# Organic Centre-Lake Sediments—Application in the Geochemical Exploration for Gold in the Canadian Shield of Saskatchewan

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ABSTRACT

*Preliminary investigations indicate that organic lake sediments offer some potential for gold exploration within the Canadian Shield of northwestern Saskatchewan. It is also apparent that certain precautions must be taken.*

*Gold is primarily related to the organic fraction of the lake sediments, which, although giving consistant Au contents to those sediments, may restrict the dispersion of Au within the lake itself. It may be necessary to carry out selective extractions on the lake sediments to differentiate between Au related to organic sequestration, indicative of hydromorphic and/or chemical dispersion, and Au related to inorganics, indicative of mechanical dispersion.*

*Lake sediments are probably only of use for very detailed exploration (i.e. every lake). One to three samples per lake should be appropriate, although a single centre-lake organic-rich sediment sample may be adequate in very small lakes. Each lake sediment sample should be analyzed at least twice and the analytical data carefully monitored and evaluated.*

*The use of As in lake sediments as a pathfinder element for gold is applicable in the search for certain types of gold occurrences.*

*Following detailed lake sediment sampling, basal till sampling can possibly be used to localize areas of potential gold with or without base metal mineralization.*

## Introduction

The recent increase in gold exploration has led to an assessment of various sample media for reconnaissance geochemical surveys within the Canadian Shield. Lake sediments may offer some potential in this regard, and preliminary investigations were initiated to study the feasibility of their use in the exploration for gold. This work has been carried out by the Saskatchewan Mining Development Corporation, the Saskatchewan Research Council and the Geological Survey of Canada. It should be emphasized that the data presented are *preliminary* in nature and hopefully will be clarified with additional research.

## Gold: Transport Into and Accumulation Within the Lacustrine Environment

Gold, once liberated from its source, be that bedrock, mineralization or glacial overburden, by weathering and erosion, can be transported and accumulated within the lacustrine environment by various physical, chemical and organic phenomena, as detailed by Boyle (1979). Organic (primarily humic) components (Ong and Swanson, 1969; Curtin *et al.*, 1970; Lakin *et al.*, 1971; Fisher *et al.*, 1974; and Boyle *et al.*, 1975), and iron and manganese oxide/hydroxide complexes (Boyle, 1979) can scavenge and concentrate gold. Profundal, and in many instances littoral and slope, sediments contain abundant organic matter, which under oxidizing conditions can attain appreciable iron and manganese concentrations (Coker *et al.*, 1979). Gold can be transported in the form of numerous chemical complexes under suitable physicochemical conditions (Boyle, 1979). Gold in particulate form, as native gold and as a constituent of, or adsorbed to (particularly clay-sized) primary and secondary minerals can also constitute a portion of the total gold present in the lake sediment, particularly if the latter is inorganic in nature. The form of transport, and eventual accumulation, of gold is a function of the original nature of the gold at the source and also of the surficial and lacustrine physicochemical conditions.

## Objectives of this Research

The primary objectives of this research were to:
(1) identify and evaluate problems in the analysis of lake sediments for gold;
(2) investigate the homogeneity of gold in lake sediments with respect to gold distribution, and partitioning of gold among the various components of the sediment;
(3) measure the variation of the gold contents of sediments within individual lakes and study the causes thereof; and
(4) evaluate the use of lake sediments in reconnaissance exploration for various types of gold occurrences within the Canadian Shield of Saskatchewan.

## Area of Study

The studies have focussed on the Precambrian Shield of northern Saskatchewan (Fig. 1). Within the Churchill province, occurrences of Au, as well as Cu, Zn, Pb, Ni and Fe, are commonly restricted to volcano-plutonic complexes that occupy linear to curvilinear belts such as the La Ronge and Flin Flon belts (Coombe, 1980).

## Sulphide - Otter Lakes Area

### Geology and Mineralization

Initial work was concentrated on the Sulphide - Otter Lakes area within the La Ronge Belt (Fig. 1). The Sulphide - Otter Lakes area is underlain by metasedimentary and less extensive metavolcanic rocks wrapped around granitic intrusive rocks (Padgham 1960, 1963; Forsythe, 1968; and Fox, 1980) (Fig. 2). Bedrock is partly or wholly overlain by unconsolidated Pleistocene glacial and Recent deposits.

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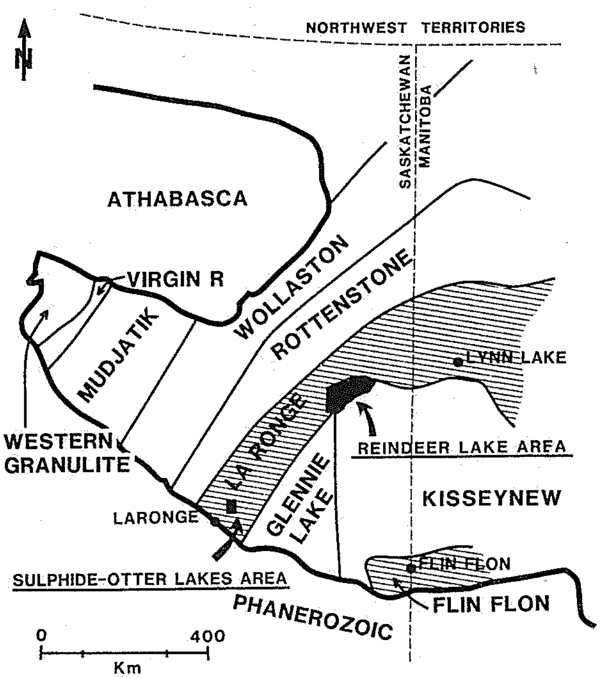


**FIGURE 1. Lithostructural domains within the Churchill province, Saskatchewan (after Sibbald *et al.,* 1976).**

The Anglo-Rouyn Mine is southwest of the Sulphide - Otter Lakes survey area (Fig. 2). Approximately 1.8 million tonnes of ore averaging 2.4% Cu, 4.5 gm per tonne Ag and 0.8 gm per tonne Au were mined during its operation (Forsythe, 1971).

There are numerous mineral occurrences within the Sulphide - Otter Lakes survey area, usually of mixed metal (Cu, Zn, Pb, Ni, Au, Ag, etc.) content (Forsythe, 1971). Examples include (Fig. 2):

1. The Sulphide Lake zones, P.A.P. Lake zones, Preview Lake zones and Ramsland Lake showing: these contain mainly Au, which is associated with arsenopyrite-bearing iron formation.
2. Zita and Eureka showings: these contain predominantly Cu with some Zn, Pb and Au.
3. Other mixed sulphide occurrences of Fe, Cu, Zn, Ni, Pb, etc.

## Detailed Studies of Individual Lakes

Three lakes, Sulphide, Preview and Mosquito, were studied in detail by the Saskatchewan Research Council. In all three lakes, bottom waters, approximately 1 m above the water-sediment interface, are warm ($>8<20°C$), generally oxygenated (2-14 ppm dissolved oxygen and oxidation reduction potentials of +43 to +235) and neutral to alkaline (pH from 6.8 to 8.3) (Table 1). The alkaline nature of these lakes probably results from proximity to Paleozoic carbonate bedrock and associated marls, located immediately to the south.

Data on the bathymetry and estimated organic content (loss-on-ignition (LOI), as determined at 500°C by X-Ray Assay Laboratories Ltd., Don Mills, Ontario) for the three lakes are shown in Figure 3 and summarized in Table 1. Sulphide Lake, in reality a fluvial-lacustrine system, has an average sediment LOI of 27% and a maximum depth of 10 m. Preview Lake has a maximum depth of 7 m and sediments averaging 34% LOI. Mosquito Lake is shallow, with a maximum depth of 4 m, and very organic, with an average sediment LOI of 50%.

The dried sediments from the three lakes were ground to minus 80 mesh, digested in a concentrated 1:9/HCl:$HNO_3$ solution, and their Zn, Cu, Ni, Co, Mn and Fe contents determined by atomic absorption spectrophotometry. Arsenic contents were determined by atomic absorption spectrophotometry using the gaseous hydride evolution method (Aslin, 1976). These analyses were carried out by the Saskatchewan Research Council.

The gold content of a 10-g portion of the dried-ground (minus 80-mesh) lake sediments from the three lakes was estimated by a combined fire assay - neutron activation method at X-Ray Assay Laboratories Ltd., Don Mills, Ontario. Triplicate analyses of two bulk samples gave results of 5, 2 and 7 ppb on the first sample (from Mosquito Lake) and 7, 11 and 7 on the second sample (from Sulphide Lake).

Trace and minor element data for the sediments from Preview, Sulphide and Mosquito lakes are summarized in Table 1 and illustrated (for Au) in Figure 3 and (for As and Cu) in Figure 4. The Au, As and Cu data for the three lakes have been interpreted using the arithmetic mean and standard deviation levels determined from the Sulphide - Otter Lakes detailed survey lake sediment data as summarized in Table 1.

Most trace and minor metals tend to be enriched in the organic sediments, a feature which is most probably because of the nature and strength of metal-organic binding and perhaps high ion-exchange capacity of organic sediments versus inorganic types (Coker *et al.,* 1979). As a result, the highest and most uniform concentrations of trace and minor metals generally occur in the deep central areas, the profundal basins of each lake, where the sediments generally have the highest and most homogeneous organic contents (Coker and Nichol, 1975; Jonasson, 1976).

The Zn, Cu, Ni, Co, Mn and Fe contents of the sediments from Preview, Sulphide and Mosquito lakes are relatively enriched in the organic-rich profundal sediments of each lake. The levels of Zn, Cu, Ni, Co, Mn and Fe in the sediments of the three lakes are, however, generally low compared to the detailed survey lake sediments (Table 1). Little variation in these metals can be seen within the sediments of the three individual lakes when interpreted using the detailed survey lake sediment arithmetic mean and standard deviation levels (see Fig. 4 - Copper). Therefore, the sediments containing the higher levels of Cu within the three lakes have been outlined on Figure 4 to verify that the highest and most homogeneous levels of Cu, and in fact of Zn, Ni, Co, Mn and Fe, although not illustrated, occur in the profundal sediments of each lake. This feature is further confirmed within Preview, Mosquito and Sulphide lakes (Table 2) by the following: strong intercorrelations among Zn, Cu, Ni, Co, Fe and Mn (excepting Mn in Sulphide Lake); correlations of Zn, Cu, Ni, Co, Fe and Mn with water depth in Mosquito and Preview lakes; correlations of Zn, Cu, Ni, Co, Mn and Fe with LOI; and correlation of lake water depth with LOI (except in Sulphide Lake). The metal distributions shown on Figure 4 and intercorrelations (Table 2) clearly indicate that the trace and minor metals react to similar geochemical controls and are generally concentrated in the organic-rich (correlation with LOI) profundal (correlation with depth) sediments. The geochemical controls in Sulphide Lake appear somewhat different, possibly indicative of its fluvial-lacustrine nature.

Gold and As do not generally coincide with Zn, Cu, Ni, Co, Mn or Fe in either distribution (Figs. 3 and 4) or level of concentration (Table 1) within the sediments of Preview, Sulphide or Mosquito lakes.

Sediments from Preview Lake have greater Au and As abundances compared to detailed survey sediment mean levels (Table 1, Figs. 3 and 4). Within the sediments of Preview Lake (Table 2), As and Au are strongly correlated: As is correlated, in decreasing order of significance, with Cu, Fe, Zn, Co, Ni, Mn and LOI; and Au is correlated, in decreasing order of significance, with Cu, Fe, Ni, LOI, Zn and Co. These intercorrelations suggest that the distributions of Au and As are probably a result of similar geochemical controls that affect the other metals, and are indicative of the chemistry of adjacent gold occurrences. The gold occurrences at Preview Lake are indicated by the Au and As contents of the organic-rich profundal sediments (Figs. 3 and 4). The position of the profundal basin, immediately adjacent to the shore on which the gold showings occur, may be fortuitous and the possibility of contamination

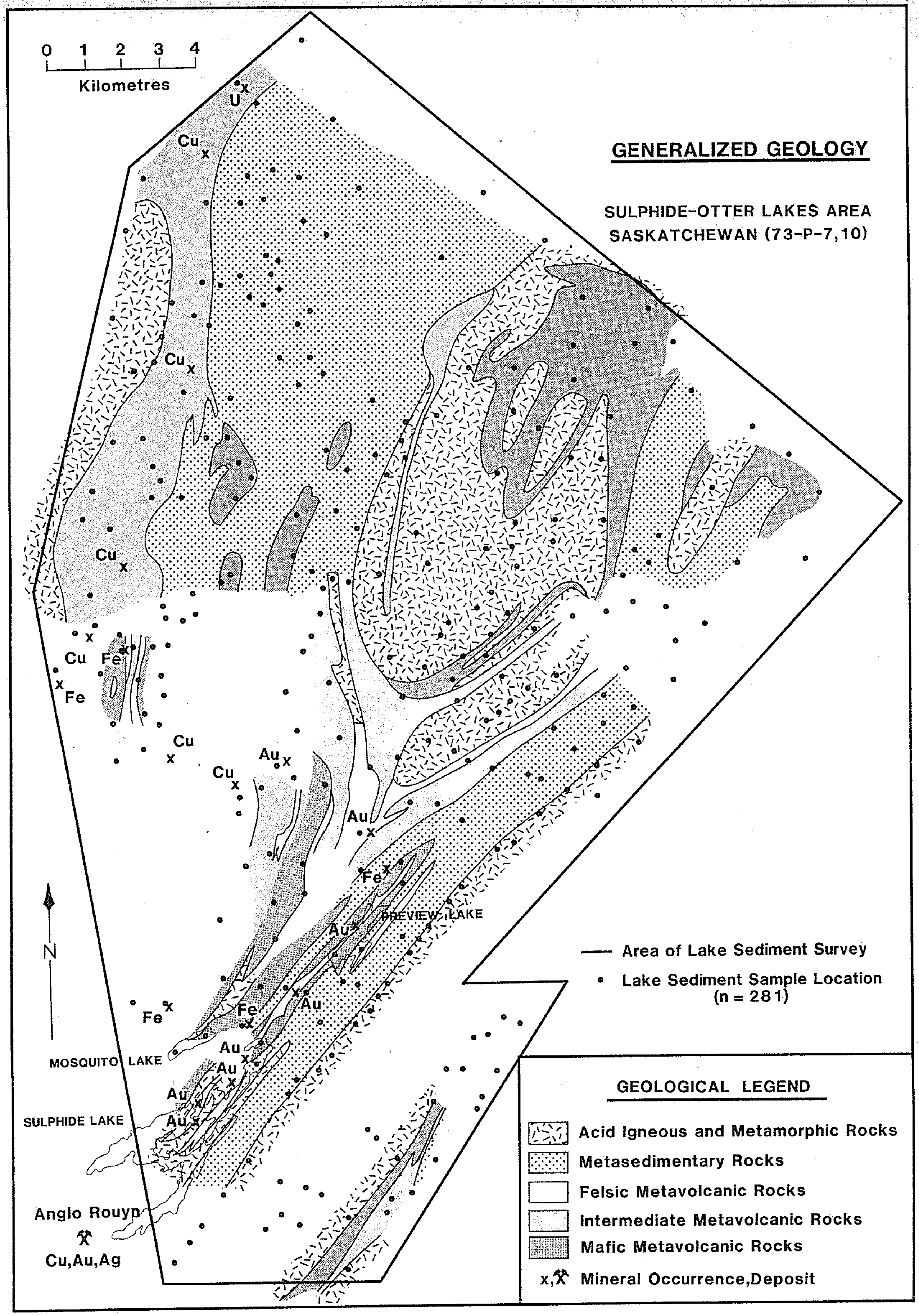


**FIGURE 2.** Generalized geology: Sulphide - Otter Lakes area (73-P-7, 10), Saskatchewan (after Padgham 1960, 1963; Forsythe, 1968; and Fox, 1980).

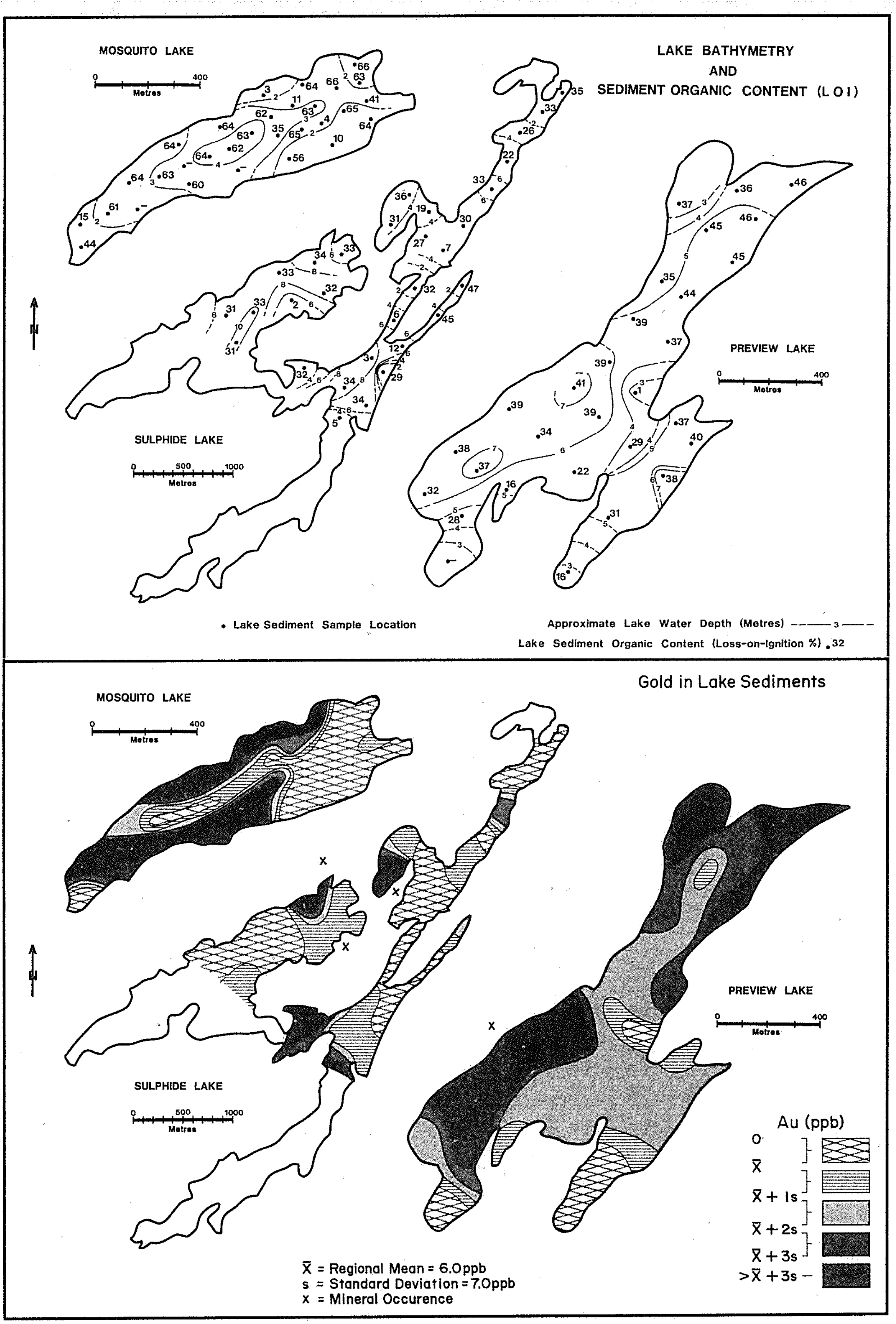


FIGURE 3. Lake bathymetry and sediment organic content (LOI), and gold (ppb) in lake sediments: Sulphide, Preview and Mosquito lakes.

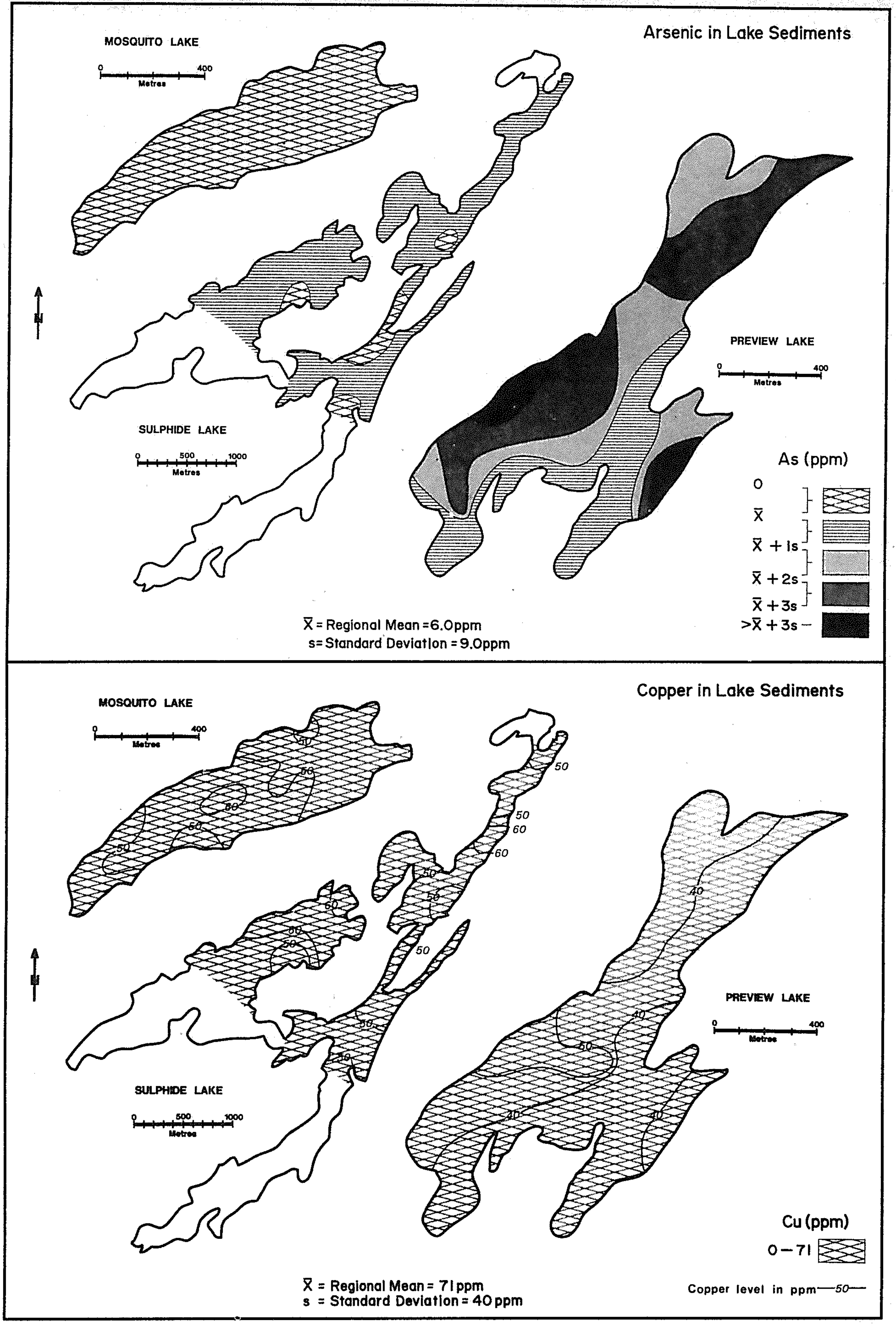


FIGURE 4. Arsenic (ppm) and copper (ppm) in lake sediments: Sulphide, Preview and Mosquito lakes.

cannot be negated. Nevertheless, it should be noted that increased abundances of Au occur right across the southern end of the lake, and significant levels of Au also occur in sediments in the northeast end of the lake. These could be related to other known occurrences of gold to the north, other undiscovered occurrences, or gold-bearing glacial sediments (Fig. 6) within and around the lake that were derived from either of the aforementioned.

Sulphide Lake is characterized by sediments with slightly increased Au and As abundances compared to detailed survey sediment mean levels (Table 1, Figs. 3 and 4). Arsenic is strongly intercorrelated with LOI, Mn, Fe, Zn, Ni, Cu and Co in decreasing order of significance, whereas Au is not significantly correlated to any of the measured parameters (Table 2). The distributions of As and the other metals, excepting Au, appear to be governed by similar physicochemical controls, that is sediment organic content, water oxygen levels and Fe-Mn oxide/hydroxide coprecipitation phenomena as outlined by Coker *et al.* (1979). In general, the sediments containing significant levels of Au are relatively organic-rich and in some cases in close proximity to the shore on which the gold occurrences are situated (Fig. 3).

The sediments of Mosquito Lake have greatly increased Au abundances and very minor As abundances relative to the detailed survey sediment mean abundances (Table 1, Figs. 3 and 4). Only Au and As, of the parameters measured, have any significant degree of correlation (Table 2). Whereas Zn, Cu (Fig. 4), Ni, Co, Mn and Fe are highest and most homogeneous in the organic-rich profundal sediments of Mosquito Lake, significantly elevated and quite homogeneous levels of gold generally occur in the organic-rich sediments along the north-central and south-southwest edges of the lake (Fig. 3). In two cases, inorganic sediments within these regions also contain greatly increased abundances of Au. Relatively insignificant levels of Au occur in the organic-rich lake-centre sediments. The greatest As abundances in Mosquito Lake occur in sediments along the north-central edge (2.8 and 5.8 ppm), the south-southwest edge (1.0 and 1.2 ppm) and in a band across the northeast end (1.1, 1.1, 1.1, 1.4 and 1.8 ppm) of the lake. Hence the correlation of As and Au (Table 2). The gold anomaly at Mosquito Lake remains to be explained, although base-of-till Au anomalies are about 300 m north and about 1 km north-northwest and up-ice from Mosquito Lake (Fig. 6).

It appears that Au is being transported from its source of bedrock, mineral occurrences or glacial overburden into the lakes and incorporated into the sediments. Elevated Au abundances occur predominatly in the more organic sediments, although there are exceptions to this. In Preview and Sulphide lakes, sediments with elevated levels of Au are found in relatively deeper waters, but these are generally immediately adjacent to the shore on which there are gold occurrences. In Mosquito Lake, both organic and inorganic sediments from the littoral and slope regions of the lake contain increased abundances of Au.

**TABLE 1.** Summary statistics—lake waters and sediments: Preview Lake, Sulphide Lake, Mosquito Lake and detailed regional survey, Sulphide - Otter Lakes area (73-P-7, 10), Saskatchewan

| | Sulphide - Otter Lakes Area | | | |
|---|---|---|---|---|
| | **Preview Lake** | **Sulphide Lake** | **Mosquito Lake** | **Detailed Survey** |
| Depth(m) | 5(1)<br>3 - 7 | 6(2)<br>1 - 10 | 2(1)<br>1 - 4 | |
| Temperature (°C) | 12.8(0.5)<br>11.7 - 13.7 | 11.5(1.5)<br>8.3 - 13.5 | 16.6(2.0)<br>13.2 - 19.1 | |
| pH | 8.2(0.2)<br>7.8 - 8.3 | 7.5(0.3)<br>6.9 - 8.1 | 7.4(0.2)<br>6.8 - 7.8 | |
| Conductivity (μmhos) | 103(4)<br>95 - 107 | 46(4)<br>40 - 54 | 48(5)<br>42 - 68 | |
| Dissolved Oxygen (ppm) | 9.8(0.6)<br>8.5 - 10.7 | 8.9(2.2)<br>2.1 - 10.5 | 9.6(1.0)<br>7.4 - 13.8 | |
| Oxidation Reduction Potential (mV) | +118(31)<br>+85 - +235 | +106(27)<br>+43 - +141 | +122(22)<br>+64 - +162 | |
| Au (ppb) | 28(30)<br>1 - 130 | 16(35)<br>0.5 - 190 | 34(43)<br>0.5 - 120 | 6(7)<br>0.5 - 45 |
| Zn (ppm) | 57(17)<br>10 - 78 | 58(23)<br>8 - 94 | 57(22)<br>10 - 89 | 107(40)<br>10 - 280 |
| Cu (ppm) | 38(12)<br>7 - 58 | 42(19)<br>5 - 66 | 43(17)<br>5 - 67 | 71(40)<br>5 - 340 |
| Ni (ppm) | 34(9)<br>8 - 43 | 34(13)<br>5 - 49 | 28(9)<br>6 - 38 | |
| Co (ppm) | 13(3)<br>3 - 18 | 14(5)<br>4 - 20 | 11(3)<br>3 - 16 | |
| Mn (ppm) | 418(121)<br>86 - 626 | 295(202)<br>55 - 1115 | 221(104)<br>38 - 421 | 553(563)<br>79 - 5800 |
| Fe (%) | 1.72(0.56)<br>0.39 - 2.52 | 1.71(0.61)<br>0.40 - 2.72 | 1.34(0.83)<br>0.49 - 3.85 | 2.04(1.24)<br>0.22 - 6.80 |
| As (ppm) | 26.9(21.1)<br>7.0 - 125.5 | 8.1(2.8)<br>1.0 - 14.9 | 0.9(1.1)<br>0.1 - 5.8 | 6.0(9.0)<br>0.5 - 96.0 |
| Loss-On-Ignition (%) | 34.5(10.2)<br>1.1 - 46.0 | 27.0(12.0)<br>1.5 - 47.1 | 50.4(21.9)<br>3.0 - 66.3 | 37.6(20.1)<br>1.3 - 88.4 |
| n | 29 | 30 | 30 | 281 |

28(30) = arithmetic mean (standard deviation)
1 - 130 = minimum - maximum
n = number of samples

The physiochemical data (temperature, pH, conductivity, dissolved oxygen and oxidation reduction potential) refer to lake-bottom waters approximately 1 metre above the water-sediment interface.

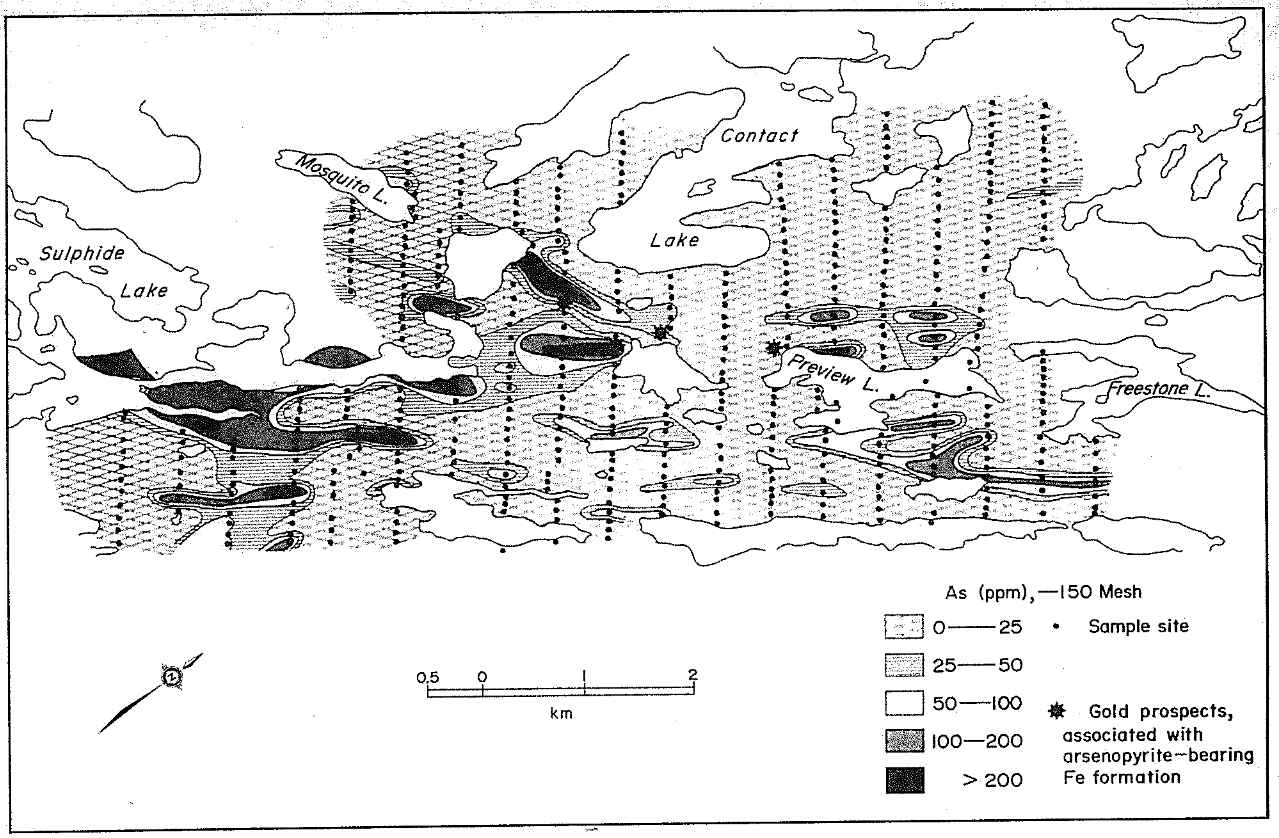


FIGURE 5. Arsenic (ppm) in basal tills (-150 mesh): Preview, Mosquito and Sulphide Lakes area: Sulphide - Otter Lakes area (73-P-7, 10), Saskatchewan.

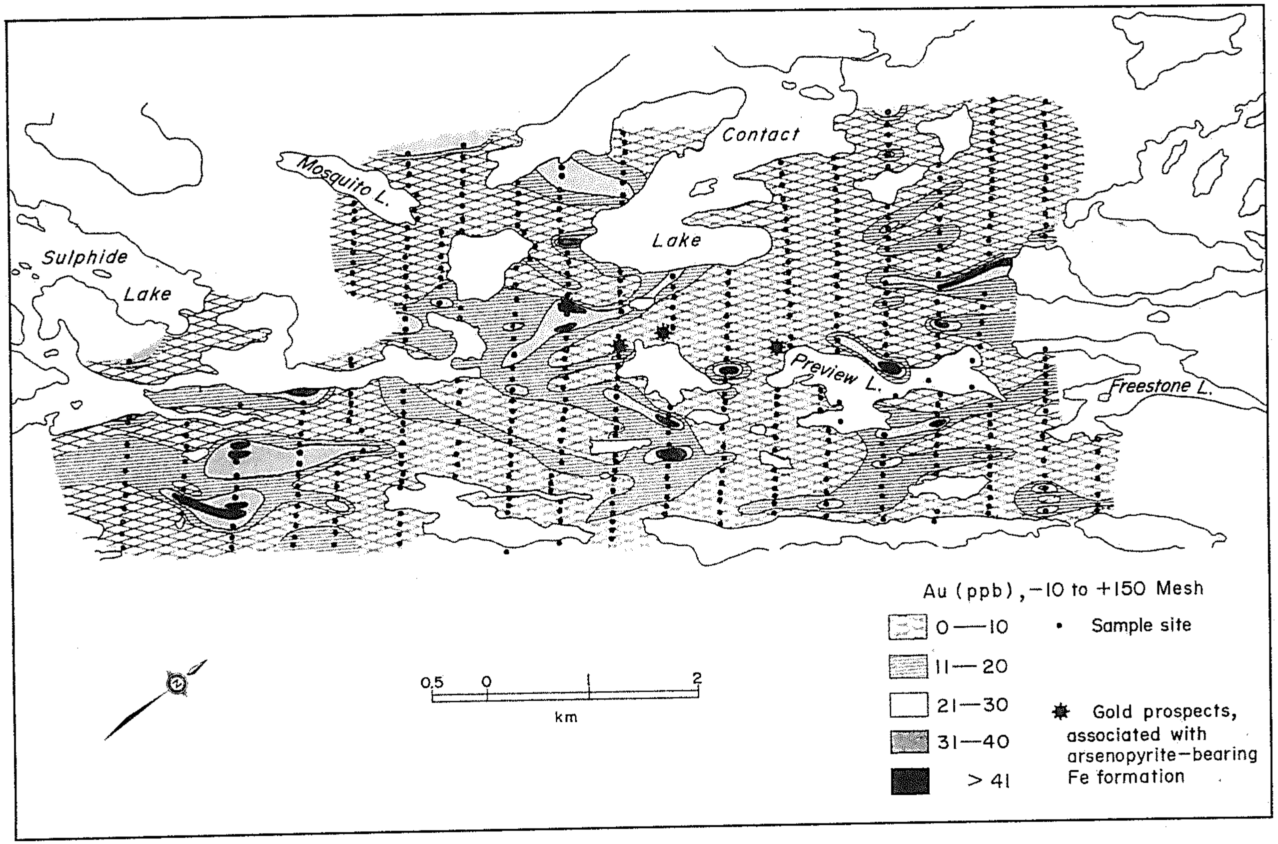


FIGURE 6. Gold (ppb) in basal tills (-10 to +150 mesh): Preview, Mosquito and Sulphide Lakes area: Sulphide - Otter Lakes area (73-P-7, 10), Saskatchewan.

## Gold in Lake Sediments: Mode of Occurrence

To identify which components of the lake sediments actually contain the gold, selective extractions were performed on eight (three in duplicate) lake sediment samples. The samples were first subjected to a sodium hypochlorite (i.e. Javex) extraction and the residues analyzed for Au by combined fire assay - neutron activation at X-Ray Assay Laboratories Ltd., Don Mills, Ontario. The sodium hypochlorite extraction primarily identifies the metal related to organic matter, but may also identify the metal associated with exchangeable ions and sulphide minerals.

The results of this work indicate that a major proportion of the Au in the lake sediment samples is probably associated with organic matter. However, inconsistencies present in the data indicate that further selective extraction analyses are required to confirm this phenomenon. In the five lake sediment samples (LOI = 34.7% to 66.5%) analyzed from Mosquito Lake, 74% to 99% of the Au appears to be related to organic matter. Similarly, 74 to 94% of the Au appears to be related to organic matter in the three lake sediment samples (LOI = 37.3% to 63.6%) analyzed from Preview Lake. The fact that a major proportion of the Au is related to organic matter, and that the lake sediment samples adjacent to the lake shores have high organic contents, is perhaps one reason for the lack of dispersion of Au into any lake-centre sediments (Fig. 3).

## Basal Till Survey

Basal till sampling was done by the Saskatchewan Research Council, for the Saskatchewan Mining Development Corporation, in the region of Preview, Mosquito and Sulphide lakes to localize areas of potential for gold with or without base metals (Figs. 5 and 6) (Simpson and McNamara, 1979). A total of 550 samples were collected over an area of approximately 40 km$^2$. The samples were collected using light-weight petrol-operated percussion drills and 'flow-through' bits. Overburden thickness varied from 1 to 16 m.

The -10 to +150-mesh portion of each sample was analyzed for Au and the -150-mesh fraction was analyzed for Au, As, Ag, Cu and Zn. Each sample was digested in a concentrated 1:9/HCl:$HNO_3$ solution and the Cu, Zn and Ag contents were

**TABLE 2.** Correlation matrices: Preview, Mosquito and Sulphide Lakes

**Preview Lake**

| | LOI | As | Fe | Mn | Co | Ni | Cu | Zn | Au | ORP | $O_2$ | Cond. | pH | Temp. | Depth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | .43 | .44 | .85 | .79 | .84 | .73 | .78 | .82 | .11 | -.22 | -.68 | -.14 | -.62 | -.58 | |
| Temp. | .21 | -.20 | -.33 | -.30 | -.29 | -.08 | -.17 | -.23 | .07 | -.29 | .76 | .54 | .86 | | |
| pH | .00 | -.24 | -.45 | -.39 | -.37 | -.20 | -.27 | -.30 | -.05 | -.35 | .94 | .57 | | | |
| Cond. | .22 | -.11 | .10 | .02 | .04 | .24 | .L6 | .L5 | .05 | -.83 | .43 | | | | |
| $O_2$ | .02 | -.31 | -.51 | -.48 | -.43 | -.29 | -.34 | -.39 | -.11 | -.22 | | | | | |
| ORP | -.42 | -.04 | -.37 | -.26 | -.31 | -.49 | -.44 | -.41 | -.15 | | | | | | |
| Au | .36 | .69 | .37 | .23 | .30 | .37 | .42 | .34 | | | | | | | |
| Zn | .85 | .52 | .95 | .86 | .95 | .96 | .97 | | | | | | | | |
| Cu | .85 | .57 | .96 | .86 | .95 | .97 | | | | | | | | | |
| Ni | .92 | .45 | .94 | .85 | .94 | | | | | | | | | | |
| Co | .77 | .48 | .95 | .90 | | | | | | | | | | | |
| Mn | .63 | .41 | .87 | | | | | | | | | | | | |
| Fe | .77 | .53 | | | | | | | | | | | | | |
| As | .35 | | | | | | | | | | | | | | |
| LOI | | | | | | | | | | | | | | | |

n = 29

**Mosquito Lake**

| | LOI | As | Fe | Mn | Co | Ni | Cu | Zn | Au | ORP | $O_2$ | Cond. | pH | Temp. | Depth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | .28 | -.13 | .70 | .66 | .71 | .57 | .55 | .67 | .01 | -.56 | -.16 | .44 | -.66 | -.79 | |
| Temp. | -.17 | .04 | -.68 | -.61 | -.59 | -.43 | -.41 | -.55 | -.07 | .57 | .02 | -.54 | .68 | | |
| pH | -.23 | .16 | -.64 | -.56 | -.55 | -.42 | -.35 | -.49 | .29 | .73 | -.08 | -.58 | | | |
| Cond. | -.04 | .03 | .45 | .55 | .43 | .32 | .27 | .39 | .01 | -.62 | .61 | | | | |
| $O_2$ | -.35 | .02 | -.28 | .11 | -.08 | -.06 | -.10 | -.06 | .13 | -.14 | | | | | |
| ORP | -.24 | .13 | -.56 | -.49 | -.52 | -.44 | -.40 | -.43 | .27 | | | | | | |
| Au | -.17 | .32 | -.17 | -.03 | -.07 | -.08 | -.05 | -.01 | | | | | | | |
| Zn | .82 | .08 | .73 | .92 | .95 | .94 | .95 | | | | | | | | |
| Cu | .92 | .12 | .62 | .88 | .94 | .98 | | | | | | | | | |
| Ni | .92 | .08 | .60 | .88 | .95 | | | | | | | | | | |
| Co | .82 | .09 | .77 | .95 | | | | | | | | | | | |
| Mn | .78 | .12 | .71 | | | | | | | | | | | | |
| Fe | .42 | .03 | | | | | | | | | | | | | |
| As | .11 | | | | | | | | | | | | | | |
| LOI | | | | | | | | | | | | | | | |

n = 30

**Sulphide Lake**

| | LOI | As | Fe | Mn | Co | Ni | Cu | Zn | Au | ORP | $O_2$ | Cond. | pH | Temp. | Depth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | -.05 | -.10 | .10 | -.35 | .15 | .08 | .23 | .06 | -.11 | -.33 | -.67 | .33 | -.62 | -.63 | |
| Temp. | -.19 | -.07 | -.18 | .07 | -.23 | -.20 | -.40 | -.12 | .07 | .34 | .86 | -.72 | .85 | | |
| pH | -.18 | -.06 | -.33 | .19 | -.35 | -.34 | -.52 | -.29 | .09 | .25 | .82 | -.53 | | | |
| Cond. | -.02 | -.09 | -.07 | -.15 | .06 | -.03 | .18 | -.13 | .07 | -.05 | -.40 | | | | |
| $O_2$ | -.22 | -.17 | -.32 | .11 | -.33 | -.32 | -.44 | -.28 | .10 | .57 | | | | | |
| ORP | -.31 | -.28 | -.41 | .07 | -.46 | -.44 | -.43 | -.39 | -.19 | | | | | | |
| Au | .09 | .19 | .06 | -.05 | .06 | .09 | .13 | -.00 | | | | | | | |
| Zn | .80 | .67 | .97 | .32 | .96 | .98 | .92 | | | | | | | | |
| Cu | .80 | .60 | .93 | .22 | .96 | .96 | | | | | | | | | |
| Ni | .81 | .65 | .97 | .28 | .98 | | | | | | | | | | |
| Co | .76 | .60 | .95 | .21 | | | | | | | | | | | |
| Mn | .69 | .73 | .30 | | | | | | | | | | | | |
| Fe | .75 | .68 | | | | | | | | | | | | | |
| As | .81 | | | | | | | | | | | | | | |
| LOI | | | | | | | | | | | | | | | |

n = 30
(- indicates a negative correlation)

determined by standard atomic absorption spectrophotometric methods. Arsenic contents were determined by atomic absorption spectrophotometry using the gaseous hydride generation technique (Aslin, 1976). After digestion of 10-g portions of each sample using aqua regia and extraction using methyl isobutyl ketone, the Au content of each sample was determined by atomic absorption spectrophotometry.

The surveyed area is underlain by numerous sulphide-rich iron formations which locally host arsenides and associated gold (Forsythe, 1971). Basal tills in the surveyed area have a high mean As content (31 ppm, Table 2). Elevated As levels occur in basal tills (Fig. 5) overlying certain portions of the conductive horizons between Sulphide and Preview lakes. Basal tills have an over-all low mean Au content (3.8 ppb, Table 3) and although significant levels of Au are associated with some As-enriched zones (between Sulphide and Preview lakes), most Au highs are displaced from areas of elevated As (Fig. 6). There is a significant intercorrelation of Cu, Zn and Ag, but Au has no correlation with As in the basal tills within the surveyed area (Table 3). There is an indication of an enrichment of Au in basal tills north and north-northwest of Mosquito Lake, but most of the area to the north and west remains unsampled.

Gold occurrences in the surveyed area are generally indicated by increased, but not necessarily coincident, As and Au abundances in the basal tills. The mineral occurrences and bedrock, or glacial overburden sources of Au, As and associated metals, are generally depicted by corresponding abundances in the sediments of adjacent lakes.

## Detailed Lake Sediment Survey

A detailed centre-lake organic-rich sediment survey was carried out over the Sulphide - Otter Lakes area (Fig. 1) during August 1979 by the Saskatchewan Mining Development Corporation (Fox, 1980).

The lake sediment samples were dried, ground to minus 80 mesh and analyzed by X-Ray Assay Laboratories Ltd., Don Mills, Ontario. The Au content of a 10-g portion of the lake sediments was estimated by a combined fire assay - neutron activation technique. Arsenic was determined by neutron activation. The Zn, Cu, Fe and Mn contents of the lake sediments were determined by standard atomic absorption spectrophotometric methods. Loss-on-ignition (LOI) was determined at 500°C.

Thirty-three samples, covering the range of Au in these lake sediments, were resubmitted for a second Au analysis (Fig. 7). These data give some idea of the amount of analytical variability and sample homogeneity. The replicate data have a correlation coefficient of 0.68. Most of the variability is at the lower levels. Samples with significant levels of Au retain significant levels on re-analysis. It appears, therefore, that the lake sediment samples have relatively consistent levels of Au, as is also shown by the detailed studies of the three lakes, a feature indicating that such samples can be used for detailed-scale geochemical exploration for Au within this area.

At the detailed scale of sampling employed, there is a definite relationship between elevated levels of Au in the lake sediments (Fig. 8) and known occurrences of gold (Fig. 2).

Examination of the interrelationships among Au, Cu, Zn, Mn, Fe, As and the organic content (LOI) of the lake sediments shows that Au does not correlate with any other measured parameter (Table 4). Zinc, Mn and Fe are interrelated, as are Zn, Cu and LOI (Table 4). The distribution of Zn in the lacustrine environment, particularly within the La Ronge lithostructural domain, is related to and partitioned between Fe-Mn oxide/hydroxides and organic complexes (Coker *et al.*, 1979; Sopuck *et al.*, 1980). Copper varies with sediment organic content (LOI) and correlates with zinc because of a similar affinity for organic complexes (Coker *et al.*, 1979; Sopuck *et al.*, 1980).

Lake sediment samples having metal levels greater than the arithmetic mean plus two standard deviation value ($>(\bar{x} + 2s)$)

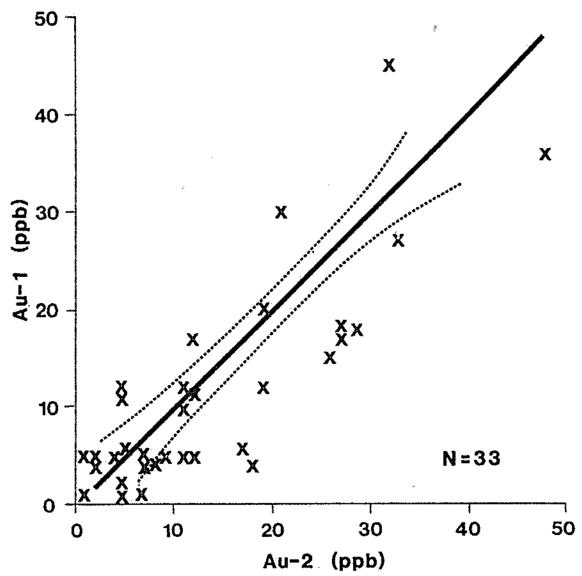


**FIGURE 7.** Replicate gold analysis (fire assay - neutron activation) of selected lake sediment samples: Sulphide - Otter Lake area (73-P-7, 10), Saskatchewan.

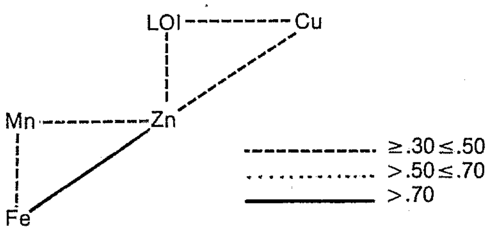
**TABLE 3.** Summary statistics and correlation matrix — basal tills: Preview, Mosquito and Sulphide Lakes area, Sulphide - Otter Lakes area (73-P-7,10), Saskatchewan

| Summary Statistics | | Correlation Matrix | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Au | Ag | As | Zn | Cu |
| Cu(ppm) | 53(47)<br>2 - 713 | Cu | −.01 | .37 | .13 | .41 | |
| Zn(ppm) | 45(26)<br>2 - 257 | Zn | .09 | .32 | .09 | | n = 550 |
| As(ppm) | 31(63)<br>1 - 567 | As | −.02 | .10 | (-indicates a negative correlation) | | |
| Ag(ppm) | 0.41(0.39)<br>0.01 - 2.40 | Ag | .09 | | | | |
| Au(ppb) | 3.8(3.3)<br>1.0 - 420 | Au | | | | | |

53(47) = arithmetic mean (standard deviation)
2 -713 = minimum - maximum
n = number of samples

**TABLE 4.** Correlation matrix and schematic representation of the significant chemical associations in lake sediments: Sulphide - Otter Lakes area (73-P-7,10), Saskatchewan

| | Au | As | Zn | Cu | Mn | Fe | LOI |
|---|---|---|---|---|---|---|---|
| LOI | −.07 | .06 | .32 | .43 | .05 | −.21 | |
| Fe | −.07 | .00 | .50 | .07 | .29 | | |
| Mn | −.03 | .03 | .34 | .03 | | | |
| Cu | −.04 | −.02 | .44 | | n = 281 | | |
| Zn | −.13 | −.06 | (− indicates a negative correlation) | | | | |
| As | .13 | | | | | | |
| Au | | | | | | | |



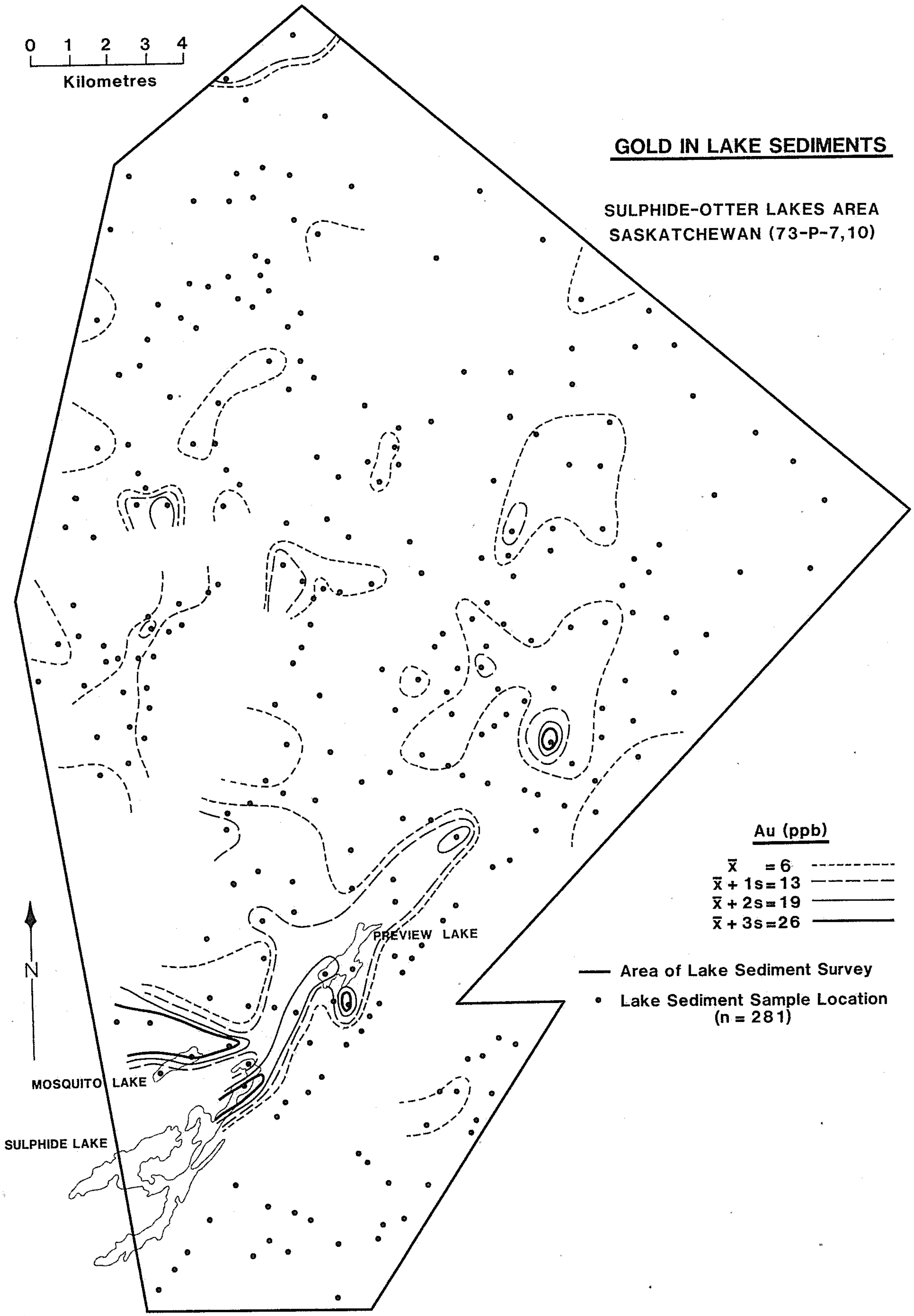


**FIGURE 8.** Gold (ppb) in lake sediments: Sulphide - Otter Lakes area (73-P-7, 10), Saskatchewan.

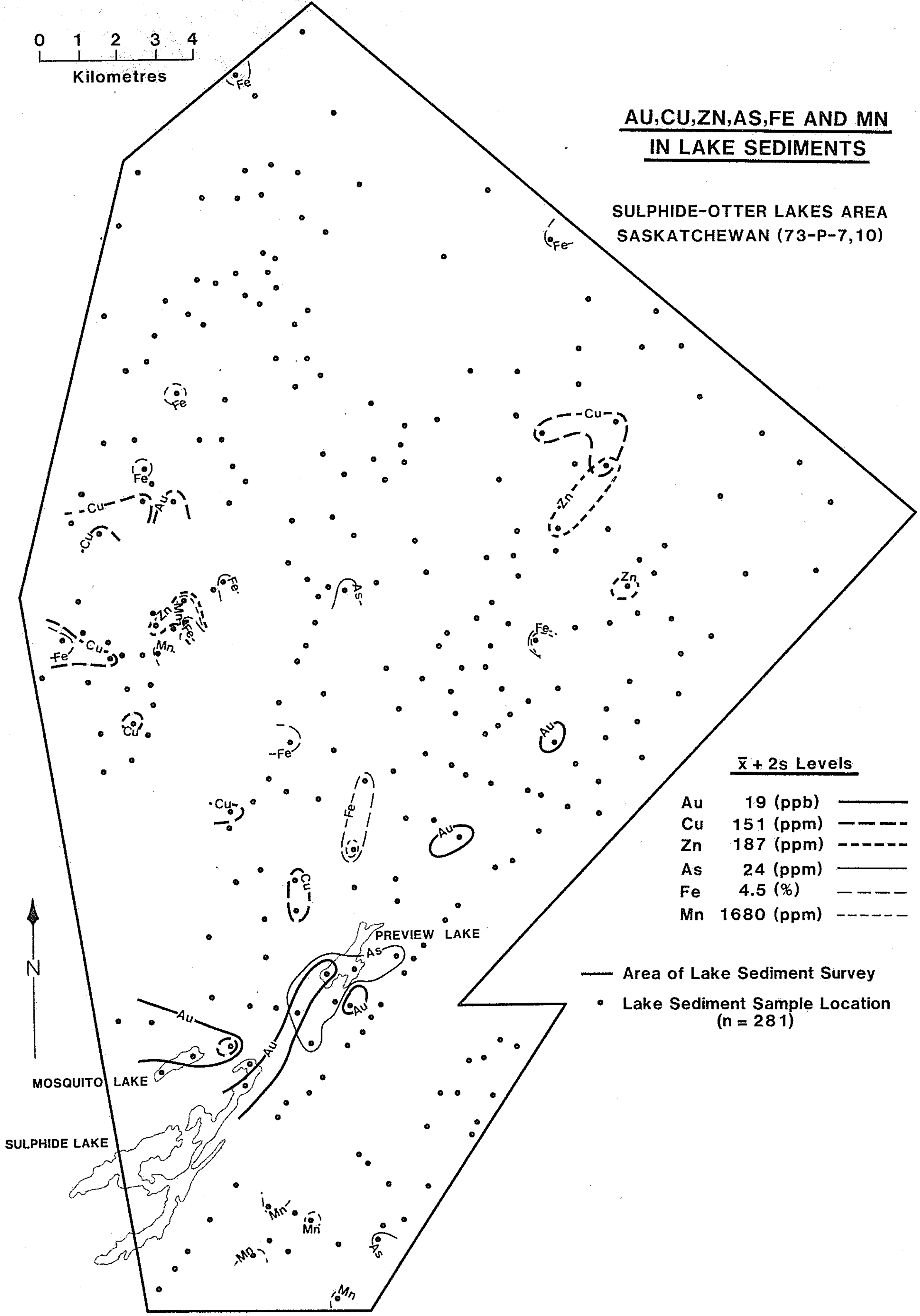


FIGURE 9. Au, Cu, Zn, As, Fe and Mn (>($\bar{x}$ + 2s) levels) in lake sediments: Sulphide - Otter Lakes area (73-P-7, 10), Saskatchewan.

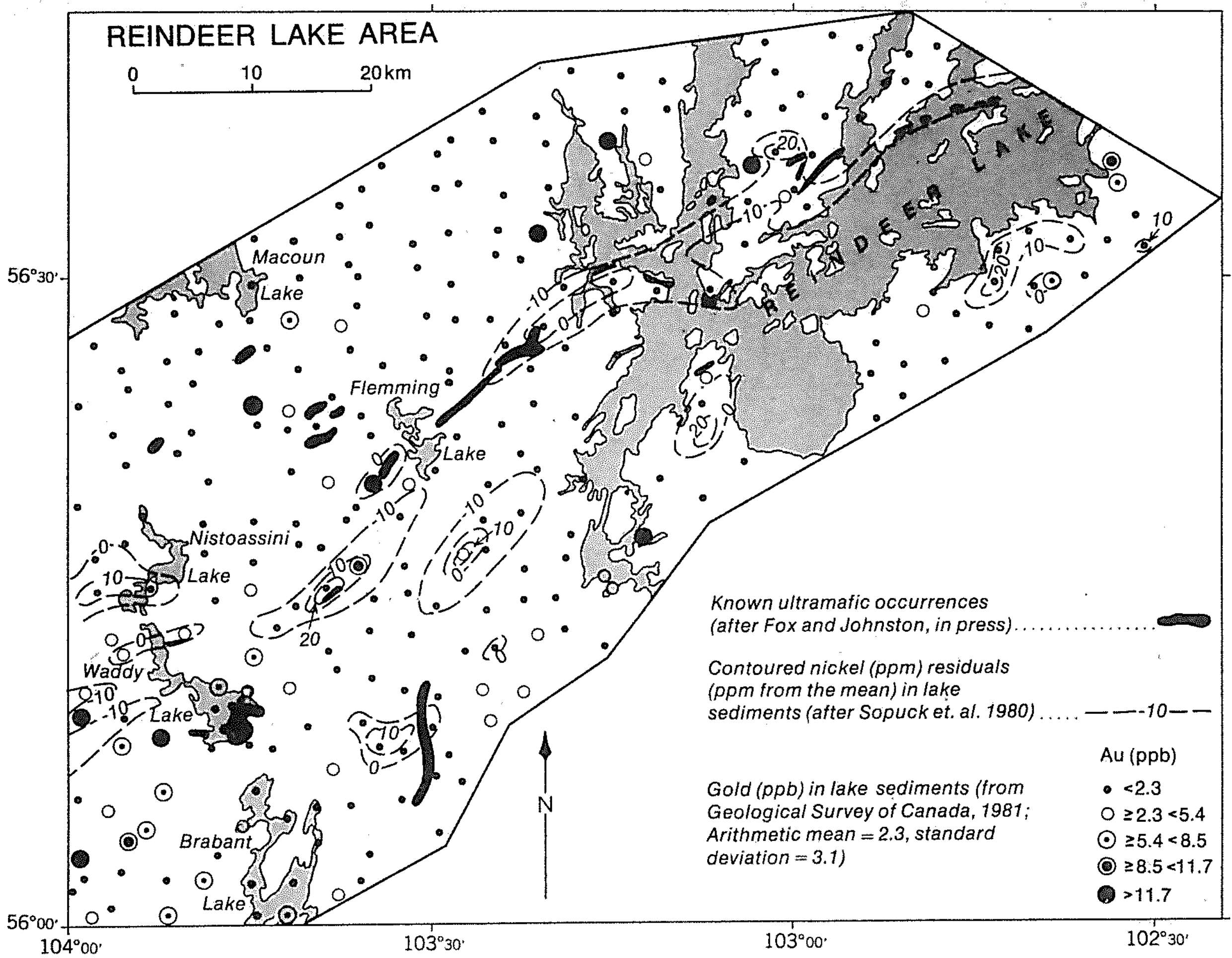


**FIGURE 10. The relationship between Ni (Ni (ppm) residuals from the mean) and Au (ppb) in lake sediments and ultramafic bedrock: Reindeer Lake area (64D), Saskatchewan.**

for Au, Cu, Zn, As, Fe and Mn in lake sediments from the Sulphide - Otter Lake area are indicated by this simplistic form of cluster analysis (Fig. 9). Whereas Au and As appear to have no mathematical correlation (0.13), they certainly appear to be spatially related to some of the known gold occurrences within the surveyed area. Other relationships are apparent, as follows:

1. Elevated Cu in lake sediments is related to known copper occurrences (Fig. 2).
2. Fe and Mn, and Fe, Mn and Zn associations are indicative of Fe-Mn oxide/hydroxide precipitation and trace-metal coprecipitation phenomena.
3. Several unexplained trace-metal patterns are present, which may be related to several unknown sources: bedrock, glacial overburden, mineralization, and physicochemical and limnological phenomena.

## Reindeer Lake Area

### Regional Reconnaissance Lake Sediment Survey

As another aspect of this research, centre-lake organic-rich sediment samples collected in the Reindeer Lake area (64D), Saskatchewan (Fig. 1), as part of a joint undertaking by the Geological Survey of Canada and the Saskatchewan Geological Survey (Hornbrook *et al.,* 1975 and 1977), were selected from the archives for the analytical determination of their Au contents (Geological Survey of Canada, 1981). The abundance of ultramafic rocks, the genetic relationship between gold ore and picritic rocks at the Agassiz deposit, Lynn Lake, and the numerous gold occurrences in both boninites and komatiites between Waddy and Reindeer lakes were felt to be possible indicators of the potential for gold to occur within the central portion of the La Ronge lithostructural domain (Fox and Johnston, 1981). Furthermore, as the Waddy-Reindeer Lakes gold occurrences are essentially nonconductive, rendering their geophysical detection unpredictable, lake sediment geochemistry was thought to be a potential reconnaissance exploration tool for gold-bearing mineralization within the central La Ronge lithostructural domain.

Analytical problems arose in the initial stages of this work and uncertainty arose as to their exact nature: whether because of lake sediment sample inhomogeneity or the analytical technique (fire assay - neutron activation). Repeat and check analyses indicated that the centre-lake organic-rich sediment samples are consistent in their Au content. The problem lay in losses or additions of Au during the fire assay stage, at the ppb levels of Au present. Ultimate verification of the analytical data required re-analysis of all the lake sediment samples, with a high percentage (10%) of inserted standard and replicate samples. Work continues on this problem and on the over-all problem of Au analysis. It should also be emphasized that this problem was only identified by the analyses of standard samples and replicate analyses of the lake sediment samples. Accordingly, analytical determinations for Au must be controlled or costly problems in subsequent stages of exploration can be expected.

The distributions of ultramafic bedrock, and of Ni (contoured Ni (ppm) residuals after hydroxide correction) and Au (ppb) in lake sediments within the Reindeer Lake area of Saskatchewan are depicted on Figure 10. Known occurrences of ultramafic bedrock within the Reindeer Lake area are clearly delineated by high residual Ni levels in the lake sediments of the area. Some high residual Ni contours are coincident with, or encircle (generally elongated in the direction of glaciation), the ultramafic bodies and others are displaced in a down-ice direction. Other elevated residual Ni patterns are unexplained, but are possibly related to unmapped or buried ultramafic bedrock. Elevated levels of Au in lake sediments are in places coincident with and in other places displaced down-ice from elevated residual Ni patterns with or without ultramafic bedrock. There are also numerous unexplained instances of elevated contents of Au in lake sediments, that are generally grouped and not isolated (particularly in the southwest corner of the area).

The utilization of gold in centre-lake organic-rich sediments for differentiating between possible gold occurrences related to ultramafic bedrock with or without trace levels of gold within the ultramafic bedrock itself in the Reindeer Lake area remains to be evaluated. It is evident that a coincidence exists between some of the ultramafic bedrock occurrences and residual Ni levels in lake sediments at the reconnaissance scale of sampling (1 sample per 13 km$^2$) employed in the Reindeer Lake area. The relationship between Au in lake sediments and ultramafic bedrock is tenuous at the reconnaissance scale of sampling. A more detailed scale of sampling (i.e. every lake), as employed in the Sulphide - Otter Lakes area, could well provide a more concise definition of the relationship of Au and Ni in lake sediments and hence the potential of gold-bearing mineralization associated with ultramafic bedrock in the Reindeer Lake area.

## Conclusions

On the basis of preliminary data, it is apparent that organic lake sediments do offer some potential in detailed exploration for gold within the Canadian Shield of Saskatchewan. It is also evident that certain precautions must be taken.

The distribution patterns of Au in centre-lake organic-rich sediments, collected on a detailed scale (i.e. every lake) in the Sulphide - Otter Lakes area, are indicative of known gold occurrences, whereas those collected on a regional reconnaissance scale (1 per 13 km$^2$) in the Reindeer Lake area require further evaluation of their potential to indicate gold. However, data from the three lakes studied in detail indicate that Au is primarily related to the organic fraction of the lake sediments, which, although giving consistent Au contents to these sediments, may restrict the dispersion of Au within the lake itself (e.g. Mosquito Lake). From this, it follows that in any detailed survey it may be necessary to design sampling and analytical techniques to account for these features. It may be necessary to carry out selective extractions on the lake sediments to differentiate between the proportion of the Au related to organics sequestration, indicative of hydromorphic and chemical dispersion, and the proportion related to inorganics, indicative of mechanical dispersion.

Lake sediments are probably only of use on a very detailed scale of exploration (i.e. every lake). One to three samples per lake should be appropriate, although a single centre-lake organic-rich sediment sample may be adequate in very small lakes. The results of the surveys suggest that up to three samples should be taken from large lakes as follows: one centre-lake organic-rich sediment sample and one sediment sample (organic if present) from near both shores which most closely parallel the direction of glacial transport in the survey area. Each of these samples should be analyzed at least twice.

The use of As in lake sediments as a pathfinder element for gold is applicable in the search for certain types of gold occurrences. In addition to the regularly examined suite of commonly associated elements, including Zn, Cu, Pb, Ni, Co and Ag, other pathfinder elements, such as Se, Te, Sb, Hg, B and W, need to be examined in lake sediments to determine their usefulness in the search for the types of gold occurrences in which they are present. Following detailed lake sediment sampling, basal till sampling can possibly be used to localize areas of potential gold with or without base metals.

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