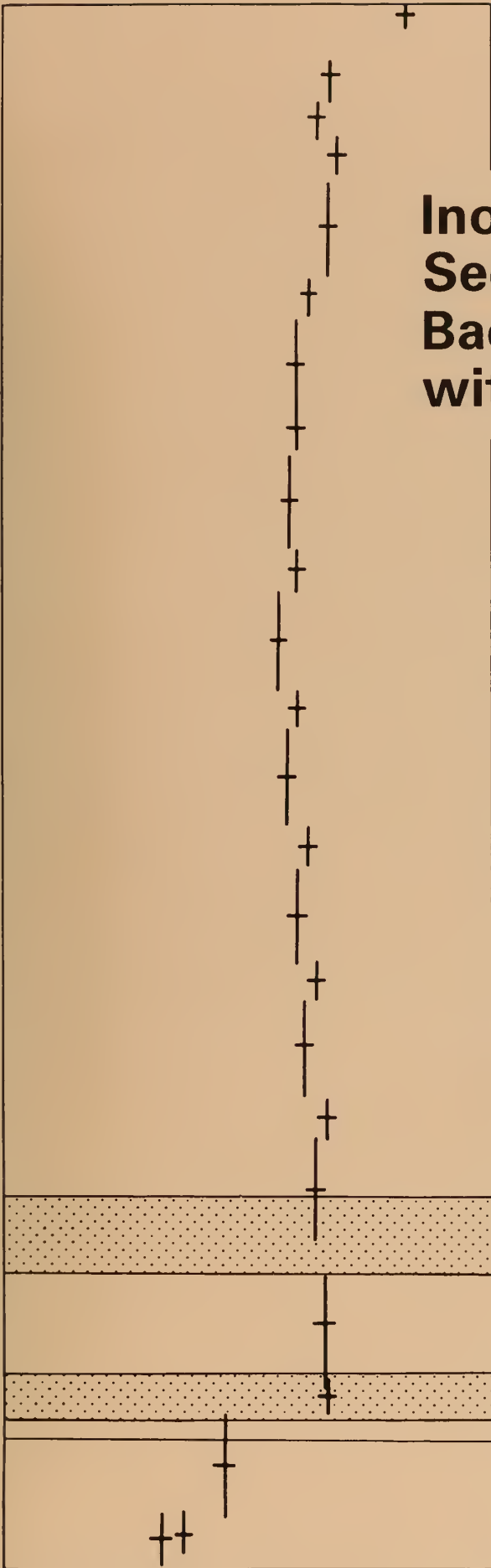


# Inorganic Composition and Sedimentation Rates of Backwater Lakes Associated with the Illinois River

Richard A. Cahill  
John D. Steele

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# **INORGANIC COMPOSITION AND SEDIMENTATION RATES OF BACKWATER LAKES ASSOCIATED WITH THE ILLINOIS RIVER**

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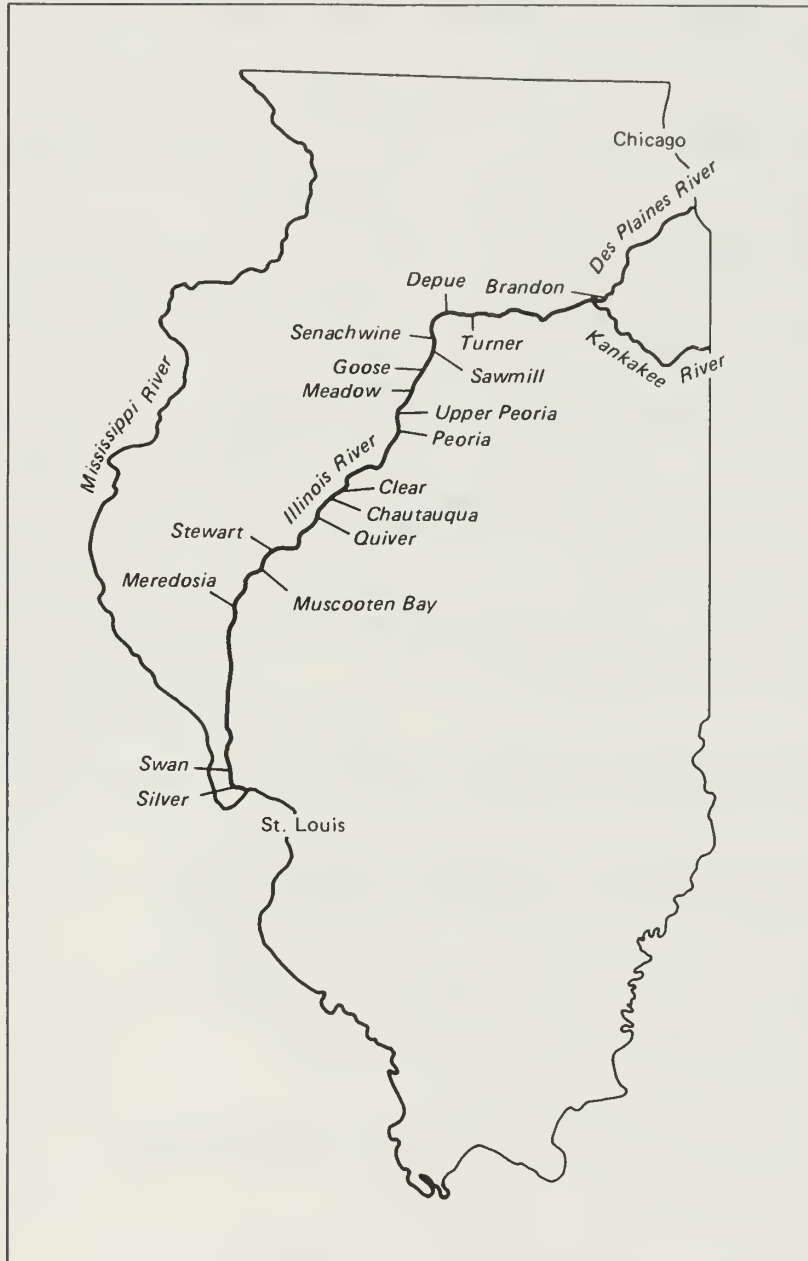
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ISGS 1986

**Figure 1**  
Lakes sampled along the Illinois River.



## ABSTRACT

The completion of seven major navigational dams on the main channel of the Illinois River in 1933 created 53 backwater lakes along the lower two-thirds of the river. Twenty-seven sediment cores were collected from 18 of those backwater lakes along 455 km of the river from Silver Lake to the Brandon Road Pool (upstream of origin of Illinois River). Sediment grain size and concentrations of as many as 40 elements were determined for 112 subsamples. The concentrations of Zn, Pb, Cd and several other metals are enriched in the upstream lakes compared to the downstream lakes. Zinc concentrations range from 5,000 ppm in Depue Lake to 132 ppm at Silver Lake. Sedimentation rates, which ranged from 1.0 cm/yr in Swan Lake to 3.2 cm/yr in Depue Lake, were obtained by measuring the  $^{137}\text{Cs}$  content of sediment samples. In addition, sedimentation rates at four locations were measured with  $^{210}\text{Pb}$ ; the agreement between the two techniques is generally good.

## INTRODUCTION

Chemical analysis of recent sediments can reveal the impact of man on lakes and rivers. By determining the rate of accumulation and composition of the sediment of an area, researchers can assess the degree of pollution, the results of introducing methods of pollution control, and the effects of changing agricultural and navigational practices on sedimentation rates. The contrasting conditions of the Illinois Waterway provide a unique opportunity for relating sediment patterns to human activity: the waterway is heavily polluted in some places, but almost uncontaminated in others.

The Illinois Waterway includes the Illinois, Chicago, and Des Plaines Rivers and the Calumet Sag Channel; the Waterway measures 526 km in length and drains an area of 75,135 km<sup>2</sup>. The Illinois River, the largest part of the Waterway, originates at the junction of the Kankakee and Des Plaines Rivers and flows 439 km southwest to join the Mississippi River north of St. Louis. Included in the Illinois River valley (fig. 1) are 53 backwater lakes.

A backwater lake is a currentless body of water that generally follows the same trend as the river and is usually affected at the lower end by back flow from the river. Backwater lakes along the Illinois River are directly affected by changes in the use of the river. The diversion of Lake Michigan waters from Chicago in 1903 brought with it a combined municipal and industrial sewage that adversely affected the biota of the Illinois Waterway (Boruff and Buswell, 1929; Mills, Starret and Bellrose, 1966; Starrett, 1971; and Bellrose et al., 1983). Channeling and dredging of the Illinois River by the Army Corps of Engineers increased river barge traffic, which in turn increased sediment load in the river and the rate of siltation in many backwater lakes (Bhowmik et al., 1981).

Many studies have documented changes in the biota and rapid losses in water storage capacities of a number of the lakes. Development of the Illinois River was reported in detail by the Illinois Department of Conservation (1969). Historic changes in the river's use and potential

development of the area were also discussed. Bellrose et al. (1983) discussed the changes in siltation rates between 1903-1956 and 1956-1976 as well as the effects of the changing water levels on the ability of the lakes to provide flood control protection.

Butts (1974) and Butts, Evans, and Lin (1975) measured the sediment oxygen demand and water quality of the upper Illinois River. The sediment oxygen demand, which ranged from 0.56 to 5.00 g/m<sup>2</sup>/day, imposes significant stress on the dissolved oxygen levels of the overlying waters. Brandon Road Pool was the worst case. Coliform bacteria counts ranged from a maximum of 9,900,000/100 ml in the Upper Illinois River to a minimum of 200/100 ml in the Middle Illinois River. The physical and chemical water quality of the Illinois waterway has recently been evaluated by Kothandaraman, Sinclair, and Evans (1981). Twenty-eight stations along the entire length of the river were sampled in 1977 and 1978. The upper section of the river (miles 231-271) had higher levels of ammonium (1.24 mg/l), total phosphate (0.52 mg/l), and chloride (57.8 mg/l) than the lower section (miles 3-75) (0.03, 0.39, and 45.3 mg/l, respectively).

In contrast, the lower section of the river had higher suspended solids (104 mg/l) and turbidity (29.4 Jackson Turbidity Units) than the upper section (44 mg/l and 17.2 JTU). Ewing et al. (1977) sampled 14 locations along the Illinois River in 1976. The water samples were analyzed for organic and inorganic contamination as well as water quality. Turbidity ranged from 65 JTU at mile 21 to 14 JTU at mile 278. Concentrations of Cr, Pb, and Zn ranged from 15 to 45 µg/l, 9 to 30 µg/l, and 22 to 205 µg/l when lower section (miles 21-120) values are compared with upper river (miles 294-319) values.

The chemical compositions of the sediments from the Illinois River and its backwater lakes record man's impact on the Illinois River system. Increased urbanization of an area is often reflected by a subsequent rise in levels of phosphates and nitrates in natural waters, which in turn, influence productivity and promote algal bloom. In contrast, the input of toxic trace metals and organic residues contributes directly to the disappearance of a number of species along the river system (Sparks, Sandusky, and Paparo, 1981; Blodgett et al., 1984).

The surficial materials in the Illinois River valley are the predominant source of sediments to the backwater lakes along the Illinois River. The geology along the Illinois River has been discussed by Willman (1973). The report contains seven surficial geology maps that show the distribution of the earth materials exposed in the valley floor bordering the river and within about 1 mile from the valley bluffs. Poorly sorted and unsorted silt and clay alluvium dominate the surficial materials along the Illinois River. The bluff materials in the area include loess and tills that have a high clay mineral content. The clay minerals present would be expected to serve as sites for the adsorption of trace metals and organics from the water column.

Lee and Stall (1977) included chemical analysis in 4 of the 15 lakes they surveyed for sedimentation studies. The chemical composition of sediments from Peoria Lake has been reported by Collinson and Shimp (1972) and Mathis and Cummings (1971). The above studies of sediments associated with the Illinois River system have been incomplete or limited either to a single lake,

or to channel sediments. Because the studies were not comprehensive in their coverage, no trends in composition among lakes could be noted. A systematic survey of the chemical composition of the bottom sediments of the backwater lakes associated with the Illinois River was proposed by Collinson and Shimp (1972).

The present study attempts to fill the gaps in previous work by including backwater lakes from the entire length of the Illinois River for a broader comparison. In addition, radiometric techniques were used to determine sedimentation rates for the first time. These techniques made possible a more accurate record of the amount of sediment that has accumulated in the last 30 years. Moreover, dating cores provides a time scale for the deposition of trace metals in the lake sediments. Between 1975-1983 the Illinois State Geological Survey (ISGS) sampled 18 lakes along the Illinois River between miles 3 and 286. Sediment cores from these lakes were analyzed to determine concentrations of metals in the sediment. In addition, sedimentation rates were determined by measuring  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  levels. The results of these analyses document the impact of man's activities locally (within a particular lake) and regionally (by tracing the downstream movement of pollutants attributed to the urban areas of Chicago and Peoria).

## EXPERIMENTAL METHODS

### Shipboard Procedures

The locations of the 18 lakes sampled are shown in figure 1; table 1 lists the lakes, their locations with respect to river mile, and the year of sampling. Sampling sites were plotted on charts of the Army Corps of Engineers (1974) or 7 1/2-minute topographic maps by orientation with cultural and natural features. When site names differed, we chose the name used on the 7 1/2-minute topographic map. The 1975 samples were collected by Illinois State Water Survey staff. Their sampling procedures are discussed in Lee and Stall (1977). The remaining cores were collected by ISGS staff using a Benthos coring device. The corer can collect relatively undisturbed cores 67 mm in diameter and up to 1 m in length at a controlled rate. The length of the sediment core is measured before and after extraction from the tube. Cores for chemical analyses were described and subsampled in the laboratory whenever possible.

### Chemical Methods

Sediment samples were dried at 110°C until a constant weight was achieved. Methods of analysis included instrumental neutron activation analysis, X-ray fluorescence, and optical emission and atomic absorption spectroscopy. Radiochemical neutron activation analysis was used for mercury determination in all samples except the 1983 samples, for which cold vapor atomic absorption spectroscopy was used. Elements determined by each method are

X-ray fluorescence: Si, Al, Fe, Mg, Ca, K, Ti, P, S, Cl;

Atomic absorption: Cd, Cu, Mg, Ni, Pb, Zn;

Optical emission: Cu, Mo, Pb, Zn;

Instrumental neutron activation: Na, As, Ba, Br, Ce, Co, Cr, Cs, Eu, Ga, Hf, La, Lu, Mn, Mo, Ni, Rb, Sb, Sc, Sm, Ta, Tb, Th, W, Yb.

The total and inorganic carbon contents of the 1975 samples were gravimetrically measured. The remainder of the samples were analyzed using a Coulometrics Total and Carbonate Carbon analyzer. Details of the analytical procedures are given in Kothandaraman et al. (1977) and Cahill (1981).

### Sediment Dating Methods

For accurate sediment dating, the grain size must be uniform throughout the core; the depositional rate, greater than 1 mm/yr; and the marker undisturbed by physical or chemical processes following deposition, during the coring operation, or resulting from storage. The first two requirements were usually met. High sedimentation rates are common for the backwater lakes. The grain size distribution is generally uniform with coarse, sand-sized particles occurring only at or just above pre-lake soil horizons. However, because the lakes sampled are shallow and often directly connected to the main river channel, the upper sediment intervals are physically mixed by waves generated by wind and barge traffic. Chemical diffusion of  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  downward in the sediment column is another possible source of error.

Sediment cores collected for radiometric dating were stored at 4°C until subsampled in the laboratory. The wet sediment samples were dried at 110°C, and the water content determined from the weight loss. Porosity values ( $\phi$ ) were calculated using the formula

$$\phi = \frac{M_w/\rho_w}{M_w/\rho_w + M_s/\rho_s}$$

where  $M_w$  is the mass of water,  $M_s$  is the mass of dry sediment, and  $\rho_w$  ( $1.0\text{g/cm}^3$ ) and  $\rho_s$  ( $2.45\text{g/cm}^3$ ) are densities of water and sediment, respectively. Porosity values were used to correct for changes in water content as a result of compaction in sediment cores.

$^{137}\text{Cs}$  profiles were determined at five locations.  $^{137}\text{Cs}$ , an isotope produced by atmospheric testing of atomic weapons, was initially deposited in 1954. It has a half-life of 30.7 years. The  $^{137}\text{Cs}$  activity was counted directly on Ge(Li) detectors; 10 g of sediment were gamma counted for periods of 24 to 48 hours. The activity was compared to that of the National Bureau of Standards Environmental Radioactivity Standard, NBS 4350B. The lowest specific activity that can be detected in 10 g samples by using 24-hour counting times is approximately  $0.53 \times 10^{-2}$  Bq/g. (A becquerel [Bq] is defined as 32.2 picocurie [pCi], where 1 pCi equals  $3.7 \times 10^{-2}$  disintegrations per second.) A plot of the  $^{137}\text{Cs}$  activity versus depth in the cores can be related to the beginning of nuclear weapons testing in the atmosphere in 1954 or to the peak of testing in 1963. Sedimentation rates can be calculated with either of these dates as a marker.

$^{210}\text{Pb}$  activities were measured at four locations.  $^{210}\text{Pb}$  is a member of the  $^{238}\text{U}$  decay series and has a half-life of 22 years.  $^{222}\text{Rn}$ , which has a half-life of 3.8 days, diffuses from the soil into the atmosphere and remains chemically inert until it decays to  $^{210}\text{Pb}$ .  $^{210}\text{Pb}$  particles are quickly removed from the atmosphere by precipitation and fallout. Two types of  $^{210}\text{Pb}$

Table 1. Location, year of collection, and sample numbers for backwater lakes along the Illinois River sampled for chemical analysis.

|                   | River<br>mile | Symbol | Year samples<br>collected | Sample no.    |
|-------------------|---------------|--------|---------------------------|---------------|
| Silver Lake       | 3             | SIL    | 1983                      | R15041-R15044 |
| Swan Lake         | 7             | SWN    | 1983                      | R15045-R15050 |
| Meredosia Lake    | 73            | MR3    | 1975                      | R12240-R12248 |
|                   | 74            | MR6    | 1975                      | R12249-R12257 |
| Muscooten Bay     | 90            | MUS    | 1977                      | R13678-R13680 |
| Stewart Lake      | 102           | STW    | 1977                      | R13671-R13677 |
| Matanzas Lake     | 116           | MA     | 1975                      | R12444-R12451 |
| Quiver Lake       | 123           | QV     | 1977                      | R13652-R13658 |
| Lake Chautauqua   | 125           | CHT    | 1977                      | R13659-R13666 |
| Clear Lake        | 131           | CLR    | 1977                      | R13667-R13670 |
| Peoria Lake       | 164           | PEO    | 1978                      | R14188-R14190 |
| Upper Peoria Lake | 171           | UPL    | 1978                      | R14185-R14187 |
|                   | 171           | UPL    | 1982                      | R15583-R15589 |
|                   | 176           | UPU    | 1978                      | R14182-R14184 |
|                   | 176           | UPL    | 1982                      | R15590-R15596 |
| Meadow Lake       | 184           | MED    | 1978                      | R14179-R14181 |
| Goose Lake        | 191           | GO     | 1978                      | R14175-R14178 |
| Sawmill Lake      | 198           | SML    | 1975                      | R12438-R12443 |
|                   | 198           | SML    | 1978                      | R14172-R14174 |
|                   | 198           | SML    | 1982                      | - a           |
| Senachwine Lake   | 201           | SCN    | 1978                      | R14169-R14171 |
| Depue Lake        | 212           | LDP    | 1975                      | R12433-R12437 |
|                   | 212           | DP     | 1978                      | R14164-R14168 |
|                   | 212           | DP     | 1982                      | R15037-R15039 |
|                   | 212           | DP     | 1982                      | - a           |
| Turner Lake       | 216           | TUR    | 1983                      | R15031-R15033 |
| Brandon Road Pool | 286           | BRD    | 1983                      | R15034-R15036 |

a These cores were collected and extruded for  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  analysis only; no sample analysis numbers were assigned.

enter sediments: 1) excess or atmospherically derived  $^{210}\text{Pb}$  particles, which enter a water body via fallout or runoff and are quickly incorporated into the sediments; 2) supported  $^{210}\text{Pb}$ , which is the isotope in radioactive equilibrium within the  $^{238}\text{U}$  decay series and represents the background level of  $^{210}\text{Pb}$ .

Table 2. Physical parameters for backwater lakes sampled along Illinois River.

|                 | Surface<br>area (acres) | Shoreline<br>length (km) | Maximum<br>depth (m) | Condition |
|-----------------|-------------------------|--------------------------|----------------------|-----------|
| Silver Lake     | 40                      | 4.5                      | 1.5                  | Fair      |
| Swan Lake       | 2345                    | 25.9                     | 1.5                  | Fair      |
| Meredosia Lake  | 1692                    | 29.                      | 1.5                  | Fair      |
| Muscooten Bay   | 1646                    | 13.                      | 1.8                  | Poor      |
| Stewart Lake    | 1578                    | 17.7                     | 1.2                  | Poor      |
| Matanzas Lake   | 861                     | 11.3                     | 2.4                  | Poor      |
| Quiver Lake     | 407                     | 3.9                      | 1.2                  | Poor      |
| Lake Chautauqua | 3562                    | 22.5                     | 1.2                  | Poor      |
| Clear Lake      | 1463                    | 14.8                     | 0.9                  | Poor      |
| Goose Lake      | 2822                    | 19.3                     | 1.5                  | Poor      |
| Sawmill Lake    | 630                     | 11.3                     | --                   | Poor      |
| Senachwine Lake | 3324                    | 22.5                     | 1.5                  | Poor      |
| Depue Lake      | 524                     | 11.3                     | 1.8                  | Poor      |
| Turner Lake     | 300                     | 5.8                      | --                   | Unknown   |

Source: 1978 Assessment and classification of Illinois Lakes, IEPA.

Three basic methods for the measurement of  $^{210}\text{Pb}$  have been developed: 1) counting the beta activity of  $^{210}\text{Bi}$ , daughter of  $^{210}\text{Pb}$ , with a radiochemical procedure adopted from Joshi and Durham (1976); 2) directly counting the low-energy gamma ray of  $^{210}\text{Pb}$  using an intrinsic low-energy Ge(Li) detector with a procedure established by Gaggeler, Von Gunten, and Nyffeler (1976); 3) counting the alpha activity of  $^{210}\text{Po}$ , the granddaughter of  $^{210}\text{Pb}$ , with a radiochemical procedure adapted from Martin and Rice (1981).

The relatively small surface area of each lake, which limits the amount of atmospherically derived  $^{210}\text{Pb}$  entering the system, and the high sedimentation rates, which tend to dilute the amount of  $^{210}\text{Pb}$ , led us to choose a method with the lowest detection limits. For this reason, we chose the  $^{210}\text{Po}$  procedure. Five g of sediment were dried in an oven at  $110^\circ\text{C}$  and transferred to a 100 ml Teflon beaker. Five ml of concentrated  $\text{HNO}_3$  was added, and the mixture was evaporated to dryness. The sample was digested three times with 30 percent  $\text{H}_2\text{O}_2$  and twice with 8M  $\text{HCl}$ . After each digestion, the sample was evaporated to dryness. Five ml of 8M  $\text{HCl}$ , 5 ml of 20 percent hydroxylamine hydrochloride, 2 ml of 25 percent sodium citrate, and 1 ml of 0.05M  $\text{BiNO}_3$  were added, and the pH was adjusted to between 1.8 and 1.9. The  $^{210}\text{Po}$  was plated onto a silver disk (0.125 mm thick, 17 mm diameter) from a plating cell suspended in the solution at  $80^\circ$  to  $90^\circ\text{C}$  for 90 minutes. The silver disk was rinsed and mounted for counting in a Gamma Product low-level alpha beta gas-flow proportional counter. At least 1,000 counts were obtained to ensure adequate statistics. The  $^{210}\text{Po}$  activity was corrected for counting efficiency, normalized for water content using the porosity data, and plotted in relation to depth in core. A best-fit line was constructed for the linear portions of the plots, and sedimentation rates were determined from the excess  $^{210}\text{Pb}$  curves.

The  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  measurements were checked by analysis of duplicate and reference samples. Where possible, sedimentation rates were checked by matching presumed dates against identifiable events recorded in the sediment.

Table 3. Change in surface areas of Illinois River backwater lakes.

|                   | Surface area (acres) |      | Change (%) |
|-------------------|----------------------|------|------------|
|                   | 1903                 | 1969 |            |
| Swan Lake         | 462                  | 2873 | +522       |
| Meredosia Lake    | 1043                 | 1484 | +42        |
| Muscooten Bay     | 892                  | 1231 | +38        |
| Stewart Lake      | 1263                 | 1400 | +11        |
| Matanzas Bay      | 316                  | 479  | +52        |
| Quiver Lake       | 403                  | 277  | -31        |
| Lake Chautauqua   | 586                  | 3763 | +543       |
| Clear Lake        | 828                  | 1931 | +133       |
| Peoria Lake       | 1643                 | 2582 | -57        |
| Upper Peoria Lake | 6390                 | 9239 | +45        |
| Meadow Lake       | 124                  | 679  | +450       |
| Goose Lake        | 343                  | 1068 | +211       |
| Sawmill Lake      | 566                  | 698  | +23        |
| Senachwine Lake   | 2644                 | 4086 | +54        |
| Depue Lake        | 378                  | 658  | +74        |
| Turner Lake       | 391                  | 348  | -11        |

Source: Bellrose et al., 1983

#### DESCRIPTION OF LAKES SAMPLED

Table 2 lists the surface area, shoreline length, maximum depth, and condition rating for 14 of the lakes sampled (IEPA, 1978). This assessment judged the lakes to be in generally poor condition because of unstable water levels, high turbidity, and active sediment deposition.

The changing surface area of 16 of the lakes is reported in Bellrose et al. (1983). Table 3 compares the surface areas of the lakes as measured in 1969 to measurements made on maps prepared by the U.S. Army Corps of Engineers (1903). The increase in surface areas of these lakes is directly related to the construction of navigation dams along the Illinois River and the diversion of Lake Michigan waters (Sparks, 1984).

The sedimentation rates measured by Bellrose et al. (1983) for nine lakes are summarized in table 4. Table 5 summarizes sedimentation rates for eight lakes measured by Lee (1984). The discrepancies between the two data sets are due in part to the fluctuating water levels and the poorly defined water surfaces of many of the lakes.

Sediment accumulation has been extreme in several of the lakes, among them Peoria Lake and Muscooten Bay. The data on Peoria Lake suggest that the sedimentation problem has become more severe in Upper Peoria Lake, where the sedimentation rate was nearly two times greater (3.06 cm/yr) during 1965-1976 than the long-term average of 1.67 cm/yr from 1903-1976. The increased rate for this 11-year period resulted in 34 cm of sediment or nearly 1/4 of the total sediment deposited (138 cm).

Table 4. Sedimentation rates and depth of sediment in backwater lakes of the Illinois River by time periods.

|                   | Time interval | Sedimentation rate (cm/yr) | Sediment depth (cm) |
|-------------------|---------------|----------------------------|---------------------|
| Senachwine Lake   | 1903-1978     | 1.27                       | 95                  |
| Sawmill Lake      | 1903-1978     | 1.11                       | 83                  |
| Goose Lake        | 1903-1978     | 1.07                       | 80                  |
| Upper Peoria Lake | 1903-1965     | 1.67                       | 104                 |
|                   | 1965-1976     | 3.06                       | 34                  |
|                   | 1903-1976     | 1.88                       | 137                 |
| Clear Lake        | 1903-1978     | 1.56                       | 117                 |
| Lake Chautauqua   | 1926-1950     | 1.05                       | 25                  |
|                   | 1950-1976     | 1.06                       | 27                  |
|                   | 1926-1976     | 1.05                       | 52                  |
| Matanzas Lake     | 1903-1979     | 1.62                       | 123                 |
| Meredosia Lake    | 1903-1956     | 1.30                       | 69                  |
|                   | 1956-1978     | 1.19                       | 26                  |
|                   | 1903-1978     | 1.27                       | 95                  |
| Swan Lake         | 1903-1978     | 0.85                       | 64                  |

Source: Bellrose et al., 1983

Table 5. Sedimentation rates in backwater lakes.

| Location        | Sedimentation rate (cm/yr) | Location        | Sedimentation rate (cm/yr) |
|-----------------|----------------------------|-----------------|----------------------------|
| Swan Lake       | 0.46                       | Peoria Lake     | 1.02                       |
| Meredosia Lake  | 1.09                       | Sawmill Lake    | 1.19                       |
| Muscooten Bay   | 7.92                       | Senachwine Lake | 0.76                       |
| Lake Chautauqua | 0.83                       | Depue Lake      | 1.50                       |

Source: Lee (1984)

Erosion of banks, bluffs, and adjacent and upland soils all contribute to the sediment load of the Illinois River. The principal source of sediment in the backwater lakes seems to be the fine-grained part of the sediment wash load that the Illinois River carries from the upland watersheds, where it originated as wash load (Lee, 1984).

The combination of large surface areas and shallow depths has changed many of the lakes that once supported a diversity of aquatic plants and fish into shallow, saucer-shaped basins filled with soft sediments that support little or no life (Sparks, 1984). Wind- and barge-generated waves and



recreational boating cause a resuspension of the bottom sediments. Resuspension of sediments contributes to further degradation of the lake's quality in a variety of ways: increased turbidity, reduced photosynthesis, and reintroduction of contaminants that might otherwise have settled out of the active biological zone. Several lakes have filled to the point where they have become bottomland forest and now support the growth of willows and cottonwoods (Bellrose et al., 1983).

## **Chemical Results**

The geologic descriptions of the cores selected for chemical analysis are summarized in appendix 1. The descriptions include grain size, Munsell color, the presence of biological markers such as shell layers, soil horizons, and structure. Results of chemical analysis of cores collected during the five sampling years are found in appendix 2.

The mean, standard deviation, number of "less than" values, and the range of concentration of the elements in all the samples are shown in table 6. In the statistical analysis, "less than" values were included and treated as real values. This treatment affects the statistical analysis only for cadmium and molybdenum, which had a significant number of "less than" values. Excluded from the calculations and from further statistical analysis were two samples (R14182 and R13658) that contained over 40 percent calcite. Because abundant shell fragments were noted in these cores, we decided these samples were unrepresentative, and would bias any statistical analysis.

## **RESULTS AND DISCUSSION**

### **Comparison of Chemical Analyses of Samples from Illinois River Lakes with other Illinois Lakes**

In table 7 the chemical composition of sediments from backwater lakes of the Illinois River is compared with the composition previously determined for sediments from Lake Paradise, Fox Chain of Lakes, Kankakee River, Lake Michigan, and three lakes in southern Illinois. The average values for Cr, Cu, Hg, Pb, Sb, and Zn in backwater lakes of the Illinois River are higher than the values determined for other Illinois lakes. This difference is explained in part by the very high levels of these metals found in Brandon Locks, Depue Lake, and to some extent in Upper Peoria Lake. Mean Cd levels are difficult to compare because Cd results for 79 of the 112 samples in the present study are below the limit of detection. High levels of Cd in Depue Lake (2 to 116 ppm) and Brandon Locks (37 to 73 ppm) bias the mean value.

Mean concentrations of Cr, Cu, Hg, Ni, P<sub>2</sub>O<sub>5</sub>, Sb, Zn, and organic C are all higher in sediments of Illinois River backwater lakes than in an average soil (Brownlow, 1979). In contrast, concentration of the elements in the other lakes often falls in the same range as reported for average soil (Brownlow, 1979).

### **Composition of Sediments in Meredosia, Peoria, Sawmill and Depue Lakes**

Meredosia, Depue, Sawmill, and Peoria Lakes were sampled at more than one location to measure the variation of sediment composition within the lakes.

Table 6. Mean values for the chemical composition of sediments associated with the Illinois River.

| Element                            | Mean | Standard deviation | Relative standard deviation (%) | Minimum | Maximum | Number of "less than" values |
|------------------------------------|------|--------------------|---------------------------------|---------|---------|------------------------------|
| SiO <sub>2</sub> (%)               | 58.2 | 5.7                | 9.8                             | 34.5    | 72.5    |                              |
| Al <sub>2</sub> O <sub>3</sub> (%) | 13.5 | 2.2                | 16.4                            | 3.4     | 17.8    |                              |
| Fe <sub>2</sub> O <sub>3</sub> (%) | 5.7  | 0.9                | 15.1                            | 2.8     | 8.9     |                              |
| MgO (%)                            | 2.0  | 0.7                | 32.8                            | 0.5     | 5.0     |                              |
| CaO (%)                            | 3.3  | 1.3                | 39.6                            | 0.8     | 7.8     |                              |
| Na <sub>2</sub> O (%)              | 0.61 | 0.14               | 23.4                            | 0.3     | 1.2     |                              |
| K <sub>2</sub> O (%)               | 2.4  | 0.4                | 17.3                            | 1.1     | 3.9     |                              |
| TiO <sub>2</sub> (%)               | 0.76 | 0.08               | 10.4                            | 0.37    | 0.93    |                              |
| P <sub>2</sub> O <sub>5</sub> (%)  | 0.44 | 0.33               | 76.7                            | 0.05    | 2.13    |                              |
| MnO (%)                            | 0.08 | 0.02               | 24.5                            | 0.02    | 0.15    | 2                            |
| S (%)                              | 0.08 | 0.06               | 76.5                            | 0.01    | 0.27    | 10                           |
| Cl                                 | 135. | 0.08               | 58.2                            | 10.     | 440.    |                              |
| Tot. C (%)                         | 3.3  | 1.8                | 52.5                            | 0.6     | 14.3    |                              |
| In. C (%)                          | 0.7  | 0.4                | 64.7                            | 0.01    | 26.3    | 1                            |
| Org. C (%)                         | 2.7  | 1.5                | 55.5                            | 0.6     | 12.1    |                              |
| As                                 | 12.8 | 7.0                | 53.4                            | 0.3     | 48.0    |                              |
| Ba                                 | 644. | 157.               | 24.                             | 270.    | 1600.   |                              |
| Br                                 | 5.2  | 1.8                | 35.7                            | 1.0     | 11.0    | 3                            |
| Cd                                 | 7.3  | 17.0               | 234.                            | 0.5     | 116.    | 81                           |
| Ce                                 | 79.  | 18.7               | 23.7                            | 32.     | 135.    |                              |
| Co                                 | 14.  | 5.                 | 38.7                            | 3.9     | 32.0    |                              |
| Cr                                 | 127. | 89.                | 69.2                            | 35.     | 700.    |                              |
| Cs                                 | 7.8  | 1.8                | 24.1                            | 3.1     | 12.0    |                              |
| Cu                                 | 67.  | 72.                | 108.                            | 10.     | 500.    |                              |
| Eu                                 | 1.5  | 0.3                | 20.0                            | 0.8     | 3.7     |                              |
| Ga                                 | 18.5 | 3.6                | 19.5                            | 2.0     | 37      |                              |
| Hf                                 | 7.3  | 2.2                | 30.0                            | 0.7     | 14.     |                              |
| Hg                                 | 0.35 | 0.48               | 134.7                           | 0.04    | 2.5     |                              |
| La                                 | 47.4 | 7.2                | 15.3                            | 26.0    | 67.0    |                              |
| Lu                                 | 0.6  | 0.1                | 28.1                            | 0.2     | 0.9     |                              |
| Mo                                 | 10.  | 7.7                | 75.9                            | 1.0     | 24.0    | 51                           |
| Ni                                 | 46.4 | 37.9               | 82.6                            | 11.     | 299.    | 8                            |
| Pb                                 | 76.6 | 106.               | 138.                            | 2.0     | 738.    | 4                            |
| Rb                                 | 161. | 38.                | 23.7                            | 78.     | 240.    |                              |
| Sb                                 | 2.4  | 5.0                | 212.                            | 0.3     | 54.     |                              |
| Sc                                 | 15.0 | 2.6                | 17.6                            | 6.8     | 20.0    |                              |
| Sm                                 | 7.3  | 1.2                | 16.0                            | 3.7     | 14.0    |                              |
| Ta                                 | 0.9  | 0.2                | 22.6                            | 0.4     | 1.8     |                              |
| Tb                                 | 1.7  | 0.7                | 42.7                            | 0.5     | 3.2     |                              |
| Th                                 | 12.8 | 3.5                | 27.6                            | 3.9     | 20.0    |                              |
| Yb                                 | 2.9  | 0.7                | 23.8                            | 1.0     | 4.8     |                              |
| Zn                                 | 483. | 863.               | 178.                            | 38.     | 5000.   |                              |

Concentrations in ppm except where percent is indicated. All values reported on 110°C, moisture-free basis.

Table 7. Comparison of the chemical composition of sediments from the Illinois River with sediments from other lakes in Illinois. Concentrations are in ppm except where percent is indicated.

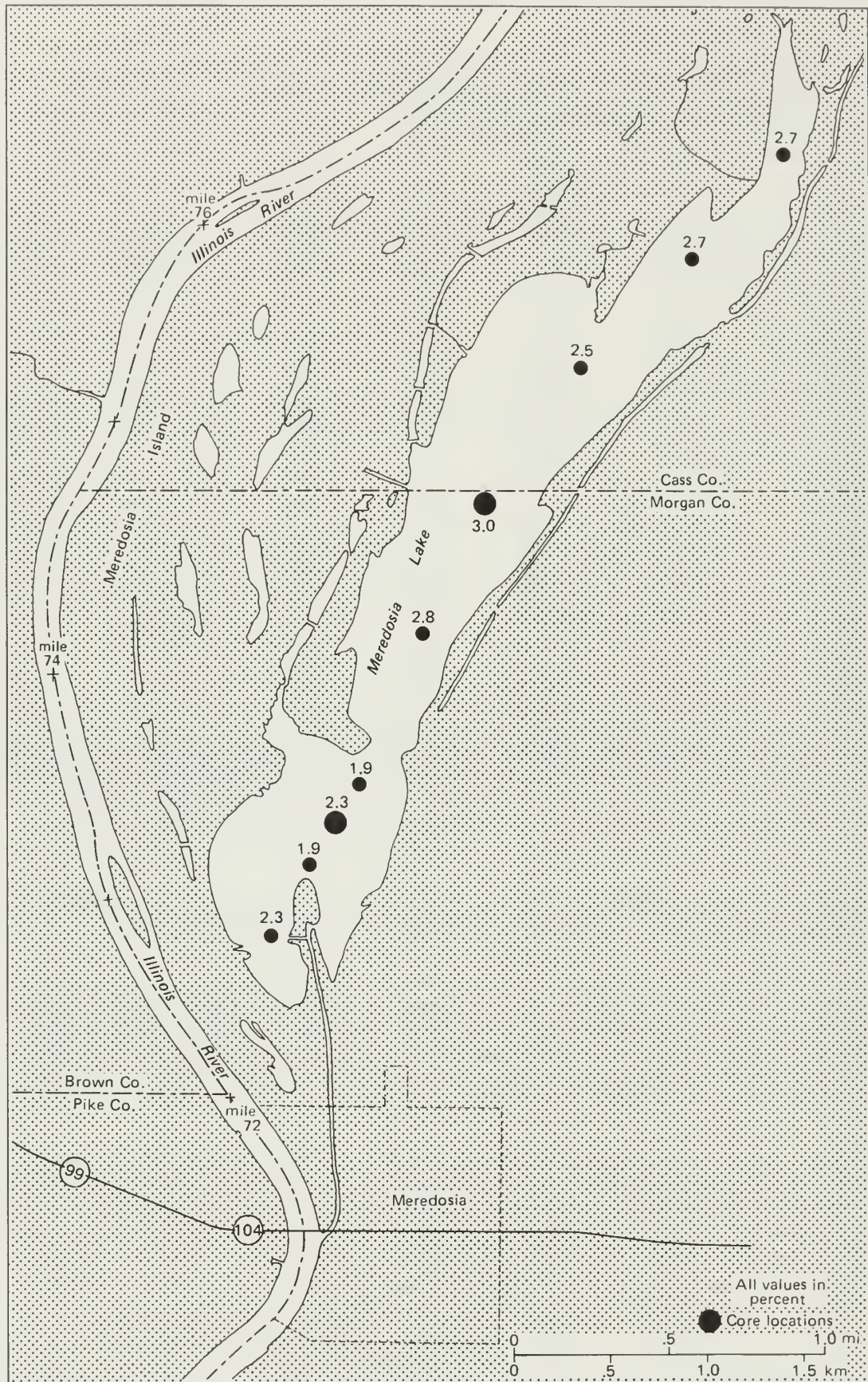
|                                   | Illinois River | Lake Michigan | Fox Chain of Lakes | Kankakee River | Southern Illinois Lakes | Lake Paradise | Avg. Soil |
|-----------------------------------|----------------|---------------|--------------------|----------------|-------------------------|---------------|-----------|
| As                                | 12.8           | 10.5          |                    | 5.8            |                         | 8.6           | 5.5-12    |
| Br                                | 5.2            | 33            |                    | 2.6            |                         | 7             |           |
| Cd                                | 0.8            | 0.9           | <0.6               | <4             |                         | <0.8          |           |
| Cr                                | 127            | 46            |                    | 34             | 47                      | 87            | 15-70     |
| Cu                                | 67             | 22            | 20                 | 13             | 47                      | 24            | 10-39     |
| Hg                                | 0.35           | 0.11          | 0.22               |                |                         |               | 0.03-0.07 |
| Ni                                | 47             | 24            | 26                 | <36            | 27                      | 49            | 2-18      |
| P <sub>2</sub> O <sub>5</sub> (%) | 0.44           | 0.16          | 0.22               | 0.04           | 0.10                    | 0.22          | 0.04-0.18 |
| Pb                                | 77             | 40            | 44                 | <70            |                         | <5            | 3-27      |
| Sb                                | 2.4            | 1.1           |                    | 0.4            |                         | 1.0           |           |
| Zn                                | 483            | 97            | 90                 | 65             | 81                      | 94            | 37-68     |
| Org.C (%)                         | 2.7            | 2.0           | 5.5                |                |                         | 2.9           | 0.9-2.2   |

Sources: Lake Michigan data from Cahill (1981); Fox Chain of Lakes data from Kothandaraman et al. (1977); Southern Illinois lake information from Dreher, Muchmore, and Stover (1977); Lake Paradise data from unpublished ISGS results. Averages for chemicals in soil are taken from Brownlow (1979).

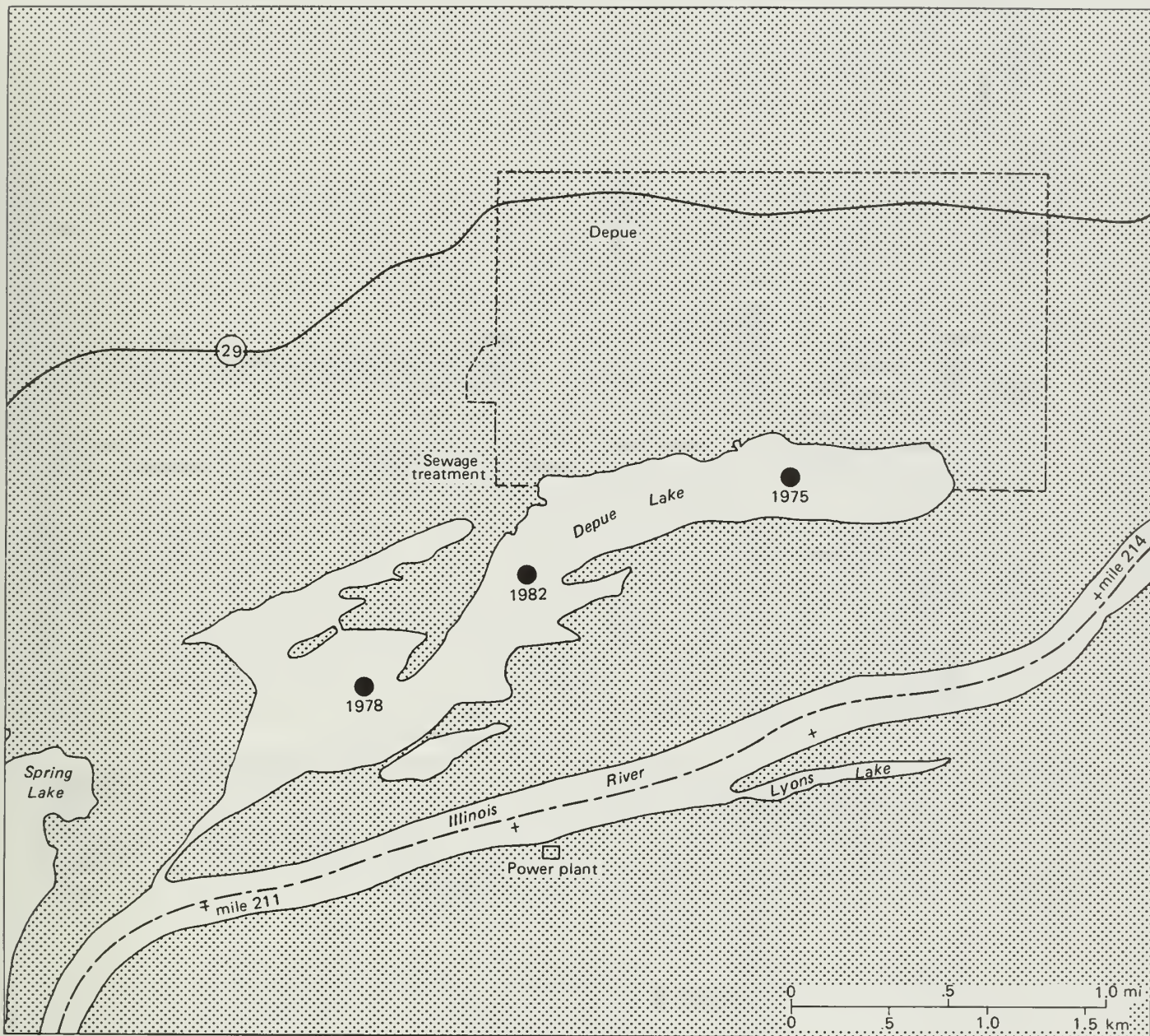
Depue Lake and Sawmill Lake were sampled in different years. This makes direct comparison of those results more difficult to evaluate.

Nine locations were sampled in Meredosia Lake for the report of Lee, Stall and Botts (1976), but were not included in that report. Grain size and carbon content were measured at each of the nine locations, and complete chemical analysis was done on cores collected at two locations. The organic carbon distribution for Meredosia Lake is shown in figure 2. The results for grain size and carbon for the nine sites are in appendix 3.

Meredosia Lake consists of two basins separated by a narrow channel. The lower basin, which is near the mouth of the Illinois River, averages 46 percent clay and 1.6 percent organic carbon; the upper basin, in contrast, is 61 percent clay and 2.2 percent organic carbon. The two basins were found to be different at the 99 percent confidence level on the basis of the standard T test. The two cores selected for chemical analysis were obtained at sites 3 and 6, roughly at the center of each basin. Those elements that are preferentially associated with the clay-sized, organic-rich sediments would be expected to have higher concentrations at core site 6, which is from the upper basin where sediment contains 61 percent clay, than at core site 3, which is from the lower basin where sediment is only 46 percent clay. This was found



**Figure 2**  
Organic carbon distribution in the upper 5 cm of sediment in Meredosia Lake.



**Figure 3**  
Sampling locations in Depue Lake.

for ten of the elements (Al, Fe, P, Mn, Br, Cu, Ni, Pb, Sb, and Zn). The silt-sized sediments at site 3, however, had higher concentrations of Si, Na, Hf and Ta. There were no significant differences in the concentrations of other elements at the two sites. Thus, we concluded that Meredosia Lake has received most of its sediment from the connection with the Illinois River at the southern end and that the clay-sized sediments were being transported into the upper basin of Meredosia Lake, while the silt-sized particles were settling out in the lower basin.

Depue Lake is connected to the Illinois River by a narrow channel to the west (fig. 3). The lake has a wide, shallow marshy area with a deeper area adjacent to the city of Depue. The lake was a popular site for boating before

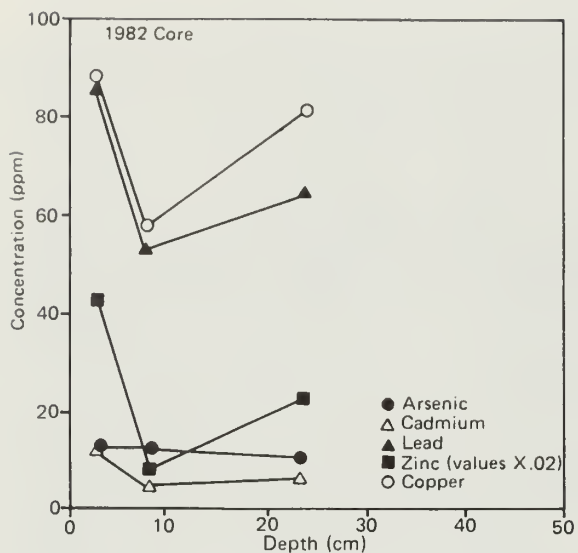
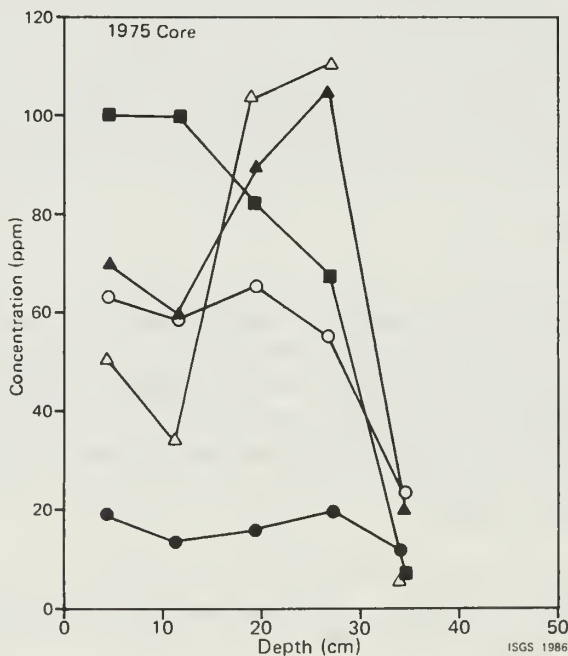
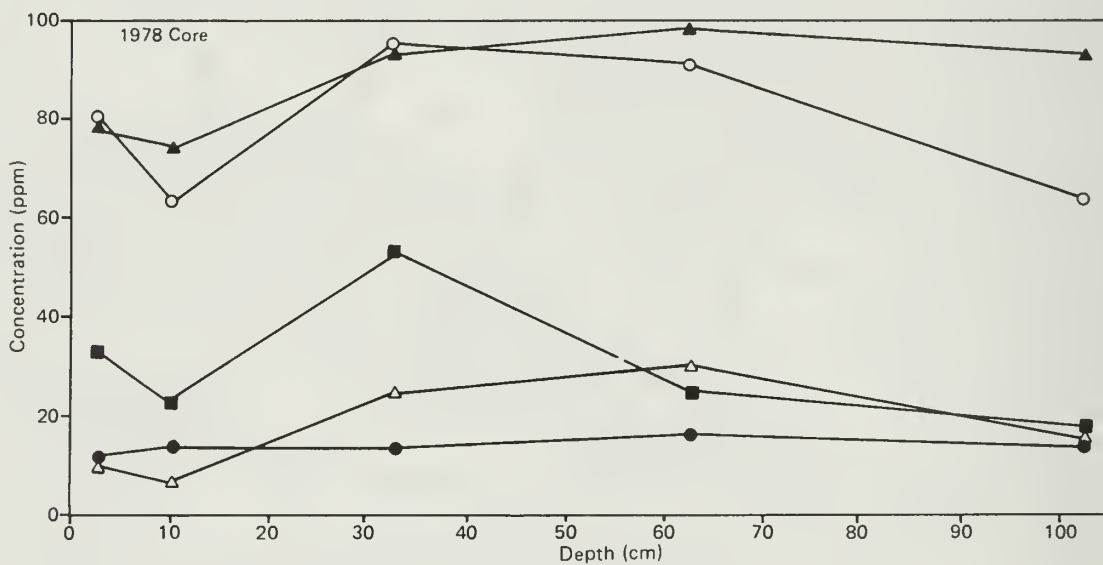


Figure 4  
Arsenic, copper, cadmium, lead, and zinc distributions in Depue Lake.



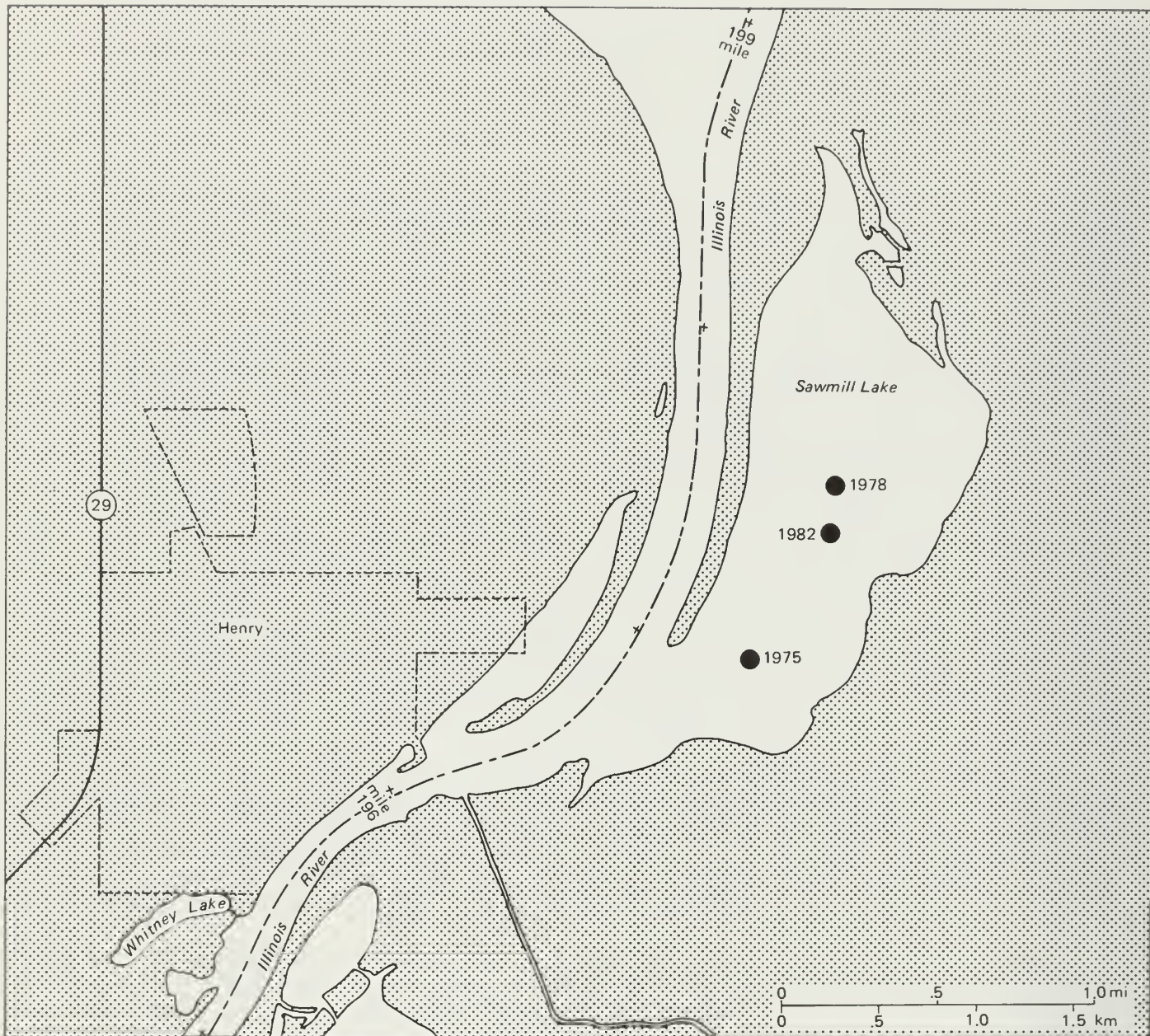
World War II, when it had a reported depth of 18 to 20 feet. Since then, suspended sediment has been carried into the lake during flood stages of the river. In addition, sediment from a tributary input has increased because of erosion from agricultural lands. From 1903 to 1975 the lake's water storage capacity dropped 72.6 percent from 2,837 to 778 acre-feet, and the average water depth declined to 0.5 m (Lee and Stall, 1976).

The three sites sampled are shown in figure 3. Because the cores were collected in three different years (1975, 1978, 1982), direct comparison of the chemical results from site to site may not be valid. Concentrations of Cd, Cu, Pb, and Zn show the greatest variation between the three sites (fig. 4). Zinc levels range from 348 to 5,000 ppm at the 1975 location, 870 to 2,640 ppm at the 1978 site, and 390 to 2,090 ppm at the 1982 location. Cadmium levels range from 5 to 116 ppm at the 1975 site, to 6 to 30 ppm at the 1978 site, and 2 to 13 ppm at the 1982 location. A zinc company operated a zinc smelter in Depue from 1906 until 1971. In 1967, the company's capacity was 71,000 ton per year, processing ore from Elmo, Wisconsin, and Gilman, Colorado. A sulfuric acid and fertilizer plant was also in operation up to 1971. Waste from such plants is usually in the form of metal-rich cinders. At this site a 40-foot high pile covers about 12 acres, and a 1- to 5-foot thick layer of cinders covers the remaining 90 acres of the plant complex (Gibb and Cartwright, 1982). Lead and copper levels vary more widely at the 1975 site (42 to 211 ppm and 46 to 130 ppm) than they do at the other sites, which range from 53 to 98 ppm and 57 to 90 ppm. Copper and Pb concentrations probably reflect the input from the zinc smelter, but other sources (such as the city of Depue) may also be responsible for the contamination. The concentrations of Zn, Cr, and As vary widely, unlike the concentrations for Cd, Cu, and Pb, which are more nearly uniform at all three sites sampled.

In Sawmill Lake, cores were collected from two sites (fig. 5): near the river in 1975 and near the center of the lake in 1978 and 1982. The elemental concentration profiles and levels are comparable at the two locations for 29 of the 40 elements determined. Arsenic, Cu, Hg, Pb and Sb concentrations, however, are significantly higher at the 1975 core site adjacent to the river. In contrast, the mid-lake site has higher levels of Cd, Co, Ni, and P.

Figure 6 is a plot of As, Cr, Pb, Sb, Zn, and organic C concentrations as a function of depth for the two sites. In the plot, the surface layer is adjusted to correspond to the amount of sediment accumulating in the time between the two samplings. The mid-lake site has relatively uniform composition; the other site has high surface enrichments of As, Pb, and Sb. Baseline values in the deeper core layers are generally comparable at both sites, although Cd, Co, Cr, Cu, Hg, Pb, Sb, and Zn levels are higher at the mid-lake location than at the marginal site.

The source for the high levels of metals at the marginal site is not clear. The concentration of Sb here is 54 ppm at the surface layer. The next highest value for Sb is 14 ppm, and 115 of the 120 samples contained less than 3 ppm. Antimony, which is used in the manufacture of flame-proofing compounds, batteries, and various metal alloys, generally occurs in low concentrations in sediments. It is released to the environment through incineration and other high-temperature metal processing activities. If the Sb results from a high-temperature process, it would probably be widely dispersed. Because high levels of Sb were not observed elsewhere in this



**Figure 5**  
Sampling locations in Sawmill Lake.

ISGS 1986

study or in a subsequent re-sampling of the lake, a localized source for Sb is suggested. There is also a high level of concentration for those elements chemically similar to Sb (As, Cd, Pb, and Zn) and associated with metal processing. These facts reinforce the possibility of metal processing as the source for Sb and the other metals at this site.

Peoria Lake is formed by the Peoria lock and dam. At mile 166, it is divided into Upper Peoria and Peoria Lake by a narrow section of river. Peoria and Upper Peoria Lakes are probably the most intensively studied of the lakes along the Illinois River because they provide both the water supply and recreation to the city of Peoria. Because of their size (21 km long) and nearness to the large urban and industrial center of Peoria, the lakes are affected by a number of local pollution sources. Peoria and Upper Peoria



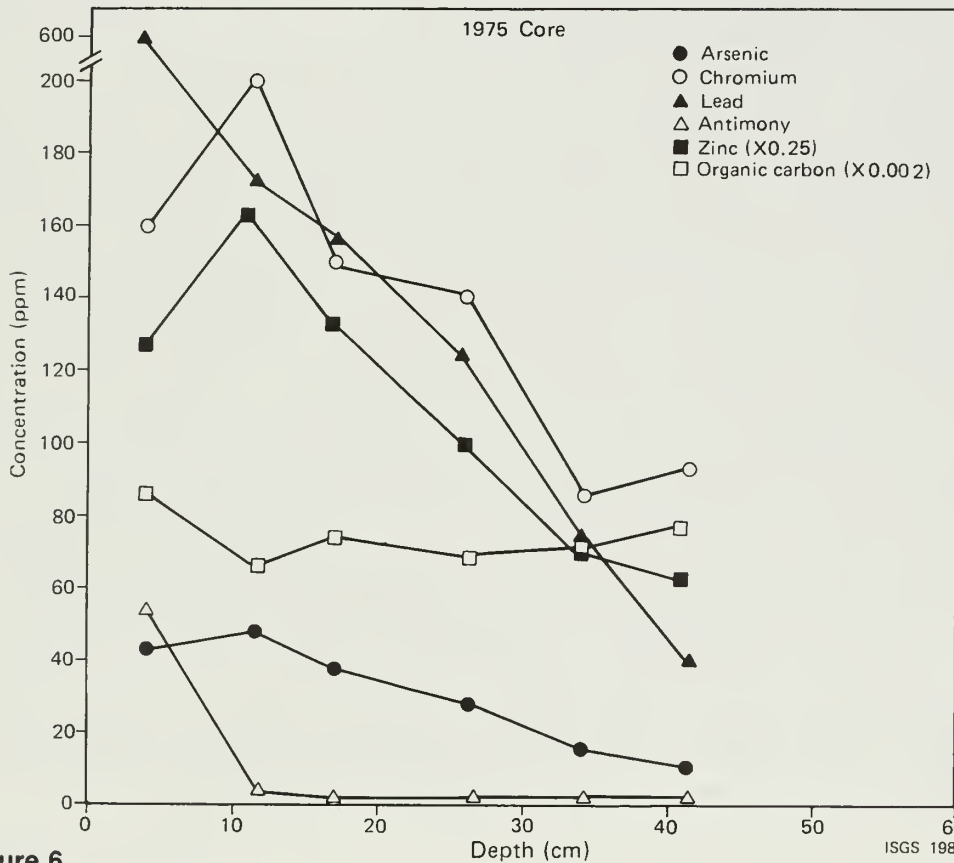
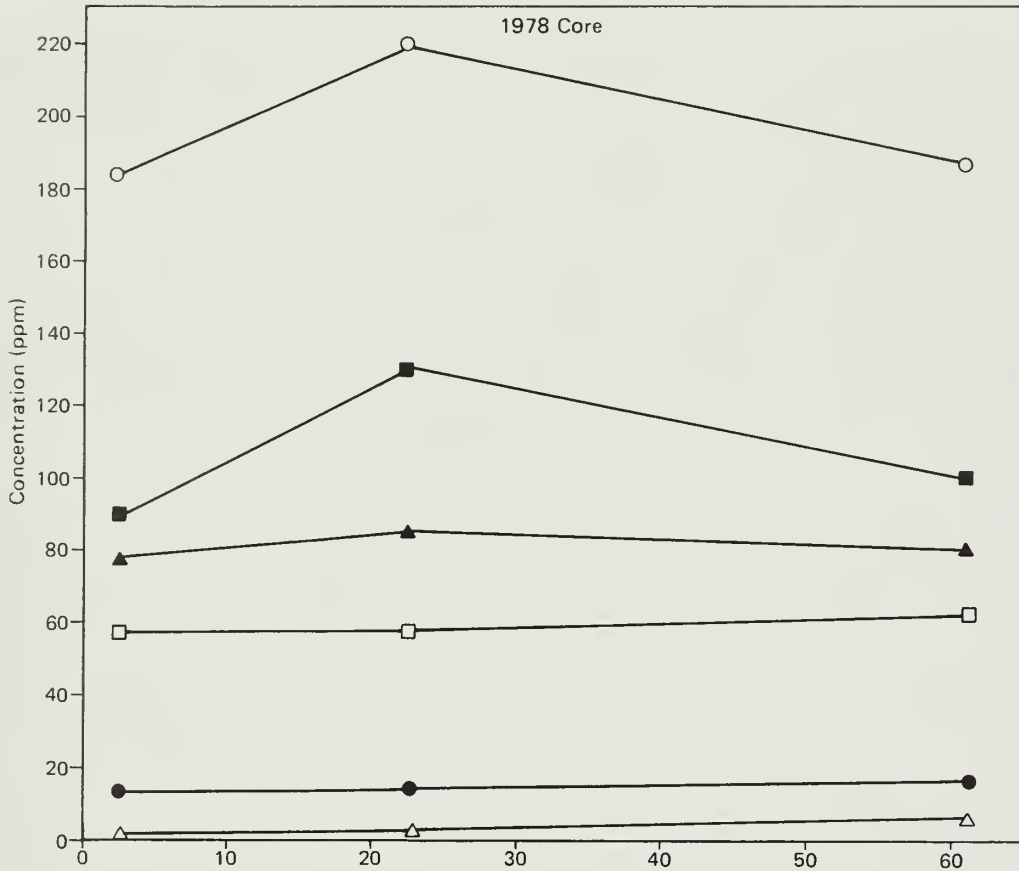


Figure 6 Arsenic, chromium, lead, antimony, zinc, and organic carbon distribution in Sawmill Lake. ISGS 1986

Lakes, because they are used for navigation, have routine channel dredging. Although this maintenance dredging results in a flow that is generally faster than that in the backwater lakes, it has not contributed significantly to the retention of lake capacity (Lee and Stall, 1977). The inorganic composition of the sediments of Peoria Lake has been determined by Mathis and Cummings (1971), Harrison et al. (1981), and Collinson and Shimp (1971). Figure 7 shows the location of the 5 cores from this study and the location of the cores collected and reported on by Collinson and Shimp (1971) and by Harrison et al. (1981). Sedimentation rates were also determined on the two cores collected in 1982. To use the composition data from the 1978 cores, we tried to collect samples in 1982 from approximately the same locations. Tables 8 and 9 compare results from the 1978 cores with those of Collinson and Shimp (1971) and of Harrison et al. (1981), respectively.

The sedimentation rates that were determined by radiometric analysis of the 1982 cores can be used to estimate the corresponding time interval for a particular sediment layer. The sampling locations in Upper Peoria Lake (fig. 7) for which sedimentation rates were determined by  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  are at miles 171 and 176. The measured rates were 1.7 to 2.0 cm per yr at mile 171 and 0.8 cm per yr at mile 176. The 0 to 5 cm interval represents sediment that was deposited since 1971 in both of the 1978 cores. The 20 to 25 cm interval in the cores represents sediment that was deposited between 1967 and 1964 at mile 171 and between 1954 and 1948 at mile 176. These dates are approximate because they are based on different cores. This information indicates that the lake is becoming cleaner with respect to Pb, Cd, and Zn and that the highest levels of these metals appear to have entered the lake prior to 1967. The highest levels of Pb in Upper Peoria Lake occur in the 1971 core at mile 169. The elevated levels of Pb may be due to the nearness of these sites to urban runoff associated with the city of Peoria.

Table 9 compares Peoria Lake channel samples that contain significantly more sand (Harrison et al., 1981) with 1978 cores that were collected away from the channel and contain predominately clay and silt-sized sediments. Cores from the Harrison et al. (1981) data are a composite of 0 to 60 cm interval; thus, any surface metal contamination would be missed. The core at 23B has high levels of Cd, Hg, Pb, and Zn; these high levels are surprising because the core was collected in the middle of the navigational channel where coarse sand and gravel would normally occur. This sample was described, however, as "clay to black ooze," high in organic carbon (Harrison et al., 1981). Trace elements such as Cd, Hg, Pb, and Zn have been shown to be positively correlated with clay-sized sediment and organic carbon and negatively correlated to coarse-sized sediment in Lake Michigan sediments (Cahill, 1981). The fine-grained, organic-rich sediment that was collected in core 23B would be expected to be removed from the channel during periods of high flow and by dredging activities needed to maintain the channel depth. Thus, the apparently anomalous correlation for this channel sample with Cd, Hg, Pb, and Zn is explained by the unusual composition of the sample.

Chemical analysis of subsamples from cores dated by  $^{137}\text{Cs}$  and  $^{210}\text{Pb}$  provided a more accurate picture of the history of metal input into Peoria Lake.

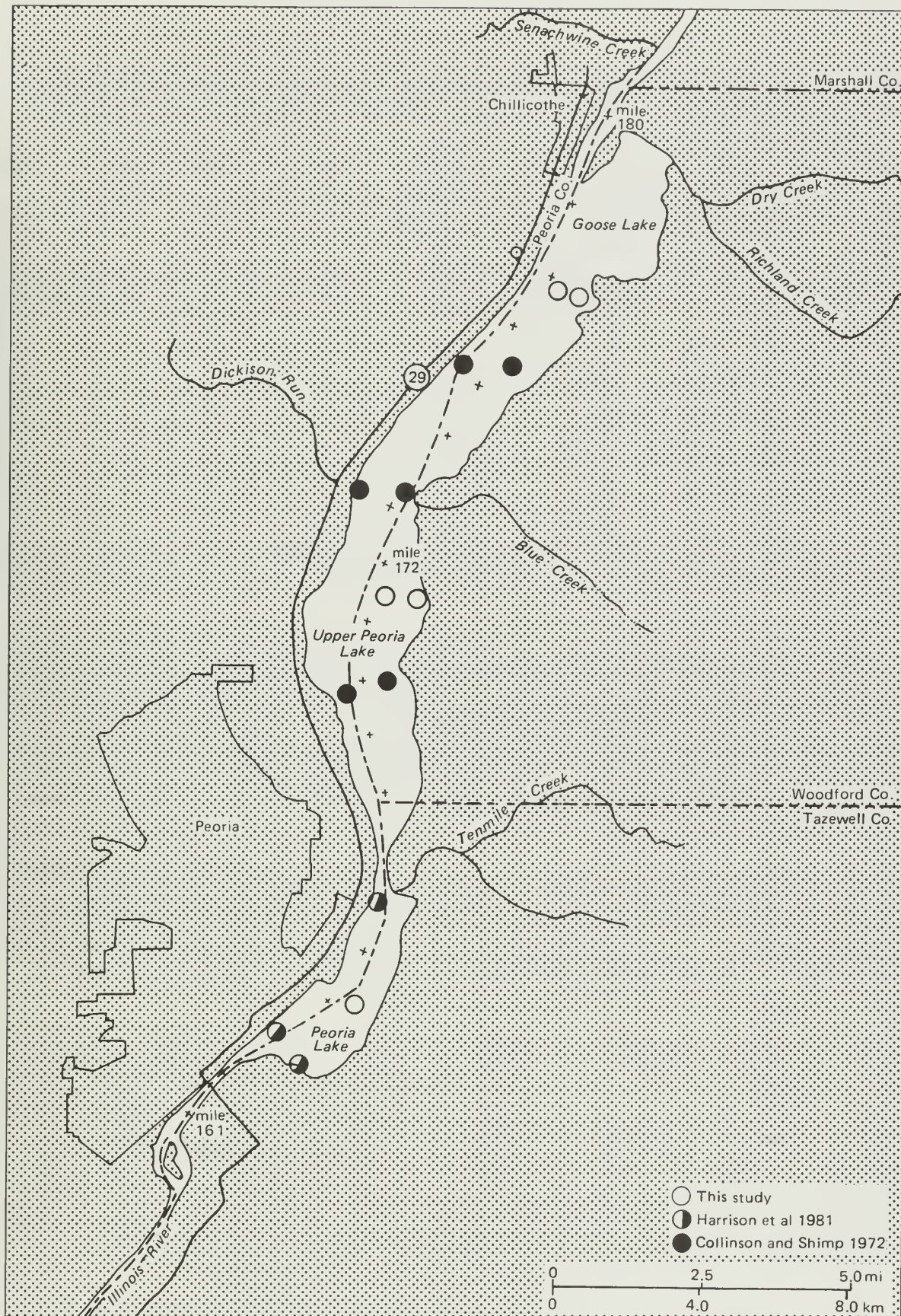


Figure 7  
Sampling locations in Peoria Lake.

Table 8. Comparison of As, Cd, Cr, Cu, Hg, Pb, and Zn results on sediment from Upper Peoria Lake sampled in 1971 and 1978. Concentrations in ppm.

| Station | 3         | 4    | 5    | 6    | 7    | 8    | IR51      | IR51  | IR52 | IR52  |
|---------|-----------|------|------|------|------|------|-----------|-------|------|-------|
| Depth   | 0-15      | 0-5  | 0-10 | 0-5  | 0-5  | 0-5  | 0-5       | 20-25 | 0-5  | 20-25 |
| Mile    | 175       | 175  | 173  | 173  | 169  | 169  | 171       | 171   | 176  | 176   |
|         | June 1971 |      |      |      |      |      | June 1978 |       |      |       |
| As      | 13        | 9    | 11   | 11   | 12   | 12   | 11        | 13    | 7    | 36    |
| Cd      | 8         | 9    | 9    | 9    | 5    | 11   | 3.8       | 9     | 4    | 4     |
| Cr      | 117       | 127  | 119  | 150  | 199  | 152  | 160       | 117   | 68   | 182   |
| Cu      | 48        | 62   | 59   | 55   | 72   | 82   | 58        | 74    | 25   | 101   |
| Hg      | 0.25      | 0.37 | 0.28 | 0.24 | 0.12 | 0.26 | 0.34      | 0.38  | 0.22 | 1.52  |
| Pb      | 123       | 132  | 130  | 131  | 176  | 198  | 64        | 73    | 51   | 120   |
| Zn      | 469       | 479  | 450  | 382  | 475  | 543  | 360       | 520   | 180  | 520   |

Source: 1971 data from Collinson and Shimp, 1972.

The chemical compositions of sediments from the 1982 cores were divided into time intervals on the basis of results for radiometric dating. The sedimentation rate used in the first core was 1.8 cm per yr and in the second core, 1.1 cm per yr. A constant sedimentation rate in the cores and no physical or biological mixing of the sediments was assumed. To allow for the complex flow of Peoria Lake and scouring and dredging near the main channel, we chose core sites relatively undisturbed by navigational activities, away from the main channel.

Bioturbation results in a uniform metal profile within a core because it mixes and homogenizes the sediment. Shell layers, which would indicate biological activity if the shells were the result of live organisms at that site, were noted in both cores. Radiometric tests of both sites indicated the metal profiles were not uniform; thus, any biological mixing that resulted from the clams was not considered significant.

In a study of fingernail clams in the Illinois River, Sparks, Sandusky, and Paparo (1981) noted that a major die-off occurred in the early 1950s. A population was known to survive near Spring Bay on Upper Peoria Lake near our site at mile 176. The porosity data, used in the radiometric dating of sediments, can also be used to indicate layers in a core where shells are present. The plots are shown in figure 8. The core at mile 171 indicates shell layers at 63 to 65 cm and 70 to 75 cm, which would be before the 1950 die-off. The core at mile 176 indicates at least four shell layers, the most recent deposited around 1975. This layer may be equivalent to the thick layer of shells observed in the 1978 core from near this site.

The concentrations of the elements As, Cd, Cr, Cu, Pb, Zn, and P<sub>2</sub>O<sub>5</sub> are shown in table 10 for the time intervals calculated from the sedimentation rate data. The highest levels of all these elements were found in the 1951-

Table 9. Comparison of chemical results on sediment in Peoria Lake sampled in 1978 and 1980. Concentrations in ppm.

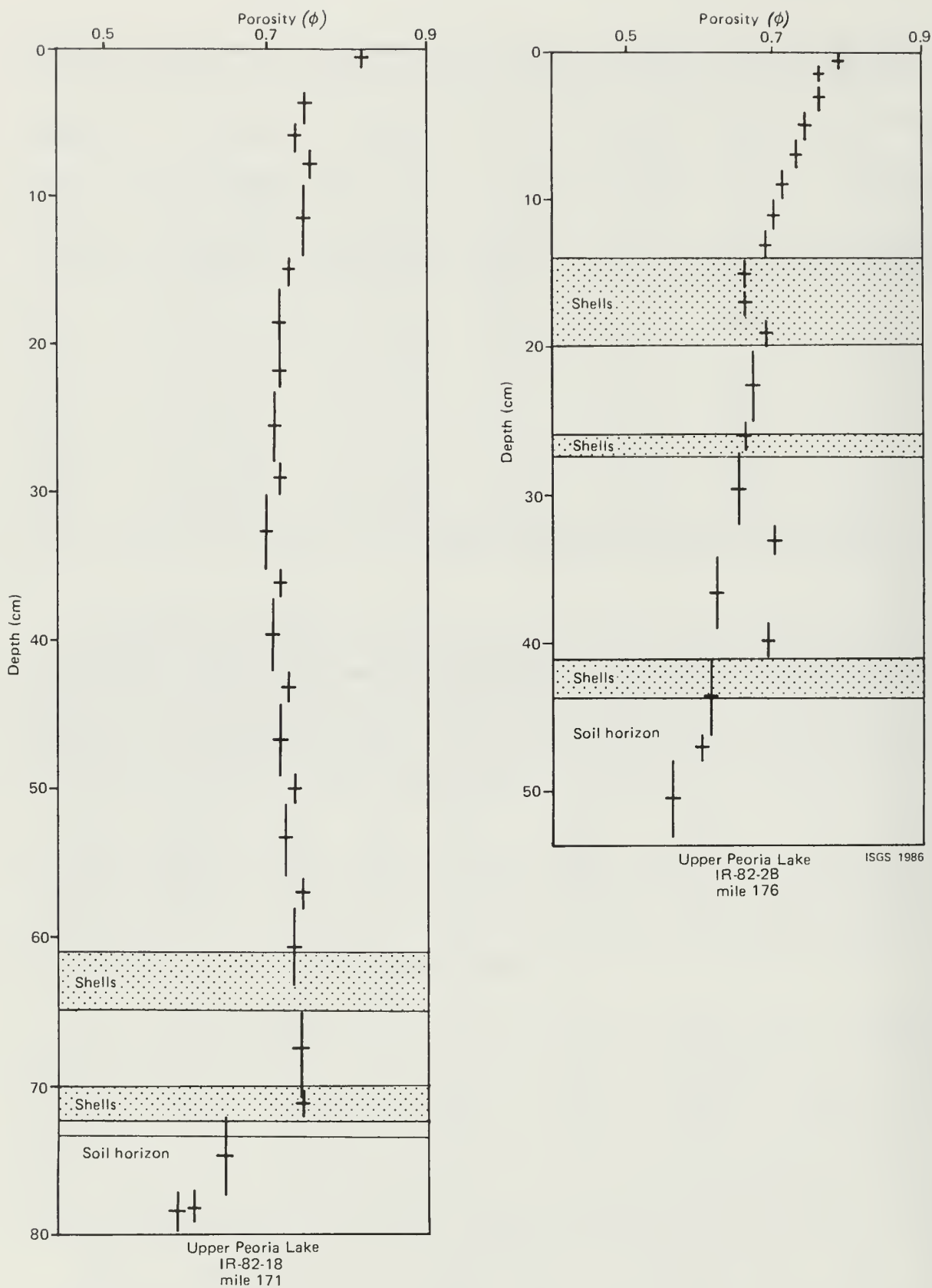
| Site         | 22    | 23A   | 23B   | IR50 | IR50  | IR50  |
|--------------|-------|-------|-------|------|-------|-------|
| Year Sampled | 1980  |       |       | 1978 |       |       |
| Mile         | 166.3 | 163.2 | 163.2 | 164  | 164   | 164   |
| Interval(cm) | 0-60  | 0-60  | 0-60  | 0-5  | 20-25 | 40-44 |
| As           | 1.0   | 14    | 24    | 12   | 18    | 4     |
| Cd           | 0.85  | 3.6   | 5.2   | 4.6  | <4    | <4    |
| Cr           | 29    | 120   | 50    | 164  | 117   | 82    |
| Cu           | 21    | 55    | 53    | 64   | 38    | 26    |
| Pb           | 12    | 70    | 120   | 72   | 68    | <46   |
| Hg           | 0.10  | 0.26  | 1.7   | 0.35 | 0.23  | 0.09  |
| Zn           | 97    | 320   | 403   | 400  | 300   | 130   |

Source: 1980 data from Harrison et al., 1981.

Table 10. As, Cd, Cr, Cu, Pb, Zn, and P<sub>2</sub>O<sub>5</sub> concentrations in Upper Peoria Lake in radiometric dated cores. (All values in ppm except where % noted.)

|                 | As   | Cd   | Cr  | Cu | Pb | Zn  | P <sub>2</sub> O <sub>5</sub> (%) |
|-----------------|------|------|-----|----|----|-----|-----------------------------------|
| River mile 171  |      |      |     |    |    |     |                                   |
| 1982-1978       | 11.2 | 2.2  | 134 | 66 | 57 | 258 | 0.34                              |
| 1977-1974       | 13.1 | 4.0  | 165 | 72 | 81 | 351 | 0.41                              |
| 1969-1951       | 14.6 | 7.3  | 182 | 78 | 89 | 436 | 0.57                              |
| River mile 176  |      |      |     |    |    |     |                                   |
| 1980-1973       | 12.5 | 2.5  | 133 | 59 | 66 | 281 | 0.44                              |
| 1969-1959       | 12.0 | 3.3  | 136 | 57 | 96 | 305 | 0.52                              |
| 1951-1946       | 15.1 | <0.9 | 122 | 47 | 51 | 273 | 0.27                              |
| 1939 (old soil) | 6.4  | <0.9 | 105 | 25 | 10 | 99  | 0.20                              |

1969 layer in the core at mile 171. The levels of Cd, Pb, Zn, and P<sub>2</sub>O<sub>5</sub> were highest in the 1959-1969 period in the core at mile 176. The highest level of As occurs earlier (approximately 1946-1951), and Cu is highest in the most recent layers. The background or natural levels of these elements is represented by the old soil horizon analyzed in the mile 176 core. For example, the results indicate that for Cd, the sediments are now about 3 times cleaner than older sediment layers. For the elements Pb, Zn, and P, the levels are



**Figure 8**  
Porosity relative to depth in Upper Peoria Lake cores collected in 1982.

about 60 percent lower today in the sediments than in the older layers. It is apparent that, in terms of sediment quality, Upper Peoria Lake is much cleaner now than it was 20 years ago. This is no doubt a result of such factors as the control of point source pollution, a decline in the industrial productivity in the area, reduced lead in gasoline, and a general overall improvement in the quality of the Illinois River. Of potential concern is that dredging of either Peoria Lake or Upper Peoria Lake could expose those sediments now safely out of the biologically active zone and release the metals and other trace organic contaminants contained in them into the water column.

### **Comparison of the Sediment Composition of the Lakes**

To compare the chemical composition of the sediments found in 18 lakes is difficult because of the variation in time and techniques used. Sampling of the lakes spanned 9 years; different coring, subsampling, and chemical procedures were used. Despite the difficulties in comparing the sediments, a comparison could provide valuable insights into regional differences and the impact of urban areas on those regions thought to be pristine.

The point source discharges into the Illinois waterway have been compiled by Jackson et al. (1981). Of the 60 sources noted on the Illinois Waterway, 48 of them occur above mile 158 at the Peoria Lock and Dam. The Metropolitan Sanitary District of Greater Chicago discharged 93 percent of all waste flow that enters the Upper Illinois River (Butts, Evans, and Lin, 1975). Of this discharge, 68 percent came from industrial sources; the rest, from municipal sources. The sediments of the upper sections of the river would be expected to contain higher levels of elements associated with these discharges, an expectation that has generally been confirmed by our findings.

For comparison, the cores were divided into three groups based on the relative depth of the sampling interval. The first group is made up of samples from the upper interval. This group is the most difficult to compare, not only because the uppermost sediment layers are fluid and easily lost during coring, but also because of changes in depth and composition. For instance, the surface interval collected in 1975 may be buried to a depth of 7 to 14 cm in a core collected in 1982. Moreover, changes in the way the land along the river is used control the source of sediment, so that different lithologies may be represented in this interval. At ten of the sites, an old soil horizon was collected under the lake deposits; samples from this interval make up the second group. The third group consists of the remaining sediment samples. The mean concentrations of the elements in these three groups were calculated for all samples and are summarized in table 11.

The elements As, Br, Cu, Hg, Ni, Pb, Sb, Zn, and P<sub>2</sub>O<sub>5</sub> are significantly higher in the upper interval than in the soil horizon. A significant difference is a ratio of greater than 1.5 when the upper interval concentration is divided by the concentration in the soil horizon. When the upper interval is divided by the older sediment, the ratios range from 1.0 to 1.4 for the same elements, the highest of which is for Cu. For most of the elements the ratio is approximately 1.0 when the upper interval is divided by either the soil horizon or the older lake sediments to normalize the data. This consistency of ratio indicates a uniform sediment composition. The elements that are significantly higher indicate anthropogenic sources.

Table 11. Average elemental composition of Illinois River backwater lake sediments by sampling interval. (All values are in ppm except where percent is indicated.)

| Element                            | Upper interval<br>(19) <sup>a</sup> | Soil horizon<br>(10) | Older lake sediment<br>(67) |
|------------------------------------|-------------------------------------|----------------------|-----------------------------|
| As                                 | 12.4                                | 5.5                  | 12.1                        |
| Br                                 | 6.2                                 | 3.8                  | 5.2                         |
| Ce                                 | 76.8                                | 80.7                 | 81.8                        |
| Co                                 | 15.0                                | 14.0                 | 15.7                        |
| Cr                                 | 151                                 | 123                  | 120                         |
| Cs                                 | 7.1                                 | 7.4                  | 7.5                         |
| Cu                                 | 81.0                                | 30.8                 | 59.4                        |
| Eu                                 | 1.4                                 | 1.5                  | 1.5                         |
| Ga                                 | 18.5                                | 18.2                 | 18.3                        |
| Hf                                 | 7.3                                 | 7.6                  | 7.3                         |
| Hg                                 | 0.4                                 | 0.08                 | 0.3                         |
| La                                 | 44.2                                | 44.2                 | 47.2                        |
| Lu                                 | 0.6                                 | 0.6                  | 0.6                         |
| Ni                                 | 52.4                                | 33.2                 | 48.7                        |
| Pb                                 | 84.1                                | 50.4                 | 66.4                        |
| Rb                                 | 156                                 | 158                  | 157                         |
| Sb                                 | 2.3                                 | 0.8                  | 2.0                         |
| Sc                                 | 14.6                                | 16.0                 | 14.8                        |
| Sm                                 | 7.2                                 | 8.0                  | 7.2                         |
| Ta                                 | 1.0                                 | 1.0                  | 0.9                         |
| Tb                                 | 1.5                                 | 1.8                  | 1.8                         |
| Th                                 | 12.2                                | 12.1                 | 13.5                        |
| Yb                                 | 3.1                                 | 3.3                  | 2.9                         |
| Zn                                 | 436                                 | 120                  | 327                         |
| SiO <sub>2</sub> (%)               | 56.9                                | 61.8                 | 57.6                        |
| Al <sub>2</sub> O <sub>3</sub> (%) | 13.3                                | 13.3                 | 13.3                        |
| Fe <sub>2</sub> O <sub>3</sub> (%) | 5.6                                 | 5.0                  | 5.8                         |
| MgO (%)                            | 2.1                                 | 1.4                  | 1.9                         |
| CaO (%)                            | 3.4                                 | 1.4                  | 3.7                         |
| Na <sub>2</sub> O (%)              | 0.59                                | 0.62                 | 0.60                        |
| K <sub>2</sub> O (%)               | 2.3                                 | 2.4                  | 2.3                         |
| TiO <sub>2</sub> (%)               | 0.7                                 | 0.7                  | 0.7                         |
| P <sub>2</sub> O <sub>5</sub> (%)  | 0.54                                | 0.21                 | 0.43                        |
| MnO (%)                            | 0.09                                | 0.05                 | 0.08                        |
| Org. C (%)                         | 2.84                                | 2.95                 | 2.52                        |

<sup>a</sup> (n) = number of subsamples.



The ratios of the upper interval to the lowest interval in each core that was considered lake sediment were calculated for individual lakes for the elements As, Cr, Hg, Pb, Sb, and Zn. The ratios or enrichment factors are summarized in table 12. The ratios are highly variable. They range from 0.2 to 3.9 for As, 0.6 to 2.0 for Cr, 0.2 to 5.2 for Hg, 0.4 to 16.5 for Pb, 0.3 to 36 for Sb, and 0.7 to 14.3 for Zn. The two 1975 cores from Depue and Sawmill Lakes have higher ratios than the cores collected in 1978 from the same lakes. Ratios do not seem to correlate with location. The lakes in the upper Illinois River might be expected to have higher trace element levels, and therefore, higher ratios because they are closer to the Chicago area. However, if the levels of a metal were uniformly low or high throughout a core, then the ratio would be near 1.0 in either case. A ratio lower than 1.0 indicates that the most recent sediments are "cleaner" in terms of that particular element than the older sediments. Conversely, a ratio higher than 1.0 indicates an increase of that element in more recent sediments.

Using the three intervals previously defined, the lakes were compared graphically. Figures 4a-4g (appendix 4) are plots of the concentrations of Al, As, Cr, Pb, P<sub>2</sub>O<sub>5</sub>, Zn, and organic C in the three sediment intervals as a function of position along the Illinois River.

The distribution for Al was uniform as a function of depth and position along the Illinois River except for the sample at Brandon Road Pool. This site had high levels of organic carbon (12%), which tended to physically dilute the Al content. The predominance of silt and clay-sized sediment accounts for the uniform nature of the Al distribution. In all cases, the concentration is lower in the soil horizon than in the middle or the top of the sediment cores.

The levels of As are relatively uniform in terms of distance along the Illinois River, except in Sawmill Lake and at Brandon Road Pool where they are high. The middle of the core often had higher levels of As than the top of the core, a fact that indicates a reduction of the As input in the sediments.

The Cr distribution is uniform in the lower 140 miles of the Illinois River. In the upper section of the river, the Cr levels are higher than the soil horizon, which is also higher than the lower sections of the river. The highest Cr levels are at the Brandon Road Pool site.

The Pb levels are higher in the upper sections of the river, and in most cases, the levels are uniform within a given core. In five lakes the Pb levels are higher in the older lake sediments, which indicates a reduction of Pb input.

The P<sub>2</sub>O<sub>5</sub> levels generally are higher in the upper section of the river and often at the top of the cores. The P<sub>2</sub>O<sub>5</sub> content varies in the soil horizons with higher levels occurring in the soil in the upper section of the Illinois River.

The Zn levels are clearly much higher in the upper sections of the river, and the composition of the lake sediments is generally uniform in the cores. In most cases, the levels of Zn are enriched over soil concentrations. The levels of Zn in Depue Lake and Brandon Road Pool are dramatically high.

Table 12. Sediment enrichment factors for backwater lakes along the Illinois River.

|                     | River<br>mile | Elements |     |     |      |     |      |
|---------------------|---------------|----------|-----|-----|------|-----|------|
|                     |               | As       | Cr  | Hg  | Pb   | Sb  | Zn   |
| Silver Lake         | 3             | 1.0      | 1.0 | 3.8 | 0.8  | 1.8 | 1.0  |
| Swan Lake           | 7             | 1.0      | 0.9 |     | 1.0  | 0.8 | 1.0  |
| Meredosia Lake      | 73            | 1.2      | 1.1 | 1.4 | 1.0  | 0.9 | 1.1  |
| Meredosia Lake      | 74            | 1.3      | 1.0 | 1.4 | 1.4  | 1.2 | 1.2  |
| Muscooten Bay       | 90            | 0.9      | 1.1 | 1.4 | 1.0  | 1.2 | 0.9  |
| Stewart Lake        | 102           | 1.0      | 1.0 | 1.5 | 1.3  | 0.7 | 1.2  |
| Matanzas Lake       | 116           | 0.9      | 0.9 | 1.3 | 1.4  | 0.8 | 1.2  |
| Quiver Lake         | 123           | 0.4      | 0.6 | 0.5 | 1.0  | 0.4 | 0.7  |
| Lake Chautauqua     | 125           | 0.8      | 1.3 | 0.2 | 1.0  | 0.6 | 0.9  |
| Clear Lake          | 131           | 0.9      | 0.9 | 1.2 | 1.0  | 0.9 | 1.2  |
| Peoria Lake         | 164           | 0.7      | 1.4 | 1.5 | 1.0  | 1.0 | 1.3  |
| Upper Peoria Lake   | 171           | 0.8      | 1.4 | 0.9 | 0.9  | 1.5 | 0.7  |
| Upper Peoria Lake   | 176           | 0.2      | 0.4 | 0.2 | 0.4  | 0.3 | 1.0  |
| Meadow Lake         | 184           | 0.4      | 0.9 | 0.2 | 0.8  | 0.7 | 0.8  |
| Goose Lake          | 191           | 0.7      | 1.0 | 0.7 | 1.0  | 0.6 | 0.9  |
| Sawmill Lake (1975) | 198           | 3.9      | 1.7 | 5.2 | 16.5 | 36  | 2.0  |
| Sawmill Lake (1978) | 198           | 0.9      | 1.0 | 1.0 | 1.0  | 0.6 | 0.9  |
| Senachwine Lake     | 201           | 1.0      | 1.1 | 1.2 | 1.0  | 0.9 | 1.1  |
| Depue Lake (1975)   | 212           | 1.6      | 1.3 | 2.0 | 3.3  | 1.8 | 14.3 |
| Depue Lake (1978)   | 212           | 0.9      | 1.2 | 1.6 | 0.8  | 1.0 | 1.9  |
| Depue Lake (1982)   | 212           | 1.2      | 2.0 | 1.3 | 1.3  | 1.8 | 1.9  |
| Turner Lake         | 216           | 1.0      | 0.8 | 0.8 | 0.7  | 0.9 | 0.7  |
| Brandon Road Pool   | 286           | 1.5      | 1.0 | 1.3 | 0.8  | 0.9 | 1.0  |

The organic carbon content of the lake sediments shows a modest increase as a function of river mile with very high levels occurring at the Brandon Road Pool site. The soil concentrations vary considerably. This variation may be due partly to plant materials that were included in the analysis.

The Illinois backwater lake samples were divided into three groups on the basis of their locations and calculated mean concentrations. Table 13 shows the results and the mean level of sediments from two areas of the Mississippi

River (Cahill and Autrey, 1985). The concentrations of Cd, Cr, Cu, Ni, Pb, Sb, Zn, and P<sub>2</sub>O<sub>5</sub> are significantly higher in the middle Illinois River than in either the lower Illinois River or the Mississippi River sediments. The concentrations of these same elements are very high in the upper Illinois River sites. The concentrations of As, Ba, Co, Ga, Sc, Th, Al<sub>2</sub>O<sub>3</sub> and organic C are relatively uniform. The higher levels of SiO<sub>2</sub> in the Mississippi and lower Illinois River sites result from their higher sand-sized sediment content.

Table 13. Comparison of selected mean sediment concentrations. All values in ppm unless otherwise noted.

| Element                            | Mississippi River            |                             | Illinois River             |                             |                            |
|------------------------------------|------------------------------|-----------------------------|----------------------------|-----------------------------|----------------------------|
|                                    | Pool 19<br>(22) <sup>e</sup> | Pool 26 <sup>a</sup><br>(6) | Lower <sup>b</sup><br>(10) | Middle <sup>c</sup><br>(94) | Upper <sup>d</sup><br>(16) |
| As                                 | 7.8                          | 9.1                         | 9.9                        | 12.4                        | 15.3                       |
| Ba                                 | 808                          | 728                         | 750                        | 568                         | 290                        |
| Cd                                 | <1.6                         | <1.3                        | <1.2                       | 2.8                         | 37                         |
| Co                                 | 12                           | 12                          | 14                         | 13                          | 19                         |
| Cr                                 | 76                           | 78                          | 84                         | 105                         | 252                        |
| Cu                                 | 24                           | 24                          | 33                         | 46                          | 150                        |
| Ga                                 | 15                           | 14                          | 18                         | 19                          | 18                         |
| Hg                                 | --                           | --                          | --                         | 0.28                        | 0.73                       |
| Ni                                 | 18                           | 26                          | 29                         | 40                          | 87                         |
| Pb                                 | 24                           | 31                          | 36                         | 57                          | 195                        |
| Sb                                 | 0.9                          | 0.9                         | 1.2                        | 2.1                         | 4.2                        |
| Sc                                 | 10                           | 10                          | 13                         | 15                          | 15                         |
| Th                                 | 11                           | 9                           | 11                         | 13                          | 12                         |
| Zn                                 | 117                          | 113                         | 138                        | 211                         | 2285                       |
| Org. C (%)                         | 2.1                          | 1.4                         | 1.7                        | 2.4                         | 4.5                        |
| P <sub>2</sub> O <sub>5</sub> (%)  | 0.22                         | 0.23                        | 0.28                       | 0.36                        | 0.88                       |
| Al <sub>2</sub> O <sub>3</sub> (%) | 11.9                         | 14.2                        | 16.1                       | 13.7                        | 14.0                       |
| SiO <sub>2</sub> (%)               | 67.9                         | 69.0                        | 62.9                       | 58.9                        | 53.9                       |

<sup>a</sup> Only samples collected on the Mississippi River included.

<sup>b</sup> Silver and Swan Lakes, lower Illinois River.

<sup>c</sup> Results from sampling of 18 lakes along length of Illinois River.

<sup>d</sup> Samples from Depue Lake and Brandon Road Pool excluded from mean of column 4.

<sup>e</sup> (n) = number of samples used to calculate mean.

Harrison et al. (1981) sampled the sediments of the river channel from mile 319 to mile 121. Concentrations of 11 trace metals were determined. Most samples consisted of fine sand to gravel and contained low levels of metals. Samples at site 11 (mile 281), site 13 (mile 274), site 23A (mile 163), and site 28B (mile 121) were collected off the main river channel in areas that contained silts or clay-sized sediments and higher levels of metals. These four sites had the following ranges of metal concentrations expressed in ppm: As, 2-14; Cd, 0.4-49; Cr, 28-290; Cu, 20-570; Pb, 25-380; Hg, 0.3-1.8; and Zn, 115-1690. The highest levels of metals consistently occurred at site 13 in amounts comparable to those in our sample at mile 286. Levels of metals reported at their downstream site are comparable to concentrations observed in samples from Quiver Lake (mile 123).

### Statistical Analysis

Interelemental correlations were determined by using a standard correlation and cluster program as adapted from Davis (1973). Selected correlations observed in Illinois River backwater lakes sediments are listed in table 14. Organic carbon, Cu, Pb, Zn, and clay-sized sediments were factors chosen for discussion. Clay-sized sediment and organic carbon often control the distribution of trace metals. Copper, Pb, and Zn--prevalent anthropogenic elements--are useful tracers of man's impact on the Illinois River.

The mineralogy of the clay-sized fraction of Illinois River backwater sediments has not been determined. Sly and Thomas (1974) related the bulk mineralogical compositions of sediments to their major-element compositions in Great Lakes sediments. They found that the clay minerals illite and chlorite correlated with  $Al_2O_3$ ,  $TiO_2$ ,  $K_2O$ , and  $MgO$ . Quartz and feldspar correlated with  $Na_2O$  and  $SiO_2$  respectively.

Clay-sized sediments correlated positively with the major elements Al, Fe, Mg, Ti, and P at the 95 percent confidence level. This is indirect evidence that clay minerals make up a significant portion of the clay-sized sediments. A direct measurement of the mineral compositions of the Illinois River sediments would help to predict the ability of the sediments to trap trace metals.

Organic carbon has a high correlation with the trace elements Br, Cd, Co, Cr, Cu, Hg, Ni, Pb, and Zn. Organic carbon does not correlate well with any of the three grain-size classes, or with most of the major elements except Mg and P. Organic carbon may occur as coating on silt and clay-sized sediments and be acting as the site for adsorption of trace elements.

Copper, Pb, and Zn have high correlations with many trace elements. These correlations may indicate either a common source for some elements or a similarity of their chemical properties.

A Parks cluster analysis program used by Hopke (1976) and Cahill (1981) to group sediment samples was used to investigate the groupings of the elements studied and also to group the sediment samples. The measure of similarity used to make the groupings was the correlation coefficient. The results of clustering the elements are summarized in table 15.

Table 14. Selected correlations observed in Illinois River backwater lake sediments.

| Element                        | Clay  | Org. C | Cu    | Pb    | Zn    |
|--------------------------------|-------|--------|-------|-------|-------|
| SiO <sub>2</sub>               | 0.11  | -0.61  | -0.67 | -0.47 | -0.21 |
| Al <sub>2</sub> O <sub>5</sub> | 0.54  | -0.11  | -0.28 | -0.12 | 0.11  |
| Fe <sub>2</sub> O <sub>3</sub> | 0.29  | -0.38  | 0.34  | 0.29  | 0.25  |
| MgO                            | 0.62  | 0.63   | 0.74  | 0.60  | 0.45  |
| CaO                            | -0.14 | 0.20   | 0.22  | 0.17  | 0.06  |
| Na <sub>2</sub> O              | -0.02 | -0.41  | -0.28 | -0.26 | -0.25 |
| K <sub>2</sub> O               | 0.26  | 0.14   | -0.03 | 0.10  | 0.20  |
| TiO <sub>2</sub>               | 0.37  | -0.33  | -0.40 | -0.28 | -0.01 |
| P <sub>2</sub> O <sub>5</sub>  | 0.57  | 0.65   | 0.78  | 0.64  | 0.57  |
| MnO                            | 0.10  | 0.18   | 0.22  | 0.18  | 0.14  |
| As                             | -0.01 | 0.31   | 0.41  | 0.50  | 0.26  |
| Ba                             | 0.51  | 0.12   | -0.01 | -0.06 | 0.07  |
| Br                             | 0.27  | 0.46   | 0.44  | 0.33  | 0.34  |
| Cd                             | -0.94 | 0.47   | 0.63  | 0.57  | 0.82  |
| Ce                             | 0.40  | -0.25  | -0.35 | -0.27 | -0.04 |
| Co                             | -0.74 | 0.49   | 0.55  | 0.45  | 0.37  |
| Cr                             | 0.35  | 0.74   | 0.96  | 0.82  | 0.53  |
| Cs                             | 0.56  | -0.01  | -0.17 | -0.05 | 0.19  |
| Cu                             | 0.40  | 0.80   |       | 0.88  | 0.55  |
| Eu                             | 0.16  | -0.28  | -0.45 | -0.26 | -0.02 |
| Ga                             | 0.11  | -0.16  | -0.22 | -0.18 | -0.02 |
| Hf                             | 0.33  | -0.41  | -0.30 | -0.28 | -0.17 |
| Hg                             | -0.09 | 0.69   | 0.81  | 0.76  | 0.41  |
| La                             | 0.49  | -0.29  | -0.34 | -0.19 | 0.05  |
| Lu                             | 0.12  | -0.11  | -0.29 | -0.20 | 0.02  |
| Ni                             | -0.44 | 0.71   | 0.91  | 0.74  | 0.38  |
| Pb                             | -0.89 | 0.70   | 0.88  |       | 0.46  |
| Rb                             | 0.61  | -0.07  | -0.23 | -0.08 | 0.17  |
| Sb                             | -0.03 | 0.32   | 0.39  | 0.76  | 0.18  |
| Sc                             | 0.40  | -0.12  | -0.27 | -0.18 | 0.07  |
| Sm                             | 0.07  | -0.30  | -0.40 | -0.30 | -0.04 |
| Ta                             | -0.45 | -0.20  | -0.15 | -0.17 | -0.11 |
| Tb                             | 0.01  | -0.28  | -0.28 | -0.22 | -0.10 |
| Th                             | 0.64  | -0.28  | -0.37 | -0.27 | -0.02 |
| Yb                             | -0.29 | -0.20  | -0.18 | -0.21 | -0.03 |
| Zn                             | -0.25 | 0.43   | 0.55  | 0.46  |       |
| Sand                           | 0.10  | 0.17   | -0.79 | -0.23 | -0.64 |
| Silt                           | -0.99 | 0.19   | -0.15 | 0.90  | 0.32  |
| Clay                           |       | -0.21  | 0.40  | -0.89 | -0.25 |
| Org. C                         | -0.21 |        | 0.80  | 0.76  | 0.43  |

Table 15. Cluster analysis of elements in Illinois River backwater lake sediments.

| Cluster | Elements   | Source        | Association                          |
|---------|--|---------------|--------------------------------------|
| Ia      | Cr, Cu, Ni, Pb, P, C,<br>Org. C, Mg, Co, As,<br>Hg, Br, Sb                           | Anthropogenic | Organic<br>carbon<br>coatings        |
| Ib      | Cd, Zn, silt   | Anthropogenic | Silt-sized                           |
| Ic      | Ca, In. C, sand  | Soil erosion  | Sand-sized<br>and shell<br>fragments |
| IIa     | Si, Na, Hf   | Soil erosion  | Uncertain                            |
| IIb     | Lu, Yb, Ta, Ba, clay,<br>Al, Ti, K, Sm, Ce, Th,<br>Rb, Sc, Cs, Eu, La,<br>Tb, Fe, Ga | Soil erosion  | Clay-sized<br>sediments              |

The elements clustered into two broad groups based primarily on the grain size of the sediment. The two broad groups were then subdivided. The elements in clusters Ia and Ib are of anthropogenic origin. Elements in cluster Ia are strongly associated with organic carbon, independent of grain size. In contrast Cd and Zn have a strong association with silt-sized sediments. This cluster is also controlled by the high concentration of these two elements in Depue Lake and Brandon Road Pool. Inorganic carbon, Ca, and sand-sized sediments are grouped in a single cluster. Shell fragments of sand and larger sizes were noted at a number of sample locations. The second broad cluster is subdivided into two subgroups associated with normal crustal weathering. Cluster IIa is made up of Si, Na, and Hf. Their association is unexpected because these elements are usually associated with the lithophile elements in cluster IIb. This association may be an artifact of the statistical procedure, but Cahill (1981) observed a similar association in sediments in Lake Michigan. In that case, sodium was attributed to road salt; Si, with quartz and diatoms; and Hf, with resistant heavy minerals. Perhaps the same explanation is true here as well. In cluster IIb, 18 elements are associated with clay-size sediments derived largely from soil erosion and composed predominately of clay minerals.

A cluster analysis based on the constituents Al, As, Cr, Hg, La, Pb, and Zn was used to separate the samples into three clear groupings. Depue Lake and Brandon Road Pool sediments formed two distinct clusters; the remaining samples, which were chemically similar, made up a single cluster.

Table 16. Summary of sedimentation rates determined by  $^{137}\text{Cesium}$  radiometric dating.

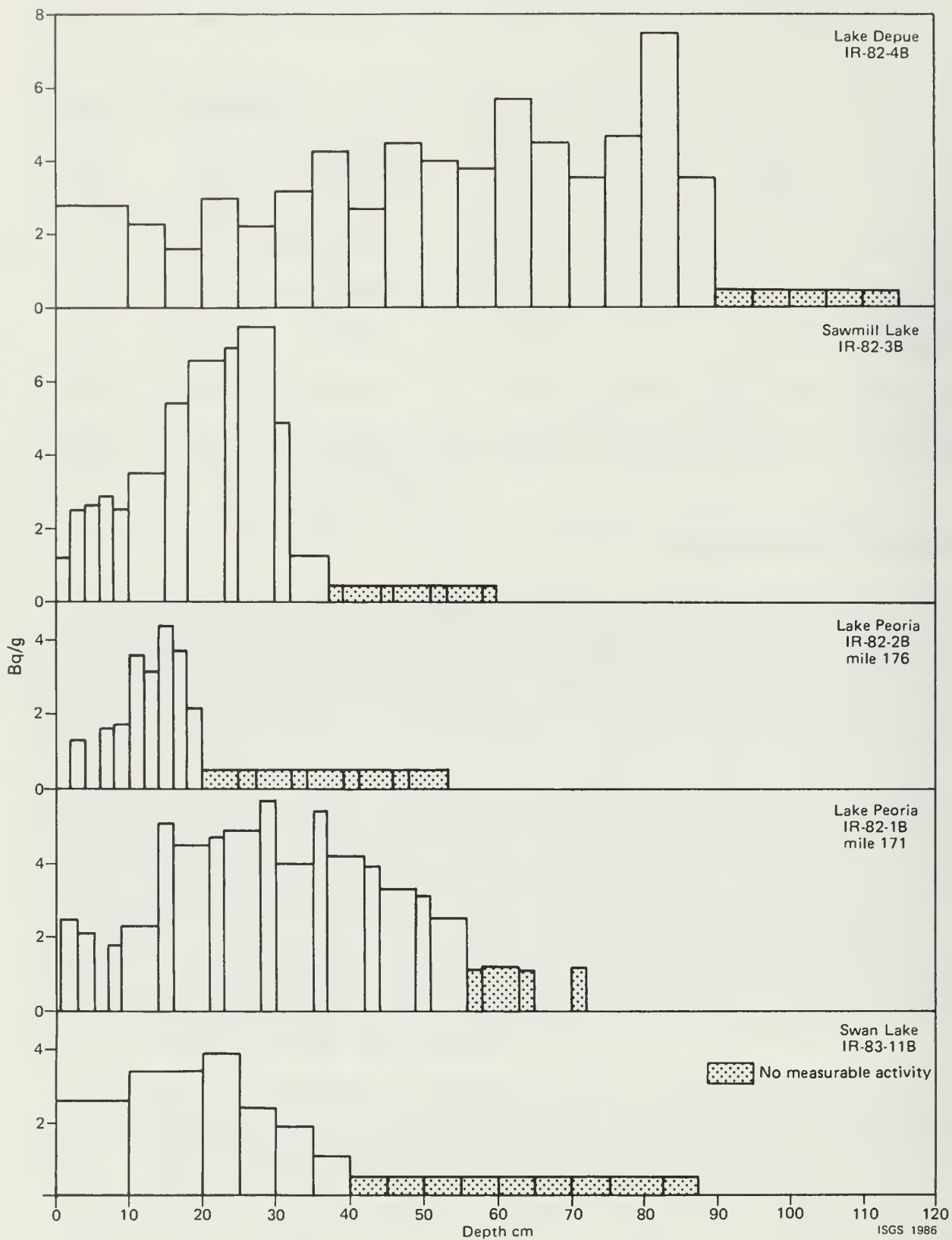
|                              | Number sub-samples | Max. activity (Bq/g) | Depth of max. activity (cm) | Depth of no activity (cm) | Sedimentation Rates  |                      |
|------------------------------|--------------------|----------------------|-----------------------------|---------------------------|----------------------|----------------------|
|                              |                    |                      |                             |                           | 1963 to date (cm/yr) | 1954 to date (cm/yr) |
| Depue Lake                   | 22                 | 75                   | 80-85                       | 90-95                     | 3-4                  | 3.1                  |
| Sawmill Lake                 | 25                 | 76                   | 25-30                       | 37-39                     | 1.4                  | 1.4                  |
| Upper Peoria Lake (mile 171) | 26                 | 57                   | 28-30                       | 56-58                     | 1.5-1.9              | 2.0                  |
| Upper Peoria Lake (Mile 176) | 20                 | 44                   | 14-16                       | 20-25                     | 0.8                  | 0.7                  |
| Swan Lake                    | 16                 | 39                   | 20-25                       | 40-45                     | 1.2                  | 1.4                  |

### Sedimentation Rates Results

The  $^{137}\text{Cs}$  results for five cores are shown graphically in figure 9, and the data are summarized in table 16. Sedimentation rates obtained for Swan and Sawmill Lakes are in good agreement with the long-term sedimentation rates determined by Bellrose et al. (1983). In general, the reported rates from 1954 or 1963 to date are in agreement. Differences between reported rates may be the result either of a change in the sedimentation rate or variation in the subsampling of the cores.

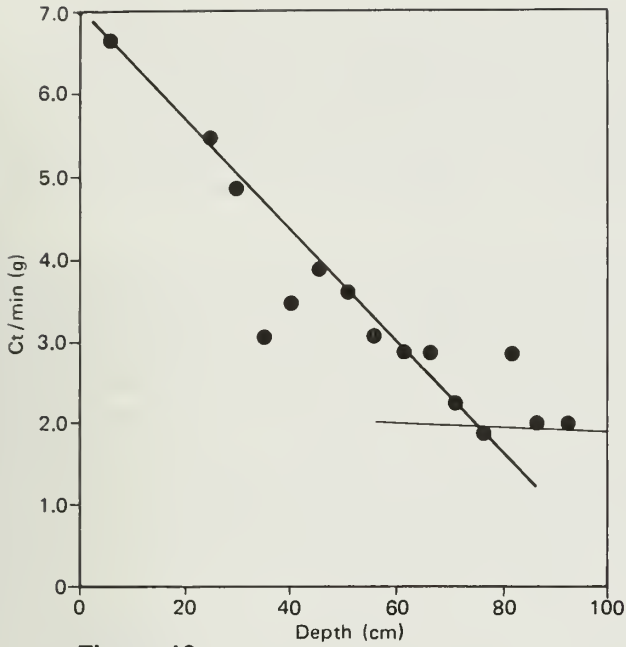
$^{210}\text{Pb}$  profiles were measured at four locations. The samples are splits of the same cores used for  $^{137}\text{Cs}$  dating. The profile for Swan Lake (fig. 10) yields a sedimentation rate of 1.2 cm/yr, which agrees with that obtained by the  $^{137}\text{Cs}$ . Periods of flooding may be indicated at 30 to 40 cm where lower activity is observed. The  $^{210}\text{Pb}$  profile (fig. 11) is from Upper Peoria Lake at mile 171. The sedimentation rate estimated from the best-fit line was 1.7 cm/yr. The sediment intervals between 1 to 9 cm have low levels of  $^{210}\text{Pb}$ , which indicate recent flood deposits or resuspended sediment with low  $^{210}\text{Pb}$  activity. The sedimentation rate determined by the  $^{210}\text{Pb}$  procedure in Sawmill Lake was 1.7 cm/yr. The value is higher than the 1.4 cm/yr obtained by the  $^{137}\text{Cs}$  procedure or the 1.1 cm/yr obtained by Bellrose et al. (1983).

The disagreement between the two radiometric techniques is, however, one way of measuring the precision that can be expected in the estimation of sedimentation rates by radiometric techniques. In the case of Sawmill Lake the agreement is within 20 percent, which is very good because of the difficulty in fulfilling the requirements for optimal sediment dating. In the case of Depue Lake (fig. 12), no sedimentation rate could be determined using the  $^{210}\text{Pb}$  procedure. The entire core displays nearly constant  $^{210}\text{Pb}$  activity with no radioactive decay as shown in the Swan or Upper Peoria lakes. Depue Lake is not receiving a significantly high input of excess  $^{210}\text{Pb}$  from direct

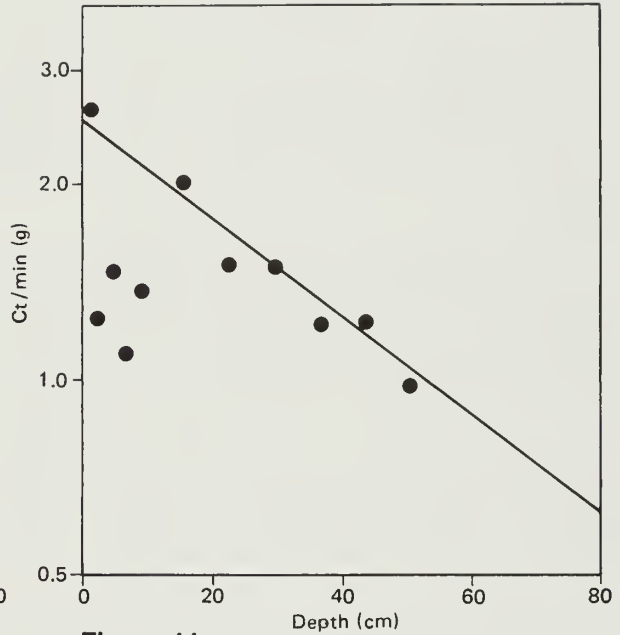


**Figure 9**  
<sup>137</sup>Cs profiles at four locations along the Illinois River.

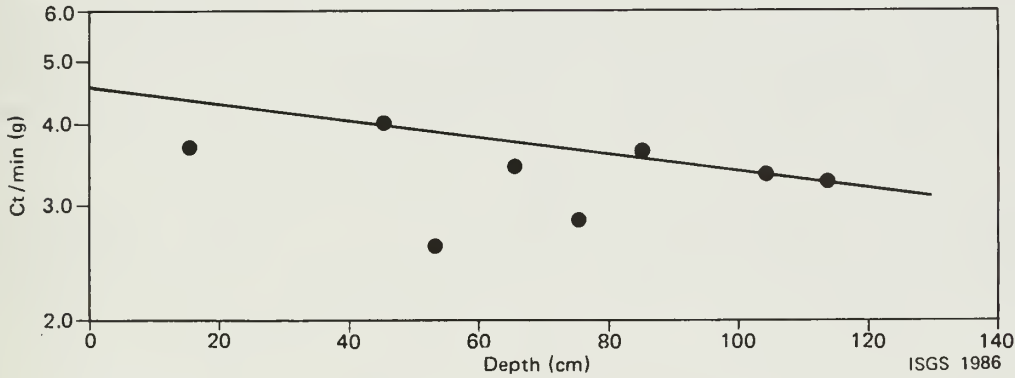




**Figure 10**  
<sup>210</sup>Pb profile, Swan Lake.



**Figure 11**  
<sup>210</sup>Pb profile, Upper Peoria Lake.



**Figure 12**  
<sup>210</sup>Pb profile, Depue Lake.

atmospheric deposition to overcome the dilution effects of background, or supported <sup>210</sup>Pb activity of the sediment entering the lake. A second factor is physical or biological mixing of the sediment that would homogenize the <sup>210</sup>Pb activity and remove any surface enrichments. The <sup>137</sup>Cs determined sedimentation rate was 3 cm/yr in Depue Lake, which is significantly higher than the 1.5 cm/yr reported by Lee and Stall (1977). The <sup>137</sup>Cs profile may have been displaced downward by physical or biological mixing which would result in an overestimate of the sedimentation rate. Lee and Stall's estimate is also a lake-wide average and it is very possible that concentrations at our core location in the center of a basin would be higher than the lake-wide average. The <sup>210</sup>Pb profile and the poorly defined <sup>137</sup>Cs 1963 peak demonstrate that it is difficult to use radiometric techniques at all locations and that some independent cross-check is important with these techniques.

We have found that the way sediment cores are subsampled is the most critical aspect of  $^{210}\text{Pb}$  or  $^{137}\text{Cs}$  dating. If nonrepresentative subsamples are taken, an inaccurate time record results. It is not always practical to collect as many subsamples as needed within one core to define the peak activity or lead decay curve. For example, if a lake has a sedimentation rate of 1 cm/yr, a minimum of 35, 1-cm subsamples are required to establish precisely the  $^{137}\text{Cs}$  activity profile.

A direct comparison of radiometric dating and the traditional approaches of Bellrose et al. (1983) and Lee (1985) is not always appropriate because differences in techniques may be reflected in the results. For example, the rates determined by radiometric dating are based on single cores that are usually collected in the center of a lake. Traditional sedimentation rates, on the other hand, are lake-wide averages. The two procedures are most likely to agree in lakes that have simple geometries and bottom topographies, which is the case for many of the backwater lakes along the Illinois River. Sediment focusing in lakes of complicated bottom topographies is known to occur and results in higher sedimentation rates in deeper areas of a lake.

In Swan Lake the reported sedimentation rates determined by traditional methods were 0.85 and 0.46 cm/yr, which represent the average since 1903. The rates obtained by  $^{137}\text{Cs}$  indicate that the rates from 1954 or 1965 to date were 1.4 to 1.2 cm/yr. This implies that the sedimentation rate has increased in Swan Lake to as much as three times more than the long-term average, at least at the location where the core was collected. In the case of Sawmill Lake the long-term rates were 1.19 and 1.11 cm/yr, while the  $^{137}\text{Cs}$  rate from 1963 or 1954 to date is 1.4 cm/yr. In this case the sedimentation rates are probably not significantly different. The cores in Peoria Lake exhibit a wide range of sedimentation rates and site-specific sedimentation rates would not be expected to agree with lake-wide averages. The long-term rates range from 1.0 to 1.7 cm/yr; the rates from  $^{137}\text{Cs}$  range from 0.7 to 2.0 cm/yr. The 3.06 cm/yr sedimentation rate reported by Bellrose et al. in Peoria Lake for the period 1963-1976 was not confirmed at the two coring sites in this study.

## SUMMARY

Twenty-seven cores from 18 backwater lakes associated with the Illinois River have been analyzed in the first truly comprehensive study of sediments from these lakes. The cores were collected from a wide variety of locations, ranging from an urban area above the Brandon Road Pool lock and dam at mile 286 to the rural setting of Silver Lake at mile 3 near the junction of the Illinois and Mississippi Rivers.

Sediments were analyzed for up to 40 chemical elements and grain size. When the results were grouped by region, the upper Illinois River was found to have high levels of As, Cd, Cr, Hg, Pb, Sb, Zn,  $\text{P}_2\text{O}_5$ , and organic C. These elements are associated with anthropogenic activities of the urban areas near Chicago. The sediments in the lower Illinois River had low levels of the same metals and compositions comparable to those of sediments of the Mississippi River.

The analysis of cores provided a historical perspective of the input of metals into the sediment of lakes associated with the Illinois River. The recently deposited sediments of the upper intervals of the cores often had lower concentrations than the middle sections of the cores for elements associated with anthropogenic activities. This association can be observed in appendix 4, or in table 12.

The feasibility of measuring sedimentation rates by  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  has been demonstrated. The sedimentation rates determined indicate that sedimentation rates in Peoria Sawmill Lakes have not increased in the last 30 years compared to long-term averages. In contrast, the sedimentation rates in Swan and Depue lakes have increased by as much as a factor of 3 over long-term averages.

This study provides an effective methodology that should be used in making informed decisions in the management of the Illinois River as a natural resource. For the future management of the backwater lakes along the Illinois River, not only the quantity of sediment present but also its composition must be considered. Radiometric dating provides sedimentation rates for the last 30 years, and the combination of radiometric dating and chemical analysis provides a time element for the input of contaminants into the sediments. For example, the combination of techniques revealed that the levels of Pb, Zn, and  $\text{P}_2\text{O}_5$  are about 60 percent lower in present day sediment in Peoria Lake than in older sediment layers. Moreover, it confirms the die-off of fingernail clams in the early 1950s. The issue of what has prevented their return to most of the Illinois River is no doubt related to sediment quality. Because dredging activities may expose layers of sediments that have high contaminant levels, a knowledge of the variability in the composition of sediments in these backwater lakes is even more critical.

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APPENDIX 1

Geologic Description of Cores Collected in Backwater Lakes  
of the Illinois River

| Lake Name          | Depth (cm) | Description and Remarks   |
|--------------------|------------|---|
| Muscooten Bay      | 0-8        | Clay, with some silt, dark gray 5 Y3/1  |
|                    | 8-30       | Clay, silty, hard and firm, faint bedding, 10 YR5/3   |
| Stewart Lake       | 0-53       | Silt, clayey, soft and fluid, 10 YR3/1, shell fragments in the lower-part, sharp lower contact                            |
|                    | 53-72      | Clay, silty, crumbly soil structure, wood fragments gray N/4, plow zone   |
|                    | 72-88      | Clay, very firm, greenish gray gleyed color   |
| Quiver Lake        | 0-65       | Clay, slightly silty, very soft and fluid at top, 10 YR3/2. Grading downwards into dark gray 5 Y3/1, few shells scattered |
|                    | 65-102     | Clay, some silt, very dark gray 5 Y3/1, firmer than sediment, scattered small clam shells, trace black mottling           |
|                    | 102-116    | Peaty sand, very fine, lots of organic material and small snail shells  |
| Lake Chautauqua    | 0-10       | Silt, clayey, trace of sand, very soft and fluid, 10 YR3/1  |
|                    | 10-58      | Silt, clayey, soft but firmer than above, dark gray 5 Y3/1, 58 cm break in levee 1926                                     |
|                    | 58-70      | Clay, silty, plant fragments, stiff and firm, black 5 Y2/1  |
|                    | 70-84      | Clay, very firm and hard, plant fragments - N/4 - bottomland soil   |
| Clear Lake         | 0-20       | Clay, silt, very soft and fluid, gray 5 Y4/1  |
|                    | 20-53      | Clay, silty, very firm but crumbly soil structure, wood fragments, 5 Y3/1   |
|                    | 53-58      | Clay, very stiff, no bedding, few wood fragments, very dark gray N/3  |
| Peoria Lake (1978) | 0-16       | Silt clayey, very soft and fluid, dark gray 5 Y3/1  |
|                    | 16-30      | Clay, silty, fibrous organic matter, snail and clam shells, trace of black mottling firmer than above, 5 Y2/1             |
|                    | 30-42      | Clay, silty, some brown fibrous organic matter, broken shells, 5 Y3/1   |

|                                 |         |   |
|---------------------------------|---------|---|
| Upper Peoria Lake<br>(L) (1978) | 0-44    | Silt, clayey, very soft and fluid, very dark gray 5 Y3/1                                  |
|                                 | 44-56   | Silt, clayey, firm, black 5 Y2/1, clam shell bed at the top, 5 Y2/1                       |
|                                 | 56-65   | Clay, silty, very firm and hard, mealey; wood fragments at top                            |
| Upper Peoria Lake<br>(U) (1978) | 0-2     | Whole and broken fingernail clams   |
|                                 | 2-9     | Clayey silt, soft, abundant clams, very dark gray 5 Y3/1                                  |
|                                 | 9-43    | Silt, clayey, very dark gray 5 Y3/1, faint bedding, black mottling, shell layer at base   |
|                                 | 43-59   | Firm with mealey texture, organic fragments   |
| Meadow Lake                     | 0-3     | Silt, clayey, very dark gray 5 Y3/1, very soft and fluid                                  |
|                                 | 3-27    | Silt, clayey, black 5 Y2/1, soft and fluid, gas bubbles                                   |
|                                 | 27-55   | Silt, clayey, black 5 Y2/1, black mottling, firmer than above                             |
|                                 | 55-81   | Silt, very clayey, black 5 Y2/1, faint bedding  |
|                                 | 81-88   | Clay, silty, black 5 Y2/1, firm with a mealey texture                                     |
| Goose Lake                      | 0-6     | Silt, little clay, grayish brown 2.5 Y3/2   |
|                                 | 6-35    | Silt, clayey, 5 Y3/1, soft, somewhat mealey texture                                       |
|                                 | 35-105  | Silt, clayey, faint black mottling, soft; gas bubbles                                     |
|                                 | 105-110 | Layer of plant detritus some clayey silt  |
|                                 | 110-138 | Clay, silty, 10 YR2/1, very peaty grading downward to clay, firm mealey texture at bottom |
| Sawmill Lake<br>(1978)          | 0-2     | Silt, 5 Y3/1, very soft and fluid   |
|                                 | 2-40    | Silt, little clay, 5 Y3/1, soft   |
|                                 | 40-110  | Silt, clayey, black 5 Y2/1, black mottling, faint bedding                                 |
|                                 | 110-129 | Dark brownish gray 10 YR3/1, peat, clayey; plant fragments                                |



|                      |        |  |
|----------------------|--------|--|
| Senachwine Lake      | 0-13   | Silt, little clay, 5 Y3/1, very soft and fluid                               |
|                      | 13-31  | Silt, clayey, 5 Y3/1, soft   |
|                      | 31-46  | Silt, clayey, 5 Y2/1, black mottling   |
|                      | 46-57  | Clay, silty, peaty, 5 Y2/1, firm; plant fragments                            |
|                      | 57-77  | Clay, silty, 5 Y3/1, mealey texture  |
| Depue Lake<br>(1978) | 0-10   | Silt, little clay, 5 Y3/1, very soft and fluid                               |
|                      | 10-70  | Silt, clayey, 5 Y3/1, soft, some wood fragments                              |
|                      | 70-124 | Silt, clayey, 5 Y2/1, faint bedding, soft but firmer than above              |
| Swan Lake            | 0-3    | Clayey, silt 5 Y4/3, soft and fluid  |
|                      | 3-80   | Clayey, silt 5 Y3/2, grading downward 5 Y2/1, black fingernail clams         |
|                      | 80-107 | Clayey, silt, 5 Y3/2, mealey structure, wood fragments, hard and dry at base |
| Silver Lake          | 0-3    | Clayey, silt, 2.5 Y4/4, soft and fluid                                       |
|                      | 18-82  | Silt and clay, 5 Y4/2, massive, few plant fragments at base                  |

## APPENDIX 2

The heading "Geologist number" gives an abbreviation for each lake and the depth of the interval sampled. The results of grain-size analysis (complete for selected samples) are also included. Blanks in the table indicate that no determination was made for that particular sample. All values are reported on a moisture-free basis.

| LAP. NO. | GEDL. NO. | SI02 (%) | AL203 (%) | FE203 (%) | MGO (%) | CAO (%) | NA2O (%) | K2O (%) | TIO2 (%) | P2O5 (%) |
|----------|-----------|----------|-----------|-----------|---------|---------|----------|---------|----------|----------|
| R12240   | MR300-08  | 61.25    | 13.28     | 5.28      | 1.71    | 2.69    | 0.85     | 2.24    | 0.87     | 0.37     |
| R12241   | MR308-15  | 61.31    | 13.91     | 5.30      | 1.48    | 2.01    | 0.88     | 2.24    | 0.68     | 0.55     |
| R12242   | MR315-23  | 63.73    | 3.44      | 5.09      | 1.69    | 1.99    | 0.93     | 2.26    | 0.93     | 0.60     |
| R12243   | MR323-30  | 61.87    | 13.47     | 5.52      | 1.82    | 2.04    | 0.84     | 2.25    | 0.92     | 0.27     |
| R12244   | MR330-39  | 66.14    | 12.24     | 5.58      | 1.82    | 2.13    | 0.81     | 2.23    | 0.85     | 0.34     |
| R12245   | MR338-46  | 57.18    | 15.15     | 5.96      | 1.33    | 2.00    | 0.62     | 2.27    | 0.90     | 0.23     |
| R12246   | MR346-53  | 55.86    | 14.78     | 5.98      | 1.66    | 2.17    | 0.61     | 2.26    | 0.85     | 0.57     |
| R12247   | MR353-61  | 57.61    | 15.12     | 5.98      | 1.81    | 2.15    | 0.62     | 2.26    | 0.85     | 0.30     |
| R12248   | MR361-69  | 59.28    | 14.76     | 6.00      | 1.82    | 2.06    | 0.67     | 2.28    | 0.88     | 0.39     |
| R12249   | MR600-08  | 52.48    | 15.46     | 6.72      | 1.86    | 2.34    | 0.44     | 2.20    | 0.82     | 0.64     |
| R12250   | MR608-15  | 52.52    | 15.19     | 6.52      | 1.91    | 3.95    | 0.50     | 2.14    | 0.77     | 0.50     |
| R12251   | MR615-23  | 52.56    | 14.28     | 6.08      | 1.79    | 5.83    | 0.53     | 2.05    | 0.73     | 0.57     |
| R12252   | MR623-30  | 55.81    | 16.04     | 7.13      | 1.84    | 1.87    | 0.59     | 2.26    | 0.88     | 0.43     |
| R12253   | MR630-38  | 54.77    | 15.36     | 7.06      | 1.86    | 3.13    | 0.54     | 2.27    | 0.83     | 0.57     |
| R12254   | MR638-46  | 56.67    | 15.25     | 6.86      | 1.91    | 3.04    | 0.59     | 2.18    | 0.85     | 0.32     |
| R12255   | MR646-53  | 56.33    | 14.32     | 6.41      | 2.06    | 2.41    | 0.50     | 2.20    | 0.83     | 0.87     |
| R12256   | MR653-61  | 55.26    | 14.74     | 6.31      | 2.06    | 4.20    | 0.55     | 2.13    | 0.70     | 0.41     |
| R12257   | MR661-69  | 72.48    | 7.73      | 2.80      | 1.79    | 5.19    | 0.84     | 1.73    | 0.37     | 0.39     |
| R12433   | LDF00-08  | 59.69    | 16.03     | 6.56      | 2.71    | 3.38    | 0.50     | 2.73    | 0.84     | 0.90     |
| R12434   | LDF08-15  | 57.39    | 14.73     | 6.35      | 2.56    | 3.66    | 0.50     | 2.66    | 0.80     | 1.10     |
| R12435   | LDF15-23  | 60.10    | 15.66     | 6.56      | 2.65    | 3.93    | 0.50     | 2.75    | 0.83     | 0.82     |
| R12436   | LDF23-30  | 61.00    | 15.84     | 6.41      | 2.47    | 3.86    | 0.57     | 2.85    | 0.78     | 0.55     |
| R12437   | LDF30-38  | 61.98    | 16.32     | 6.31      | 2.29    | 2.56    | 0.57     | 2.94    | 0.82     | 0.37     |
| R12438   | SML00-08  | 59.23    | 15.96     | 6.63      | 2.52    | 4.58    | 0.46     | 3.13    | 0.77     | 0.37     |
| R12439   | SML08-15  | 58.42    | 15.09     | 6.79      | 2.25    | 3.64    | 0.46     | 3.00    | 0.73     | 0.36     |
| R12440   | SML15-23  | 59.27    | 15.70     | 6.67      | 2.21    | 3.82    | 0.47     | 3.04    | 0.76     | 0.33     |
| R12441   | SML23-30  | 59.41    | 15.50     | 6.73      | 2.60    | 3.95    | 0.50     | 3.13    | 0.76     | 0.40     |
| R12442   | SML30-38  | 58.56    | 15.76     | 6.57      | 2.67    | 3.98    | 0.50     | 3.07    | 0.78     | 0.32     |
| R12443   | SML38-45  | 56.38    | 15.68     | 6.38      | 2.40    | 4.32    | 0.44     | 3.06    | 0.75     | 0.24     |
| R12444   | MA800-08  | 70.37    | 13.24     | 6.49      | 1.71    | 2.79    | 0.80     | 2.36    | 0.84     | 0.27     |
| R12445   | MA808-15  | 68.79    | 14.06     | 5.48      | 1.69    | 3.15    | 0.74     | 2.38    | 0.84     | 0.27     |
| R12446   | MA815-23  | 69.42    | 14.03     | 5.36      | 1.77    | 4.01    | 0.70     | 2.34    | 0.79     | 0.20     |
| R12447   | MA823-30  | 69.62    | 13.60     | 5.31      | 1.80    | 4.08    | 0.75     | 2.39    | 0.83     | 0.22     |
| R12448   | MA830-38  | 63.15    | 13.40     | 5.58      | 1.87    | 6.39    | 0.62     | 2.31    | 0.77     | 0.12     |
| R12449   | MA838-45  | 66.19    | 13.90     | 5.56      | 1.53    | 4.29    | 0.67     | 2.36    | 0.89     | 0.17     |
| R12450   | MA845-52  | 70.09    | 14.89     | 5.80      | 1.57    | 2.31    | 0.73     | 2.46    | 0.88     | 0.17     |
| R12451   | MA852-60  | 69.39    | 14.53     | 5.51      | 1.75    | 2.67    | 0.73     | 2.47    | 0.87     | 0.16     |
| R13652   | QV 00-05  | 59.45    | 9.69      | 4.95      | 1.53    | 3.75    | 0.75     | 1.81    | 0.65     | 0.30     |
| R13653   | QV 10-15  | 56.07    | 11.03     | 5.32      | 1.53    | 3.33    | 0.61     | 2.01    | 0.70     | 0.50     |
| R13654   | QV 20-25  | 56.86    | 11.36     | 5.75      | 1.38    | 2.85    | 0.63     | 2.05    | 0.72     | 0.23     |
| R13655   | QV 40-45  | 56.56    | 12.26     | 6.15      | 1.49    | 2.50    | 0.55     | 2.02    | 0.75     | 0.27     |
| R13656   | QV 60-65  | 61.65    | 11.75     | 6.36      | 1.24    | 2.55    | 0.62     | 1.78    | 0.77     | 0.30     |
| R13657   | QV 80-85  | 53.57    | 11.00     | 9.86      | 1.59    | 4.56    | 1.19     | 3.90    | 0.67     | 0.27     |
| R13658   | QV110-15  | 35.34    | 3.46      | 3.63      | 1.41    | 24.99   | 0.47     | 0.70    | 0.20     | 0.50     |
| R13659   | CHT00-05  | 56.20    | 11.45     | 6.19      | 1.54    | 3.72    | 0.67     | 2.24    | 0.75     | 0.32     |
| R13660   | CHT10-15  | 56.35    | 12.24     | 5.98      | 1.53    | 4.16    | 0.62     | 2.29    | 0.73     | 0.41     |
| R13661   | CHT20-25  | 52.09    | 11.71     | 3.86      | 1.59    | 4.32    | 0.30     | 1.10    | 0.68     | 0.34     |
| R13662   | CHT30-35  | 52.39    | 11.87     | 5.26      | 1.72    | 4.04    | 0.49     | 1.88    | 0.70     | 0.30     |
| R13663   | CHT40-45  | 54.51    | 12.91     | 5.60      | 1.61    | 3.02    | 0.53     | 2.31    | 0.73     | 0.18     |
| R13664   | CHT50-55  | 53.12    | 12.26     | 5.10      | 1.58    | 2.67    | 0.55     | 2.36    | 0.70     | 0.21     |
| R13665   | CHT60-65  | 55.66    | 12.13     | 4.46      | 1.13    | 1.27    | 0.60     | 1.92    | 0.68     | 0.14     |
| R13666   | CHT75-80  | 60.13    | 12.70     | 4.22      | 1.33    | 1.06    | 0.62     | 2.24    | 0.72     | 0.07     |
| R13667   | CLR00-05  | 54.42    | 11.54     | 5.05      | 1.53    | 3.61    | 0.53     | 1.72    | 0.73     | 0.37     |
| R13668   | CLR10-15  | 54.93    | 11.71     | 5.10      | 1.72    | 3.32    | 0.61     | 2.30    | 0.70     | 0.41     |
| R13669   | CLR20-25  | 57.16    | 11.36     | 6.12      | 1.67    | 3.53    | 0.62     | 1.89    | 0.70     | 0.30     |
| R13670   | CLR40-45  | 55.68    | 11.90     | 5.36      | 1.09    | 1.16    | 0.54     | 2.04    | 0.72     | 0.07     |
| R13671   | STW00-05  | 54.27    | 12.62     | 6.48      | 1.54    | 3.06    | 0.54     | 1.95    | 0.77     | 0.34     |
| R13672   | STW10-15  | 52.32    | 12.24     | 5.80      | 1.43    | 3.53    | 0.54     | 1.90    | 0.73     | 0.32     |
| R13673   | STW20-25  | 53.50    | 12.47     | 6.38      | 1.51    | 3.95    | 0.53     | 1.93    | 0.75     | 0.39     |
| R13674   | STW30-35  | 52.30    | 11.96     | 6.29      | 1.54    | 4.66    | 0.53     | 1.90    | 0.73     | 0.34     |
| R13675   | STW40-45  | 54.01    | 12.89     | 6.48      | 1.34    | 2.43    | 0.53     | 1.92    | 0.77     | 0.23     |
| R13676   | STW60-65  | 67.32    | 10.17     | 3.10      | 0.65    | 0.87    | 0.82     | 1.81    | 0.70     | 0.05     |
| R13677   | STW77-82  | 69.29    | 10.30     | 4.12      | 0.51    | 0.83    | 0.82     | 1.76    | 0.73     | 0.07     |

| LAB. NO. | GEOL. NO. | SI02 (%) | AL203 (%) | FE203 (%) | MGO (%) | CAO (%) | NA2O (%) | K2O (%) | TI02 (%) | P2O5 (%) |
|----------|-----------|----------|-----------|-----------|---------|---------|----------|---------|----------|----------|
| R13678   | MUS00-05  | 59.58    | 11.02     | 5.50      | 1.03    | 1.62    | 0.70     | 1.81    | 0.77     | 0.23     |
| R13679   | MUS10-15  | 60.97    | 12.00     | 5.06      | 1.18    | 1.37    | 0.62     | 1.72    | 0.77     | 0.16     |
| R13680   | MES20-25  | 63.88    | 10.77     | 4.83      | 1.46    | 1.80    | 0.74     | 1.75    | 0.77     | 0.18     |
| R14164   | DP 00-05  | 56.63    | 13.93     | 5.69      | 2.27    | 3.79    | 0.51     | 2.75    | 0.77     | 0.80     |
| R14165   | DP 05-15  | 57.29    | 13.55     | 5.65      | 2.37    | 3.05    | 0.51     | 2.61    | 0.78     | 0.64     |
| R14166   | DP 30-35  | 55.92    | 13.36     | 5.73      | 2.37    | 3.51    | 0.53     | 2.60    | 0.73     | 0.89     |
| R14167   | DP 60-65  | 56.95    | 14.08     | 5.75      | 2.52    | 4.06    | 0.50     | 2.65    | 0.75     | 0.69     |
| R14168   | DP100-05  | 56.95    | 14.19     | 5.70      | 2.16    | 3.05    | 0.50     | 2.73    | 0.78     | 0.39     |
| R14169   | SCN00-05  | 56.11    | 14.08     | 5.90      | 2.74    | 4.30    | 0.51     | 2.70    | 0.75     | 0.50     |
| R14170   | SCN20-25  | 56.93    | 15.78     | 6.25      | 2.42    | 3.69    | 0.47     | 2.70    | 0.75     | 0.55     |
| R14171   | SCN60-65  | 69.63    | 15.57     | 5.55      | 1.89    | 1.65    | 0.63     | 2.85    | 0.80     | 0.41     |
| R14172   | SML00-05  | 56.48    | 14.96     | 6.13      | 3.30    | 3.78    | 0.44     | 2.76    | 0.73     | 0.46     |
| R14173   | SML20-25  | 53.89    | 14.64     | 5.98      | 2.42    | 4.80    | 0.44     | 2.70    | 0.75     | 0.85     |
| R14174   | SML60-65  | 56.22    | 13.83     | 5.68      | 2.09    | 3.86    | 0.40     | 2.61    | 0.73     | 0.39     |
| R14175   | GO 00-05  | 55.39    | 15.61     | 6.10      | 2.19    | 3.13    | 0.44     | 2.79    | 0.78     | 0.39     |
| R14176   | GO 20-25  | 54.92    | 14.74     | 6.36      | 2.54    | 4.73    | 0.44     | 2.98    | 0.75     | 0.37     |
| R14177   | GO 60-65  | 53.93    | 13.13     | 6.23      | 2.69    | 5.48    | 0.36     | 2.82    | 0.75     | 0.69     |
| R14178   | GO130-35  | 55.62    | 13.02     | 6.39      | 2.06    | 3.72    | 0.42     | 2.78    | 0.75     | 0.55     |
| R14179   | MED00-05  | 53.02    | 15.44     | 4.48      | 1.67    | 1.90    | 0.43     | 2.67    | 0.77     | 1.56     |
| R14180   | MED20-25  | 56.48    | 14.45     | 6.28      | 2.19    | 3.65    | 0.40     | 2.70    | 0.78     | 0.53     |
| R14181   | MED60-65  | 53.55    | 15.63     | 6.55      | 2.16    | 3.89    | 0.43     | 2.87    | 0.75     | 0.32     |
| R14182   | UPU00-05  | 44.54    | 5.54      | 2.19      | 2.49    | 23.91   | 0.53     | 1.43    | 0.30     | 0.48     |
| R14183   | UPU20-25  | 56.67    | 13.07     | 5.76      | 2.32    | 3.48    | 0.53     | 2.66    | 0.75     | 0.46     |
| R14184   | UPU50-55  | 58.48    | 15.51     | 6.32      | 1.87    | 1.60    | 0.47     | 2.95    | 0.78     | 0.32     |
| R14185   | UPL00-05  | 60.54    | 12.07     | 4.69      | 2.62    | 4.39    | 0.65     | 2.36    | 0.73     | 0.53     |
| R14186   | UPL20-25  | 59.34    | 11.83     | 4.92      | 2.45    | 4.59    | 0.61     | 2.49    | 0.73     | 0.73     |
| R14187   | UPL60-65  | 59.41    | 15.12     | 5.93      | 1.84    | 1.22    | 0.49     | 2.99    | 0.80     | 0.34     |
| R14188   | PE000-05  | 57.91    | 13.87     | 5.68      | 2.82    | 4.16    | 0.53     | 2.67    | 0.77     | 0.64     |
| R14189   | PE020-25  | 52.61    | 13.08     | 5.96      | 2.19    | 5.99    | 0.44     | 2.66    | 0.70     | 0.41     |
| R14190   | PE040-44  | 58.23    | 14.91     | 6.00      | 1.64    | 1.43    | 0.49     | 3.05    | 0.80     | 0.25     |
| R15031   | TUR00-05  | 57.2     | 14.3      | 4.96      | 2.74    | 4.1     | 0.65     | 2.95    | 0.75     | 0.34     |
| R15032   | TUR07-22  | 57.5     | 15.3      | 5.22      | 2.52    | 3.6     | 0.54     | 3.06    | 0.77     | 0.36     |
| R15033   | TUR30-45  | 58.4     | 16.3      | 5.49      | 2.35    | 3.0     | 0.56     | 3.14    | 0.78     | 0.37     |
| R15034   | BRD00-05  | 34.5     | 8.7       | 6.37      | 4.32    | 6.0     | 0.47     | 2.00    | 0.51     | 1.63     |
| R15035   | BRD07-22  | 35.8     | 8.1       | 7.94      | 5.02    | 7.8     | 0.50     | 1.91    | 0.47     | 2.13     |
| R15036   | BRD30-43  | 38.9     | 10.5      | 7.18      | 4.12    | 6.8     | 0.51     | 2.40    | 0.59     | 1.97     |
| R15037   | DP 00-05  | 56.5     | 16.2      | 5.64      | 2.34    | 2.9     | 0.51     | 3.15    | 0.79     | 0.53     |
| R15038   | DP 05-10  | 55.9     | 17.1      | 5.79      | 2.34    | 2.7     | 0.46     | 3.25    | 0.79     | 0.31     |
| R15039   | DP 20-27  | 56.9     | 15.9      | 5.31      | 2.44    | 3.3     | 0.54     | 3.12    | 0.79     | 0.42     |
| R15041   | SIL00-05  | 62.7     | 16.0      | 5.21      | 1.42    | 1.6     | 0.71     | 2.33    | 0.83     | 0.29     |
| R15042   | SIL20-25  | 68.1     | 14.3      | 4.35      | 1.38    | 1.8     | 0.96     | 2.49    | 0.82     | 0.24     |
| R15043   | SIL40-45  | 66.6     | 14.7      | 4.50      | 1.42    | 1.9     | 0.84     | 2.51    | 0.81     | 0.29     |
| R15044   | SIL60-65  | 63.4     | 14.9      | 5.04      | 1.50    | 1.8     | 0.74     | 2.53    | 0.82     | 0.25     |
| R15045   | SWN00-05  | 60.7     | 16.1      | 5.57      | 1.60    | 3.9     | 0.66     | 2.51    | 0.78     | 0.26     |
| R15046   | SWN20-25  | 59.7     | 16.0      | 5.49      | 1.53    | 4.4     | 0.65     | 2.53    | 0.79     | 0.28     |
| R15047   | SWN30-35  | 58.1     | 16.5      | 5.96      | 1.52    | 4.0     | 0.61     | 2.54    | 0.78     | 0.22     |
| R15048   | SWN50-55  | 62.6     | 17.8      | 5.92      | 1.53    | 2.1     | 0.63     | 2.67    | 0.82     | 0.24     |
| R15049   | SWN70-74  | 60.9     | 17.8      | 6.03      | 1.49    | 1.9     | 0.61     | 2.64    | 0.81     | 0.25     |
| R15050   | SWN90-95  | 66.4     | 16.5      | 4.49      | 1.30    | 0.9     | 0.78     | 2.59    | 0.86     | 0.17     |
| R15583   | 171-0001  | 58.9     | 11.1      | 4.7       | 2.93    | 4.9     | 0.75     | 2.60    | 0.66     | 0.36     |
| R15584   | 171-0305  | 58.6     | 12.7      | 5.1       | 2.67    | 4.1     | 0.68     | 2.75    | 0.70     | 0.33     |
| R15585   | 171-0507  | 58.9     | 11.7      | 4.8       | 2.49    | 4.7     | 0.73     | 2.65    | 0.67     | 0.33     |
| R15586   | 171-0914  | 57.6     | 11.5      | 4.9       | 2.84    | 4.6     | 0.73     | 2.65    | 0.67     | 0.41     |
| R15587   | 171-2328  | 59.8     | 11.3      | 4.8       | 2.79    | 4.7     | 0.77     | 2.57    | 0.67     | 0.57     |
| R15588   | 171-3741  | 58.5     | 11.2      | 4.8       | 2.88    | 4.8     | 0.77     | 2.65    | 0.67     | 0.65     |
| R15589   | 171-5156  | 56.7     | 12.9      | 5.4       | 2.70    | 4.1     | 0.65     | 2.91    | 0.71     | 0.49     |
| R15590   | 176-0204  | 58.2     | 13.0      | 5.3       | 2.75    | 4.1     | 0.65     | 2.85    | 0.70     | 0.37     |
| R15591   | 176-0608  | 58.0     | 11.3      | 4.8       | 2.97    | 5.1     | 0.73     | 2.60    | 0.64     | 0.52     |
| R15592   | 176-1012  | 58.4     | 11.0      | 4.7       | 2.95    | 5.0     | 0.79     | 2.55    | 0.63     | 0.49     |
| R15593   | 176-1415  | 58.3     | 10.4      | 4.7       | 3.15    | 6.0     | 0.80     | 2.46    | 0.59     | 0.71     |
| R15594   | 176-2025  | 59.8     | 11.8      | 4.7       | 2.65    | 4.1     | 0.77     | 2.73    | 0.67     | 0.34     |
| R15595   | 176-3439  | 61.4     | 11.8      | 4.5       | 2.44    | 4.1     | 0.77     | 2.62    | 0.65     | 0.27     |
| R15596   | 176-4853  | 64.5     | 13.4      | 6.2       | 1.69    | 1.0     | 0.76     | 3.00    | 0.77     | 0.20     |

| LAB. NO. | GEOL. NO. | MNO (%) | TOT-S (%) | CL (PPM) | AS (PPM) | BA (PPM) | RR (PPM) | CD (PPM) | CE (PPM) | CO (PPM) |
|----------|-----------|---------|-----------|----------|----------|----------|----------|----------|----------|----------|
| R12240   | MR300-08  | 0.08    | 0.05      | 54.      | 12.      | 680.     | 4.3      | <0.7     | 110.     | 7.4      |
| R12241   | MR308-15  | 0.08    | 0.05      | 90.      | 12.      | 600.     | 5.9      | <0.7     | 100.     | 8.6      |
| R12242   | MR315-23  | 0.07    | 0.03      | 42.      | 12.      | 690.     | 4.8      | <0.7     | 110.     | 7.7      |
| R12243   | MR323-30  | 0.08    | 0.06      | 50.      | 12.      | 530.     | 6.6      | <0.7     | 85.      | 6.6      |
| R12244   | MR330-39  | 0.08    | 0.09      | 51.      | 11.      | 690.     | 5.0      | <0.7     | 100      | 7.3      |
| R12245   | MR338-46  | 0.08    | 0.09      | 30.      | 11.      | 730.     | 6.0      | <0.7     | 110.     | 6.4      |
| R12246   | MR346-53  | 0.08    | 0.09      | 49.      | 11.      | 520.     | 7.1      | <0.7     | 88.      | 8.2      |
| R12247   | MR353-61  | 0.09    | 0.09      | 102.     | 11.      | 840.     | 6.5      | <0.7     | 110.     | 8.6      |
| R12248   | MR361-69  | 0.08    | 0.09      | 63.      | 10.      | 600.     | 3.9      | <0.7     | 94.      | 10.      |
| R12249   | MR600-08  | 0.10    | 0.04      | 36.      | 14.      | 590.     | 11.      | <0.7     | 100.     | 8.3      |
| R12250   | MR608-15  | 0.12    | 0.06      | 139.     | 13.      | 760.     | 8.7      | <0.7     | 98.      | 8.3      |
| R12251   | MR615-23  | 0.10    | 0.12      | 38.      | 10.      | 620.     | 4.6      | <0.7     | 74.      | 9.2      |
| R12252   | MR623-30  | 0.10    | 0.23      | 42.      | 8.3      | 410.     | 5.4      | <0.7     | 96.      | 9.4      |
| R12253   | MR630-38  | 0.11    | 0.17      | 79.      | 9.6      | 650.     | 5.3      | <0.7     | 98.      | 8.4      |
| R12254   | MR638-46  | 0.11    | 0.18      | 10.      | 9.4      | 560.     | 4.2      | <0.7     | 93.      | 8.4      |
| R12255   | MR646-53  | 0.09    | 0.09      | 142.     | 12.      | 820.     | 4.2      | <0.7     | 110.     | 8.6      |
| R12256   | MR653-61  | 0.09    | 0.10      | 46.      | 11.      | 1020.    | 4.1      | <0.7     | 100.     | 8.4      |
| R12257   | MR661-69  | 0.06    | 0.08      | 36.      | 3.8      | 440.     | 2.4      | <0.7     | 48.      | 3.9      |
| R12433   | LDP00-08  | 0.10    | 0.20      | 157.     | 19.      | 730.     | 5.9      | 51.5     | 84.      | 18.      |
| R12434   | LDP08-15  | 0.10    | 0.19      | 229.     | 14.      | 690.     | 8.1      | 34.2     | 91.      | 18.      |
| R12435   | LDP15-23  | 0.10    | 0.21      | 143.     | 16.      | 790.     | 6.8      | 104.     | 95.      | 13.      |
| R12436   | LDP23-30  | 0.11    | 0.20      | 77.      | 20.      | 800.     | 5.7      | 116.     | 96.      | 12.      |
| R12437   | LDP30-38  | 0.09    | 0.07      | 108.     | 12.      | 690.     | 6.0      | 5.5      | 99.      | 9.3      |
| R12438   | SML00-08  | 0.10    | 0.14      | 123.     | 43.      | 670.     | 5.1      | 4.0      | 91.      | 9.7      |
| R12439   | SML08-15  | 0.11    | 0.15      | 170.     | 48.      | 720.     | 5.0      | 3.2      | 100.     | 10.      |
| R12440   | SML15-23  | 0.10    | 0.12      | 57.      | 38.      | 640.     | 6.1      | 1.4      | 96.      | 10.      |
| R12441   | SML23-30  | 0.10    | 0.13      | 47.      | 27.      | 690.     | 4.9      | 0.8      | 110.     | 9.2      |
| R12442   | SML30-38  | 0.09    | 0.17      | 43.      | 16.      | 490.     | 5.1      | <0.5     | 68.      | 12.      |
| R12443   | SML38-45  | 0.09    | 0.23      | 56.      | 11.      | 670.     | 7.1      | <0.5     | 88.      | 9.4      |
| R12444   | HAB00-08  | 0.09    | 0.04      | 88.      | 8.0      | 660.     | 3.6      | <0.6     | 82.      | 7.9      |
| R12445   | HAB08-15  | 0.09    | 0.05      | 60.      | 8.0      | 590.     | 4.1      | <0.6     | 90.      | 9.1      |
| R12446   | HAB15-23  | 0.07    | 0.05      | 38.      | 6.8      | 690.     | 4.0      | <0.6     | 93.      | 9.2      |
| R12447   | HAB23-30  | 0.08    | 0.05      | 108.     | 8.2      | 650.     | 4.1      | <0.5     | 90.      | 9.6      |
| R12448   | HAB30-38  | 0.09    | 0.09      | 95.      | 7.2      | 580.     | 4.4      | <0.6     | 96.      | 9.6      |
| R12449   | HAB38-45  | 0.09    | 0.11      | 94.      | 7.2      | 520.     | 3.5      | <0.5     | 97.      | 9.1      |
| R12450   | HAB45-52  | 0.09    | 0.07      | 32.      | 7.6      | 720.     | 4.1      | <0.5     | 110.     | 7.9      |
| R12451   | HAB52-60  | 0.07    | 0.06      | 31.      | 8.6      | 720.     | 4.4      | <0.6     | 100.     | 10.      |
| R13652   | QV 00-05  | 0.10    | 0.05      | 131.     | 9.6      | 370.     | 4.0      | <4.2     | 64.      | 12.      |
| R13653   | QV 10-15  | 0.12    | 0.05      | 123.     | 14.7     | 576.     | 5.6      | <4.2     | 84.      | 13.5     |
| R13654   | QV 20-25  | 0.09    | 0.06      | 62.      | 10.6     | 520.     | 3.8      | <4.2     | 81.      | 14.4     |
| R13655   | QV 40-45  | 0.09    | 0.07      | 157.     | 11.4     | 490.     | 4.6      | <4.2     | 88.      | 13.6     |
| R13656   | QV 60-65  | 0.08    | 0.08      | 101.     | 10.5     | 540.     | 3.1      | <4.2     | 98.      | 14.1     |
| R13657   | QV 80-85  | 0.09    | 0.11      | 124.     | 24.4     | 730.     | 7.5      | <4.2     | 136.     | 20.6     |
| R13658   | QV110-15  | 0.06    | 0.13      | 93.      | 5.4      | 322.     | 4.1      | <4.2     | 39.      | 9.7      |
| R13659   | CHT00-05  | 0.09    | 0.05      | 155.     | 11.6     | 510.     | 4.0      | <4.2     | 83.      | 14.7     |
| R13660   | CHT10-15  | 0.06    | 0.06      | 223.     | 12.6     | 490.     | 4.6      | <4.2     | 88.      | 14.      |
| R13661   | CHT20-25  | 0.12    | 0.10      | 156.     | 5.3      | 270.     | 3.5      | <4.2     | 55.      | 8.7      |
| R13662   | CHT30-35  | 0.12    | 0.13      | 122.     | 8.9      | 500.     | 4.8      | <4.2     | 81.      | 13.8     |
| R13663   | CHT40-45  | 0.09    | 0.15      | 108.     | 11.6     | 520.     | 4.2      | <4.2     | 89.      | 14.7     |
| R13664   | CHT50-55  | 0.09    | 0.13      | 124.     | 14.3     | 540.     | 5.5      | <4.2     | 86.      | 14.8     |
| R13665   | CHT60-65  | 0.06    | 0.20      | 93.      | 10.1     | 524.     | 5.6      | <4.2     | 80.      | 13.6     |
| R13666   | CHT75-80  | 0.06    | 0.03      | 108.     | 3.4      | 555.     | 1.6      | <4.2     | 83.      | 12.5     |
| R13667   | CLR00-05  | 0.09    | 0.07      | 110.     | 9.4      | 490.     | 6.7      | <4.2     | 81.      | 14.4     |
| R13668   | CLR10-15  | 0.10    | 0.07      | 173.     | 13.5     | 480.     | 6.0      | <4.2     | 81.      | 14.4     |
| R13669   | CLR20-25  | 0.06    | 0.06      | 125.     | 10.2     | 580.     | 3.6      | <4.2     | 84.      | 16.4     |
| R13670   | CLR40-45  | 0.08    | 0.05      | 125.     | 4.4      | 500.     | 3.1      | <4.2     | 75.      | 12.7     |
| R13671   | STW00-05  | 0.10    | 0.08      | 220.     | 12.8     | 580.     | 5.5      | <4.2     | 84.      | 16.0     |
| R13672   | STW10-15  | 0.09    | 0.07      | 196.     | 11.6     | 530.     | 2.5      | <4.2     | 75.      | 14.8     |
| R13673   | STW20-25  | 0.12    | 0.10      | 130.     | 12.8     | 590.     | 3.3      | <4.2     | 83.      | 16.0     |
| R13674   | STW30-35  | 0.09    | 0.10      | 133.     | 10.5     | 550.     | 3.7      | <4.2     | 83.      | 15.0     |
| R13675   | STW40-45  | 0.09    | 0.12      | 75.      | 13.      | 630.     | 4.3      | <4.2     | 97.      | 16.      |
| R13676   | STW60-65  | 0.05    | 0.04      | 108.     | 3.       | 440.     | <1.      | <4.2     | 65.      | 8.       |
| R13677   | STW77-82  | 0.06    | 0.01      | 90.      | 4.3      | 580.     | 1.5      | <4.2     | 78.      | 15.      |

| LAB. NO. | GEOLOG. NO. | MNO (%)  | TOT-S (%) | CL (PPM) | AS (PPM) | BA (PPM) | BR (PPM) | CD (PPM) | CE (PPM) | CO (PPM) |
|----------|-------------|----------|-----------|----------|----------|----------|----------|----------|----------|----------|
| R13678   | MUS00-05    | 0.10     | 0.02      | 119.     | 14.4     | 610.     | 7.3      | <4.2     | 89.      | 13.      |
| R13679   | MUS10-15    | 0.10     | 0.02      | 88.      | 15.3     | 606.     | 8.0      | <4.2     | 81.      | 12.      |
| R13680   | MES20-25    | 0.08     | 0.03      | 84.      | 10.6     | 595.     | 6.6      | <4.2     | 78.      | 12.      |
| R14164   | DP 00-05    | 0.15     | 0.04      | 260.     | 12.      | 600.     | 7.6      | 10.      | 73.      | 19.      |
| R14165   | DP 05-15    | 0.09     | 0.03      | 240.     | 14.      | 700.     | 5.5      | 6.2      | 75.      | 19.      |
| R14166   | DP 30-35    | 0.11     | 0.09      | 179.     | 14.      | 650.     | 6.0      | 24.      | 72.      | 22.      |
| R14167   | DP 60-65    | 0.09     | 0.07      | 155.     | 16.      | 700.     | 4.1      | 30.      | 72.      | 16.      |
| R14168   | DF100-05    | 0.07     | 0.08      | 220.     | 14.      | 600.     | 4.3      | 14.      | 70.      | 15.      |
| R14169   | SCN00-05    | 0.11     | 0.07      | 165.     | 13.      | 600.     | 10.      | 5.9      | 71.      | 15.      |
| R14170   | SCN20-25    | 0.11     | <.01      | 155.     | 14.      | 580.     | 8.       | 5.3      | 76.      | 15.      |
| R14171   | SCN60-65    | 0.07     | <.01      | 195.     | 5.       | 580.     | 6.       | <3.9     | 76.      | 15.      |
| R14172   | SML00-05    | 0.09     | <.01      | 240.     | 14.      | 720.     | 7.       | <3.9     | 75.      | 15.      |
| R14173   | SML20-25    | 0.11     | 0.02      | 255.     | 15.      | 690.     | 6.       | 8.2      | 77.      | 16.      |
| R14174   | SML60-65    | 0.07     | 0.01      | 260.     | 16.      | 600.     | 5.       | 6.2      | 74.      | 14.      |
| R14175   | GO 00-05    | 0.09     | <.01      | 165.     | 11.      | 800.     | 7.       | <3.9     | 87.      | 19.      |
| R14176   | GO 20-25    | 0.10     | 0.01      | 205.     | 12.      | 1600.    | 4.       | <3.9     | 87.      | 20.      |
| R14177   | GO 60-65    | 0.07     | 0.07      | 200.     | 15.      | 900.     | 5.       | <3.9     | 90.      | 20.      |
| R14178   | GO130-35    | 0.04     | 0.27      | 200.     | 3.       | 860.     | 7.       | <3.9     | 85.      | 18.      |
| R14179   | MED00-05    | 0.10     | 0.02      | 275.     | 13.      | 690.     | 5.       | <3.9     | 74.      | 18.      |
| R14180   | MED20-25    | 0.10     | 0.03      | 210.     | 15.      | 640.     | 6.       | 5.9      | 77.      | 18.      |
| R14181   | MED60-65    | 0.07     | 0.04      | 180.     | 32.      | 610.     | 5.       | <3.9     | 89.      | 17.      |
| R14182   | UPU00-05    | 0.06     | 0.14      | 185.     | 7.       | 510.     | 3.       | <3.9     | 49.      | 11.      |
| R14183   | UPU20-25    | 0.09     | <.01      | 195.     | 36.      | 830.     | 4.       | <3.9     | 93.      | 19.      |
| R14184   | UPU50-55    | 0.06     | <.01      | 225.     | 9.       | 1100.    | 4.       | <3.9     | 95.      | 23.      |
| R14185   | UPL00-05    |          | <.01      | 440.     | 11.      | 700.     | 4.       | 3.8      | 81.      | 18.      |
| R14186   | UPL20-25    |          | <.01      | 230.     | 13.      | 480.     | 4.       | 9.0      | 48.      | 13.      |
| R14187   | UPL60-65    |          | <.01      | 170.     | 8.       | 1100.    | 5.       | <3.9     | 97.      | 24.      |
| R14188   | PEO00-05    |          | <.01      | 305.     | 12.      | 870.     | 5.       | 4.6      | 74.      | 19.      |
| R14189   | PEO20-25    |          | 0.22      | 295.     | 18.      | 850.     | 5.5      | <3.9     | 79.      | 21.      |
| R14190   | PEO40-44    |          | 0.02      | 240.     | 4.       | 620.     | 5.0      | <3.9     | 62.      | 19.      |
| R15031   | TUR00-05    | 635 PPM  |           |          | 10.6     | 608      | 6.5      | 1.6      | 54       | 15       |
| R15032   | TUR07-22    | 600 PPM  |           |          | 11.2     | 637      | 5.0      | 2.5      | 48       | 14       |
| R15033   | TUR30-45    | 578 PPM  |           |          | 10.6     | 658      | 5.8      | 4.3      | 54       | 16       |
| R15034   | BRD00-05    | 472 PPM  |           |          | 24.0     | 705      | 8.2      | 64.2     | 38       | 24       |
| R15035   | BRD07-22    | 626 PPM  |           |          | 16.0     | 637      | 8.8      | 37.4     | 32       | 30       |
| R15036   | BRD30-43    | 606 PPM  |           |          | 16.0     | 660      | 10.5     | 73.5     | 39       | 32       |
| R15037   | DP 00-05    | 769 PPM  |           |          | 13.5     | 666      | 6.6      | 12.6     | 106      | 28       |
| R15038   | DP 05-10    | 600 PPM  |           |          | 12.7     | 644      | 10.8     | 1.8      | 71       | 14       |
| R15039   | DP 20-27    | 614 PPM  |           |          | 11.1     | 641      | 8.2      | 6.0      | 61       | 14       |
| R15041   | SIL00-05    | 930 PPM  |           |          | 11.0     | 725      | 6.0      | <0.8     | 71       | 14       |
| R15042   | SIL20-25    | 873 PPM  |           |          | 8.6      | 686      | 4.0      | <0.9     | 65       | 12       |
| R15043   | SIL40-45    | <460 PPM |           |          | 10.7     | 735      | 3.0      | <1.2     | 68       | 13       |
| R15044   | SIL60-65    | <600 PPM |           |          | 10.9     | 741      | 3.3      | <1.1     | 66       | 12       |
| R15045   | SWN00-05    | 960 PPM  |           |          | 11.7     | 751      | 5.0      | <1.2     | 68       | 15       |
| R15046   | SWN20-25    | 736 PPM  |           |          | 9.8      | 755      | <3       | <1.2     | 67       | 14       |
| R15047   | SWN30-35    | 572 PPM  |           |          | 10.1     | 754      | <3       | <1.2     | 68       | 16       |
| R15048   | SWN50-55    | 590 PPM  |           |          | 10.3     | 804      | 3.2      | <1.2     | 68       | 16       |
| R15049   | SWN70-74    | 450 PPM  |           |          | 11.1     | 792      | 4.0      | <1.2     | 71       | 17       |
| R15050   | SWN90-95    | 238 PPM  |           |          | 5.2      | 762      | 3.0      | <1.2     | 70       | 15       |
| R15583   | 171-0001    |          |           |          | 10.3     | 557      | 5        | 2.5      | 51       | 16       |
| R15584   | 171-0305    |          |           |          | 11.8     | 593      | 5        | 2.0      | 52       | 17       |
| R15585   | 171-0507    |          |           |          | 11.6     | 568      | 4        | 2.0      | 49       | 16       |
| R15586   | 171-0914    |          |           |          | 13.3     | 535      | 4        | 4.0      | 53       | 19       |
| R15587   | 171-2328    |          |           |          | 12.8     | 582      | 2.5      | 6.0      | 50       | 18       |
| R15588   | 171-3741    |          |           |          | 14.3     | 531      | 4        | 7.7      | 51       | 18       |
| R15589   | 171-5156    |          |           |          | 16.7     | 553      | 4        | 8.1      | 56       | 19       |
| R15590   | 176-0204    |          |           |          | 13.1     | 528      | 5        | 1.8      | 52       | 18       |
| R15591   | 176-0608    |          |           |          | 12.0     | 482      | 5        | 3.3      | 55       | 17       |
| R15592   | 176-1012    |          |           |          | 11.4     | 521      | 4        | 2.2      | 52       | 17       |
| R15593   | 176-1415    |          |           |          | 11.6     | 514      | 5        | 4.3      | 48       | 18       |
| R15594   | 176-2025    |          |           |          | 12.4     | 524      | 4        | 2.3      | 56       | 16       |
| R15595   | 176-3439    |          |           |          | 15.1     | 514      | 3        | <0.9     | 54       | 15       |
| R15596   | 176-4853    |          |           |          | 6.4      | 481      | 2.5      | <0.9     | 59       | 20       |

| LAB. NO. | GEOL. NO. | CR<br>(PPM) | CS<br>(PPM) | CU<br>(PPM) | EU<br>(PPM) | GA<br>(PPM) | HF<br>(PPM) | HG<br>(PPM) | LA<br>(PPM) | LU<br>(PPM) |
|----------|-----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| R12240   | MR300-08  | 98.         | 8.6         | 30.         | 1.7         | 19.         | 12.         | 0.20        | 57.         |             |
| R12241   | MR308-15  | 100.        | 8.9         | 32.         | 1.7         | 19.         | 14.         | 0.14        | 56.         |             |
| R12242   | MR315-23  | 98.         | 8.3         | 29.         | 1.7         | 23.         | 14.         | 0.16        | 59.         |             |
| R12243   | MR323-30  | 82.         | 7.6         | 30.         | 1.7         | 17.         | 10.         | 0.12        | 57.         |             |
| R12244   | MR330-39  | 98.         | 9.0         | 29.         | 1.7         | 19.         | 11.         | 0.19        | 55.         |             |
| R12245   | MR338-46  | 103.        | 10.         | 28.         | 1.6         | 22.         | 10.         | 0.15        | 57.         |             |
| R12246   | MR346-53  | 87.         | 8.9         | 31.         | 1.6         | 19.         | 9.          | 0.14        | 56.         |             |
| R12247   | MR353-61  | 101.        | 10.         | 29.         | 1.6         | 23.         | 10.         | 0.13        | 56.         |             |
| R12248   | MR361-69  | 88.         | 8.9         | 33.         | 1.7         | 20.         | 10.         | 0.14        | 57.         |             |
| R12249   | MR600-08  | 94.         | 10.         | 39.         | 1.7         | 21.         | 7.          | 0.17        | 52.         |             |
| R12250   | MR608-15  | 96.         | 9.6         | 37.         | 1.7         | 20.         | 8.          | 0.15        | 53.         |             |
| R12251   | MR615-23  | 71.         | 7.6         | 34.         | 1.6         | 17.         | 7.          | 0.13        | 48.         |             |
| R12252   | MR623-30  | 89.         | 9.0         | 31.         | 1.5         | 18.         | 10.         | 0.16        | 48.         |             |
| R12253   | MR630-38  | 94.         | 9.4         | 33.         | 1.7         | 21.         | 9.          | 0.13        | 52.         |             |
| R12254   | MR638-46  | 88.         | 9.1         | 30.         | 1.7         | 23.         | 9.          | 0.14        | 53.         |             |
| R12255   | MR646-53  | 100.        | 11.1        | 37.         | 1.9         | 21.         | 8.          | 0.14        | 56.         |             |
| R12256   | MR653-61  | 96.         | 10.1        | 35.         | 1.8         | 22.         | 9.          | 0.12        | 56.         |             |
| R12257   | MR661-69  | 35.         | 3.1         | 10.         | 0.9         | 10.         | 9.          | 0.07        | 27.         |             |
| R12433   | LDP00-08  | 170.        | 9.8         | 128.        | 1.8         | 20.         | 6.6         | 0.60        | 60.         |             |
| R12434   | LDP08-15  | 160.        | 10.         | 119.        | 1.7         | 19.         | 7.3         | 0.52        | 55.         |             |
| R12435   | LDP15-23  | 210.        | 11.         | 130.        | 1.7         | 19.         | 7.7         | 0.76        | 55.         |             |
| R12436   | LDP23-30  | 170.        | 10.         | 107.        | 1.7         | 22.         | 7.8         | 0.73        | 59.         |             |
| R12437   | LDP30-38  | 130.        | 11.         | 46.5        | 1.8         | 20.         | 8.2         | 0.31        | 59.         |             |
| R12438   | SML00-08  | 160.        | 11.         | 105.        | 1.5         | 19.         | 6.6         | 1.25        | 57.         |             |
| R12439   | SML08-15  | 200.        | 11.         | 159.        | 1.5         | 20.         | 7.2         | 2.11        | 53.         |             |
| R12440   | SML15-23  | 150.        | 11.         | 109.        | 1.4         | 21.         | 6.4         | 1.79        | 57.         |             |
| R12441   | SML23-30  | 140.        | 11.         | 76.4        | 1.5         | 18.         | 7.1         | 1.40        | 59.         |             |
| R12442   | SML30-38  | 86.         | 8.7         | 45.8        | 1.3         | 18.         | 5.2         | 0.75        | 48.         |             |
| R12443   | SML38-45  | 93.         | 11.         | 31.2        | 1.6         | 19.         | 6.3         | 0.24        | 53.         |             |
| R12444   | HAB00-08  | 83.         | 7.5         | 30.6        | 1.5         | 14.         | 11.         | 0.14        | 58.         |             |
| R12445   | HAB08-15  | 89.         | 8.3         | 31.3        | 1.5         | 17.         | 10.         | 0.12        | 62.         |             |
| R12446   | HAB15-23  | 93.         | 8.3         | 30.2        | 1.4         | 14.         | 10.         | 0.10        | 50.         |             |
| R12447   | HAB23-30  | 91.         | 8.0         | 29.8        | 1.5         | 17.         | 11.         | 0.13        | 55.         |             |
| R12448   | HAB30-38  | 92.         | 8.9         | 30.5        | 1.4         | 14.         | 9.4         | 0.11        | 52.         |             |
| R12449   | HAB38-45  | 88.         | 8.6         | 27.5        | 1.5         | 16.         | 10.         | 0.11        | 54.         |             |
| R12450   | HAB45-52  | 93.         | 9.3         | 27.5        | 1.6         | 14.         | 11.         | 0.09        | 63.         |             |
| R12451   | HAB52-60  | 89.         | 9.1         | 29.0        | 1.6         | 19.         | 11.         | 0.11        | 63.         |             |
| R13652   | QV 00-05  | 70.         | 4.5         |             | 1.3         | 13.         | 8.2         | 0.11        | 40.         | 0.5         |
| R13653   | QV 10-15  | 75.         | 5.8         |             | 1.9         | 19.         | 7.7         | 0.14        | 50.         | 0.5         |
| R13654   | QV 20-25  | 77.         | 6.3         |             | 1.5         | 16.         | 6.7         | 0.16        | 45.         | 0.5         |
| R13655   | QV 40-45  | 76.         | 7.9         |             | 1.3         | 16.         | 7.5         | 0.13        | 40.         | 0.5         |
| R13656   | QV 60-65  | 82.         | 8.1         |             | 1.3         | 18.         | 8.8         | 0.15        | 43.         | 0.5         |
| R13657   | QV 80-85  | 114.        | 10.6        |             | 3.7         | 33.         | 1.5         | 0.22        | 67.         | 0.8         |
| R13658   | QV110-15  | 24.         | 1.6         |             | 0.7         | 4.          | 6.6         | 0.18        | 17.         | 0.2         |
| R13659   | CHT00-05  | 100.        | 8.0         |             | 1.4         | 18.         | 8.5         | 0.16        | 43.         | 0.5         |
| R13660   | CHT10-15  | 98.         | 7.9         |             | 1.5         | 20.         | 7.9         | 0.14        | 44.         | 0.5         |
| R13661   | CHT20-25  | 52.         | 4.8         |             | 0.8         | 10.         | 4.3         | 0.17        | 26.         | 0.3         |
| R13662   | CHT30-35  | 73.         | 7.3         |             | 1.4         | 18.         | 6.4         | 0.21        | 46.         | 0.4         |
| R13663   | CHT40-45  | 78.         | 8.2         |             | 1.4         | 20.         | 7.2         | 0.17        | 44.         | 0.5         |
| R13664   | CHT50-55  | 77.         | 7.5         |             | 1.5         | 22.         | 7.3         | 0.84        | 46.         | 0.4         |
| R13665   | CHT60-65  | 67.         | 8.0         |             | 1.4         | 20.         | 7.8         | 0.12        | 44.         | 0.5         |
| R13666   | CHT75-80  | 72.         | 7.5         |             | 1.6         | 21.         | 8.5         | 0.06        | 45.         | 0.5         |
| R13667   | CLR00-05  | 80.         | 7.2         |             | 1.3         | 15.         | 8.2         | 0.19        | 42.         | 0.5         |
| R13668   | CLR10-15  | 81.         | 7.5         |             | 1.5         | 20.         | 7.7         | 0.19        | 44.         | 0.5         |
| R13669   | CLR20-25  | 93.         | 7.2         |             | 1.6         | 24.         | 8.5         | 0.16        | 42.         | 0.5         |
| R13670   | CLR40-45  | 76.         | 7.2         |             | 1.2         | 20.         | 6.8         | 0.06        | 43.         | 0.5         |
| R13671   | STW00-05  | 94.         | 8.0         |             | 1.4         | 20.         | 6.3         | 0.18        | 45.         | 0.5         |
| R13672   | STW10-15  | 83.         | 7.1         |             | 1.7         | 20.         | 6.0         | 0.12        | 47.         | 0.5         |
| R13673   | STW20-25  | 92.         | 7.9         |             | 1.4         | 20.         | 6.5         | 0.19        | 45.         | 0.6         |
| R13674   | STW30-35  | 87.         | 7.6         |             | 1.6         | 20.         | 6.2         | 0.15        | 48.         | 0.5         |
| R13675   | STW40-45  | 92.         | 7.8         |             | 1.5         | 20.         | 7.          | 0.12        | 46.         | 0.6         |
| R13676   | STW60-65  | 58.         | 4.7         |             | 1.7         | 19.         | 11.         | 0.13        | 44.         | 0.5         |
| R13677   | STW77-82  | 70.         | 5.5         |             | 1.4         | 14.         | 13.         | 0.04        | 41.         | 0.6         |

| LAB. NO. | GEOLOG. NO. | CR<br>(PPM) | CS<br>(PPM) | CU<br>(PPM) | EU<br>(PPM) | GA<br>(PPM) | HF<br>(PPM) | HG<br>(PPM) | LA<br>(PPM) | LU<br>(PPM) |
|----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| R13678   | MUS00-05    | 72.         | 5.8         |             | 1.8         | 37.         | 10.         | 0.10        | 48.         | 0.6         |
| R13679   | MUS10-15    | 63.         | 5.5         |             | 1.7         | 17.         | 8.          | 0.07        | 45.         | 0.5         |
| R13680   | MES20-25    | 66.         | 5.2         |             | 1.8         | 20.         | 10.         | 0.08        | 46.         | 0.6         |
| R14164   | DP 00-05    | 200.        | 8.          | 79.         | 1.4         | 18.         | 6.          | 0.33        | 44.         | 0.7         |
| R14165   | DP 05-15    | 183.        | 8.          | 63.         | 1.4         | 19.         | 6.          | 0.31        | 46.         | 0.8         |
| R14166   | DP 30-35    | 217.        | 7.          | 90.         | 1.4         | 19.         | 6.          | 0.40        | 45.         | 0.7         |
| R14167   | DP 60-65    | 208.        | 7.5         | 81.         | 1.4         | 17.         | 6.          | 0.47        | 46.         | 0.7         |
| R14168   | DP100-05    | 160.        | 7.3         | 63.         | 1.3         | 17.         | 5.5         | 0.20        | 42.         | 0.6         |
| R14169   | SCN00-05    | 196.        | 7.          | 73.         | 1.4         | 19.         | 6.          | 0.36        | 43.         | 0.9         |
| R14170   | SCN20-25    | 185.        | 7.          | 67.         | 1.5         | 20.         | 5.          | 0.30        | 48.         | 0.8         |
| R14171   | SCN60-65    | 111.        | 8.          | 26.         | 1.5         | 20.         | 5.          | 0.05        | 46.         | 0.7         |
| R14172   | SML00-05    | 184.        | 8.          | 67.         | 1.4         | 20.         | 7.          | 0.26        | 46.         | 0.7         |
| R14173   | SML20-25    | 218.        | 8.          | 82.         | 1.5         | 20.         | 5.          | 0.62        | 47.         | 0.7         |
| R14174   | SML60-65    | 183.        | 8.          | 70.         | 1.5         | 21.         | 5.          | 0.37        | 47.         | 0.7         |
| R14175   | GO 00-05    | 147.        | 8.          | 53.         | 1.3         | 18.         | 5.          | 0.20        | 40.         | 0.7         |
| R14176   | GO 20-25    | 156.        | 8.          | 57.         | 1.3         | 17.         | 6.          | 0.27        | 43.         | 0.8         |
| R14177   | GO 60-65    | 150.        | 9.          | 53.         | 1.3         | 19.         | 5.          | 0.30        | 43.         | 0.8         |
| R14178   | GO130-35    | 110.        | 8.          | 36.         | 1.3         | 19.         | 5.          | 0.06        | 40.         | 0.8         |
| R14179   | MED00-05    | 194.        | 9.          | 66.         | 1.4         | 19.         | 5.          | 0.27        | 42.         | 0.9         |
| R14180   | MED20-25    | 198.        | 8.          | 66.         | 1.4         | 19.         | 5.          | 0.96        | 43.         | 0.9         |
| R14181   | MED60-65    | 205.        | 8.          | 96.         | 1.3         | 20.         | 5.          | 1.16        | 50.         | 0.7         |
| R14182   | UPU00-05    | 68.         | 3.          | 25.         | 0.8         | 7.          | 6.          | 0.22        | 25.         | 0.4         |
| R14183   | UPU20-25    | 182.        | 8.          | 101.        | 1.3         | 18.         | 6.          | 1.52        | 48.         | 0.7         |
| R14184   | UPU50-55    | 123.        | 8.          | 27.         | 1.5         | 2.          | 6.          | 0.12        | 46.         | 0.7         |
| R14185   | UPL00-05    | 160.        | 6.          | 58.         | 1.3         | 16.         | 8.          | 0.34        | 43.         | 0.8         |
| R14186   | UPL20-25    | 117.        | 4.          | 74.         | 1.3         | 16.         | 4.          | 0.38        | 43.         | 0.6         |
| R14187   | UPL60-65    | 124.        | 9.          | 29.         | 1.4         | 20.         | 6.          | 0.09        | 46.         | 0.7         |
| R14188   | PEO00-05    | 164.        | 6.          | 64.         | 1.4         | 19.         | 6.          | 0.34        | 41.         | 0.5         |
| R14189   | PEO20-25    | 117.        | 7.          | 38.         | 1.4         | 19.         | 5.          | 0.23        | 44.         | 0.7         |
| R14190   | PEO40-44    | 82.         | 6.          | 26.         | 1.4         | 21.         | 4.          | 0.09        | 44.         | 0.5         |
| R15031   | TUR00-05    | 112         | 6.0         | 60          | 1.3         | 16          | 6.6         | 0.21        | 40          | 0.5         |
| R15032   | TUR07-22    | 110         | 6.0         | 68          | 1.3         | 18          | 5.6         | 0.22        | 41          | 0.44        |
| R15033   | TUR30-45    | 135         | 8.4         | 63          | 1.4         | 18          | 6.0         | 0.27        | 42          | 0.5         |
| R15034   | BRD00-05    | 670         | 5.0         | 453         | 0.83        | 13          | 4.5         | 2.48        | 28          | 0.48        |
| R15035   | BRD07-22    | 454         | 4.3         | 324         | 0.80        | 11          | 4.3         | 2.06        | 26          | 0.38        |
| R15036   | BRD30-43    | 700         | 4.6         | 500         | 1.0         | 12          | 5.1         | 1.86        | 36          | 0.27        |
| R15037   | DP 00-05    | 192         | 12.0        | 87          | 1.4         | 19          | 8.3         | 0.28        | 43          | 0.8         |
| R15038   | DP 05-10    | 98          | 8.4         | 57          | 1.3         | 20          | 5.2         | 0.13        | 44          | 0.47        |
| R15039   | DP 20-27    | 98          | 6.0         | 81          | 1.3         | 16          | 5.3         | 0.22        | 40          | 0.38        |
| R15041   | SIL00-05    | 74          | 6.0         | 29          | 1.4         | 19          | 6.8         | 0.23        | 44          | 0.42        |
| R15042   | SIL20-25    | 70          | 5.1         | 29          | 1.3         | 16          | 8.6         | 0.07        | 40          | 0.40        |
| R15043   | SIL40-45    | 74          | 5.4         | 32          | 1.3         | 18          | 8.2         | 0.06        | 42          | 0.55        |
| R15044   | SIL60-65    | 75          | 5.4         | 33          | 1.4         | 16          | 6.6         |             | 43          | 0.47        |
| R15045   | SWN00-05    | 84          | 7.0         | 33          | 1.3         | 18          | 6.2         |             | 44          | 0.58        |
| R15046   | SWN20-25    | 85          | 6.7         | 36          | 1.4         | 17          | 6.0         |             | 43          | 0.53        |
| R15047   | SWN30-35    | 95          | 6.9         | 35          | 1.4         | 18          | 5.4         |             | 46          | 0.53        |
| R15048   | SWN50-55    | 93          | 7.2         | 35          | 1.5         | 18          | 5.5         |             | 49          | 0.57        |
| R15049   | SWN70-74    | 98          | 7.3         | 34          | 1.5         | 19          | 5.3         |             | 46          | 0.65        |
| R15050   | SWN90-95    | 91          | 6.6         | 36          | 1.7         | 18.         | 7.3         |             | 47          | 0.55        |
| R15583   | 171-0001    | 130         | 5.2         | 73          | 1.4         | 19          | 8.2         |             | 46          | 0.6         |
| R15584   | 171-0305    | 136         | 5.1         | 70          | 1.5         | 20          | 7.0         |             | 49          | 0.5         |
| R15585   | 171-0507    | 135         | 5.2         | 56          | 1.5         | 17          | 7.4         |             | 48          | 0.7         |
| R15586   | 171-0914    | 165         | 6.0         | 72          | 1.6         | 17          | 7.7         |             | 48          | 0.9         |
| R15587   | 171-2328    | 179         | 5.3         | 74          | 1.6         | 22          | 8.0         |             | 47          | 0.8         |
| R15588   | 171-3741    | 175         | 5.2         | 77          | 1.4         | 19          | 7.2         |             | 44          | 1.1         |
| R15589   | 171-5156    | 193         | 6.9         | 82          | 1.4         | 21          | 5.9         |             | 49          | 0.6         |
| R15590   | 176-0204    | 129         | 6.1         | 57          | 1.6         | 19          | 6.9         |             | 53          | 0.9         |
| R15591   | 176-0608    | 138         | 5.5         | 61          | 1.3         | 17          | 7.9         |             | 39          | 0.6         |
| R15592   | 176-1012    | 133         | 5.2         | 54          | 1.4         | 19          | 8.0         |             | 42          | 0.4         |
| R15593   | 176-1415    | 143         | 5.0         | 56          | 1.3         | 15          | 8.7         |             | 41          | 0.6         |
| R15594   | 176-2025    | 130         | 5.7         | 57          | 1.5         | 18          | 7.9         |             | 48          | 1.0         |
| R15595   | 176-3439    | 122         | 5.7         | 47          | 1.4         | 17          | 7.4         |             | 47          | 0.6         |
| R15596   | 176-4853    | 105         | 6.4         | 25          | 1.8         | 21          | 7.3         |             | 50          | 1.2         |



| LAB. NO. | GEOLOG. NO. | MO<br>(PPM) | NI<br>(PPM) | FB<br>(PPM) | RB<br>(PPM) | SB<br>(PPM) | SC<br>(PPM) | SM<br>(PPM) | TA<br>(PPM) | TB<br>(PPM) |
|----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| R12240   | MR300-08    | 1.8         | 34.         | 20.         | 180.        | 1.3         | 15.         | 7.4         | 0.81        | 2.6         |
| R12241   | MR308-15    | 2.1         | 31.         | 25.         | 180.        | 1.4         | 16.         | 7.6         | 0.89        | 2.1         |
| R12242   | MR315-23    | 1.8         | 33.         | 18.         | 170.        | 1.4         | 16.         | 7.4         | 0.88        | 2.8         |
| R12243   | MR323-30    | 2.0         | 29.         | 26.         | 170.        | 1.2         | 14.         | 7.7         | 0.73        | 2.5         |
| R12244   | MR330-39    | 1.9         | 33.         | 14.         | 170.        | 1.2         | 16.         | 7.3         | 0.81        | 2.7         |
| R12245   | MR338-46    | 2.3         | 33.         | 13.         | 180.        | 1.3         | 18.         | 7.6         | 0.90        | 2.0         |
| R12246   | MR346-53    | 4.1         | 35.         | 12.         | 150.        | 1.6         | 16.         | 7.2         | 0.72        | 2.5         |
| R12247   | MR353-61    | 2.7         | 35.         | 15.         | 200.        | 1.2         | 16.         | 8.0         | 0.88        | 2.0         |
| R12248   | MR361-69    | 3.1         | 38.         | 21.         | 180.        | 1.4         | 16.         | 7.8         | 0.83        | 1.9         |
| R12249   | MR600-08    | 2.6         | 43.         | 28.         | 210.        | 1.9         | 18.         | 6.5         | 0.79        | 2.4         |
| R12250   | MR608-15    | 2.6         | 44.         | 29.         | 200.        | 1.8         | 17.         | 7.3         | 0.67        | 2.5         |
| R12251   | MR615-23    | 3.0         | 40.         | 28.         | 150.        | 1.5         | 13.         | 6.2         | 0.62        | 2.1         |
| R12252   | MR623-30    | 5.6         | 37.         | 16.         | 200.        | 1.2         | 16.         | 6.2         | 0.75        | 2.4         |
| R12253   | MR630-38    | 4.4         | 38.         | 17.         | 210.        | 1.4         | 17.         | 6.8         | 0.71        | 2.5         |
| R12254   | MR638-46    | 4.2         | 32.         | 17.         | 200.        | 1.8         | 17.         | 6.7         | 0.79        | 2.3         |
| R12255   | MR646-53    | 4.2         | 38.         | 22.         | 220.        | 2.2         | 20.         | 7.5         | 0.77        | 2.5         |
| R12256   | MR653-61    | 4.6         | 33.         | 20.         | 220.        | 1.6         | 18.         | 8.3         | 0.76        | 2.3         |
| R12257   | MR661-69    | <1.         | 11.         | 2.          | 89.         | 0.6         | 6.8         | 3.7         | 0.36        | 1.2         |
| R12433   | LDP00-08    | 4.8         | 61.         | 141.        | 200.        | 3.9         | 16.         | 7.6         | 0.67        | 2.1         |
| R12434   | LDP08-15    | 7.5         | 53.         | 119.        | 220.        | 2.7         | 17.         | 7.4         | 0.72        | 1.8         |
| R12435   | LDP15-23    | 5.2         | 61.         | 183.        | 210.        | 3.3         | 17.         | 8.4         | 0.67        | 2.3         |
| R12436   | LDP23-30    | 6.9         | 44.         | 211.        | 210.        | 2.8         | 17.         | 9.0         | 0.73        | 2.5         |
| R12437   | LDP30-38    | 4.3         | 38.         | 42.         | 240.        | 2.1         | 18.         | 9.0         | 0.80        | 2.5         |
| R12438   | SML00-08    | 4.3         | 33.         | 661.        | 240.        | 54.         | 17.         | 6.5         | 0.74        | 2.3         |
| R12439   | SML08-15    | 7.0         | 36.         | 173.        | 230.        | 4.0         | 18.         | 6.8         | 0.77        | 1.6         |
| R12440   | SML15-23    | 6.1         | 31.         | 156.        | 220.        | 2.6         | 17.         | 7.2         | 0.75        | 2.0         |
| R12441   | SML23-30    | 5.0         | 30.         | 124.        | 230.        | 2.2         | 18.         | 7.1         | 0.79        | 2.3         |
| R12442   | SML30-38    | 5.7         | 28.         | 74.         | 180.        | 1.3         | 13.         | 7.0         | 0.52        | 1.6         |
| R12443   | SML38-45    | 3.8         | 27.         | 40.         | 220.        | 1.5         | 17.         | 7.1         | 0.59        | 1.9         |
| R12444   | MAB00-08    | 4.8         | 29.         | 26.         | 180.        | 1.6         | 13.         | 7.4         | 0.68        | 2.3         |
| R12445   | MAB08-15    | 4.4         | 30.         | 30.         | 170.        | 1.6         | 15.         | 8.6         | 0.84        | 1.9         |
| R12446   | MAB15-23    | 4.1         | 30.         | 25.         | 170.        | 1.4         | 15.         | 7.3         | 0.80        | 1.9         |
| R12447   | MAB23-30    | 3.5         | 31.         | 49.         | 190.        | 1.6         | 14.         | 8.4         | 0.76        | 2.4         |
| R12448   | MAB30-38    | 5.8         | 30.         | 23.         | 190.        | 1.1         | 15.         | 7.2         | 0.76        | 1.9         |
| R12449   | MAB38-45    | 3.9         | 27.         | 44.         | 180.        | 1.8         | 15.         | 8.2         | 0.77        | 1.9         |
| R12450   | MAB45-52    | 3.8         | 26.         | 33.         | 200.        | 1.8         | 17.         | 9.1         | 0.86        | 2.8         |
| R12451   | MAB52-60    | 6.1         | 24.         | 18.         | 200.        | 2.0         | 16.         | 7.8         | 0.81        | 2.6         |
| R13652   | QV 00-05    | <5.         | 40.         | 52.         | 112.        | 1.1         | 11.6        | 7.0         | 1.01        | 2.3         |
| R13653   | QV 10-15    | <5.         | 47.         | 57.         | 135.        | 1.2         | 13.6        | 7.8         | 0.94        | 2.2         |
| R13654   | QV 20-25    | <5.         | 70.         | 53.         | 136.        | 1.3         | 14.2        | 7.6         | 1.11        | 2.1         |
| R13655   | QV 40-45    | <5.         | 56.         | 54.         | 140.        | 1.8         | 14.2        | 5.7         | 1.2         | 1.9         |
| R13656   | QV 60-65    | <5.         | 59.         | 54.         | 145.        | 2.3         | 14.6        | 6.5         | 1.4         | 2.2         |
| R13657   | QV 80-85    | <5.         | 70.         | 53.         | 200.        | 2.7         | 19.7        | 11.2        | 1.8         | 2.8         |
| R13658   | QV110-15    | <5.         | 11.         | 51.         | 39.         | 0.3         | 3.9         | 3.0         | 0.43        | 1.0         |
| R13659   | CHT00-05    | <5.         | 78.         | 54.         | 151.        | 1.5         | 14.5        | 6.2         | 1.2         | 2.2         |
| R13660   | CHT10-15    | <5.         | 64.         | 65.         | 96.         | 1.3         | 13.8        | 6.2         | 1.2         | 2.0         |
| R13661   | CHT20-25    | <5.         | 30.         | 60.         | 84.         | 0.6         | 8.9         | 3.7         | 0.68        | 1.1         |
| R13662   | CHT30-35    | <5.         | 58.         | 63.         | 150.        | 1.8         | 14.1        | 7.4         | 0.85        | 2.7         |
| R13663   | CHT40-45    | <5.         | 56.         | 52.         | 167.        | 1.9         | 15.5        | 6.4         | 0.85        | 2.8         |
| R13664   | CHT50-55    | <5.         | 46.         | 53.         | 160.        | 2.3         | 14.6        | 6.6         | 0.90        | 2.5         |
| R13665   | CHT60-65    | <5.         | 29.         | 52.         | 162.        | 0.9         | 14.8        | 7.2         | 0.90        | 2.2         |
| R13666   | CHT75-80    | <5.         | 42.         | 52.         | 147.        | 0.6         | 15.6        | 6.9         | 0.80        | 2.4         |
| R13667   | CLR00-05    | <5.         | 58.         | 56.         | 152.        | 1.4         | 14.         | 6.7         | 0.86        | 2.8         |
| R13668   | CLR10-15    | <5.         | 53.         | 65.         | 150.        | 1.7         | 13.8        | 6.4         | 0.48        | 1.8         |
| R13669   | CLR20-25    | <5.         | 63.         | 58.         | 158.        | 1.6         | 15.         | 6.9         | 1.3         | 2.2         |
| R13670   | CLR40-45    | 22.         | 42.         | 52.         | 158.        | 0.8         | 15.2        | 6.7         | 1.1         | 2.4         |
| R13671   | STW00-05    | <10.        | 66.         | 68.         | 164.        | 1.6         | 16.         | 7.0         | 1.2         | 2.5         |
| R13672   | STW10-15    | <10.        | 81.         | 58.         | 150.        | 1.7         | 14.         | 7.6         | 1.0         | 2.0         |
| R13673   | STW20-25    | <10.        | 73.         | 52.         | 160.        | 1.8         | 16.         | 6.4         | 1.2         | 2.3         |
| R13674   | STW30-35    | <10.        | 69.         | 57.         | 158.        | 2.2         | 15.5        | 7.6         | 1.1         | 2.4         |
| R13675   | STW40-45    | 14.         | 54.         | 52.         | 186.        | 2.2         | 17.7        | 7.3         | 1.0         | 3.2         |
| R13676   | STW60-65    | <10.        | <30.        | 52.         | 110.        | 0.6         | 11.7        | 7.5         | 0.72        | 1.7         |
| R13677   | STW77-82    | <10.        | 30.         | 52.         | 129.        | 0.6         | 13.7        | 6.7         | 0.93        | 3.0         |

| LAB.NO. | GEOL.NO. | MO<br>(PPM) | NI<br>(PPM) | PB<br>(PPM) | RB<br>(PPM) | SB<br>(PPM) | SC<br>(PPM) | SH<br>(PPM) | TA<br>(PPM) | TB<br>(PPM) |
|---------|----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| R13678  | MUS00-05 | 9.          | 21.         | 53.         | 141.        | 1.5         | 14.8        | 8.4         | 1.0         | 1.9         |
| R13679  | MUS10-15 | 8.          | 30.         | 52.         | 139.        | 1.2         | 14.2        | 7.4         | 0.95        | 2.9         |
| R13680  | MES20-25 | <10.        | <30.        | 52.         | 143.        | 1.4         | 13.3        | 8.1         | 0.90        | 2.3         |
| R14164  | DP 00-05 | <16.        | 46.         | 78.         | 190.        | 2.4         | 17.         | 7.5         | 1.1         | 1.1         |
| R14165  | DP 05-15 | <17.        | 41.         | 74.         | 200.        | 2.1         | 18.         | 7.6         | 1.0         | 1.1         |
| R14166  | DP 30-35 | <20.        | 54.         | 93.         | 180.        | 2.4         | 17.         | 7.6         | 1.1         | 1.1         |
| R14167  | DP 60-65 | <17.        | 47.         | 98.         | 160.        | 2.8         | 16.         | 7.8         | 1.0         | 1.1         |
| R14168  | DP100-05 | <20.        | <32.        | 93.         | 200.        | 2.3         | 17.         | 6.9         | 1.1         | 1.1         |
| R14169  | SCN00-05 | <17.        | 48.         | 78.         | 180.        | 2.1         | 17.         | 8.5         | 1.0         | 0.9         |
| R14170  | SCN20-25 | <12.        | 47.         | 77.         | 200.        | 2.4         | 17.         | 9.0         | 1.0         | 0.8         |
| R14171  | SCN60-65 | <15.        | <32.        | <46.        | 170.        | 0.8         | 17.         | 14.0        | 1.0         | 1.4         |
| R14172  | SML00-05 | <16.        | 46.         | 78.         | 180.        | 1.9         | 18.         | 8.0         | 1.0         | 0.9         |
| R14173  | SML20-25 | <10.        | 62.         | 83.         | 170.        | 2.4         | 17.         | 8.0         | 0.9         | 1.0         |
| R14174  | SML60-65 | <10.        | <32.        | 79.         | 190.        | 3.1         | 18.         | 8.0         | 1.1         | 1.5         |
| R14175  | GO 00-05 | <20.        | 41.         | 61.         | 160.        | 1.4         | 16.         | 7.0         | 1.2         | 1.8         |
| R14176  | GO 20-25 | <19.        | 44.         | 62.         | 165.        | 1.6         | 16.         | 7.0         | 1.0         | 1.1         |
| R14177  | GO 60-65 | <16.        | 44.         | 58.         | 195.        | 2.4         | 18.         | 7.0         | 1.0         | 0.9         |
| R14178  | GO130-35 | <15.        | <32.        | <46.        | 160.        | 0.6         | 18.         | 7.0         | 0.9         | 1.0         |
| R14179  | MED00-05 | <24.        | 52.         | 82.         | 210.        | 2.0         | 18.         | 7.0         | 1.2         | 0.9         |
| R14180  | MED20-25 | <23.        | 61.         | 80.         | 190.        | 2.0         | 18.         | 7.0         | 1.2         | 1.1         |
| R14181  | MED60-65 | <22.        | 41.         | 100.        | 200.        | 3.0         | 19.         | 8.0         | 1.1         | 1.4         |
| R14182  | UPU00-05 | <15.        | <32.        | 51.         | 80.         | 1.0         | 6.          | 4.0         | 0.4         | 0.5         |
| R14183  | UPU20-25 | <15.        | 32.         | 120.        | 150.        | 3.0         | 16.         | 8.0         | 1.1         | 1.1         |
| R14184  | UPU50-55 | <14.        | <32.        | <46.        | 210.        | 1.2         | 20.         | 8.0         | 1.1         | 1.2         |
| R14185  | UPL00-05 | <14.        | 44.         | 64.         | 147.        | 1.8         | 14.         | 7.0         | 1.1         | 1.0         |
| R14186  | UPL20-25 | <14.        | 63.         | 73.         | 95.         | 1.2         | 9.          | 7.0         | 0.8         | 0.6         |
| R14187  | UPL60-65 | <12.        | <32.        | 44.         | 210.        | 1.0         | 20.         | 8.0         | 1.0         | 1.3         |
| R14188  | PEO00-05 | <10.        | 54.         | 72.         | 170.        | 1.9         | 14.         | 7.0         | 0.8         | 0.7         |
| R14189  | PEO20-25 | <8.         | 49.         | 68.         | 150.        | 2.0         | 15.         | 7.          | 0.8         | 0.9         |
| R14190  | PEO40-44 | <8.         | 32.         | <46.        | 130.        | 0.3         | 13.         | 8.          | 0.8         | 0.7         |
| R15031  | TUR00-05 |             | 30          | 60          | 136         | 1.5         | 13.0        | 6.9         | 1.0         | 0.8         |
| R15032  | TUR07-22 |             | 40          | 65          | 136         | 1.4         | 12.0        | 6.7         | 0.9         | 0.7         |
| R15033  | TUR30-45 |             | 41          | 80          | 147         | 1.7         | 13.0        | 7.1         | 1.0         | 1.0         |
| R15034  | BRD00-05 |             | 220         | 609         | 85          | 13.0        | 9.2         | 4.5         | 0.7         | 0.6         |
| R15035  | BRD07-22 |             | 299         | 435         | 78          | 9.0         | 7.8         | 4.1         | 0.6         | 0.5         |
| R15036  | BRD30-43 |             | 284         | 738         | 83          | 14.0        | 8.6         | 4.8         | 0.7         | 0.5         |
| R15037  | DP 00-05 |             | 47          | 86          | 211         | 2.2         | 20.0        | 7.3         | 1.7         | 1.1         |
| R15038  | DP 05-10 |             | 35          | 53          | 151         | 1.2         | 14.0        | 7.2         | 1.0         | 1.1         |
| R15039  | DP 20-27 |             | 38          | 65          | 111         | 1.2         | 11.0        | 6.7         | 1.0         | 0.9         |
| R15041  | SIL00-05 |             | 18          | 26          | 97          | 1.8         | 11.0        | 7.1         | 1.1         | 1.0         |
| R15042  | SIL20-25 |             | 17          | 28          | 93          | 0.9         | 10.0        | 7.5         | 1.1         | 0.9         |
| R15043  | SIL40-45 |             | 31          | 31          | 100         | 1.0         | 11.0        | 8.0         | 1.2         | 1.1         |
| R15044  | SIL60-65 |             | 29          | 34          | 96          | 1.0         | 11.0        | 6.9         | 1.1         | 0.7         |
| R15045  | SWN00-05 |             | 27          | 33          | 116         | 1.1         | 13.0        | 9.7         | 1.0         | 0.9         |
| R15046  | SWN20-25 |             | 34          | 42          | 110         | 1.3         | 13.0        | 7.9         | 1.1         | 1.2         |
| R15047  | SWN30-35 |             | 36          | 35          | 131         | 1.5         | 15.0        | 7.7         | 1.2         | 1.3         |
| R15048  | SWN50-55 |             | 38          | 34          | 136         | 1.5         | 15.0        | 8.1         | 1.0         | 1.1         |
| R15049  | SWN70-74 |             | 29          | 35          | 134         | 1.4         | 16.0        | 7.9         | 1.2         | 1.0         |
| R15050  | SWN90-95 |             | 31          | 62          | 120         | 0.8         | 14.0        | 8.5         | 1.3         | 1.0         |
| R15583  | 171-0001 | 14          | 35          | 51          | 137         | 1.7         | 13          | 7.3         | 0.9         | 0.8         |
| R15584  | 171-0305 | 21          | 41          | 58          | 142         | 1.4         | 14          | 8.5         | 0.9         | 1.3         |
| R15585  | 171-0507 | 22          | 29          | 58          | 115         | 1.6         | 13          | 8.2         | 0.9         | 0.9         |
| R15586  | 171-0914 | 20          | 50          | 81          | 146         | 1.8         | 14          | 8.2         | 1.0         | 1.0         |
| R15587  | 171-2328 | 23          | 55          | 101         | 143         | 2.0         | 13          | 8.1         | 0.9         | 0.9         |
| R15588  | 171-3741 | 20          | 64          | 81          | 137         | 2.1         | 13          | 7.6         | 1.0         | 1.0         |
| R15589  | 171-5156 | 24          | 53          | 86          | 145         | 2.4         | 15          | 8.2         | 1.0         | 1.3         |
| R15590  | 176-0204 | 27          | 39          | 68          | 141         | 1.6         | 15          | 8.7         | 0.9         | 1.4         |
| R15591  | 176-0608 | 41          | 43          | 64          | 137         | 1.5         | 13          | 7.3         | 1.0         | 1.0         |
| R15592  | 176-1012 | 15          | 38          | 98          | 142         | 1.5         | 12          | 7.0         | 0.9         | 0.9         |
| R15593  | 176-1415 | 15          | 37          | 98          | 130         | 1.5         | 11          | 8.2         | 0.9         | 0.9         |
| R15594  | 176-2025 | 8           | 33          | 39          | 139         | 1.9         | 13          | 8.0         | 1.1         | 1.0         |
| R15595  | 176-3439 | 15          | 21          | 51          | 140         | 1.8         | 13          | 8.5         | 1.0         | 0.8         |
| R15596  | 176-4853 | 37          | 20          | 10          | 162         | 0.7         | 15          | 9.0         | 1.1         | 1.0         |

| LAB. NO. | GEOL. NO. | TH<br>(PPM) | YR<br>(PPM) | ZN<br>(PPM) | SAND<br>(%) | SILT<br>(%) | CLAY<br>(%) | TOT-C<br>(%) | IN-C<br>(%) | ORG-C<br>(%) |
|----------|-----------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|--------------|
| R12240   | MR300-08  | 18.         | 4.          | 137.        | 0.10        | 62.1        | 37.8        | 2.10         | 0.56        | 1.54         |
| R12241   | MR308-15  | 19.         | 3.          | 122.        | 0.1         | 57.1        | 42.8        | 1.92         | 0.36        | 1.56         |
| R12242   | MR315-23  | 18.         | 4.          | 113.        | 0.1         | 64.5        | 35.4        | 1.79         | 0.36        | 1.43         |
| R12243   | MR323-30  | 15.         | 3.          | 114.        | 0.2         | 63.3        | 36.5        | 2.01         | 0.38        | 1.63         |
| R12244   | MR330-39  | 19.         | 2.          | 127.        | 0.2         | 62.7        | 37.1        | 1.84         | 0.30        | 1.54         |
| R12245   | MR338-46  | 20.         | 4.          | 119.        | 0.2         | 50.4        | 49.4        | 2.04         | 0.22        | 1.82         |
| R12246   | MR346-53  | 17.         | 3.          | 129.        | 0.2         | 47.0        | 52.8        | 2.13         | 0.33        | 1.80         |
| R12247   | MR353-61  | 20.         | 3.          | 126.        | 0.2         | 46.9        | 52.9        | 2.01         | 0.03        | 1.98         |
| R12248   | MR361-69  | 17.         | 2.          | 123.        | 0.2         | 47.0        | 52.8        | 1.99         | 0.34        | 1.65         |
| R12249   | MR600-08  | 18.         | 3.          | 154.        | 0.1         | 31.4        | 68.5        | 2.79         | 0.58        | 2.21         |
| R12250   | MR608-15  | 17.         | 3.          | 152.        | 1.7         | 36.4        | 61.9        | 3.13         | 0.65        | 2.48         |
| R12251   | MR615-23  | 13.         | 2.          | 135.        | 2.2         | 44.0        | 53.8        | 3.33         | 0.87        | 2.46         |
| R12252   | MR623-30  | 17.         | 2.          | 135.        | 0.8         | 47.1        | 52.1        | 2.87         | 0.56        | 2.32         |
| R12253   | MR630-38  | 18.         | 3.          | 135.        | 0.5         | 41.2        | 58.3        | 2.71         | 0.32        | 2.39         |
| R12254   | MR638-46  | 17.         | 2.          | 129.        | 1.3         | 32.0        | 66.7        | 2.58         | 0.44        | 2.14         |
| R12255   | MR646-53  | 20.         | 3.          | 143.        | 0.7         | 32.4        | 66.9        | 2.53         | 0.18        | 2.35         |
| R12256   | MR653-61  | 19.         | 2.          | 129.        | 1.6         | 36.6        | 61.8        | 2.51         | 0.51        | 2.00         |
| R12257   | MR661-69  | 7.          | 1.          | 38.         | 14.0        | 35.4        | 50.6        | 2.62         | 0.98        | 1.64         |
| R12433   | LDP00-08  | 15.         | 2.          | 5000        |             |             |             | 5.08         | 0.76        | 4.32         |
| R12434   | LDP08-15  | 16.         | 3.          | 5000        |             |             |             | 4.35         | 0.99        | 3.36         |
| R12435   | LDP15-23  | 16.         | 3.          | 4100        |             |             |             | 4.54         | 0.82        | 3.72         |
| R12436   | LDP23-30  | 16.         | 3.          | 3400        |             |             |             | 4.14         | 0.68        | 3.46         |
| R12437   | LDP30-38  | 17.         | 2.          | 348         |             |             |             | 3.95         | 0.45        | 3.50         |
| R12439   | SML00-08  | 16.         | 2.          | 508         |             |             |             | 4.76         | 0.89        | 3.87         |
| R12439   | SML08-15  | 17.         | 2.          | 651         |             |             |             | 4.74         | 0.75        | 3.99         |
| R12440   | SML15-23  | 15.         | 2.          | 525         |             |             |             | 5.21         | 0.79        | 4.42         |
| R12441   | SML23-30  | 17.         | 2.          | 396         |             |             |             | 4.66         | 0.87        | 3.79         |
| R12442   | SML30-38  | 12.         | 1.          | 283         |             |             |             | 4.58         | 0.86        | 3.72         |
| R12443   | SML38-45  | 15.         | 2.          | 248         |             |             |             | 5.15         | 0.80        | 4.35         |
| R12444   | MA800-08  | 14.         | 2.          | 152         |             |             |             | 2.60         | 0.55        | 2.05         |
| R12445   | MA808-15  | 16.         | 2.          | 155         |             |             |             | 2.68         | 0.54        | 2.14         |
| R12446   | MA815-23  | 16.         | 2.          | 149         |             |             |             | 3.33         | 0.75        | 2.58         |
| R12447   | MA823-30  | 16.         | 2.          | 140         |             |             |             | 2.23         | 0.73        | 1.50         |
| R12448   | MA830-38  | 16.         | 2.          | 147         |             |             |             | 3.47         | 1.24        | 2.23         |
| R12449   | MA838-45  | 17.         | 2.          | 131         |             |             |             | 2.52         | 0.78        | 1.74         |
| R12450   | MA845-52  | 18.         | 2.          | 119         |             |             |             | 2.25         | 0.39        | 1.86         |
| R12451   | MA852-60  | 17.         | 2.          | 126         |             |             |             | 2.55         | 0.51        | 2.04         |
| R13652   | QV 00-05  | 11.         | 2.6         | 126.        | 0.04        | 94.31       | 5.65        | 3.40         | 0.81        | 2.59         |
| R13653   | QV 10-15  | 12.         | 3.5         | 168.        | 0.24        | 90.29       | 9.47        | 3.19         | 0.63        | 2.56         |
| R13654   | QV 20-25  | 12.         | 2.7         | 149.        | 0.19        | 89.71       | 10.10       | 2.91         | 0.56        | 2.35         |
| R13655   | QV 40-45  | 14.         | 3.0         | 158.        | 0.12        | 89.30       | 10.58       | 2.49         | 0.49        | 2.00         |
| R13656   | QV 60-65  | 15.         | 2.8         | 159.        | 0.15        | 89.98       | 10.87       | 2.43         | 0.57        | 1.86         |
| R13657   | QV 80-85  | 20.         | 4.8         | 176.        | 0.79        | 88.62       | 10.59       | 3.97         | 0.86        | 3.11         |
| R13658   | QV110-15  | 5.          | 1.6         | 29.         | 10.01       | 86.14       | 3.85        | 9.66         | 5.35        | 4.31         |
| R13659   | CHT00-05  | 14.         | 2.7         | 177.        | 0.02        | 94.77       | 5.21        | 2.67         | 0.74        | 1.93         |
| R13660   | CHT10-15  | 13.         | 3.6         | 197.        | 0.12        | 91.88       | 8.00        | 2.89         | 0.81        | 2.07         |
| R13661   | CHT20-25  | 8.          | 2.2         | 189.        | 0.41        | 88.73       | 10.86       | 3.19         | 0.87        | 2.32         |
| R13662   | CHT30-35  | 12.         | 3.3         | 180.        | 0.17        | 89.94       | 9.89        | 3.28         | 0.76        | 2.52         |
| R13663   | CHT40-45  | 13.         | 3.5         | 167.        | 0.09        | 87.59       | 12.32       | 2.92         | 0.52        | 2.40         |
| R13664   | CHT50-55  | 12.         | 3.5         | 191.        | 0.46        | 86.96       | 12.58       | 3.45         | 0.46        | 2.99         |
| R13665   | CHT60-65  | 11.         | 3.1         | 136.        | 1.74        | 85.25       | 13.01       | 4.54         | 0.03        | 4.51         |
| R13666   | CHT75-80  | 11.         | 3.5         | 110.        | 1.89        | 84.53       | 13.58       | 1.92         | 0.01        | 1.91         |
| R13667   | CLR00-05  | 11.         | 3.4         | 203.        | 0.08        | 93.99       | 5.93        | 3.03         | 0.75        | 2.28         |
| R13668   | CLR10-15  | 11.         | 3.1         | 205.        | 0.30        | 88.06       | 11.64       | 2.96         | 0.67        | 2.29         |
| R13669   | CLR20-25  | 13.         | 2.7         | 174.        | 0.23        | 77.01       | 22.76       | 2.86         | 0.72        | 2.14         |
| R13670   | CLR40-45  | 12.         | 2.7         | 117.        | 0.34        | 87.51       | 12.15       | 3.04         | 0.02        | 3.02         |
| R13671   | STW00-05  | 13.         | 2.8         | 193.        | 0.02        | 93.61       | 6.37        | 2.75         | 0.53        | 2.22         |
| R13672   | STW10-15  | 12.         | 3.0         | 186.        | 0.23        | 89.23       | 10.54       | 2.74         | 0.60        | 2.14         |
| R13673   | STW20-25  | 13.         | 3.7         | 176.        | 0.21        | 88.72       | 11.07       | 2.70         | 0.69        | 2.01         |
| R13674   | STW30-35  | 13.         | 2.5         | 167.        | 0.44        | 88.18       | 11.38       | 2.81         | 0.81        | 2.00         |
| R13675   | STW40-45  | 15.         | 3.          | 162.        | 0.35        | 87.91       | 11.74       | 2.55         | 0.34        | 2.21         |
| R13676   | STW60-65  | 10.         | 2.6         | 71.         | 2.59        | 77.80       | 19.61       | 1.10         | 0.01        | 1.09         |
| R13677   | STW77-82  | 12.         | 2.8         | 71.         | 2.38        | 88.44       | 9.18        | 0.61         | 0.01        | 0.60         |

| LAB.NO. | GEOLOGICAL NO. | TH<br>(PPM) | YR<br>(PPM) | ZN<br>(PPM) | SAND<br>(%) | SILT<br>(%) | CLAY<br>(%) | TOT-C<br>(%) | IN-C<br>(%) | ORG-C<br>(%) |
|---------|----------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|-------------|--------------|
| R13678  | MUS00-05       | 14.         | 4.3         | 107.        | 0.01        | 93.44       | 6.55        | 2.18         | 0.26        | 1.92         |
| R13679  | MUS10-15       | 12.         | 4.0         | 113.        | 0.46        | 87.69       | 11.85       | 2.26         | 0.13        | 2.13         |
| R13680  | MES20-25       | 13.         | 2.7         | 105.        | 0.01        | 90.30       | 9.69        | 2.17         | 0.28        | 1.89         |
| R14164  | DP 00-05       | 12.         | 4.2         | 1660.       |             |             |             | 3.27         | 0.86        | 2.41         |
| R14165  | DP 05-15       | 13.         | 3.8         | 1120.       |             |             |             | 3.47         | 0.62        | 2.85         |
| R14166  | DP 30-35       | 12.         | 3.8         | 2640.       |             |             |             | 3.74         | 0.81        | 2.93         |
| R14167  | DP 60-65       | 12.         | 3.6         | 1200.       |             |             |             | 3.69         | 0.87        | 2.82         |
| R14168  | DP100-05       | 12.         | 3.4         | 870.        |             |             |             | 3.27         | 0.60        | 2.67         |
| R14169  | SCN00-05       | 12.         | 3.3         | 440.        |             |             |             | 3.73         | 0.94        | 2.79         |
| R14170  | SCN20-25       | 13.         | 3.6         | 410.        |             |             |             | 3.69         | 0.69        | 3.00         |
| R14171  | SCN60-65       | 12.         | 3.6         | 100.        |             |             |             | 2.22         | 0.21        | 2.01         |
| R14172  | SML00-05       | 13.         | 3.5         | 360.        |             |             |             | 3.66         | 0.75        | 2.91         |
| R14173  | SML20-25       | 12.         | 3.6         | 520.        |             |             |             | 3.90         | 0.97        | 2.93         |
| R14174  | SML60-65       | 13.         | 3.4         | 400.        |             |             |             | 3.65         | 0.57        | 3.08         |
| R14175  | GO 00-05       | 13.         | 3.3         | 310.        |             |             |             | 3.31         | 0.77        | 2.54         |
| R14176  | GO 20-25       | 13.         | 3.3         | 360.        |             |             |             | 3.27         | 0.70        | 2.57         |
| R14177  | GO 60-65       | 14.         | 3.3         | 350.        |             |             |             | 3.47         | 0.69        | 2.78         |
| R14178  | GO130-35       | 12.         | 3.4         | 130.        |             |             |             | 8.40         | 0.01        | 8.39         |
| R14179  | MED00-05       | 13.         | 3.8         | 410.        |             |             |             | 3.59         | 0.71        | 2.88         |
| R14180  | MED20-25       | 13.         | 4.0         | 470.        |             |             |             | 3.71         | 1.10        | 2.61         |
| R14181  | MED60-65       | 14.         | 3.6         | 480.        |             |             |             | 3.80         | 0.94        | 2.86         |
| R14182  | UPU00-05       | 6.          | 2.1         | 180.        |             |             |             | 6.50         | 5.24        | 1.26         |
| R14183  | UPU20-25       | 14.         | 3.4         | 520.        |             |             |             | 4.01         | 0.79        | 3.22         |
| R14184  | UPU50-55       | 15.         | 3.8         | 190.        |             |             |             | 3.14         | 0.17        | 2.97         |
| R14185  | UPL00-05       | 12.         | 3.6         | 360.        |             |             |             | 3.37         | 1.10        | 2.27         |
| R14186  | UPL20-25       | 8.          | 2.2         | 520.        |             |             |             | 3.21         | 1.08        | 2.13         |
| R14187  | UPL60-65       | 15.         | 4.0         | 160.        |             |             |             | 3.43         | 0.09        | 3.34         |
| R14188  | PE000-05       | 12.         | 3.0         | 400.        |             |             |             | 3.56         | 0.93        | 2.61         |
| R14189  | PE020-25       | 13.         | 3.0         | 300.        |             |             |             | 4.67         | 1.02        | 3.65         |
| R14190  | PE040-44       | 10.         | 3.0         | 130.        |             |             |             | 4.34         | 0.05        | 4.29         |
| R15031  | TUR00-05       | 7.5         | 2.8         | 241         |             |             |             | 3.96         | 1.05        | 2.91         |
| R15032  | TUR07-22       | 7.1         | 2.6         | 275         |             |             |             | 3.87         | 0.85        | 3.02         |
| R15033  | TUR30-45       | 9.2         | 3.2         | 332         |             |             |             | 3.92         | 0.69        | 3.23         |
| R15034  | BRD00-05       | 4.9         | 1.9         | 2580        |             |             |             | 14.26        | 2.20        | 12.06        |
| R15035  | BRD07-22       | 3.9         | 1.5         | 1690        |             |             |             | 13.35        | 2.63        | 10.72        |
| R15036  | BRD30-43       | 4.9         | 1.9         | 2550        |             |             |             | 10.20        | 2.58        | 7.62         |
| R15037  | DP 00-05       | 16.0        | 4.0         | 2090        |             |             |             | 3.96         | 0.57        | 3.39         |
| R15038  | DP 05-10       | 11.0        | 2.7         | 391         |             |             |             | 4.08         | 0.48        | 3.60         |
| R15039  | DP 20-27       | 9.0         | 2.3         | 1120        |             |             |             | 4.20         | 0.77        | 3.43         |
| R15041  | SIL00-05       | 10.0        | 2.7         | 132         |             |             |             | 2.18         | 0.17        | 2.01         |
| R15042  | SIL20-25       | 9.1         | 2.6         | 144         |             |             |             | 1.48         | 0.30        | 1.18         |
| R15043  | SIL40-45       | 9.6         | 2.7         | 134         |             |             |             | 1.95         | 0.28        | 1.67         |
| R15044  | SIL60-65       | 9.7         | 2.6         | 142         |             |             |             | 1.74         | 0.29        | 1.45         |
| R15045  | SWN00-05       | 9.7         | 2.8         | 137         |             |             |             | 2.51         | 0.63        | 1.88         |
| R15046  | SWN20-25       | 9.5         | 2.8         | 147         |             |             |             | 2.47         | 0.77        | 1.70         |
| R15047  | SWN30-35       | 12.0        | 3.0         | 146         |             |             |             | 2.44         | 0.67        | 1.77         |
| R15048  | SWN50-55       | 12.0        | 3.0         | 140         |             |             |             | 1.91         | 0.26        | 1.65         |
| R15049  | SWN70-74       | 13.0        | 3.0         | 144         |             |             |             | 2.25         | 0.22        | 2.03         |
| R15050  | SWN90-95       | 11.0        | 3.4         | 113         |             |             |             | 1.72         | 0.02        | 1.70         |
| R15583  | 171-0001       | 8.4         | 3.3         | 262         |             |             |             | 3.6          | 1.3         | 2.3          |
| R15584  | 171-0305       | 8.7         | 3.2         | 271         |             |             |             | 3.5          | 1.0         | 2.5          |
| R15585  | 171-0507       | 8.3         | 3.2         | 240         |             |             |             | 3.6          | 1.2         | 2.4          |
| R15586  | 171-0914       | 8.4         | 3.3         | 351         |             |             |             | 3.7          | 1.2         | 2.6          |
| R15587  | 171-2328       | 8.0         | 3.3         | 416         |             |             |             | 3.6          | 1.2         | 2.4          |
| R15588  | 171-3741       | 8.1         | 3.4         | 438         |             |             |             | 3.5          | 1.2         | 2.4          |
| R15589  | 171-5156       | 8.6         | 3.6         | 453         |             |             |             | 3.6          | 1.0         | 2.6          |
| R15590  | 176-0204       | 8.8         | 3.2         | 256         |             |             |             | 3.6          | 1.0         | 2.6          |
| R15591  | 176-0608       | 8.5         | 3.1         | 306         |             |             |             | 3.8          | 1.3         | 2.5          |
| R15592  | 176-1012       | 7.7         | 3.2         | 298         |             |             |             | 3.7          | 1.3         | 2.4          |
| R15593  | 176-1415       | 7.6         | 3.0         | 347         |             |             |             | 3.8          | 1.6         | 2.3          |
| R15594  | 176-2025       | 8.8         | 3.3         | 264         |             |             |             | 3.1          | 1.0         | 2.1          |
| R15595  | 176-3439       | 8.8         | 3.4         | 273         |             |             |             | 3.1          | 0.9         | 2.2          |
| R15596  | 176-4853       | 9.3         | 3.8         | 99          |             |             |             | 2.3          | <0.1        | 2.3          |

APPENDIX 3

Meredosia Lake, Grain Size and Carbon Content

| Site | Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Total Carbon (%) | Inorganic Carbon (%) | Organic Carbon (%) |
|------|------------|----------|----------|----------|------------------|----------------------|--------------------|
| 1    | 15-30      | 0.2      | 55.9     | 43.9     | 2.28             | 0.49                 | 1.79               |
|      | 30-45      | 0.2      | 59.6     | 40.2     | 1.84             | 0.17                 | 1.67               |
| 2    | 15-30      | 0.2      | 59.2     | 40.6     | 1.89             | 0.41                 | 1.10               |
|      | 30-45      | 0.3      | 47.3     | 52.4     | 1.78             | 0.39                 | 1.05               |
| 3    | 15-30      | 0.1      | 47.5     | 52.4     | 2.28             | 0.44                 | 1.84               |
|      | 30-45      | 0.9      | 55.1     | 44.0     | 1.79             | 0.40                 | 1.39               |
| 4    | 15-30      | 0.3      | 55.5     | 44.2     | 1.95             | 0.40                 | 1.55               |
|      | 30-45      | 0.4      | 45.7     | 53.9     | 2.45             | 0.39                 | 2.06               |
| 5    | 15-30      | 0.6      | 39.1     | 60.3     | 2.85             | 0.58                 | 2.27               |
|      | 30-45      | 0.5      | 46.2     | 59.3     | 2.63             | 0.53                 | 2.10               |
| 6    | 15-30      | 1.2      | 35.1     | 63.7     | 2.98             | 0.61                 | 2.37               |
|      | 30-45      | 0.5      | 36.2     | 63.3     | 2.83             | 0.50                 | 2.32               |
| 7    | 15-30      | 0.5      | 44.6     | 54.9     | 2.52             | 0.37                 | 2.15               |
|      | 30-45      | 0.3      | 35.4     | 64.3     | 2.67             | 0.47                 | 2.20               |
| 8    | 15-30      | 1.0      | 34.0     | 65.0     | 2.69             | 0.29                 | 2.40               |
|      | 30-45      | 0.7      | 35.4     | 63.9     | 2.55             | 0.38                 | 2.17               |
| 9    | 15-30      | 0.3      | 38.6     | 61.1     | 2.72             | 0.43                 | 2.29               |
|      | 30-45      | 0.3      | 40.3     | 59.4     | 2.28             | 0.32                 | 1.96               |

**APPENDIX 4**

Elemental Distributions in Lakes Sampled Along the Illinois River

- Figure 4-1 Aluminum oxide distribution in sediments of lakes sampled along the Illinois River.
- Figure 4-2 Arsenic distribution in sediments of lakes sampled along the Illinois River.
- Figure 4-3 Chromium distribution in sediments of lakes sampled along the Illinois River.
- Figure 4-4 Lead distribution in sediments of lakes sampled along the Illinois River.
- Figure 4-5 Phosphorous distribution in sediments of lakes sampled along the Illinois River.
- Figure 4-6 Zinc distribution in sediments of lakes sampled along the Illinois River.
- Figure 4-7 Organic carbon distribution in sediments of lakes sampled along the Illinois River.

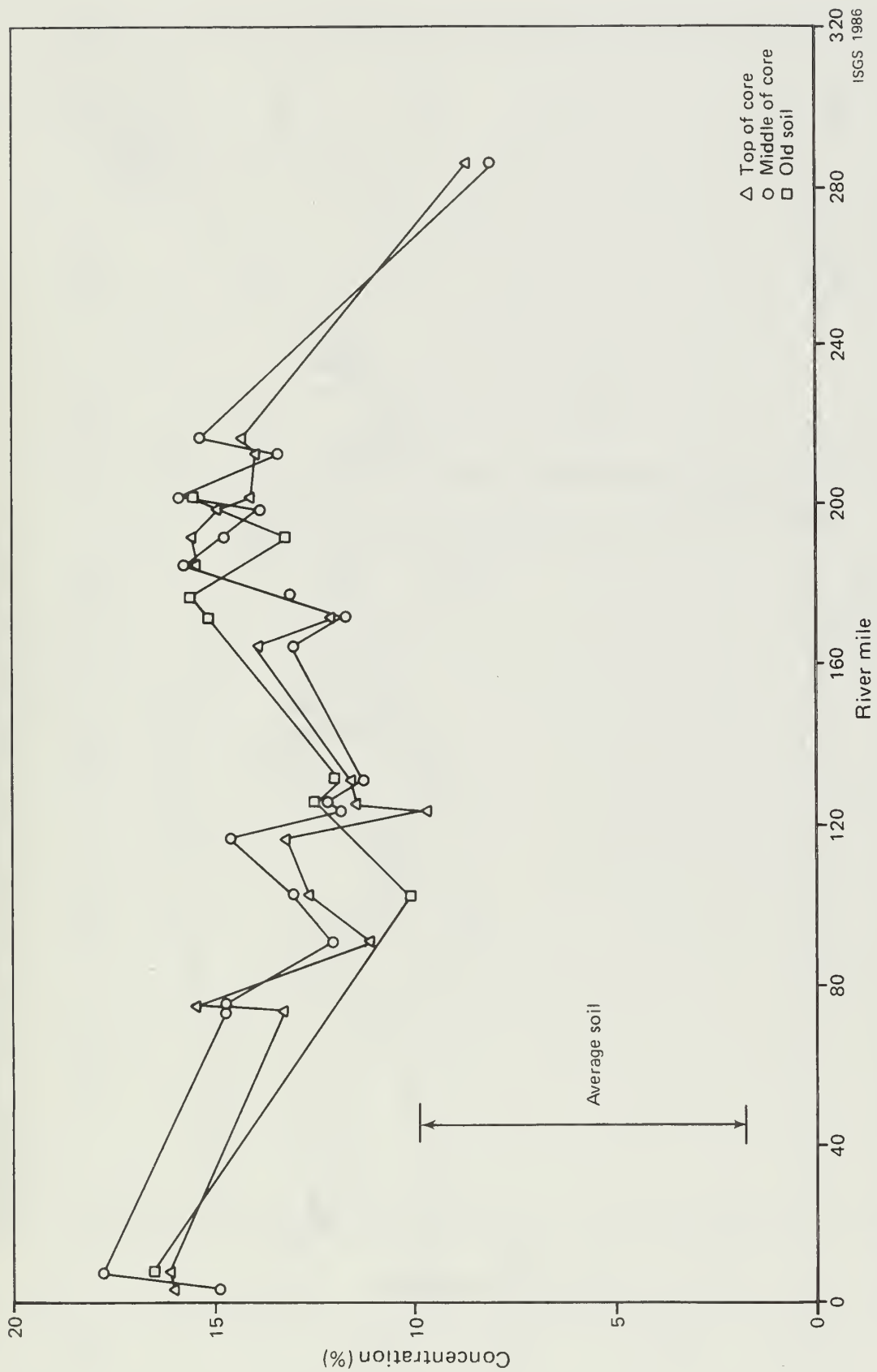


Figure 4-1  
Aluminum oxide distribution in sediments of lakes sampled along the Illinois River.

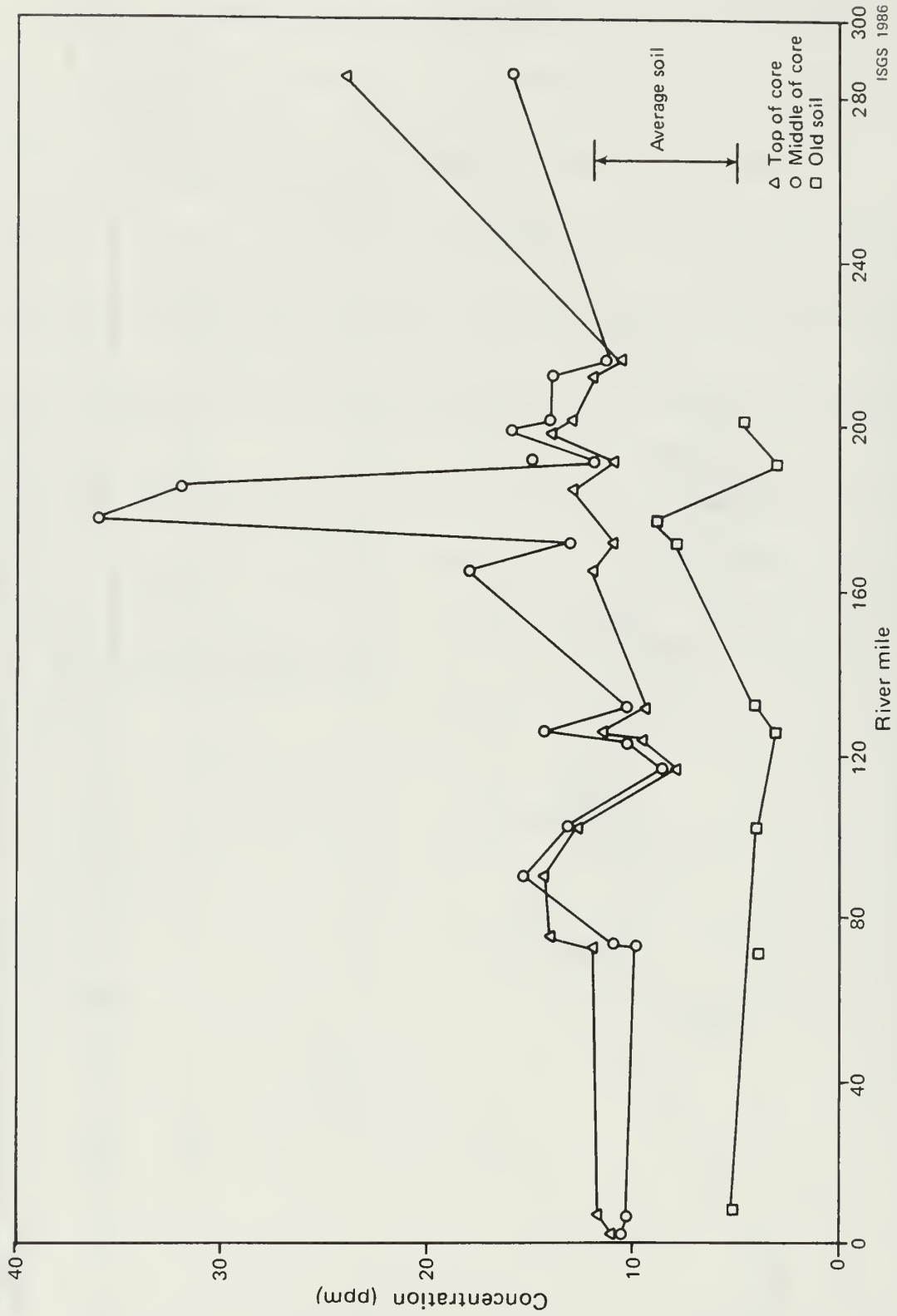


Figure 4-2  
Arsenic distribution in sediments of lakes sampled along the Illinois River.



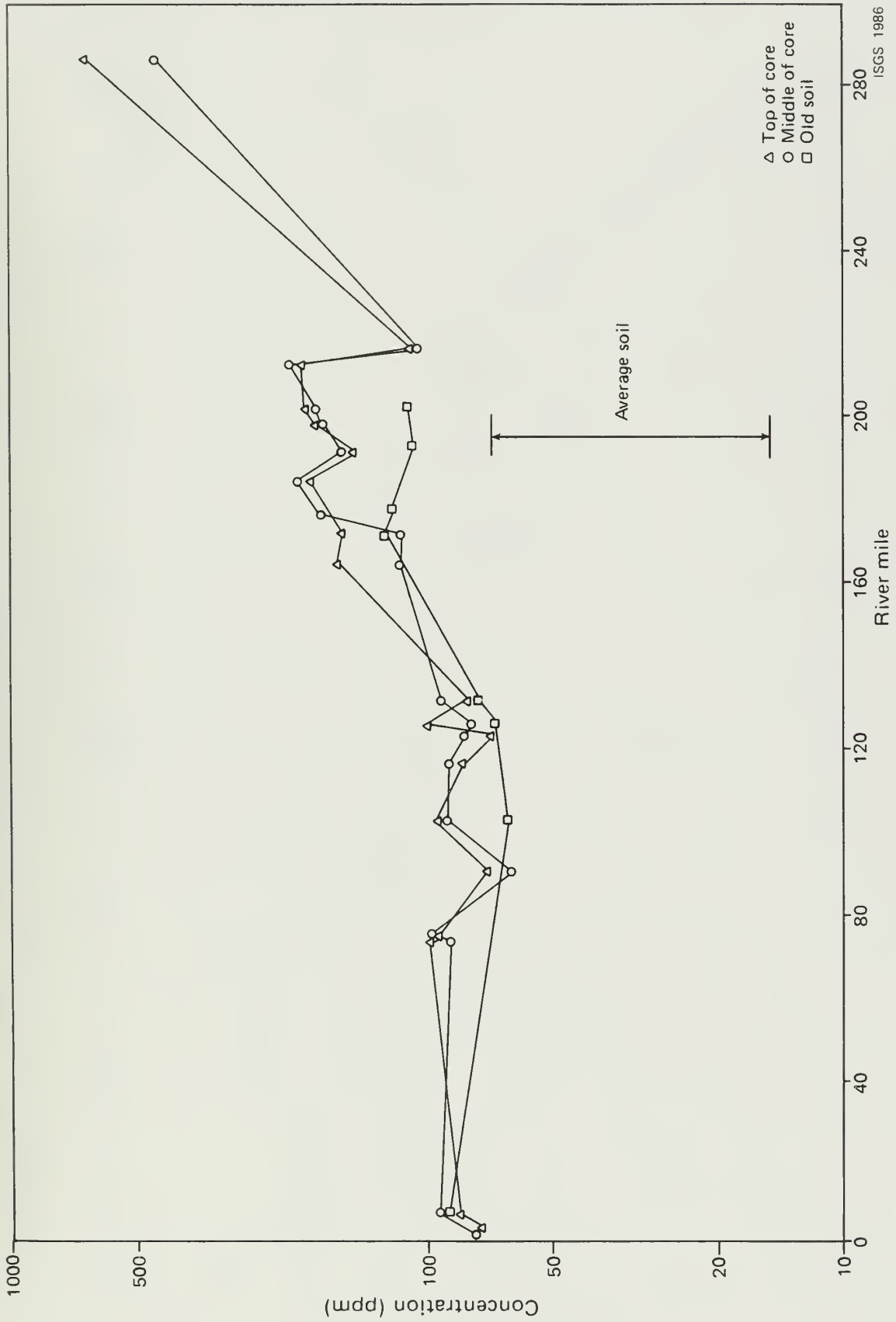


Figure 4-3  
Chromium distribution in sediments of lakes sampled along the Illinois River.

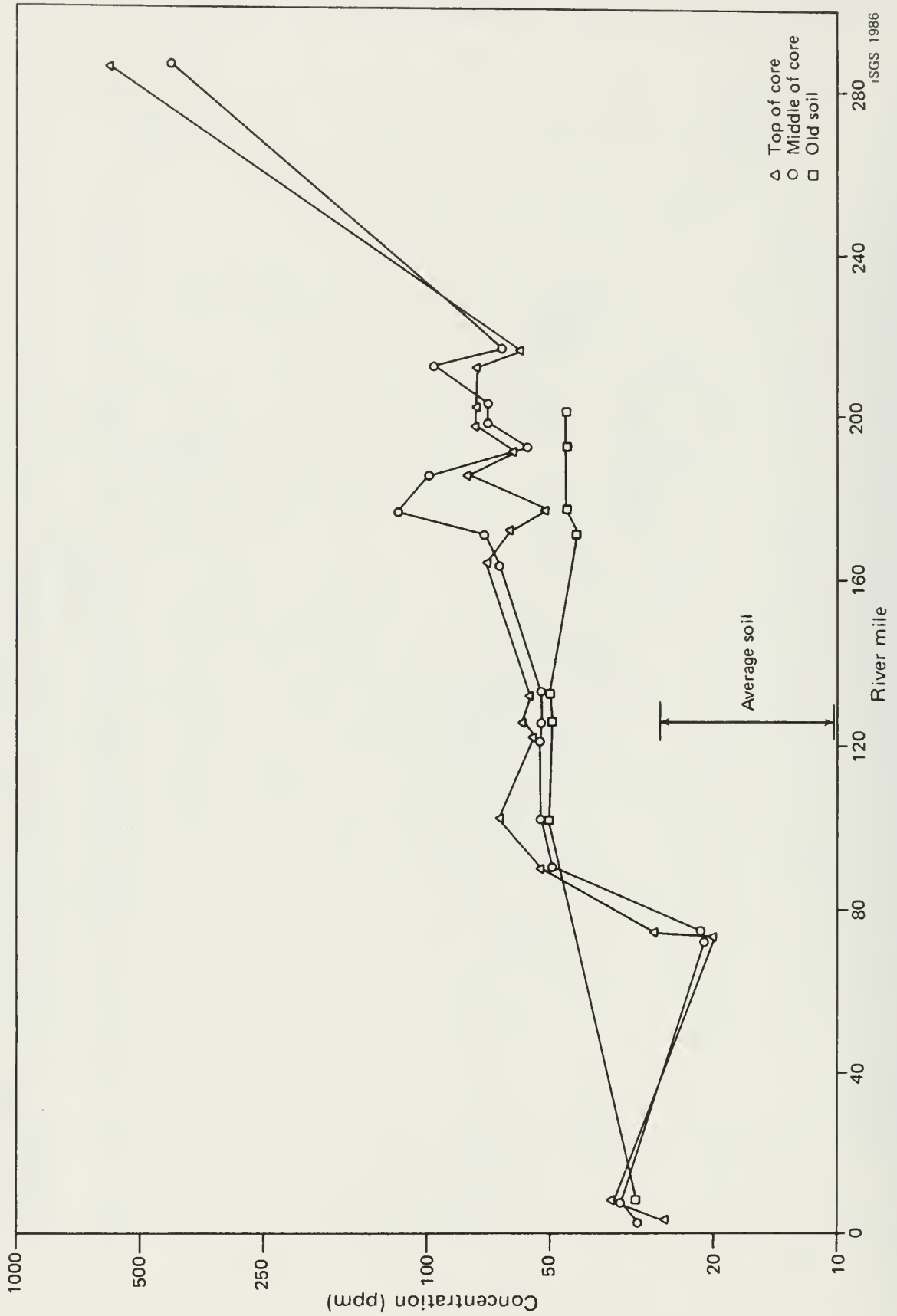
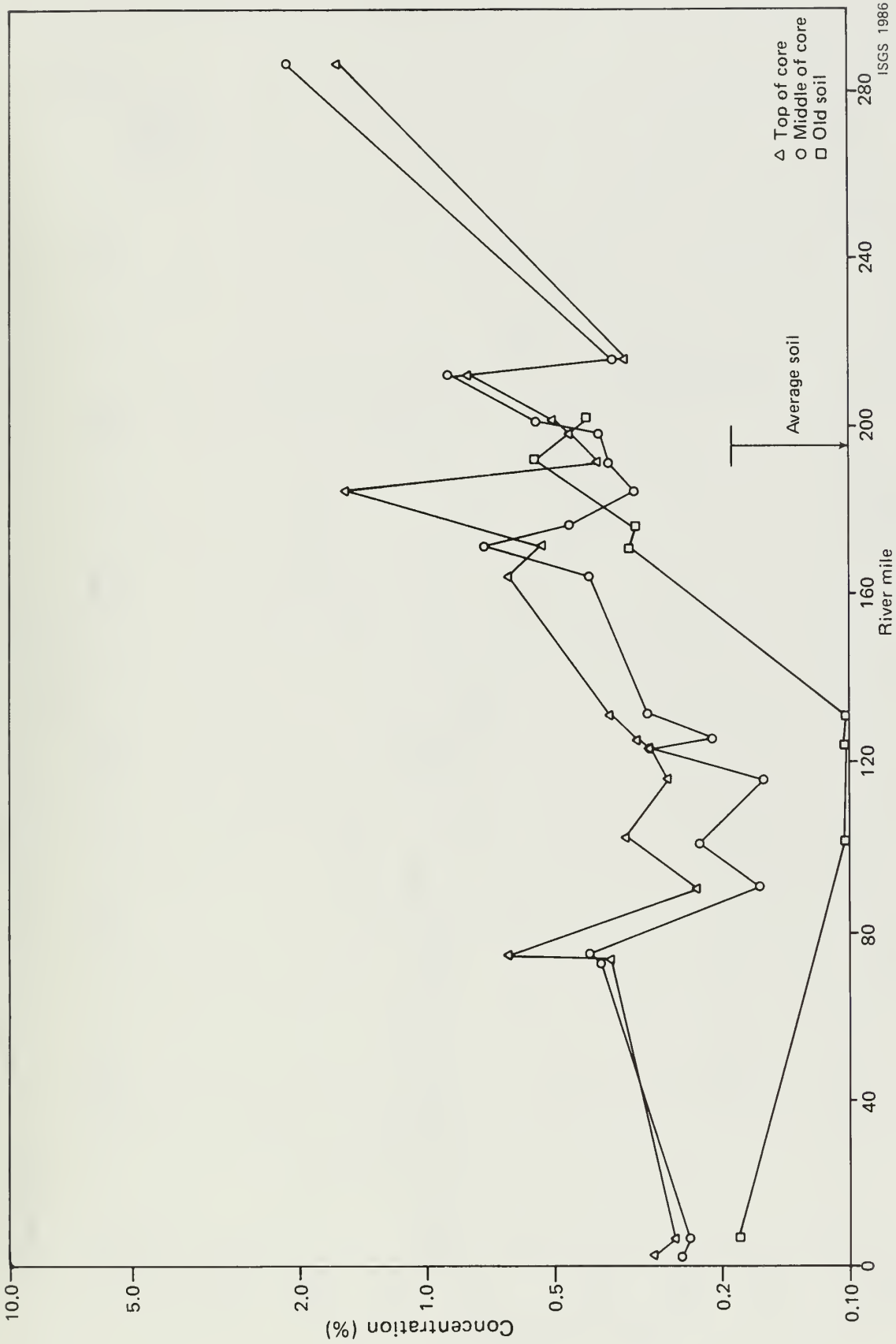


Figure 4-4  
Lead distribution in sediments of lakes sampled along the Illinois River.



**Figure 4-5**  
Phosphorous distribution in sediments of lakes sampled along the Illinois River.

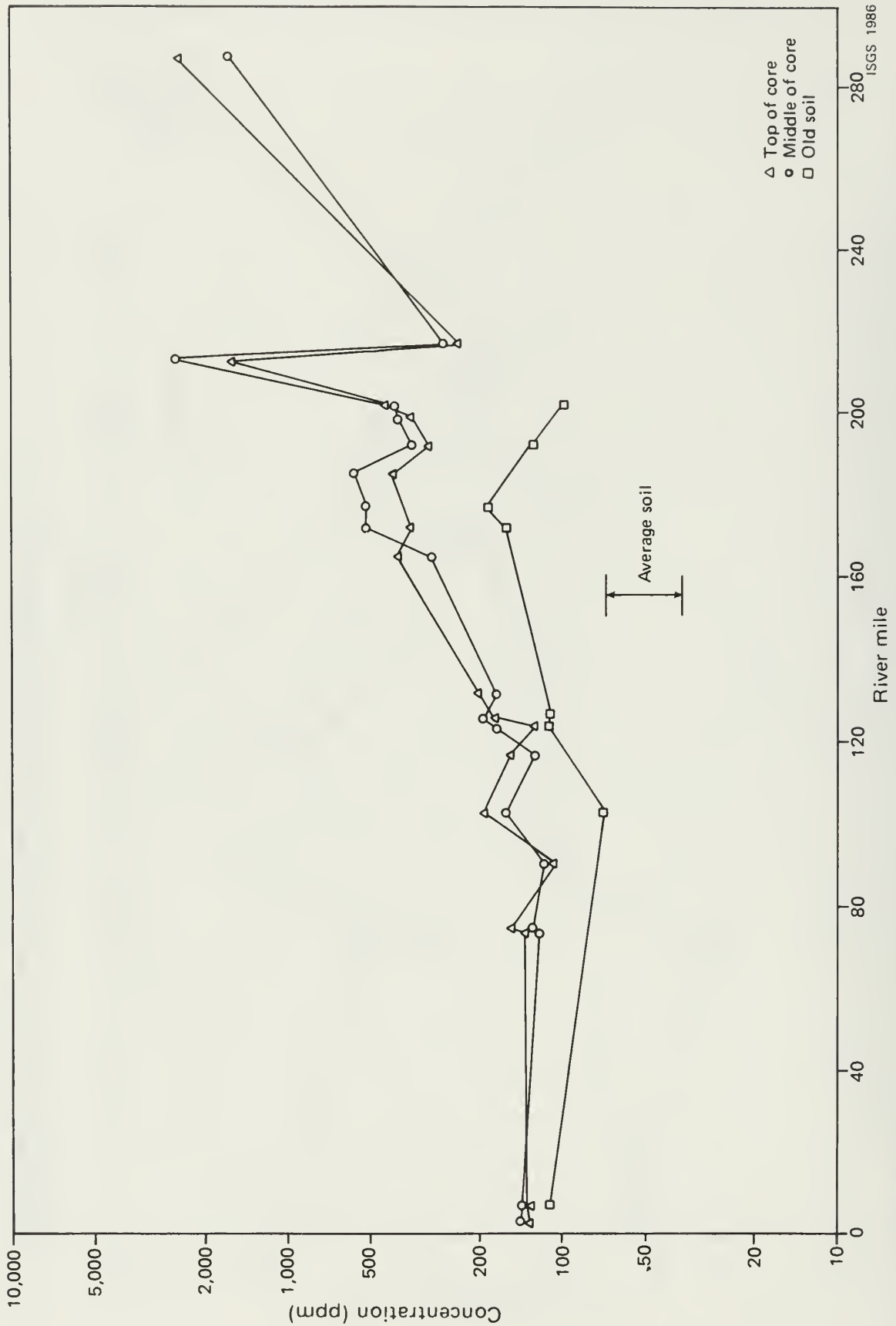


Figure 4-6  
Zinc distribution in sediments of lakes sampled along the Illinois River.

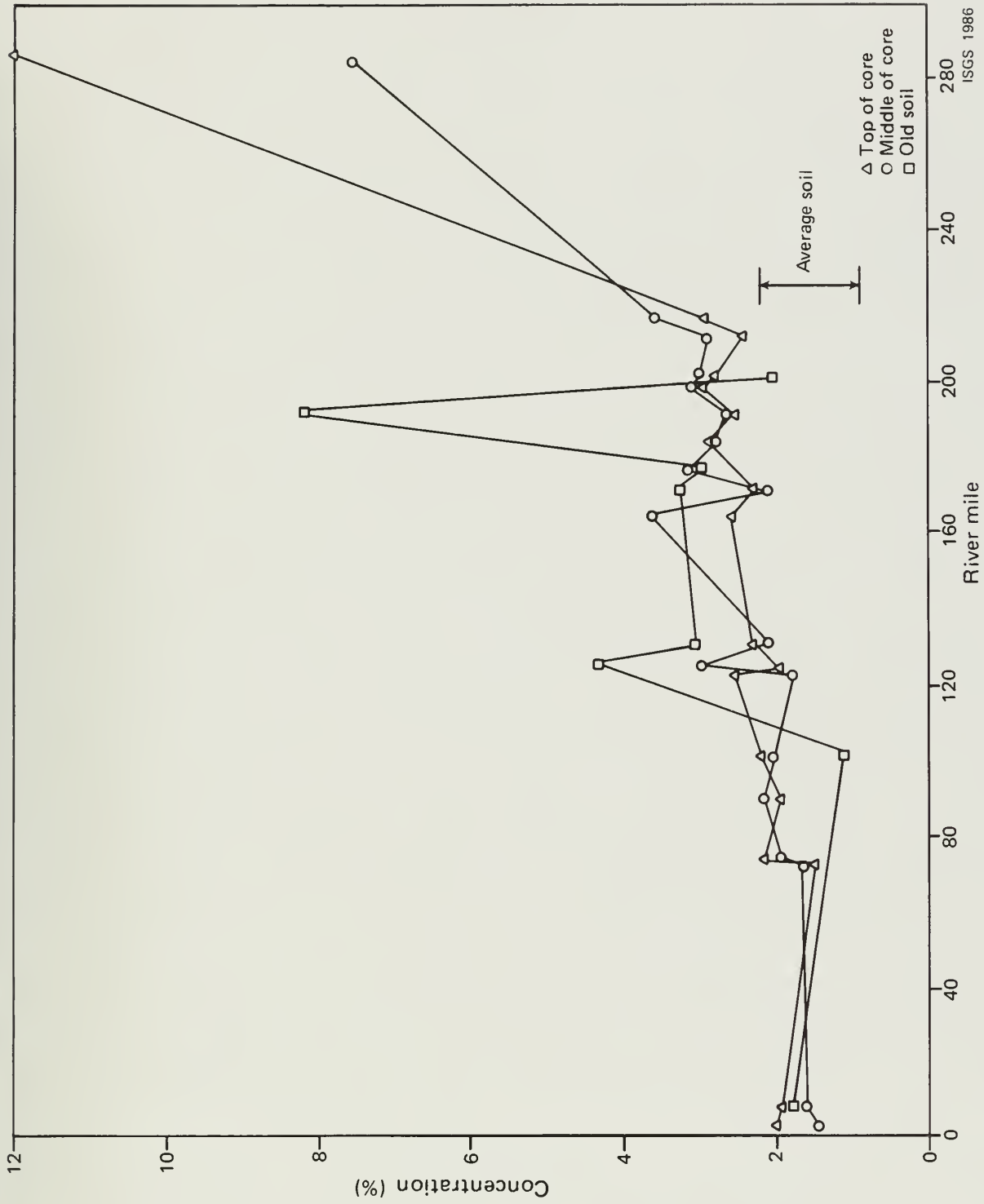


Figure 4-7  
Organic carbon distribution in sediments of lakes sampled along the Illinois River.

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