allowed to thaw at room temperature. After the sub-samples had completely thawed, they were placed in a Buchner funnel, and the interstitial water was extracted with a vacuum pump through a Whatman #41 filter (or equivalent). The sediment was placed in plastic "zip lock" bags in preparation for digestions. After drying and sealing the samples in the bags, the sediment was thoroughly mixed to ensure that a representative split could be obtained for analysis.

Sub-samples of M-91-A were split and sent to the University of Idaho Soils Department for particle-size distribution analysis of the depth intervals 0-8 cm, 8-16 cm and 16-24 cm. Particle-size fractions were separated, as discussed below, and classified according to Table 4-1.

Name	Diameter*
Sand	>50
Coarse Silt	50-20
Medium Silt	20-5
Fine Silt	5-2
Coarse Clay	2-0.2
Medium Clay	0.2-0.08
Fine Clay	<0.08

Table 4-1: Particle size classifications.
*Effective diameter in Micrometers.

Lab Techniques for Particle Size Analysis

Sample splits were homogenized and wet sieved through a 300 mesh (50 micrometer) sieve. The remaining sediment (sand) was then oven dried. The sediment passing through the sieve (<50 micrometer) was gravity separated and decanted. The sediment, coarse silt, was freeze-dried for analysis. The supernatant, medium-fine silt and clay, was then centrifuged for 3 minutes at 750 rpm to remove the silt fractions. This sediment was then mixed and centrifuged for 3 minutes at 300 rpm to remove the medium silt. The sediment and supernatant were then freeze dried. The clay fraction was mixed and centrifuged for 40 minutes at 2000 rpm to remove the coarse clay, which was then freeze-dried. The supernatant was centrifuged for 9:24 minutes at 10,000 rpm and decanted. The sediment (medium clay) and supernatant (fine clay) were both freeze-dried (Jackson, 1956). All fractions were extracted with 0.1 M HCl and analyzed by Inductively Coupled Plasma Mass Spectroscopy (ICP).

Quality Assurance

Due to the immediate freezing of water and sediment to the freeze box, some sample contamination might have occurred as the freeze box was lowered into position. In an attempt to ensure that the samples were actually representative of their respective depth interval, the frozen 10 cm samples were scrubbed with a "scotch-brite" pad and rinsed. This was then repeated when the samples were cut into the 2 cm intervals.

CHAPTER V

GEOCHEMICAL TECHNIQUES

Sample Preparation for Flame Atomic Absorption Spectrometer and ICP

The digestion procedure for the sediment was completed in accordance with the Environmental Protection Agency procedure Method 3050 for Flame Atomic Absorption Spectrometer (AA) and ICP analysis (EPA, 1987). This method consisted of digesting a homogeneous 1 to 2 g sample (weighed to the nearest 0.01 g) in nitric acid (HNO_3), hydrogen peroxide (H_2O_2) and hydrochloric acid (HCl).

The samples were prepared in Teflon beakers with 10 ml of 1:1 HNO_3 solution, heated to 95° C and refluxed for 15 minutes while being covered by a watch glass. The samples were then cooled and an additional 5 ml HNO_3 were added, whereupon the samples were covered and refluxed for an additional 30 minutes and cooled. This last step was then repeated. The samples were then covered with a ribbed watch glass, heated and allowed to evaporate to 5 ml without boiling. Two ml of deionized (DI) water were added after cooling and 10 ml of H_2O_2 were added with heating in 1 ml aliquots. Once again the sample was cooled and 10 ml DI water were added with 5 ml HCl and refluxed for 15 minutes. The cooled sample was then filtered through a Whatman #41 filter (or equivalent), and the liquid was diluted to 100 ml with DI water (EPA, 1987). The samples were transferred to Nalgene bottles and refrigerated until they could be analyzed.

Instrumental Neutron Activation Analysis

In preparing a sample for Instrumental Neutron Activation Analysis (INAA), all that is needed is the raw sediment sample. The sample is placed in plastic beakers and irradiated. The process for irradiating the sample consists of placing it in a nuclear reactor. The sample is then bombarded with neutrons from a ^{60}Co source. The result is a sample consisting of radioactive isotopes of each element. The resulting radioactive isotopes are then measured through their emission of gamma rays. Each radioactive isotope emits gamma rays specific to that element. The energy released is recorded and compared to a standard which is available from the National Institute of Standards and Technology. The recorded values and the known standard values are then compared. This comparison then yields the true concentration of the element in the sample analyzed (Rember and others, 1993).

Gamma-Ray Spectroscopy

^{137}Cs was determined in air dried samples by gamma-ray spectroscopy using a lithium-drift germanium gamma-ray spectrometer (Nuclear Data ND6700) at Washington State University's Nuclear Radiation Center. The dried samples, ranging in weight from 7 to 260 g, were placed in Marinelli beakers and counted on the above detector for 40,000 seconds. A procedure adapted from Cook (1990) was then followed. The detector was calibrated using a point source of ^{137}Cs (at 662 keV) and a point source of ^{82}Br, which has gamma-ray energies that bracket the ^{137}Cs peak (619 keV and 698 keV). By doing this, the detector was calibrated to both point sources and the activity was measured for the ^{82}Br solution. A Marinelli beaker with a ^{82}Br solution

of known activity and a volume approximating that of the samples was also counted. The ratio of the ^{82}Br point source and the ^{82}Br solution to that of the ^{137}Cs point source permitted the calculation of the detector efficiency of the ^{137}Cs in the Marinelli beaker configuration, thus resulting in a quantitative determination of ^{137}Cs in the samples (Rember and others, 1993).

Quality Control

For all samples from Medicine and Thompson Lakes, blank samples were digested and submitted for ICP analysis. The geochemical laboratory also implemented the use of blanks and known standards in each run for calibration. The final geochemical results are presented in Appendix A.

CHAPTER VI

RESULTS

Pre-mining Sediments

Bender (1991) compared the background heavy metal concentrations in sediments from Bells Lake (control lake) to uncontaminated (pre-mining) sediments from Killarney Lake. Due to the similar background concentrations in each lake, Bells Lake was deemed to be an adequate control for the study.

In this study, sediments from the lower 1/3 of cores M-91-B and T-91-B were believed to consist of pre-mining sediments. This was seen in the predomination of organic material and the lack of metal bearing silts in the samples. For this reason, the concentrations from the lower 1/3 of these cores were compared to the crustal average concentrations of each of the respective elements. These results are in Table 6-1.

ELEMENT	CRUSTAL AVERAGE*	M-91-B*	T-91-B*
Ag	0.07	1-2	1
As	1.8	16-30	15-25
Cd	0.15	2-4	32510
Cu	50	25-40	18-26
Fe	54,000	17,900-22,000	11,600-13,500
Hg	0.02	0.2-0.7	0.3-0.9
Mn	1,000	249-518	359-503
Pb	12.5	122-518	56-181
Sb	0.2	1-15	1-16
Zn	70	140-496	77-207

Table 6-1: Comparison of background heavy metal concentrations from M-91-B, T-91-B and crustal average.
*All values in ppm.

Background Concentration Values

The background concentrations of Cu, Fe and Mn from cores M-91-B and T-91-B were found to be below the actual crustal averages of these elements.

The background concentrations of Zn from the two cores ranged from 77 to 496 ppm. These values are at or slightly higher than the crustal average (Krauskopf, 1979).

Of the remaining elements, Ag, As, Cd, Hg and Pb were found to have values approximately one order of magnitude greater than the respective crustal averages (Krauskopf, 1979).

The remaining element, Sb, occurred with the highest of the relative background concentration which approached two orders of magnitude greater than the crustal average (Krauskopf, 1979).

Although some of these elements were found to exist in significantly higher concentrations than the crustal average, this should not be taken

out of context. These variations could easily be accounted for in the genesis of different lithologies; this would especially be true when considering the extremely low concentrations of heavy metals being discussed here. A more valid comparison is to similar existing sediments which are free from heavy metal contamination. This was accomplished by comparing the concentrations to those obtained by Bender (1991) from Bells Lake.

Bells Lake is situated in a similar geographic and geologic setting to Medicine Lake and Thompson Lake. The crucial difference is that the St. Joe River valley which includes Bells Lake has been, and continues to be, free of mining activities. The results of these comparisons with the control lake are seen in Table 6-2.

ELEMENT	BELLS LAKE*	M-91-B*	T-91-B*
Ag	<1	1-2	1
As	12-32	16-30	15-25
Cd	<1	2-4	1-3
Cu	12-55	25-40	18-26
Fe	3,900-31,600	17,900-22,000	11,600-13,500
Hg	-	0.2-0.7	0.3-0.9
Mn	120-640	249-518	359-503
Pb	<2-30	122-518	56-181
Sb	-	1-15	1-16
Zn	100-570	140-496	77-207

Table 6-2: Comparison of background heavy metal concentrations from samples M-91-B, T-91-B. Values for Bells Lake from 80 cm depth and below (after Bender, 1991).
*All values in ppm.

The pre-mining sediments in Medicine Lake and Thompson Lake show very little deviation in heavy metal concentration from those

found in Bells Lake. Although the As, Mn and Pb values appear to be somewhat elevated with respect to Bells Lake, these small discrepancies are insignificant in light of the extremely inflated values found in the contaminated sediments. Hg and Sb were not analyzed in Bells Lake.

In summary:

1. The pre-mining heavy metal concentrations in the lake bottom sediments from Medicine Lake and Thompson Lake are not similar to the crustal average concentrations of each respective element.

2. The pre-mining concentrations are not significantly deviant from similar sediments taken from an uncontaminated control lake.

^{137}Cs

The upper 10 cm of sample M-91-Cs consists of fresh, highly saturated organic material that constitutes the present-day lake bottom surface. Below 10 cm, the sample consists of dense sediments with varve-like features typical of heavy-metal laden sediments in the lateral lakes. The dark laminates in the sediments represent autochthonous organic material from the lake environment; the light bands represent allochthonous fine-grained mine tailings deposited during floods.

The distribution of ^{137}Cs with depth is shown in graph 6-1. The ^{137}Cs is confined to the depth interval between 8 cm and 32 cm in this sample. A distinct maximum is apparent at 18 cm.

The 14 cm interval thickness between the maximum ^{137}Cs (1963-1964) and the onset of ^{137}Cs (1951) yields an average sedimentation

rate of 1.1 cm/year during that time. Extrapolation to the top of the varve-like sediments (10-12 cm) yields and estimated date of 1969 for the uppermost tailings, a date consistent with the 1968 installation of the tailing ponds in the mining district. Thus, the upper 10 cm of sediment represents the past 25 years of sedimentation in the lake, giving a rate of 0.4 cm/yr. This shows that the tailings impoundments have drastically decreased contamination and the sedimentation rate in Medicine Lake.
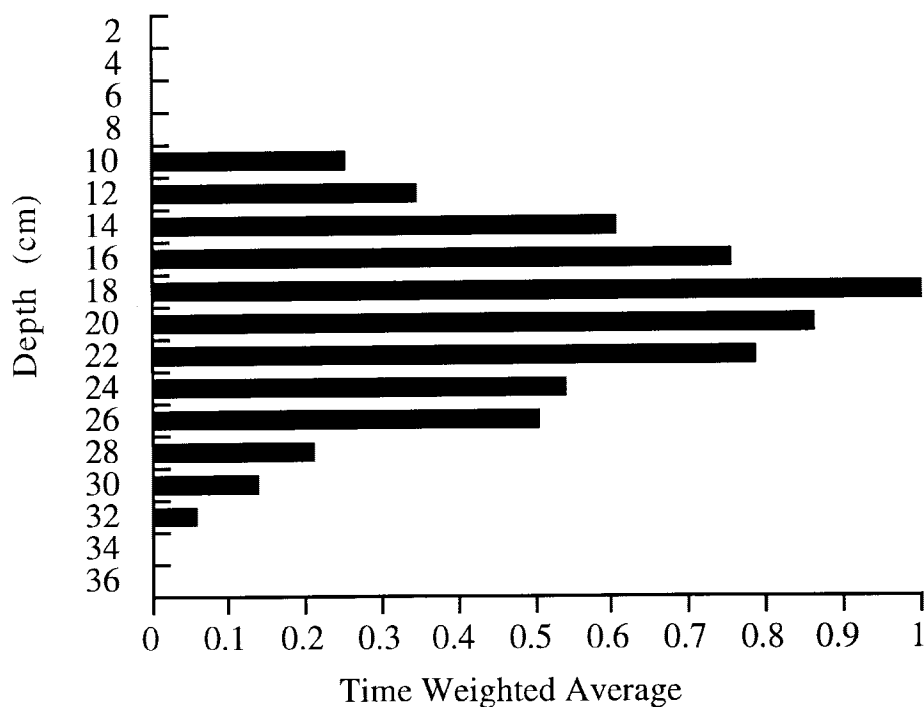
Graph 6-1: ^{137}Cs Activity (pCi/g) for sample M-91-Cs.

Shallow Lake Bottom Sediments

The following section compares the heavy metal concentrations in the shallow lake bottom sediments from 4 sample locations in Medicine Lake and Thompson Lake. The accompanying graphs depict the elemental concentrations at each 2 cm depth interval.

Preliminary visual identification of stratified contaminated sediments showed over 52 cm of laminated metal bearing silt in M-91-A (Plate 4-2), 25 cm of laminated metal bearing silt in M-91-B (Plate 4-3), and over 48 cm of laminated metal bearing silt in T-91-A (Plate 4-5). No contaminated sediment could be seen by a visual inspection of sample T-91-B (Plate 4-6).
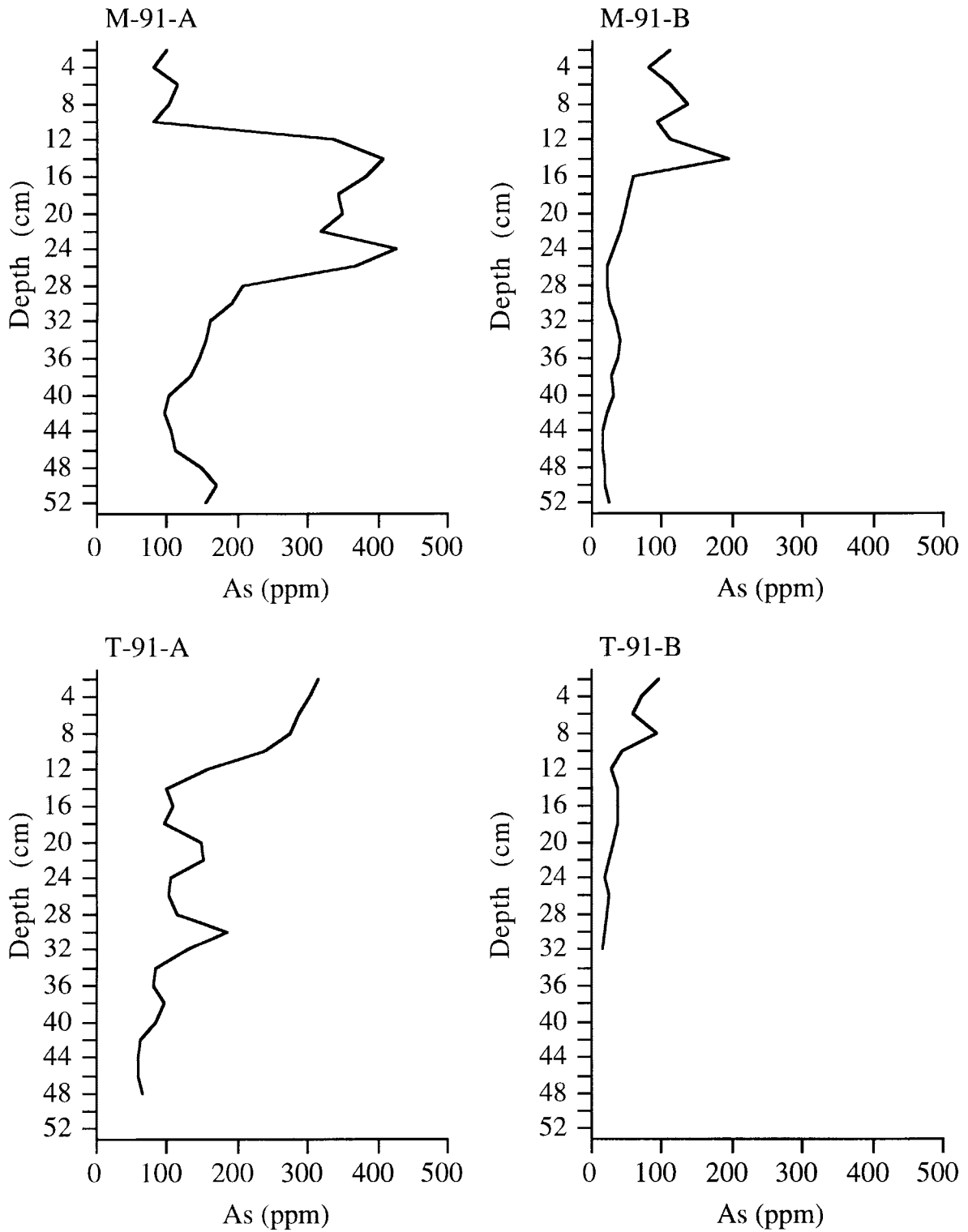
Ag Concentrations

Graph 6-2 shows the concentration of Ag in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Ag concentrations in sample M-91-A range from 11 to 24 ppm with the maximum concentration of 24 ppm at 10 cm depth. The concentrations in sample M-91-B range from 1 to 49 ppm with the maximum concentration of 49 ppm at 20 cm depth. The concentrations in sample T-91-A range from 9 to 45 ppm with the maximum concentration of 45 ppm at 48 cm depth. The concentrations in sample T-91-B range from 1 to 16 ppm with the maximum concentration of 16 ppm in the upper 2 cm of sediment.

As Concentrations

Graph 6-3 shows the concentration of As in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The As concentrations in sample M-91-A range from 79 to 427 ppm with the maximum concentration of 427 ppm at 24 cm depth The concentrations in sample M-91-B range from 17 to 193 ppm with the maximum concentration of 193 ppm at 14 cm depth. The concentrations in sample T-91-A range from 58 to 315 ppm with the maximum concentration of 315 ppm in the upper 2 cm of the sample. The concentrations in sample T-91-B range from 15 to 95 ppm with the maximum concentration of 95 ppm in the upper 2 cm of sediment.
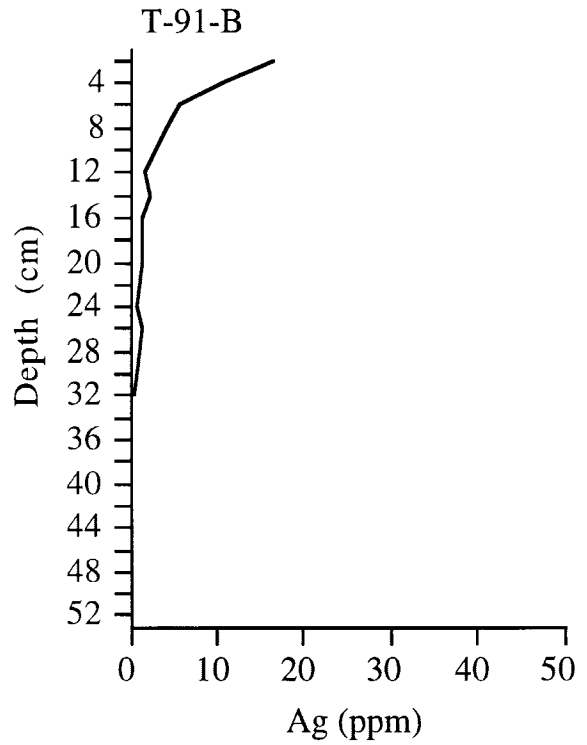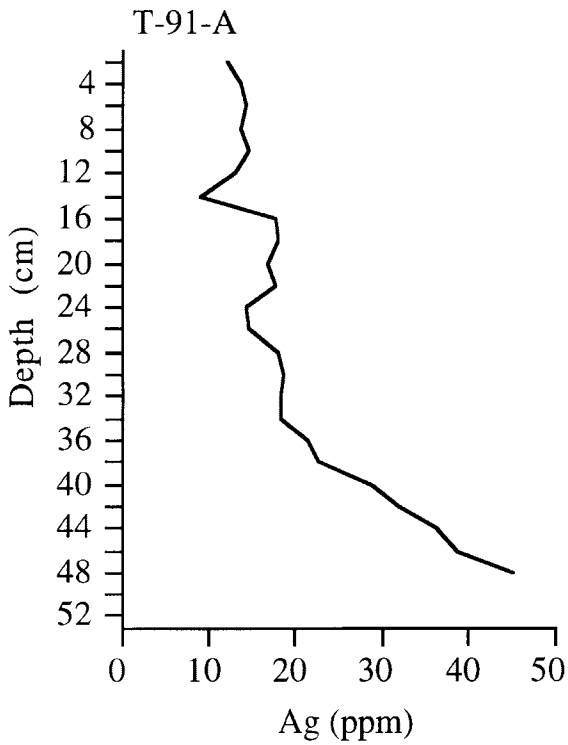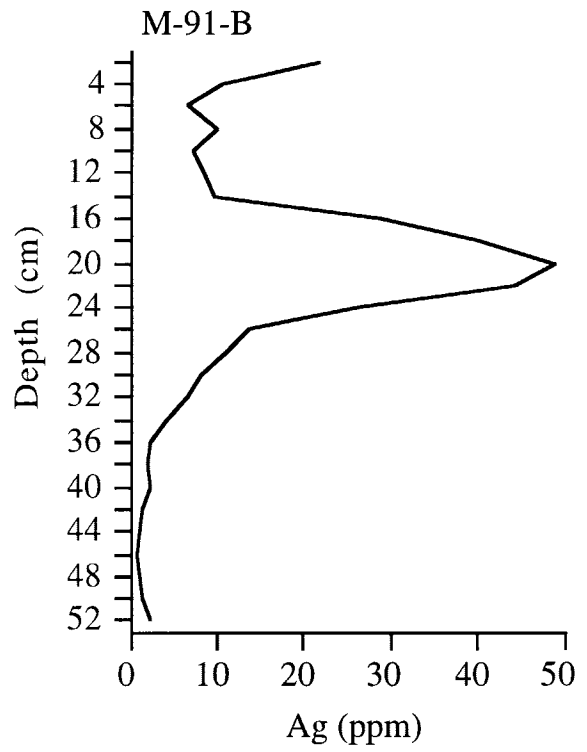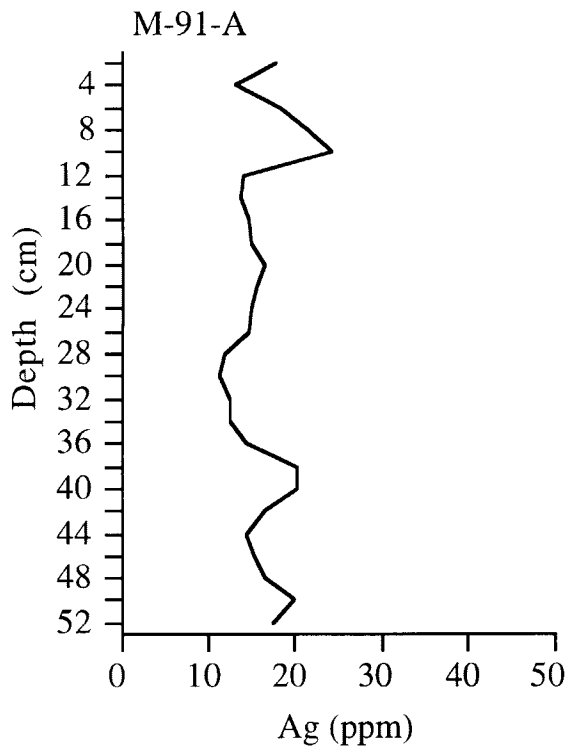
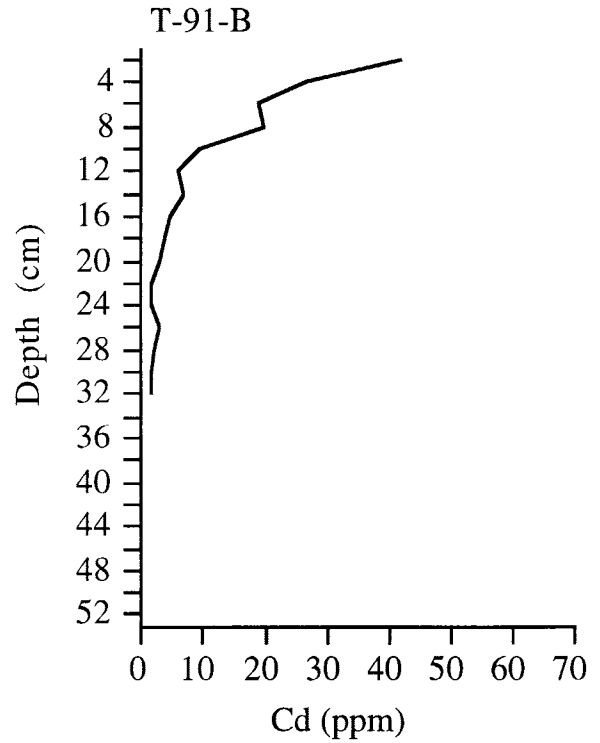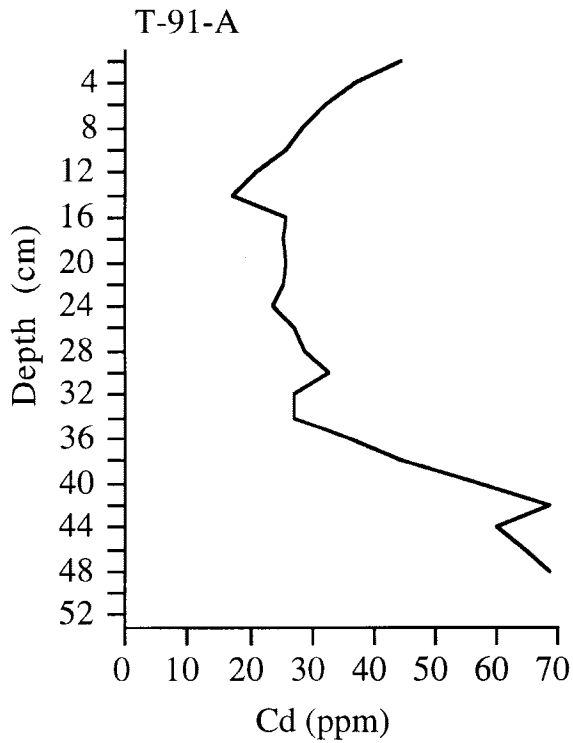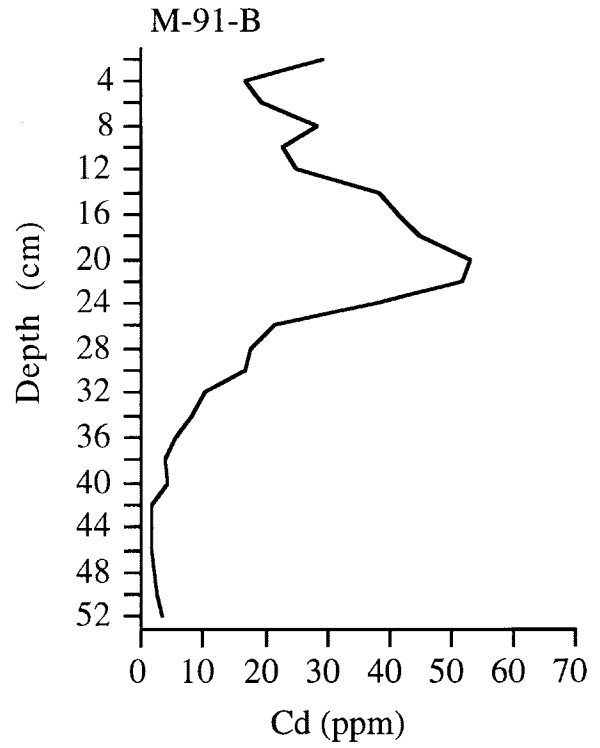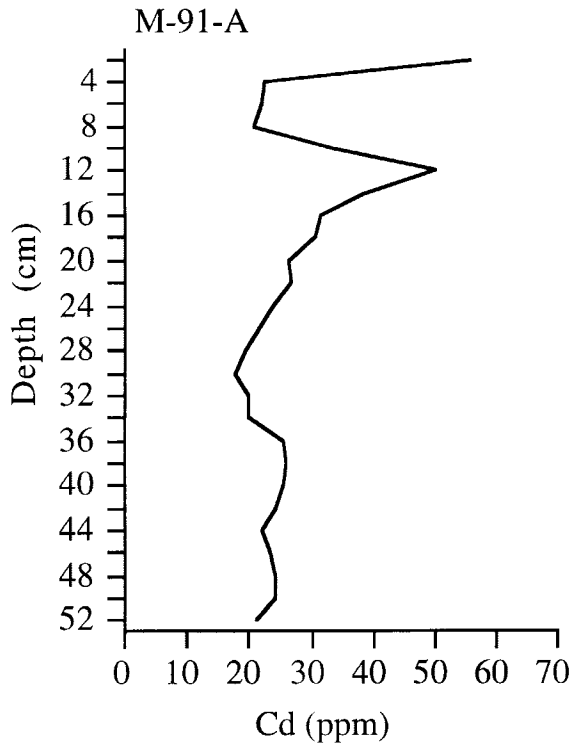Graph 6-2: Silver concentrations from ICP analysis.

Graph 6-3: Arsenic concentrations from ICP analysis.

Cd Concentrations

Graph 6-4 shows the concentration of Cd in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Cd concentrations in sample M-91-A range from 18 to 56 ppm with the maximum concentration of 56 ppm in the upper 2 cm of sediment. The concentrations in sample M-91-B range from 2 to 53 ppm with the maximum concentration of 53 ppm at 20 cm depth. The concentrations in sample T-91-A ranged from 17 to 68 ppm with the maximum concentration of 68 ppm at the 42 cm and 48 cm depths. The concentrations in sample T-91-B range from 1 to 42 ppm with the maximum concentration of 42 ppm in the upper 2 cm of sediment.
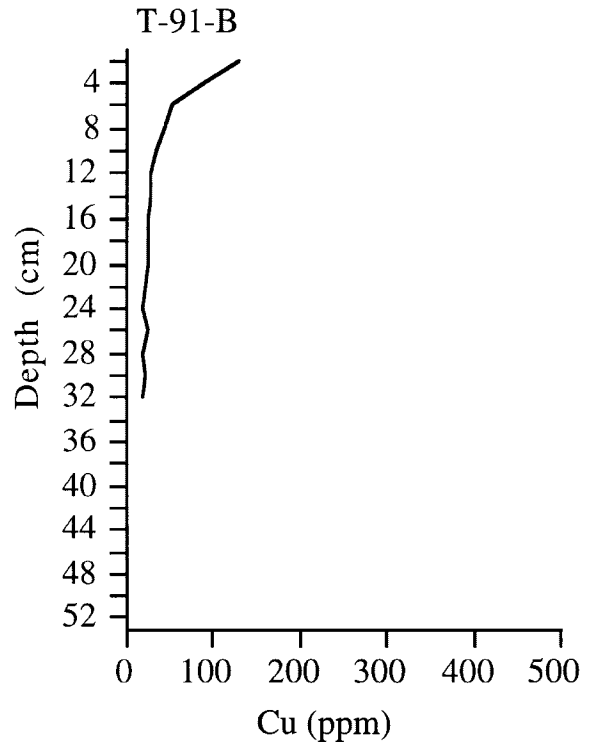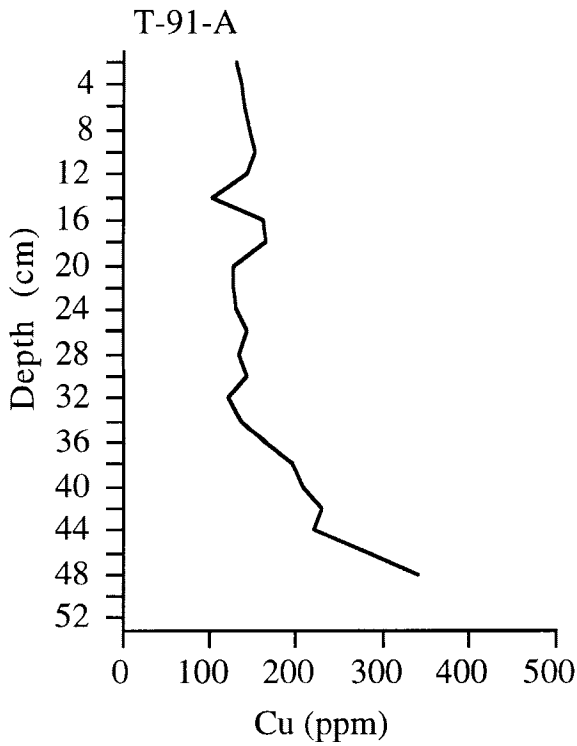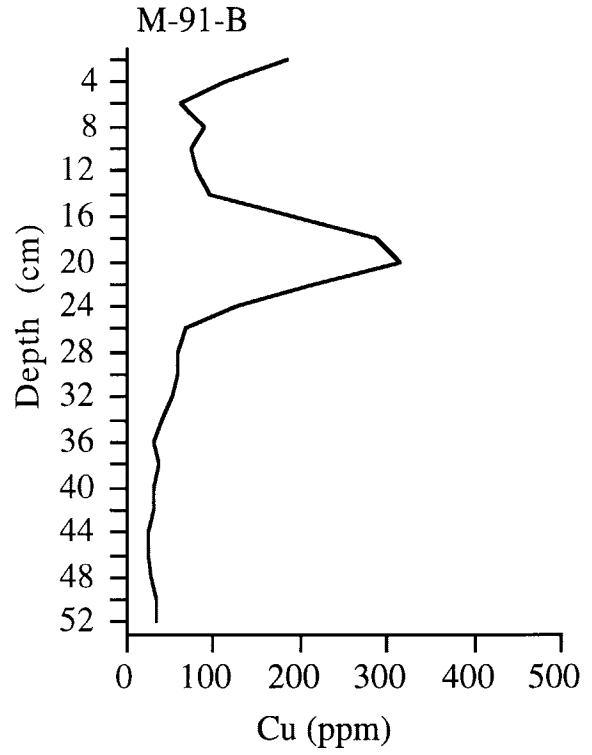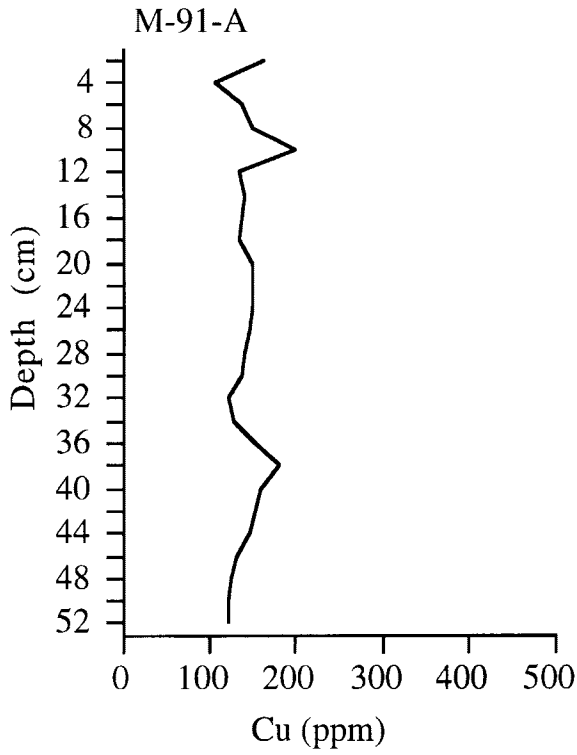
Cu concentrations

Graph 6-5 shows the concentration of Cu in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Cu concentrations in sample M-91-A range from 106 to 199 ppm with the maximum concentration of 199 ppm at 10 cm depth. The concentrations in sample M-91-B range from 25 to 314 ppm with the maximum concentration of 314 ppm at 20 cm depth. The concentrations for sample T-91-A range from 102 to 341 ppm with the maximum concentration of 341 ppm at 48 cm depth. The concentrations in sample T-91-B range from 18 to 130 ppm with the maximum concentration of 130 ppm in the upper 2 cm of sediment.
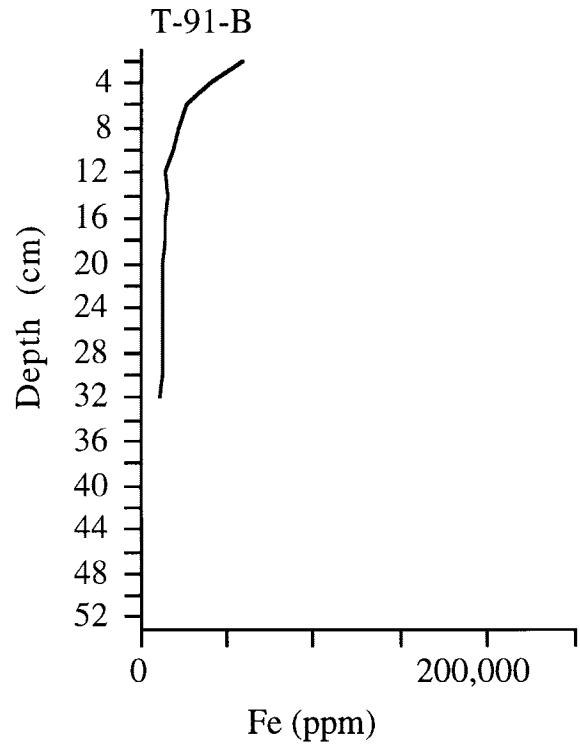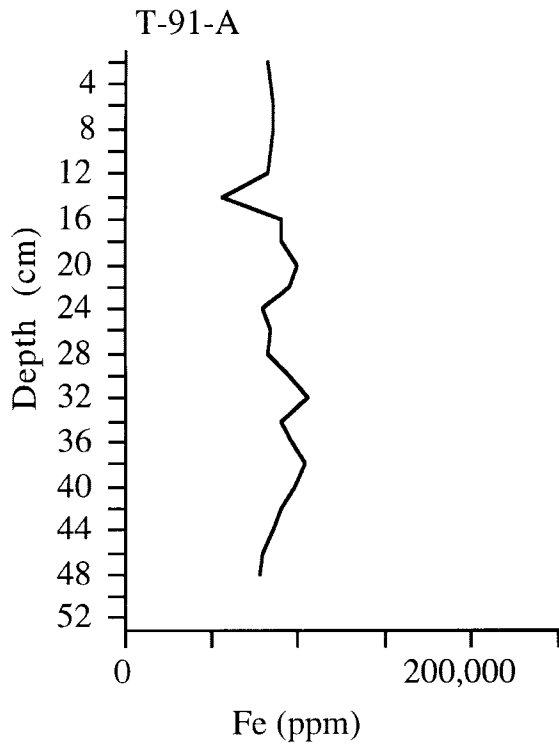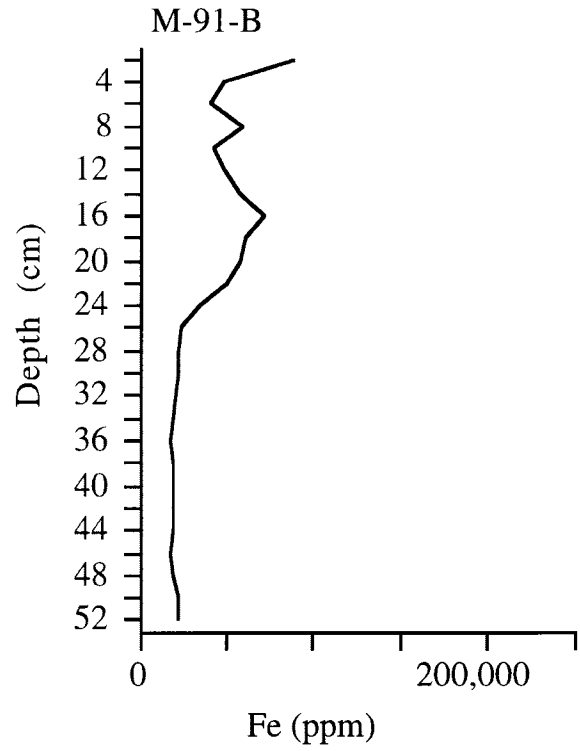
Graph 6-4: Cadmium concentrations from ICP analsis.

Graph 6-5: Copper concentrations from ICP analsis.

Fe Concentrations

Graph 6-6 shows the concentration of Fe in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Fe concentrations in sample M-91-A range from 57,063 to 108,787 ppm with the maximum concentration of 108,787 ppm at 50 cm depth. The concentrations in sample M-91-B range from 17,877 to 88,140 ppm with the maximum concentration of 88,140 ppm in the upper 2 cm of sediment. The concentrations in sample T-91-A range from 56,242 to 105,506 ppm with the maximum concentration of 105,506 ppm at 2 cm depth. The concentrations in sample T-91-B range from 11,680 to 59,112 ppm with the maximum concentration of 59,112 ppm in the upper 2 cm of sediment.

Hg Concentrations

Graph 6-7 shows the concentration of Hg in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Hg concentrations in sample M-91-A range from 0.5 to 1.2 ppm with the maximum concentration of 1.2 ppm at 42 cm depth. The concentrations in sample M-91-B range from 0.2 to 1.8 ppm with the maximum concentration of 1.8 ppm at 20 cm depth. The concentrations in sample T-91-A range from 0.6 to 1.6 ppm with the maximum concentration of 1.6 ppm in the in the 46 cm and 48 cm depth intervals. The concentrations in sample T-91-B range from 0.3 to 0.9 ppm with the maximum concentration of 0.9 ppm in the upper 2 cm of sediment.
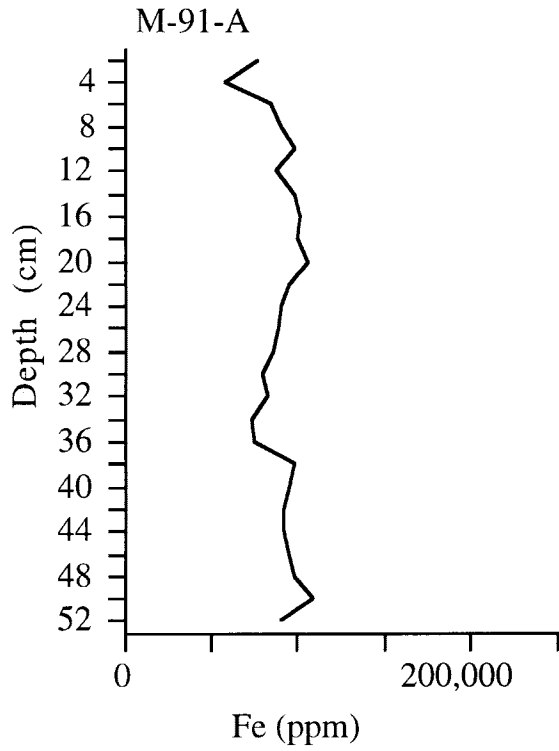
Graph 6-6: Iron concentrations from ICP Analsis.

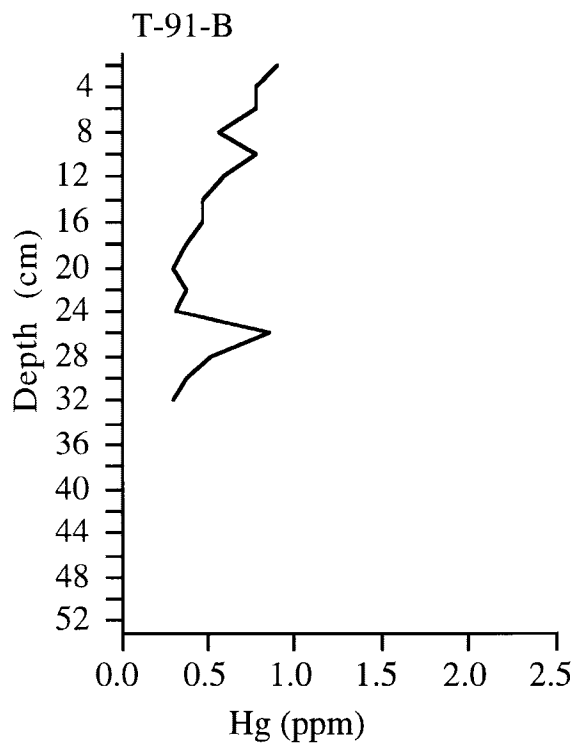Graph 6-7: Mercury concentrations from ICP analysis.
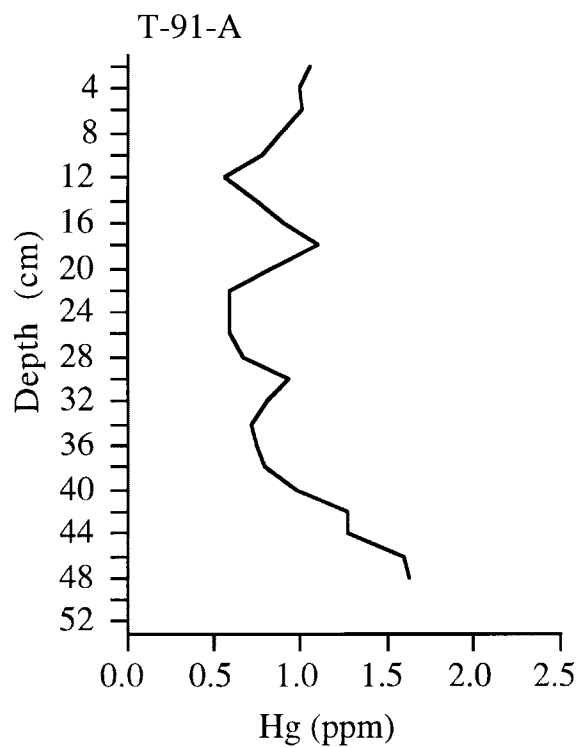
Mn Concentrations

Graph 6-8 shows the concentration of Mn in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Mn concentrations in sample M-91-A range from 4,733 to 10,361 ppm with the maximum concentration of 10,361 ppm at 50 cm depth. The concentrations in sample M-91-B range from 249 to 7,502 ppm with the maximum concentration of 7,502 ppm in the upper 2 cm of sediment. The concentrations in sample T-91-A range from 5,534 to 10,772 ppm with the maximum concentration of 10,772 ppm at 38 cm depth. The concentrations in sample T-91-B range from 359 to 5,317 ppm with the maximum concentration of 5,317 ppm in the upper 2 cm of sediment.
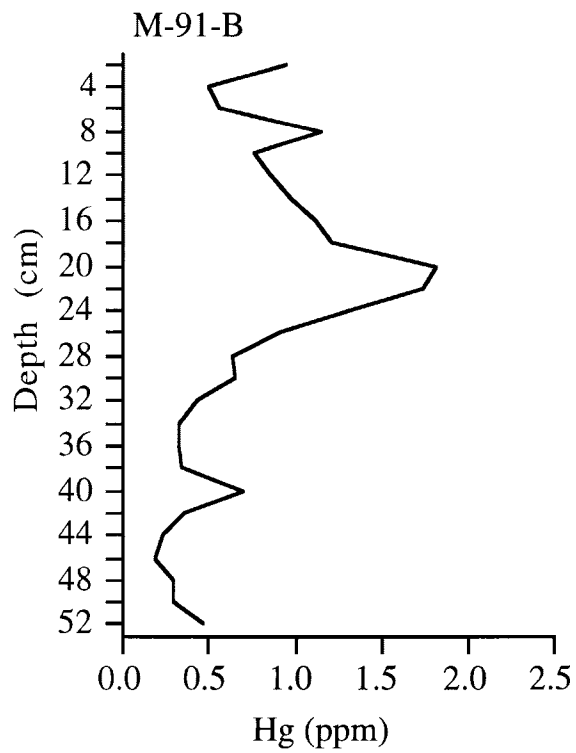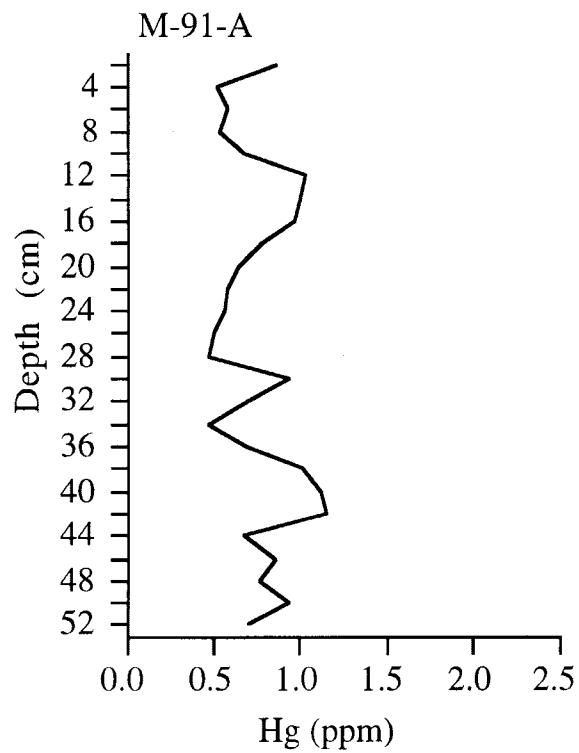
Pb Concentrations

Graph 6-9 shows the concentration of Pb in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Pb concentrations for sample M-91-A range from 2,542 to 10,473 ppm with the maximum concentration of 10,473 ppm at 10 cm depth. The concentrations in sample M-91-B range from 122 to 18,000 ppm with the maximum concentration of 18,000 ppm at 20 cm depth. The concentrations in sample T-91-A range from 2,755 to 17,435 ppm with the maximum concentration of 17,435 ppm in the lower 2 cm. The concentrations in sample T-91-B range from 56 to 6,820 ppm with the maximum concentration of 6,820 ppm in the upper 2 cm of sediment.

Graph 6-8: Manganese concentrations from ICP analysis.

Graph 6-9: Lead concentrations from ICP analysis.

Sb Concentrations

Graph 6-10 shows the concentration of Sb in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Sb concentrations in sample M-91-A range from 14 to 38 ppm with the maximum concentration of 38 ppm at 20 cm and 22 cm depth intervals. The concentrations in sample M-91-B range from 1 to 30 ppm with the maximum concentration of 30 ppm at 24 cm depth. The concentrations in sample T-91-A range from 6 to 48 ppm with the maximum concentration of 48 ppm at 46 cm depth. The concentrations in sample T-91-B range from 1 to 21 ppm with the maximum concentration of 21 ppm in the upper 2 cm of sediment.

Zn Concentrations

Graph 6-11 shows the concentration of Zn in the shallow lake bottom sediments with respect to depth beneath the lake bottom. The Zn concentrations in sample M-91-A range from 2,214 to 5,609 ppm with the maximum concentration of 5,609 ppm at 10 cm depth. The concentrations in sample M-91-B range from 140 to 7,850 ppm with the maximum concentration of 7,850 ppm at 20 cm depth. The concentrations in sample T-91-A range from 2,459 to 11,250 ppm with the maximum concentration of 11,250 ppm at 42 cm depth. The concentrations in sample T-91-B range from 77 to 5,839 ppm with the maximum concentration of 5,839 ppm in the upper 2 cm of sediment.
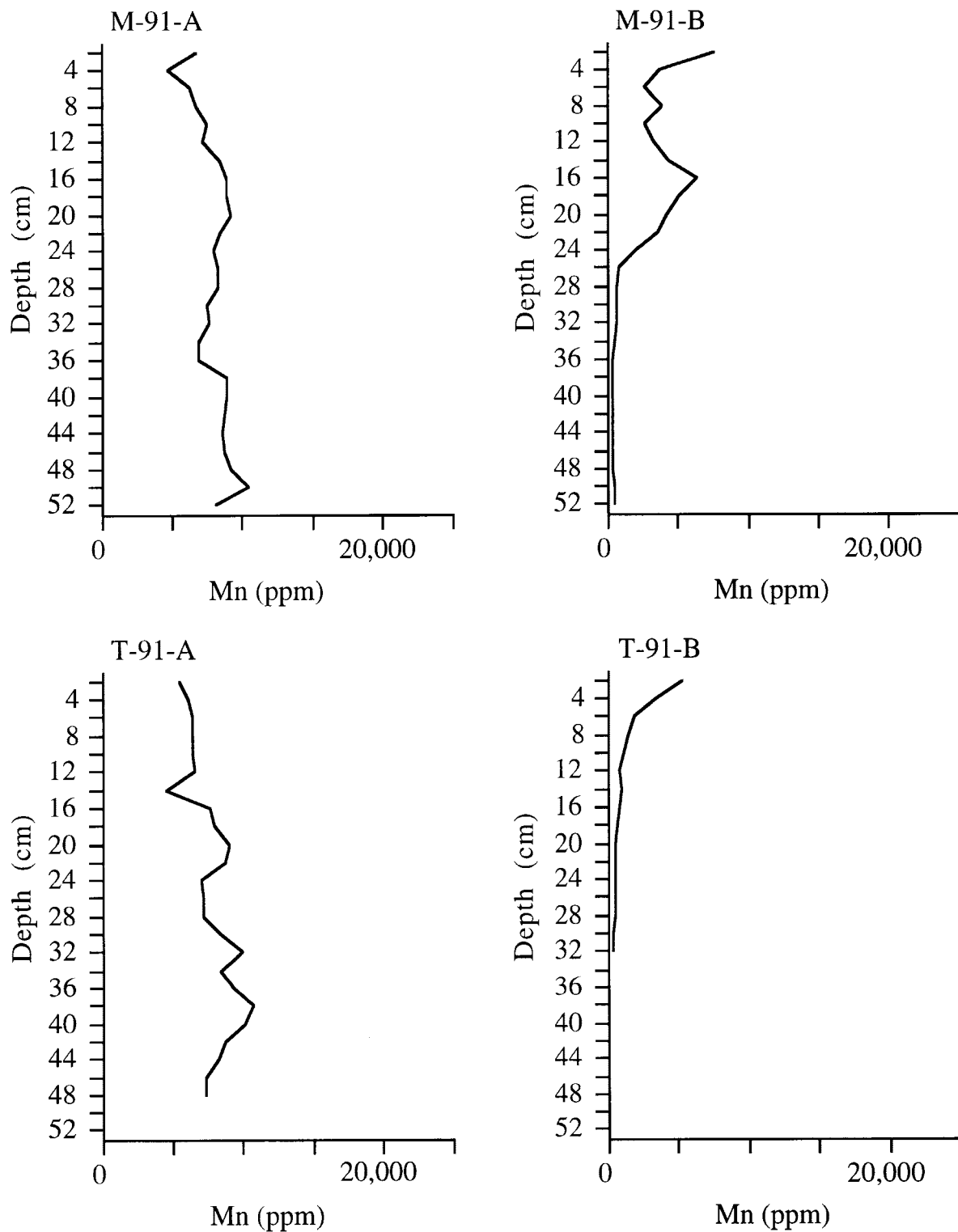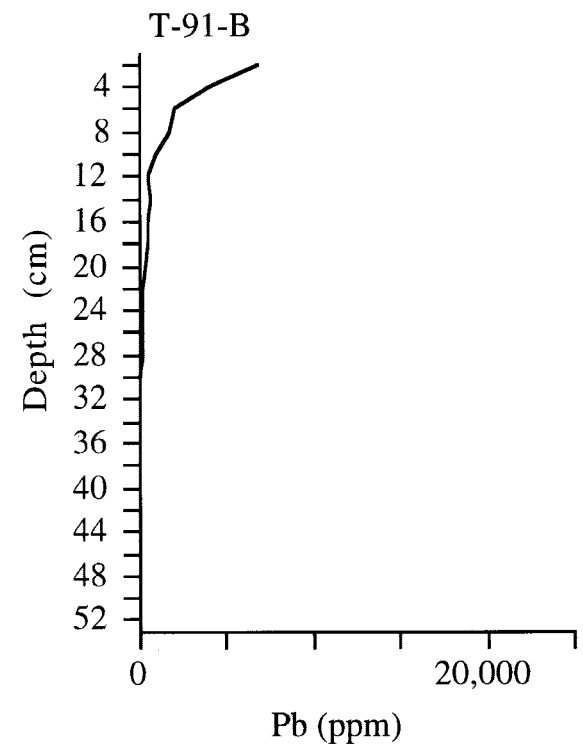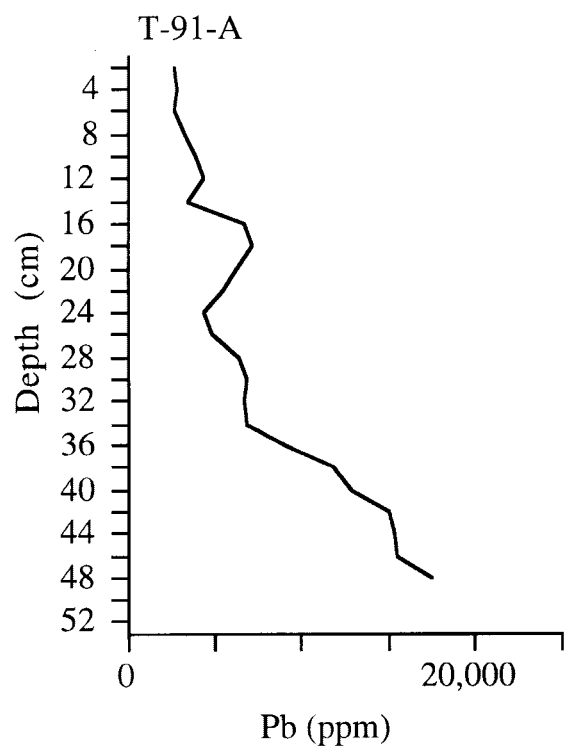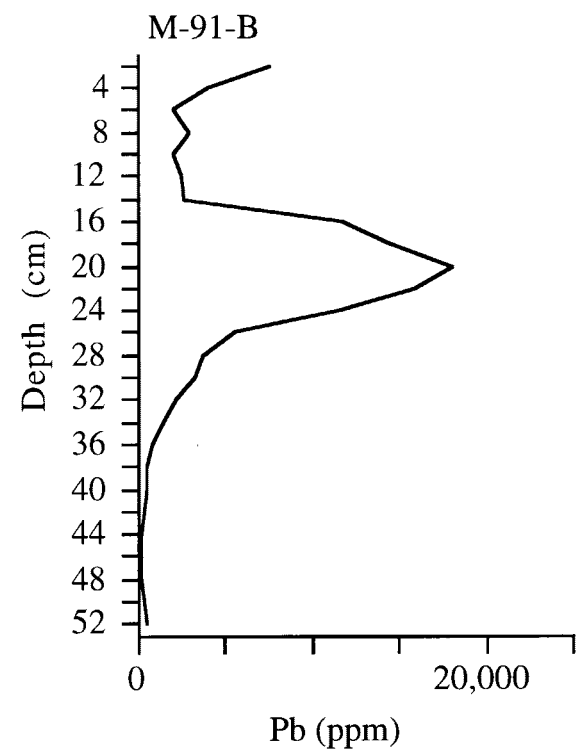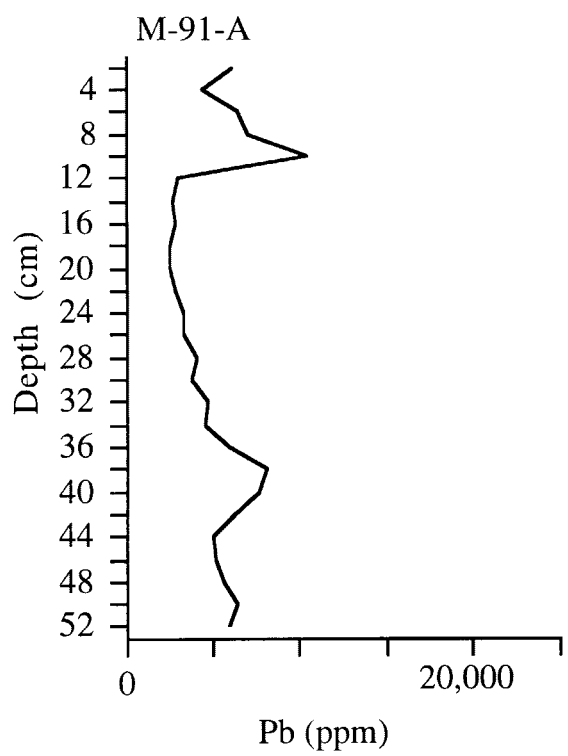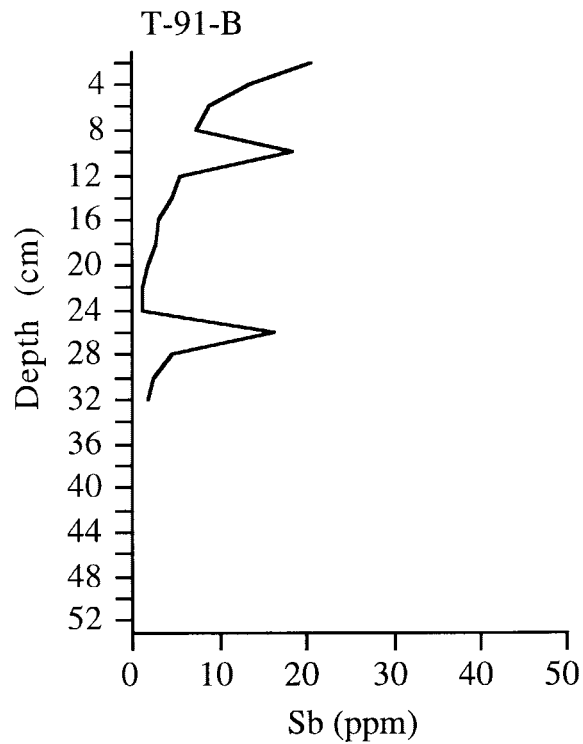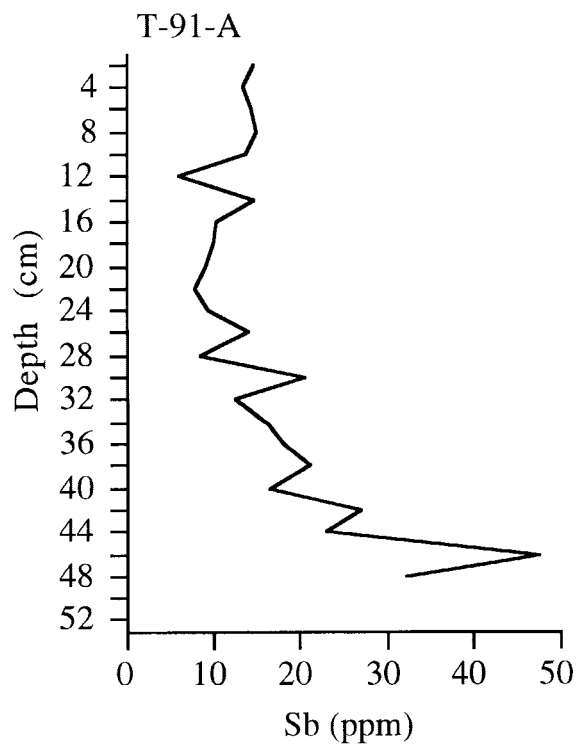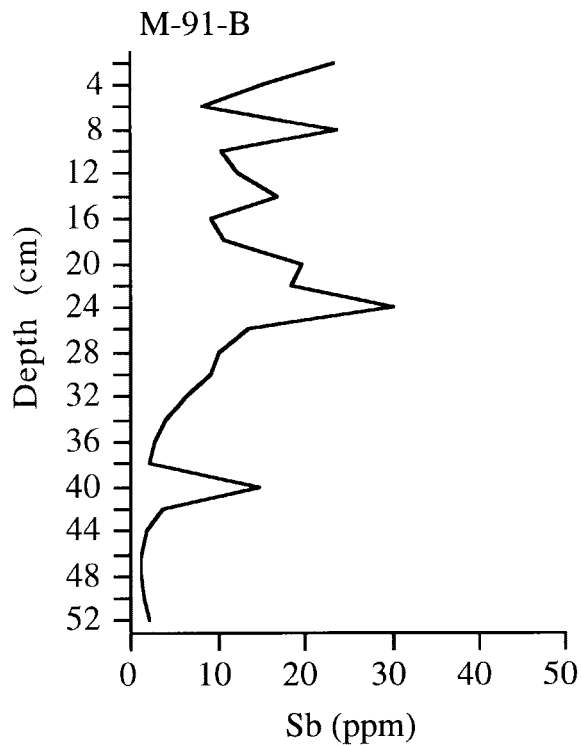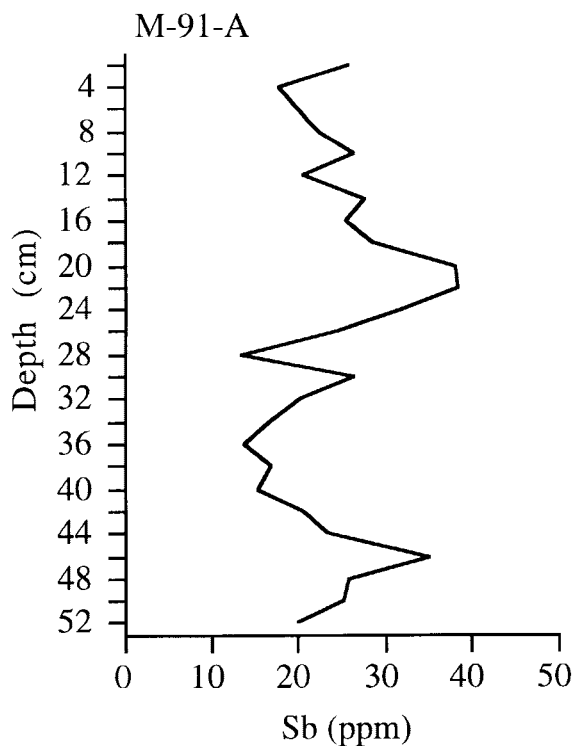
Graph 6-10: Antimony concentrations from ICP analysis.
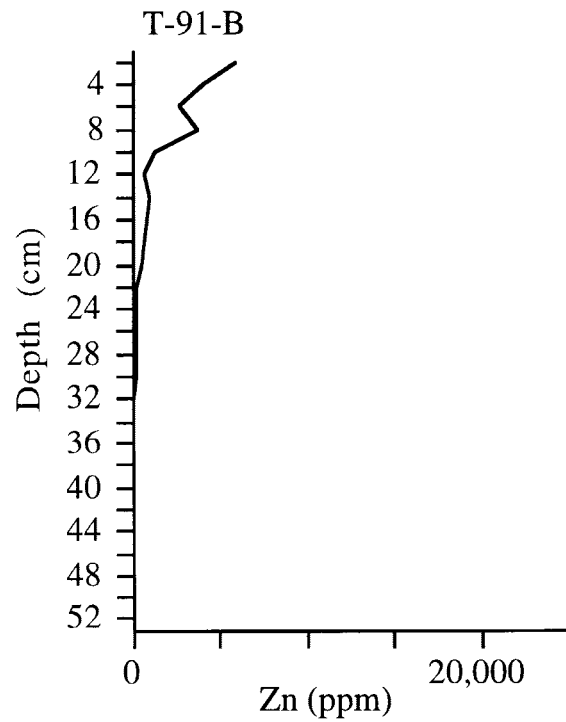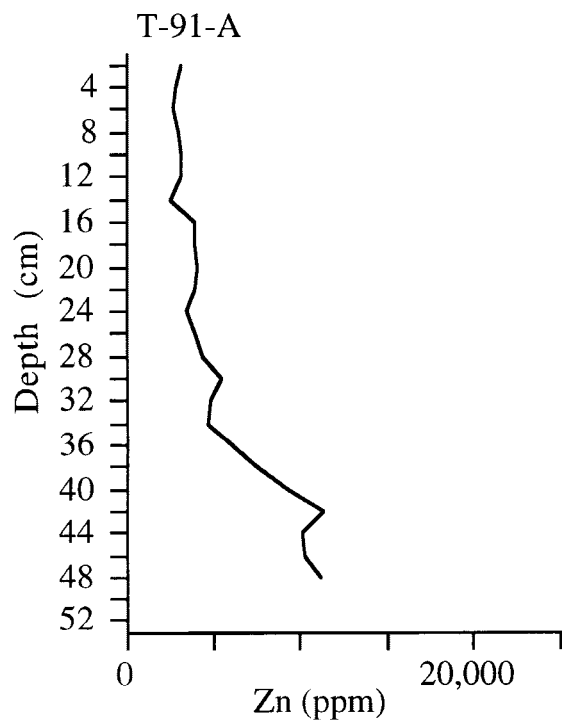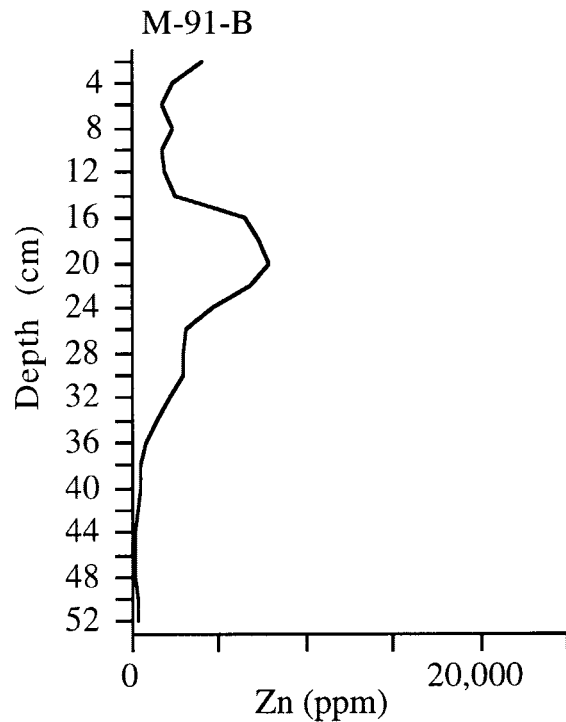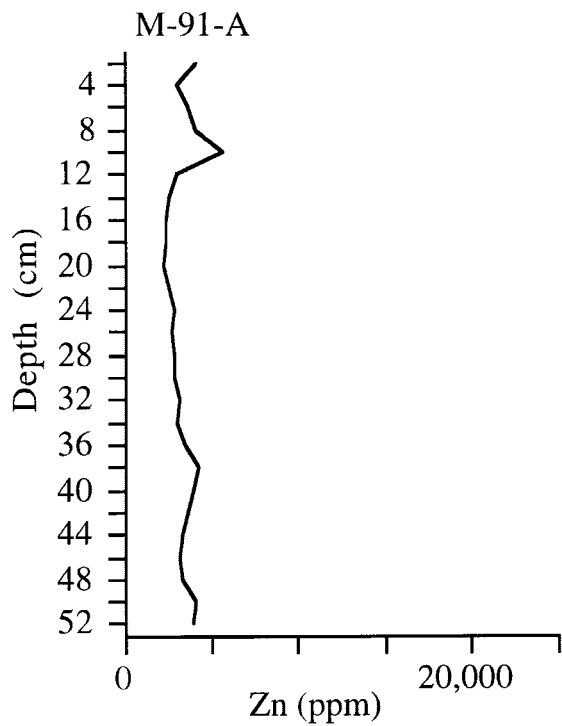
Graph 6-11: Zinc concentrations from ICP analysis.

The previous graphs show that sedimentation rates at each of the sample locations has been variable through time. The highest concentrations of heavy metals, probably having occurred in the early 1930's, is not seen at the same depth intervals. However, the general profile (best seen in the graphs of sample M-91-A) appears to be similar to that recorded by Bender (1991) and Horowitz and others (1995).

Particle Size Distribution and Analyses

Graph 6-12 shows the distribution of each particle size fraction (Table 4-1) in sample M-91-A. Here we see that the medium to coarse silt fractions make up 60-80% of the sediment in the sample. However, after ICP analysis of each size fraction, it is seen in graph 6-13 that the highest Cd values are found in the fine clay fraction which account for only 1-3% of the samples by weight.
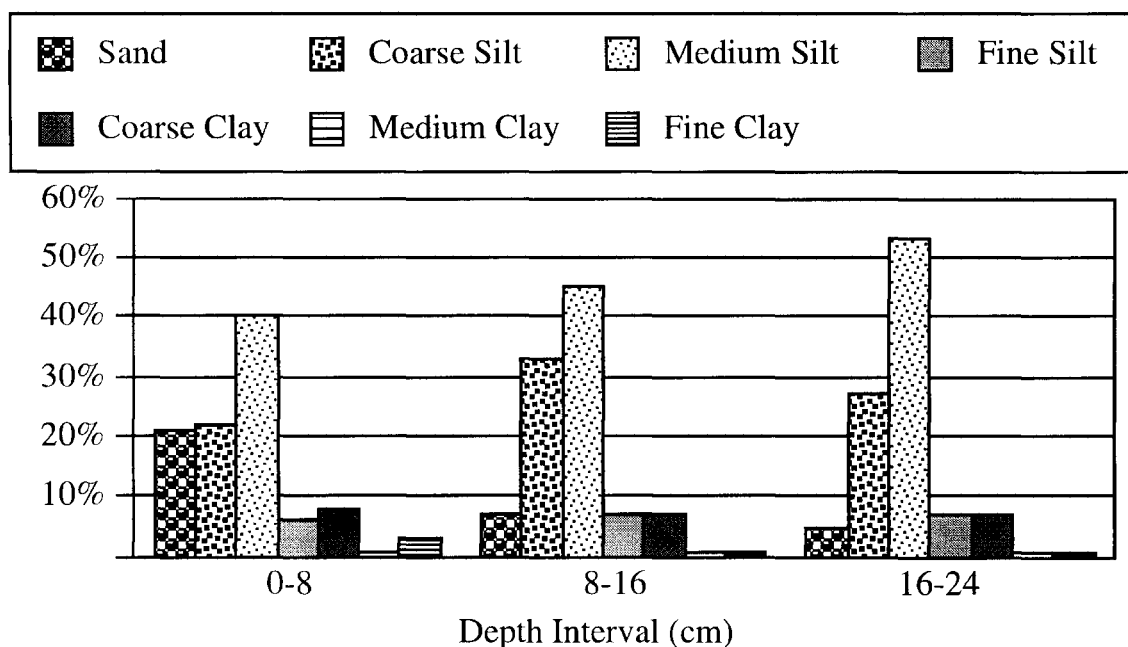
Graph 6-12: Particle size distribution by weight of sample M-91-A.
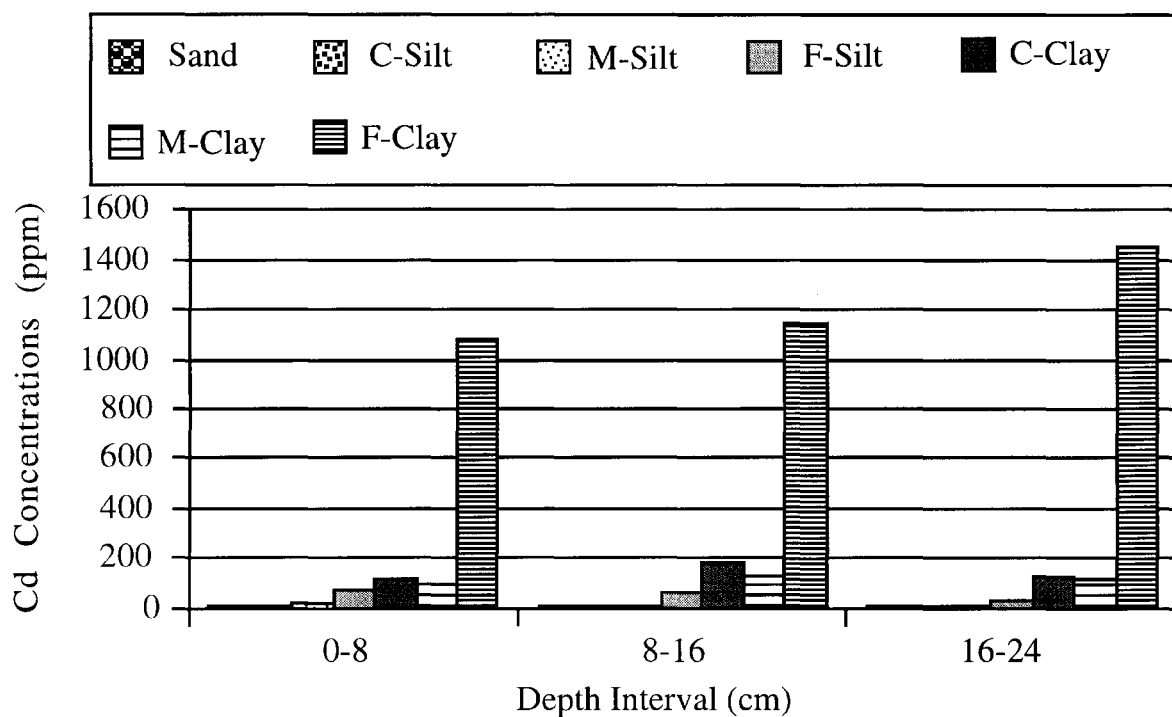
Graph 6-13: Cadmium concentrations of individual size fractions of sample M-91-A.

By multiplying the Cd values by the weight percent of each size fraction (Appendix B), Graph 6-14 shows the weighted concentrations of Cd. It is seen that the majority of the Cd contamination is localized to the fine and coarse clay size fractions of the samples.
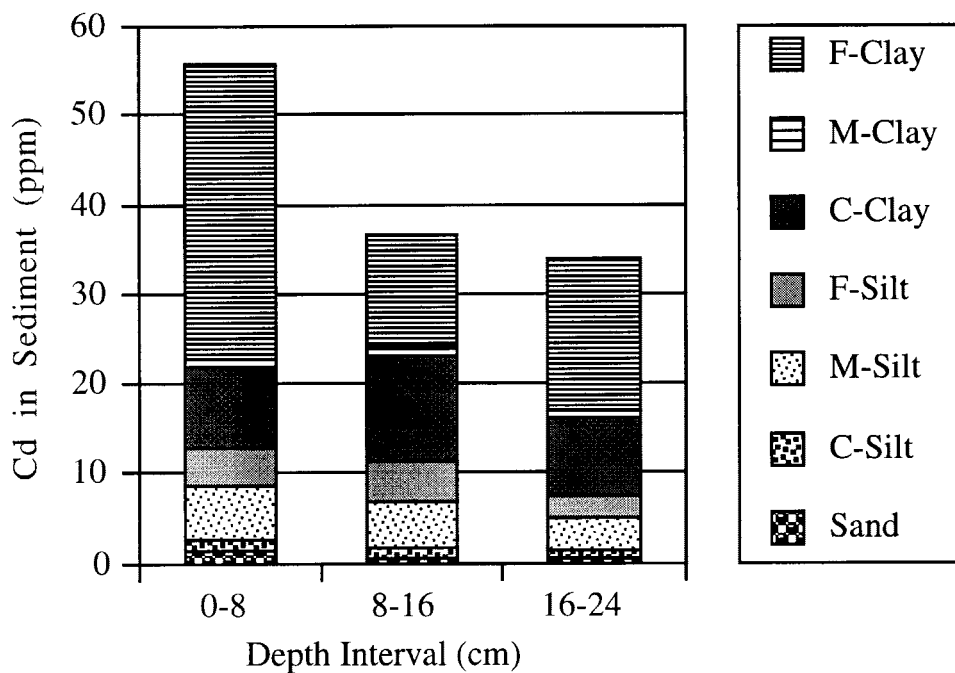
Graph 6-14: Weighted Cadmium concentrations for sample M-91-A.

Accordingly, graph 6-15 shows that the highest Cu values are found in the medium and fine clay fractions which only accounts for 2-4% of the samples by weight. Upon weighting the Cu values, graph 6-16 shows that the majority of the Cu contamination is also localized in the fine and coarse clay fractions of the samples.
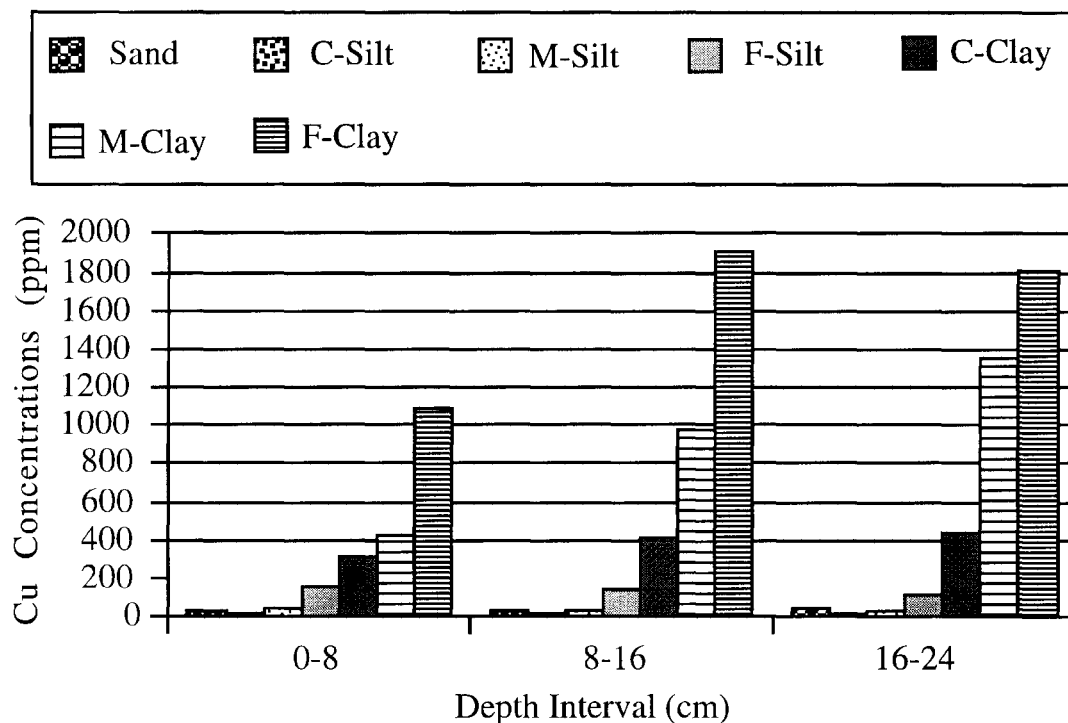
Graph 6-15:   Copper concentrations of individual size fractions of sample M-91-A.
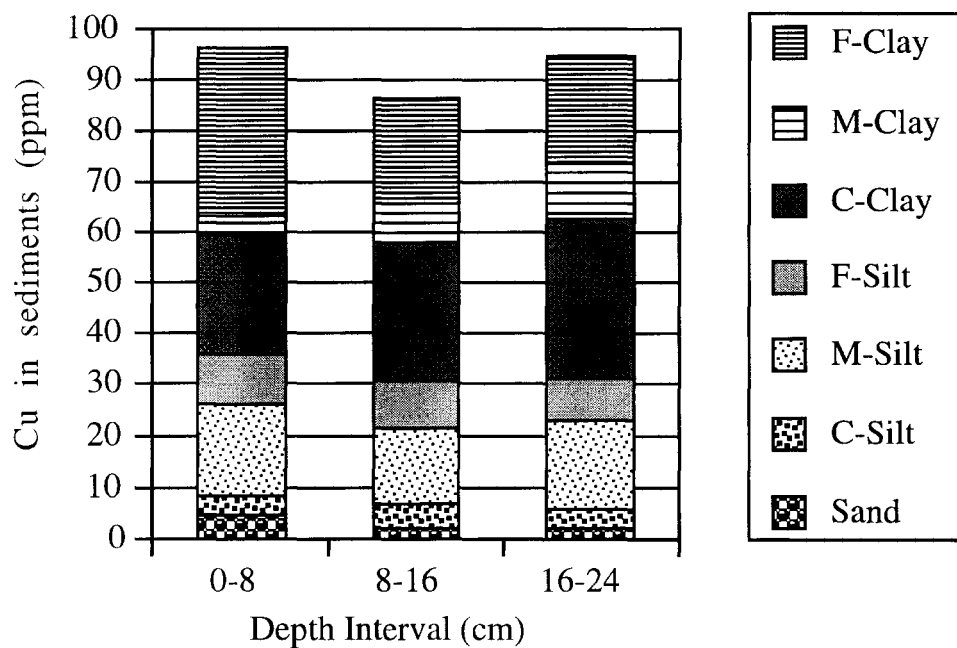
Graph 6-16:   Weighted Copper concentrations for sample M-91-A.

Graph 6-17 shows that the highest Pb values are found in the clay fractions which only account for 9-11% of the samples by weight. Upon weighting the Pb values, graph 6-18 shows that the majority of the Pb contamination is localized in the coarse clay and medium silt size fraction of the sample.
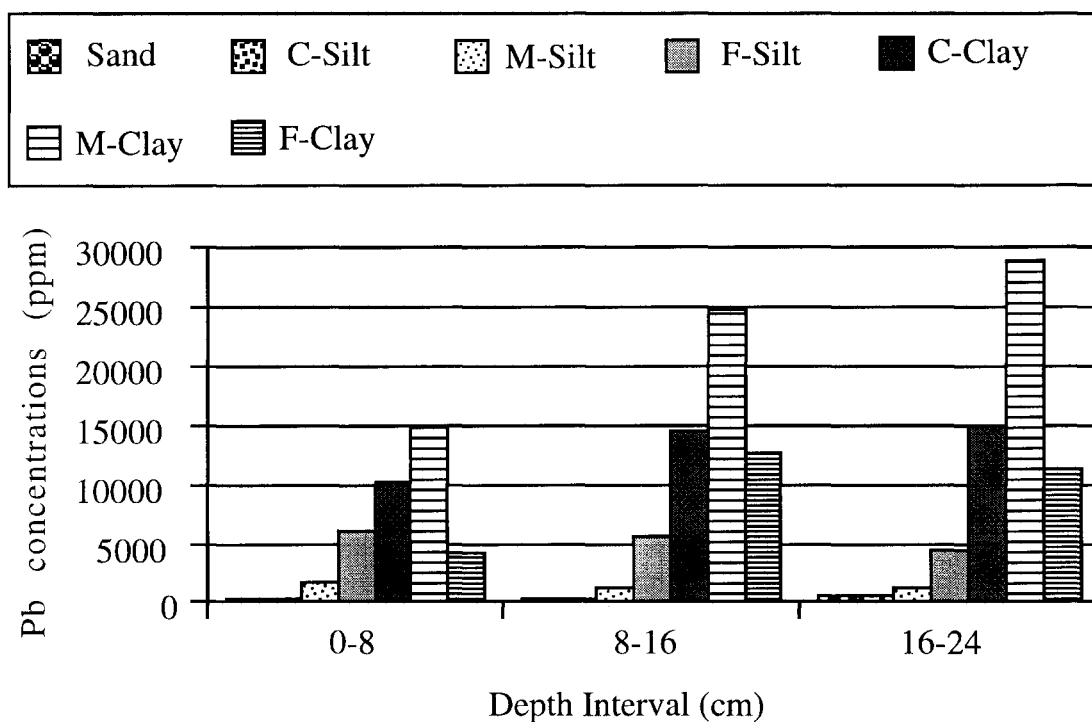
Graph 6-17: Lead concentrations of individual size fractions of sample M-91-A.
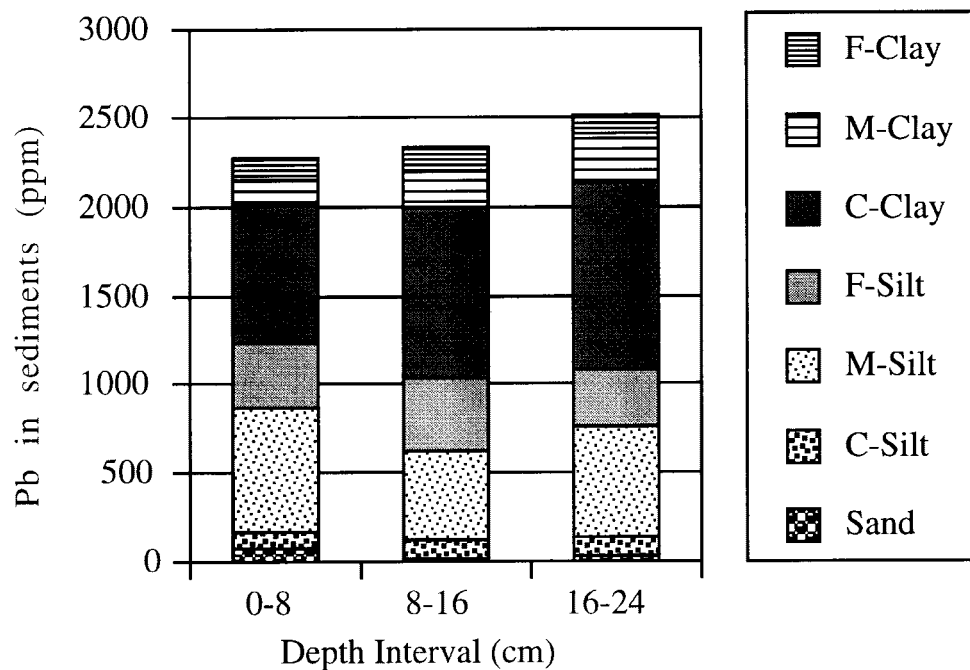
Graph 6-18: Weighted Lead concentrations for sample M-91-A.

Graph 6-19 shows that the highest Zn values are found in the fine clay fraction which only accounts for 1-3% of the samples by weight. Upon weighting the Zn values, graph 6-20 shows that the majority of the Zn contamination is localized in the medium silt and coarse clay as well as the fine clay fractions of the samples.
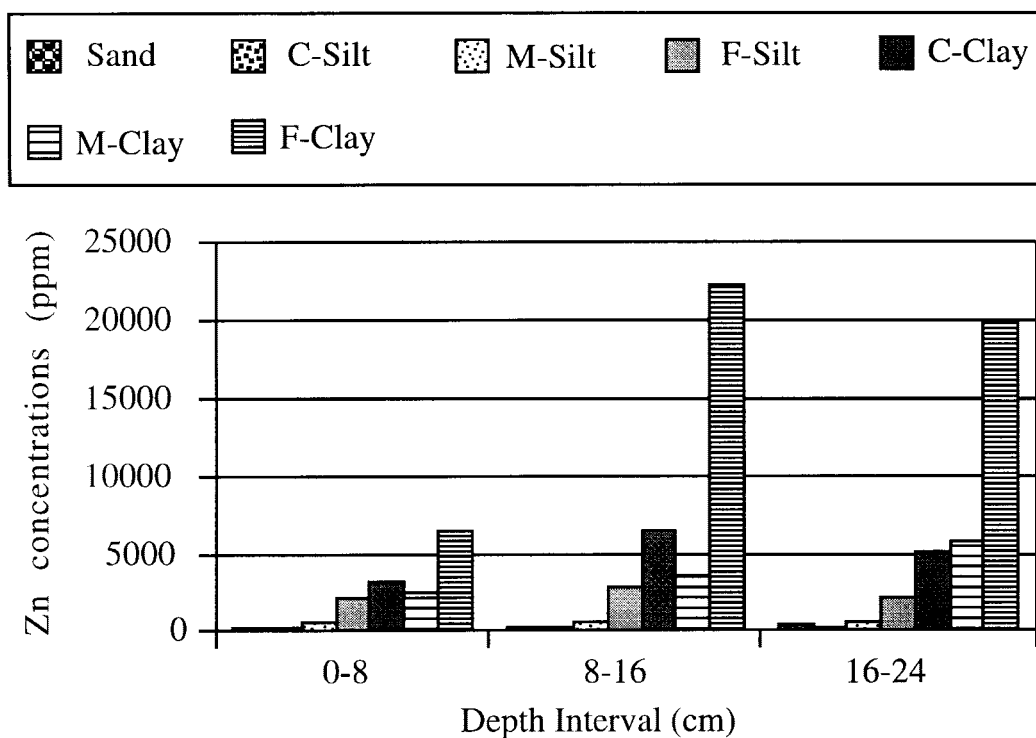
Graph 6-19: Zinc concentrations of individual size fractions of sample M-91-A.
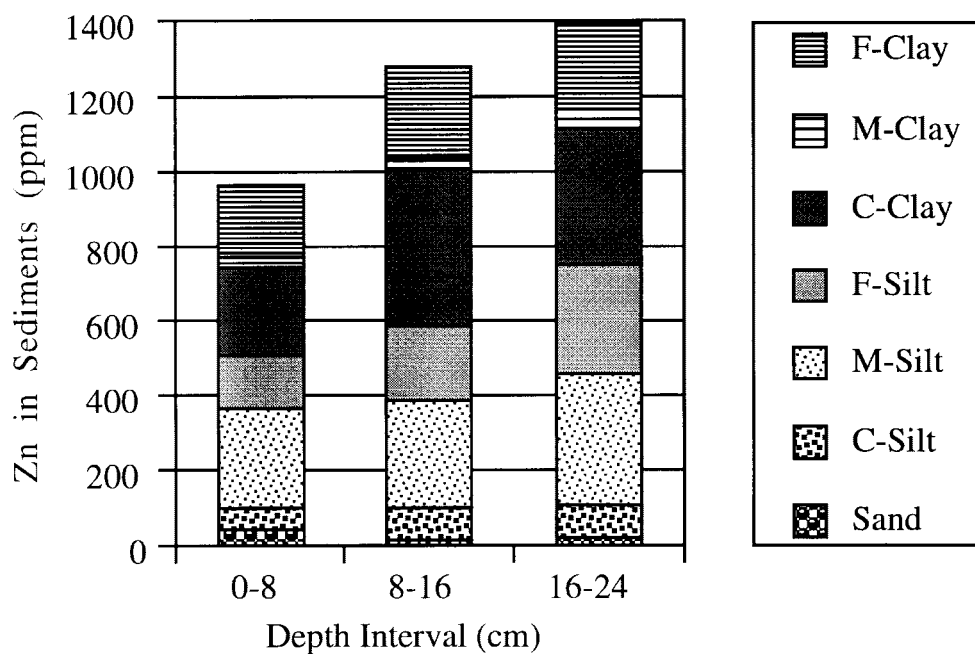
Graph 6-20: Weighted Zinc concentrations for sample M-91-A.

These graphs show that the grain size distribution is not homogeneous. The coarser fractions (sand, coarse silt and medium silt) are more abundant in the upper parts of the sample. The finer fractions (fine silt and clays) are more abundant in the deeper part of the sample. Therefore, presently, less fine material and more coarse material are being incorporated into the system.

The fractions containing the highest Cd, Cu, Pb and Zn concentrations (fine and coarse clay) are the least abundant in the samples (0.8-3%). Accordingly the most abundant size fraction (medium silt) have some of the lowest heavy metal concentrations.

CHAPTER VII

CONCLUSIONS

The sediments of Medicine and Thompson Lakes, two of eleven lateral lakes of the Coeur d'Alene River system, contain inflated heavy metal concentrations. These sediments can be interpreted to be an accurate account of local mining activity in the Coeur d'Alene mining district. Recurrent flooding events in the valley continually rework upstream contaminated sediment which is then deposited in the lateral lakes and along the banks of the Coeur d'Alene River. Sedimentation rates between and within each of the lakes studied has been variable through time. This is interpreted from the graphs of the previous chapter.

Using ^{137}Cs concentrations in the bottom sediments of Medicine Lake, it was found that mine tailings were deposited at the rate of 1.1 cm/yr prior to the 1968 installation of tailings dams in the mining district. Since the installation of the tailings dams, deposition of tailings in Medicine Lake have been greatly reduced.

Floatation recovery methods, implemented in the early 1930's, have been the main factor in the contamination of the lateral lakes. This is due to the fact that floatation recovery requires the ore to be crushed to very fine silt and clay sized particles. It is also seen that this very fine sediment contains the highest concentrations of heavy metals. This fine grained sediment is easily put into suspension and remains in suspension for a longer period of time. Given the mild turbidity of the Coeur d'Alene River, the sediment would tend to remain in the

suspended load until the water became much calmer. These locations of less energy would correspond to such objects as the flood-plain of the Coeur d'Alene River, the lateral lakes and Lake Coeur d'Alene itself.

By the late 1960's, settling ponds were being used extensively through out the mining district. These ponds have reduced the sedimentation rates in the lakes by nearly 50%. Thus, they have reduced the amount fine grained particles in the system and allowed the lakes to "rebound" from their extremely poor condition of just a few years ago. Organic sediment and coarser sand sized grains can once again be seen in the most recent sediment in the lakes. This is in contrast to the lesser abundance of organic material within the contaminated zone.

Some remediation options for the river valley have been implemented and others are currently under consideration. The physical removal of the point sources, mainly the historic tailings piles, would be the best option. However, this would incur extremely high costs to all, and probably not be time effective. Isolation of the piles is currently the most noted means of removing the sources from the system. This could be accomplished by capping the tailings piles with clean soil and revegitating the area.

With respect to the river, removal of the tailings would not be a logical option, since it would require the removal of virtually the entire flood plain. More cost and time effective options are now being used to one degree or another. Currently, reshaping the bank slope, covering the plain with clean soil and revegitaion, together with slope stabilization, is helping to dissipate water run-off energy and thus reduce the erosion of the sediments along the river channel. Also,

construction of additional settling pond and sediment traps along the river is under consideration.

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Appendix A

All values in ppm

ICP Analysis results for sample M-91-A.

Depth	Ag	As	Cd	Cu	Fe	Hg	Mn	Pb	Sb	Zn
2	18	99	56	162	76,101	0.85	6,625	6,003	26	3,997
4	13	79	22	106	57,063	0.52	4,733	4,306	18	2,920
6	18	116	22	138	83,168	0.57	6,252	6,313	20	3,559
8	21	100	21	149	90,377	0.54	6,650	7,020	22	4,000
10	24	81	33	199	97,119	0.67	7,487	10,473	26	5,609
12	14	336	50	133	87,085	1.03	7,126	3,055	21	3,018
14	14	408	38	141	97,208	0.99	8,364	2,710	27	2,503
16	14	383	32	136	101,107	0.97	8,784	2,798	25	2,344
18	15	343	31	133	99,985	0.77	8,818	2,582	29	2,378
20	16	348	26	148	105,346	0.63	9,136	2,545	38	2,214
22	16	319	27	149	94,955	0.58	8,466	2,846	38	2,462
24	15	427	24	149	89,587	0.55	7,994	3,339	32	2,847
26	15	368	22	146	89,297	0.49	8,290	3,374	25	2,614
28	12	208	19	139	85,892	0.47	8,272	4,027	13	2,781
30	11	192	18	138	78,829	0.94	7,527	3,786	26	2,833
32	13	162	20	121	82,536	0.71	7,622	4,754	20	3,173
34	12	155	20	128	73,788	0.47	6,810	4,591	16	3,013
36	14	145	25	152	75,226	0.68	6,854	5,858	14	3,510
38	20	133	26	179	97,073	1.01	8,837	8,053	17	4,199
40	20	103	26	158	94,678	1.11	8,863	7,577	15	3,930
42	16	96	24	153	92,365	1.15	8,704	6,199	20	3,600
44	14	106	22	146	91,364	0.68	8,557	5,046	23	3,345
46	15	111	23	132	93,991	0.85	8,653	5,138	35	3,142
48	16	148	24	125	97,230	0.76	9,176	5,602	26	3,253
50	20	171	24	123	108,787	0.93	10,361	6,407	25	4,017
52	17	154	21	122	90,755	0.71	8,126	5,897	20	3,936

ICP analysis results for sample M-91-B.

Depth	Ag	As	Cd	Cu	Fe	Hg	Mn	Pb	Sb	Zn
2	22	110	29	186	88,140	0.94	7,502	7,582	23	4,022
4	11	80	17	113	48,443	0.49	3,737	4,097	15	2,398
6	6	111	19	62	40,792	0.56	2,613	2,067	8	1,709
8	10	136	28	90	58,712	1.15	3,791	2,932	24	2,319
10	7	93	23	73	42,342	0.75	2,704	2,059	10	1,632
12	8	112	25	81	47,881	0.85	3,206	2,487	12	1,915
14	10	193	38	96	57,986	0.97	4,262	2,689	17	2,414
16	29	57	41	191	71,851	1.11	6,355	11,655	9	6,476
18	40	53	45	288	61,087	1.20	5,167	14,357	11	7,327
20	49	45	53	314	57,833	1.82	4,177	18,000	20	7,850
22	44	39	52	217	50,434	1.73	3,523	15,881	19	6,797
24	26	30	38	126	35,254	1.32	2,017	11,641	30	4,646
26	14	23	21	68	24,471	0.92	831	5,494	14	3,126
28	11	23	18	59	22,015	0.64	663	3,706	10	2,964
30	8	24	17	57	22,058	0.66	663	3,323	9	2,931
32	7	34	10	51	21,310	0.43	650	2,157	6	2,201
34	4	39	8	40	19,755	0.33	533	1,366	4	1,375
36	2	36	6	30	17,877	0.32	333	826	3	851
38	2	28	4	36	19,088	0.34	359	518	2	496
40	2	30	4	31	19,805	0.69	337	442	15	458
42	1	23	2	31	18,764	0.35	312	287	4	279
44	1	17	2	26	18,431	0.23	270	216	2	208
46	1	16	2	25	17,947	0.19	262	134	1	156
48	1	17	2	28	18,844	0.30	249	122	1	140
50	1	20	2	35	21,836	0.29	460	338	1	288
52	2	25	3	34	22,839	0.46	518	488	2	339

ICP analysis results for sample T-91-A.

Depth	Ag	As	Cd	Cu	Fe	Hg	Mn	Pb	Sb	Zn
2	12	315	44	130	82,340	1.05	5,534	2,755	15	3,107
4	14	303	37	137	84,382	0.99	6,146	2,875	13	2,860
6	14	286	32	140	84,745	1.01	6,312	2,745	14	2,660
8	14	274	28	147	84,827	0.89	6,338	3,255	15	3,050
10	15	239	26	153	84,482	0.78	6,407	3,939	14	3,208
12	13	158	21	144	81,894	0.56	6,616	4,404	6	3,209
14	9	98	17	102	56,242	0.74	4,569	3,520	15	2,459
16	18	108	26	160	89,782	0.90	7,677	6,628	10	3,865
18	18	96	25	164	89,451	1.09	7,950	7,146	10	3,963
20	17	147	26	127	99,943	0.83	8,999	6,276	9	4,020
22	18	151	26	127	95,382	0.58	8,652	5,421	8	3,883
24	14	106	24	130	79,249	0.60	6,934	4,405	9	3,397
26	15	101	27	144	83,410	0.59	7,227	4,903	14	3,926
28	18	114	29	135	82,508	0.67	7,183	6,440	8	4,339
30	19	186	33	143	95,225	0.93	8,337	6,925	20	5,450
32	18	131	27	120	105,506	0.81	9,959	6,702	12	4,791
34	18	84	27	138	89,952	0.72	8,363	6,890	16	4,644
36	21	80	36	166	96,779	0.74	9,343	9,025	18	6,051
38	23	96	44	196	104,228	0.79	10,772	11,756	21	7,505
40	29	82	57	207	98,438	0.98	10,043	12,938	17	9,339
42	32	61	68	229	90,825	1.27	8,774	15,069	27	11,250
44	36	58	60	221	85,460	1.27	8,184	15,316	23	10,023
46	39	59	64	286	79,924	1.59	7,321	15,458	48	10,263
48	45	64	68	341	77,996	1.62	7,240	17,435	32	11,163

ICP analysis results for sample T-91-B.

Depth	Ag	As	Cd	Cu	Fe	Hg	Mn	Pb	Sb	Zn
2	16	95	42	130	59,112	0.90	5,317	6,820	21	5,839
4	11	71	26	91	41,251	0.78	3,396	4,075	13	4,025
6	6	59	19	51	26,734	0.77	1,875	1,965	9	2,688
8	4	92	20	44	21,554	0.56	1,386	1,703	7	3,692
10	3	42	10	35	18,860	0.77	1,144	929	18	1,221
12	2	28	6	27	15,157	0.60	814	508	5	706
14	2	36	7	29	16,196	0.47	917	636	5	929
16	1	36	5	25	14,365	0.46	719	448	3	759
18	1	37	4	26	14,327	0.37	654	412	3	682
20	1	30	3	24	13,552	0.30	538	271	2	515
22	1	25	2	22	13,267	0.37	503	157	1	207
24	1	18	2	19	12,880	0.32	426	89	1	109
26	1	24	3	26	13,495	0.86	491	181	16	195
28	1	20	2	20	12,163	0.52	452	155	5	168
30	1	19	1	21	12,565	0.38	402	71	3	102
32	1	15	2	18	11,680	0.30	359	56	2	77

Depth	Sample Weight	Sand	Course Silt	Medium Silt	Fine Silt	Coarse Clay	Medium Clay	Fine Clay	Sum	Recovery
			Particle Size Recovery for For Sample M-91-A							
0-8 cm	6.28	1.298	1.377	2.516	0.384	0.474	0.058	0.190	6.30	100%
8-16 cm	10.01	0.728	3.284	4.505	0.723	0.654	0.081	0.109	10.08	101%
16-24 cm	10.01	0.524	2.727	5.270	0.720	0.704	0.084	0.117	10.15	101%

Depth	Particle Size Distribution (Weight Percent)						
0-8 cm	21%	22%	40%	6%	8%	1%	3%
8-16 cm	7%	33%	45%	7%	7%	1%	1%
16-24 cm	5%	27%	53%	7%	7%	1%	1%

Depth	Cd Concentrations (ppm)						
0-8 cm	7	5	15	71	120	96	1084
8-16 cm	6	4	11	64	181	130	1146
16-24 cm	11	3	7	33	122	120	1449

Depth	Cu Concentrations (ppm)						
0-8 cm	22	17	45	155	316	423	1084
8-16 cm	29	14	32	135	415	974	1910
16-24 cm	36	14	33	118	442	1349	1811

Depth	Pb Concentrations (ppm)						
0-8 cm	407	395	1726	6053	10240	14904	4119
8-16 cm	315	329	1117	5658	14532	24922	12605
16-24 cm	562	425	1175	4520	14908	29060	11227

Depth	Zn Concentrations (ppm)						
0-8 cm	231	256	662	2221	3199	2442	6504
8-16 cm	255	260	628	2767	6461	3584	22154
16-24 cm	482	305	666	2135	5133	5831	19919