



**GEOLOGICAL SURVEY
PAPER 76-13**

**DETAILED HYDROGEOCHEMISTRY OF
TWO SMALL LAKES IN THE
GRENVILLE GEOLOGICAL PROVINCE**

I.R. JONASSON

1976

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Catalogue No. M44-76-13

Price: Canada: \$2.50

Other countries: \$3.00

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CONTENTS

	Page
Abstract/Résumé	v
Introduction	1
Acknowledgments	1
The study area	2
Sampling and analytical methodology	4
Geology and economic geology	5
Geochemistry of lake waters	7
Geochemistry of organic lake sediments	9
General principles	9
Nature of the sediments in the study area	9
Heavy metal distribution	11
Hydrogeochemical relationships in sediments of Perch Lake	13
Comparisons of water and organic sediment data	19
Geochemistry of inorganic lake sediments	23
Influences of local geology on hydrogeochemistry	24
Implications for regional geochemical reconnaissance surveys	26
Conclusions and suggestions for further work	27
References	28
Appendices 1 to 7 Results of water and sediment analyses	29

Tables

Table 1. Surface and bottom waters: summary data (ppb)	7
2. Deepwater organic rich sediments: summary data (ppm except where noted)	11
3. Geochemical analyses for rock chips: Perch Lake	13
4. Geochemical analyses for rock chips: Lavant Long Lake	17
5. Shoreline inorganic (silty) sediments: summary data (ppm)	23
6. Geochemical comparisons of silty shoreline and organic deep water sediment samples (values in ppm unless otherwise indicated)	24
7. Geochemical comparisons of silty shoreline and organic deep water sediment samples (values in ppm unless otherwise indicated)	25
8. Geochemical comparisons of silty shoreline and organic deep water sediment samples (values in ppm unless otherwise indicated)	26

Illustrations

Figure 1. Location of study area, Lanark Co., Ontario	1
2. View of Perch Lake	2
3. View of Lavant Long Lake	2
4. Geology of the study area	3
5. Sample sites and depth contours of Perch Lake	4
6. Sampling techniques by scuba divers	4
7. Localities for all sediments and water samples	5
8. Zinc, mercury, and lead in lake waters	6
9. Copper, nickel, and uranium in lake waters	8
10. Sulphur, iron, organic carbon, and carbonate in organic lake sediments	10
11. Lead, mercury, zinc, manganese, and arsenic in organic lake sediments	12
12. Copper, nickel, uranium, and molybdenum in organic lake sediments	14

CONTENTS (cont.)

	Page
13. Water depth, iron, sulphur, and manganese distribution in organic sediments of Perch Lake	15
14. Organic carbon, zinc, lead, and arsenic distribution in organic sediments of Perch Lake	16
15. Mercury, copper, nickel, and uranium distribution in organic lake sediments	18
16. Zinc, lead, mercury, and arsenic in silty shoreline lake sediments ...	21
17. Copper, nickel, uranium, and manganese in silty, shoreline lake sediments	22

DETAILED HYDROGEOCHEMISTRY OF TWO SMALL LAKES IN THE GRENVILLE GEOLOGICAL PROVINCE

Abstract

An extensive study of some hydrogeochemistry of waters and sediments of two lakes, Perch and Lavant Long, located in forested regions of the Grenville Geological Province, Lanark County, Ontario, has been made. Although discussion is based almost entirely on simple analytical data for a number of metals, zinc, lead, copper, iron, manganese, mercury, arsenic, nickel, molybdenum and uranium and on data for organic carbon, carbonate and sulphur in organic and inorganic (silty) sediments, it is possible to postulate some hydrodynamic mechanisms to explain relative degrees of dispersion and precipitation of these metals in the sediments of the lake. Taken in conjunction with analytical data for waters, for zinc, lead, copper, mercury, nickel and uranium the different dispersion patterns present suggest that: iron and manganese hydrolyzate ions form weak associations with organic matter with which they coprecipitate and accumulate and then are fixed by sulphide ions in deep water organic sediments; zinc, lead, arsenic and possibly mercury ions precipitate mainly as stable insoluble organic complexes and subsequently are fixed by sulphide ions in sediments in zones of the lake where water movement is greatest. Copper, nickel, uranium and mercury which likely form the most stable soluble organic chelates, are most widely dispersed and eventually settle into sediments by coprecipitation-absorption mechanisms on organic particles. They too are subsequently fixed by sulphide ion except perhaps uranium which is immobilized upon reduction.

The implications of these findings on regional geochemical reconnaissance survey programs also are discussed along with the relative virtues of sampling deepwater organic sediments versus those from shoreline areas which are mainly inorganic (or silty) types.

Résumé

L'auteur a effectué une étude approfondie de la géochimie des eaux et des sédiments des lacs Perch et Lavant Long qui sont situés dans les régions boisées de la province géologique de Grenville, dans le comté de Lanark, en Ontario. Cette étude est presque entièrement fondée sur des données analytiques simples pour certains métaux tels que le zinc, le plomb, le cuivre, le fer, le manganèse, le mercure, l'arsenic, le nickel, le molybdène et l'uranium, ainsi que sur des données sur le carbone organique, les carbonates et le soufre des sédiments organiques et inorganiques (silteux); mais il est possible de poser en postulat l'existence de certains mécanismes hydrodynamiques pour expliquer les degrés relatifs de dispersion et de précipitation de ces métaux dans les sédiments de ces lacs. Considérées en relation avec les données analytiques sur les eaux, pour le zinc, le plomb, le cuivre, le mercure, le nickel et l'uranium, les différentes auréoles de dispersion présentes suggèrent que les ions de fer et de manganèse des hydrolysats forment des associations faibles avec la matière organique et sont précipités en même temps que cette dernière. Ces ions s'accumulent et sont ensuite fixés par des ions de sulfure dans les sédiments organiques d'eau profonde. Les ions de zinc, de plomb, d'arsenic et peut-être aussi ceux de mercure forment surtout des précipités organiques complexes qui sont stables et insolubles. Ils sont ensuite fixés par les ions de sulfure des sédiments dans les zones du lac où l'agitation de l'eau est maximale. Le cuivre, le nickel, l'uranium et le mercure, qui forment probablement les composés chélatés solubles les plus stables sont davantage dispersés et se fixent finalement sur les particules organiques des sédiments par des mécanismes de co-précipitation et d'adsorption. Par la suite, ils sont aussi fixés par les ions de sulfure, sauf peut-être l'uranium qui est immobilisé dès sa réduction.

L'auteur étudie aussi les conséquences de ces résultats sur les programmes régionaux d'exploration géochimique et les avantages relatifs de la prise d'échantillons de sédiments organiques en eau profonde par rapport à la prise d'échantillons de sédiments proches de la rive, lesquels sont surtout d'espèce inorganique (silteux).

Introduction

In view of the anticipated development of regional lake sediment sampling as a geochemical exploration reconnaissance tool in 1970, a very detailed, but areally limited hydrogeochemical survey in a confined drainage basin was initiated at that time. The area selected was chosen for its variable Grenville age rock types, for its relative isolation in terms of possible man-made contamination, and for the nearby presence of some sulphide mineralization of considerable geochemical complexity.

The principal objectives were to sample waters, both at surface and at depth; to sample lake sediments in whatever form they may occur, both on the shoreline and at depth across the lake concerned; and to take rock samples along the shoreline with a view to establishing qualitative interrelationships, if any, and to ascertain geochemical controls on trace element levels, on variations of level, and on modes of element dispersion throughout the lake system.

It was considered likely that any conclusions which could be drawn from the study would permit some realistic discussion to be made on the question of whether one sediment or water sample from a given lake would yield geochemical data characteristic of the entire lake and perhaps of its immediate incoming drainage.

Acknowledgments

The author wishes to express his deep appreciation of the technical and scientific contributions made to this study by R. T. Crook, L. J. Trip (now at Department of Environment, Halifax) and Dr. M. H. Timperley (now at Department of Scientific and Industrial Research, New Zealand). He also acknowledges the criticisms and discussions of this work with Dr. E. M. Cameron and Dr. W. B. Coker of the Geochemistry Section, Geological Survey of Canada.

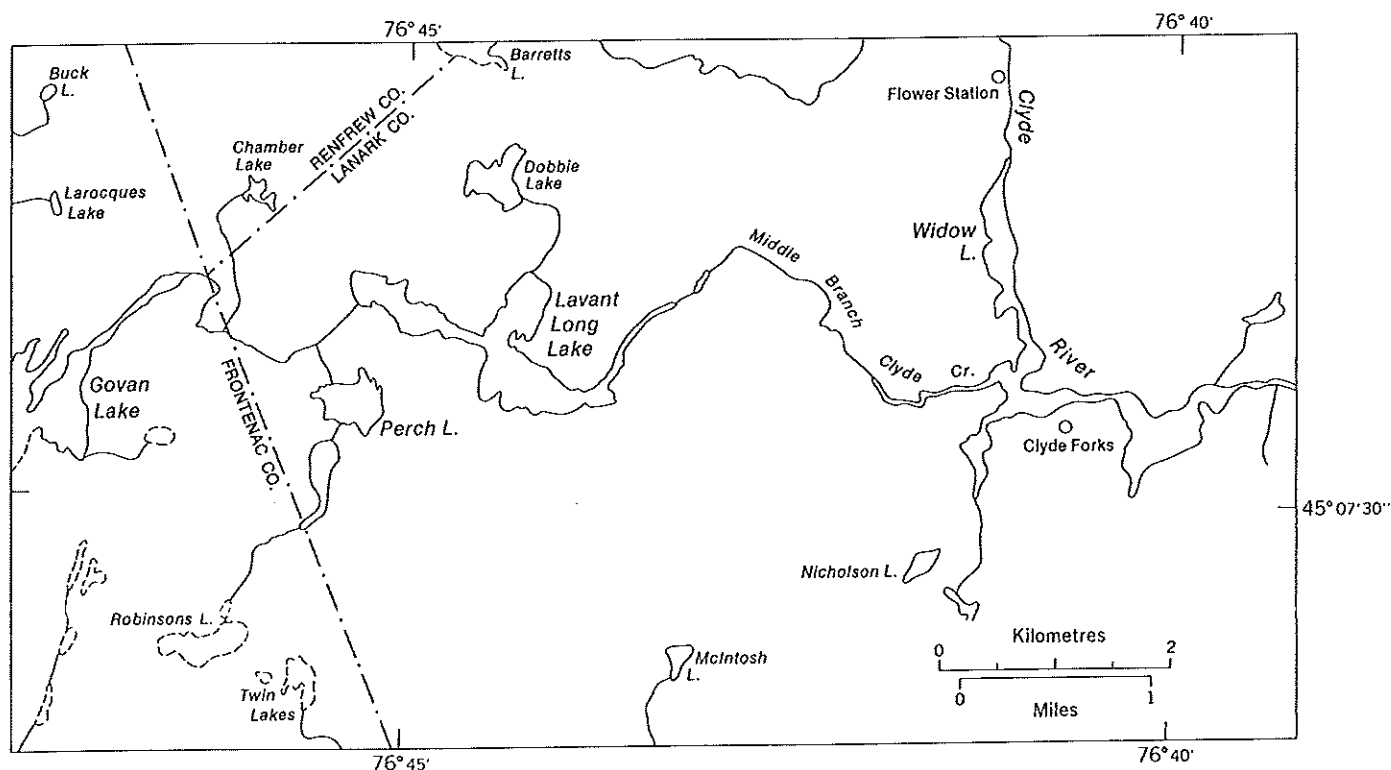
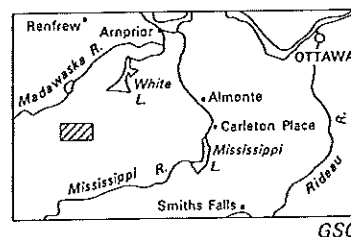


Figure 1. Location of study area, Lanark Co., Ontario.



The Study Area

The study area, located approximately 60 miles (100 km) southwest of Ottawa in Lavant Township of Lanark County, Ontario, contains two lakes, Perch and Lavant Long, and several marsh areas at the headwaters of the Clyde River (Fig. 1).

Perch Lake, with a surface area of about 57 acres (23 ha), is fed by waters from Moss Lake (Robinsons Lake) through a chain of swamps and marshes which enter the lake through a large beaver dam. The vegetation consists almost entirely of white birch, white cedar and white pine. The main outflow from the lake is shallow and filled with an assortment of waterlilies, pond weed and bullrushes. Perch Lake flows north through two interconnected outflows, one of which is intermittent, to connect with Middle Branch Creek in a

reedy, cedar swamp, which in turn leads to the west arm of Lavant Long Lake.

Lavant Long Lake covers about 200 acres (80 ha) and is surrounded by a mixture of vegetation – white birch, white cedar, poplar, white pine and white spruce predominating. Lavant Long Lake is replenished by waters originating in the drainage basin of Gowan Lake (Gowan Lake) via Middle Branch Creek. This is probably its main source of water supply. Minor contributions come from Dobbie Lake via the north arm and from local swamps to the south and east of the main body of the lake. The elongated shape of the lake is probably controlled by the structural geology of the area. It drains into Clyde Creek through a long, shallow channel, mainly bullrush filled, and ultimately to the Clyde River near the village of Clyde Forks some 3 miles (5 km) to the east.

Figure 2

View of Perch Lake.

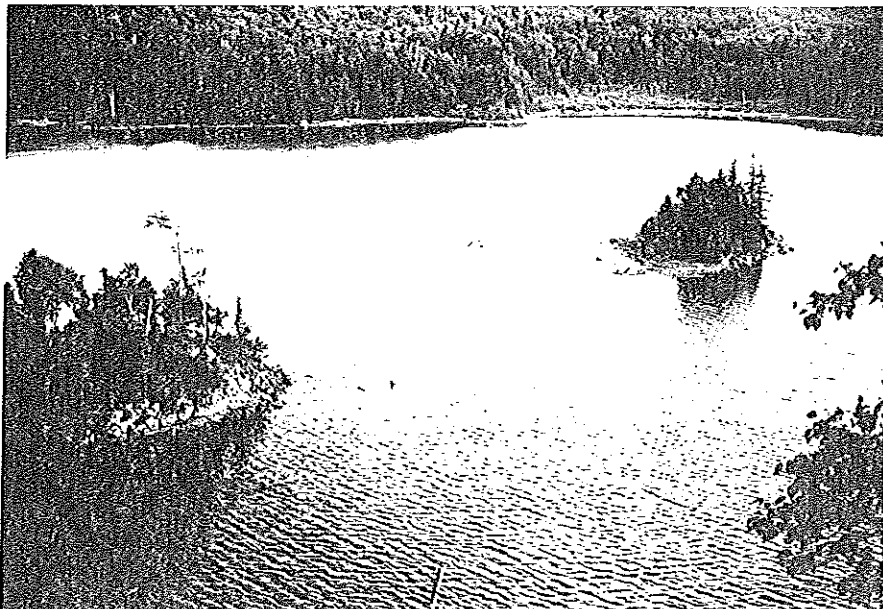
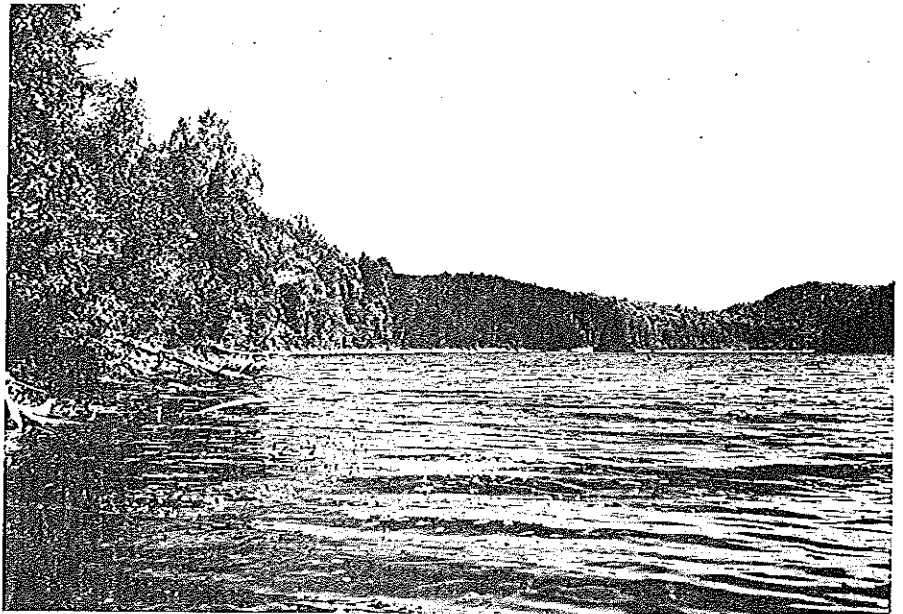


Figure 3

View of Lavant Long Lake.

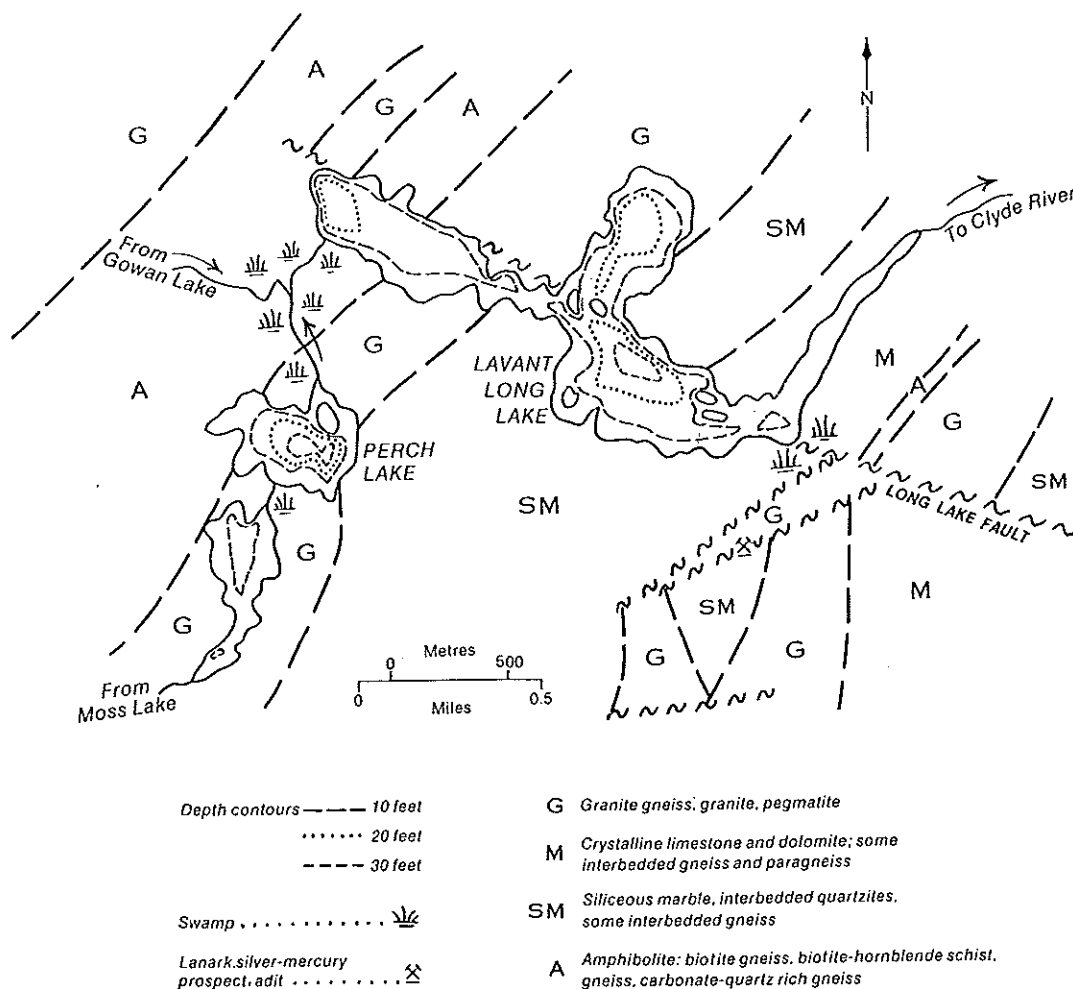


Figure 4. Geology of the study area.

The waters of Lavant Long Lake are partly dammed (or rather, restricted) by the ruins of an old sluice gate and walls which are probably leftovers from bygone logging activities.

Figures 2 and 3 show views of Perch Lake and Lavant Long Lake, respectively.

Water flow through the lakes for most of the year is very low, however, both the lakes rise more than 4 feet (120 cm) during the spring runoff when flow is rapid. Most movement of water and sediment probably occurs during the spring period. By August when flow is at a minimum and sediment in the lakes has settled, the waters are clear to depths of 20 feet (6 m) or more and the lake waters and sediment are stratified. These conditions persist until autumn, when rains replenish the lakes again and the waters become more turbid, and when the advent of freeze-up induces disruption of the water strata, i.e. hypolimnion turnover, and fine sediments mix into the waters.

Figure 4, a generalized map of the geology of the study area, shows approximate lake depth contours for Perch Marsh, Perch Lake (see also Fig. 5) and Lavant Long Lake. These contours were plotted from data derived from direct measurements using plumb-lines

and depth gauges and have been checked against contour maps derived from echo-sounding measurements made by officers of the Ontario Department of Natural Resources, Lanark District.

The greatest depths recorded were 35 feet (10.7 m) in Perch Lake, 5 feet (1.5 m) in Perch Marsh, and 50 feet (15.2 m) in Lavant Long Lake. The depth contours are typical of what may be expected in the month of August in most years.

Because the hydrogeochemical sampling was conducted only in the months of August 1970, August 1971 and August 1972, the lake waters were always stratified with respect to temperature. The thermocline in both lakes was typically between 25 and 30 feet (8 and 9 m), below which temperature was usually about 40 to 45°F (4.4 to 7.2°C) and above which climbed up to about 65°F (18.3°C) at the surface. However in the deepest part of Lavant Long Lake where a narrow trench plunges to 50 feet (15 m) below surface, the bottom temperature was found to be close to freezing in water which was very clouded with organic detritus. It is considered likely that a spring feeds cold groundwater into the lake along this trench keeping it relatively

clean of sediments. No other sources of spring water were observed in the lakes.

Water pH, measured at 25°C, ranges from 7.5 to 8.0 with no apparent pattern of variation across either lake. It is possible that dissolved organic matter accounts for the apparent buffering at these pH values. This idea was not tested.

Sampling and Analytical Methodology

All deep water samples and sediment samples were collected by hand by scuba-equipped divers who were also able to make visual observations on water turbidity, springwater sources, bottom topography, physical

nature (texture, coherence, density, presence of films and layers) of sediments, measure temperature and note depth on wrist gauges (Fig. 6). Water samples were collected unfiltered at surface and at depth from each site in Lavant Long Lake but at the surface only in the Perch system. After adding 1 ml concentrated nitric acid to each, the samples were stored in one litre polypropylene jars until required for analysis. Deep water organic-rich sediment samples were also collected in one litre jars, sun-dried, and stored for analysis in kraft paper bags. Some duplicate samples were collected intact in jars, transported to and stored in the Ottawa laboratories at -15°C for later study. All bottom samples were collected about 3 feet (90 cm) into the sediment layers if these were loosely consolidated, but at surface in areas where sediments were compacted. Nearshore and shoreline sediments were collected directly into kraft bags and sun-dried. The physical and chemical nature of all sediments will be discussed later.

Water samples were analyzed for some or all of zinc, copper, lead, nickel, cobalt, cadmium, uranium, and mercury. All except uranium and mercury were determined by atomic absorption spectrometry after extraction with ammonium pyrrolidene dithiocarbamate in methylisobutylketone. Uranium was determined fluorimetrically after a sample was evaporated to dryness, fused and redissolved. Mercury was determined by flameless atomic absorption as described by Jonasson *et al.* (1973). All water samples were analyzed as received in the laboratories.

Dried sediment samples were treated differently according to their physical texture. Sandy, silty or marly types were first sieved to collect the minus 100-mesh fraction. Organic rich samples, which tended to dry to a hard pitch-like cake, were crushed and ball milled to minus 200-mesh size. All samples were then subjected to various leaching attacks and analyzed for zinc, cadmium, copper, silver, nickel, manganese, lead and iron (4M HNO₃; 0.1M HCl; atomic absorption); for arsenic, antimony (6M HCl; colorimetry); for

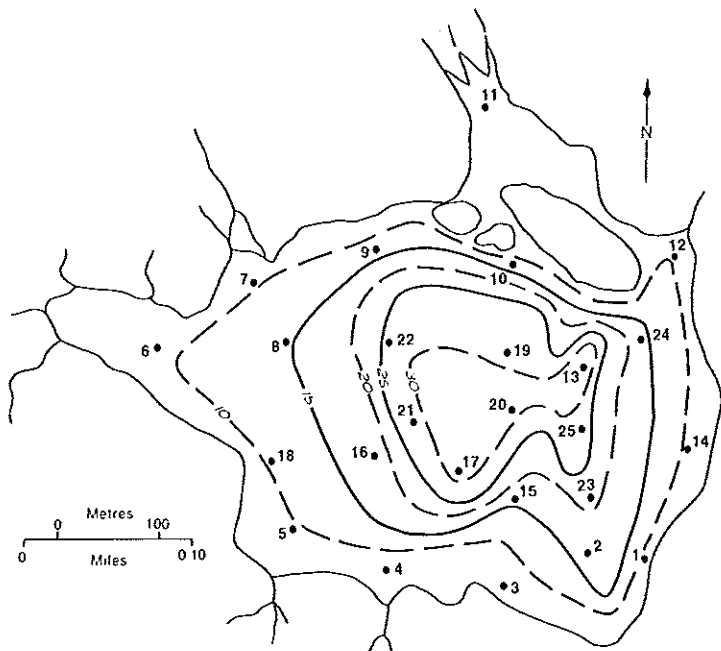


Figure 5. Sample sites and depth contours of Perch Lake.

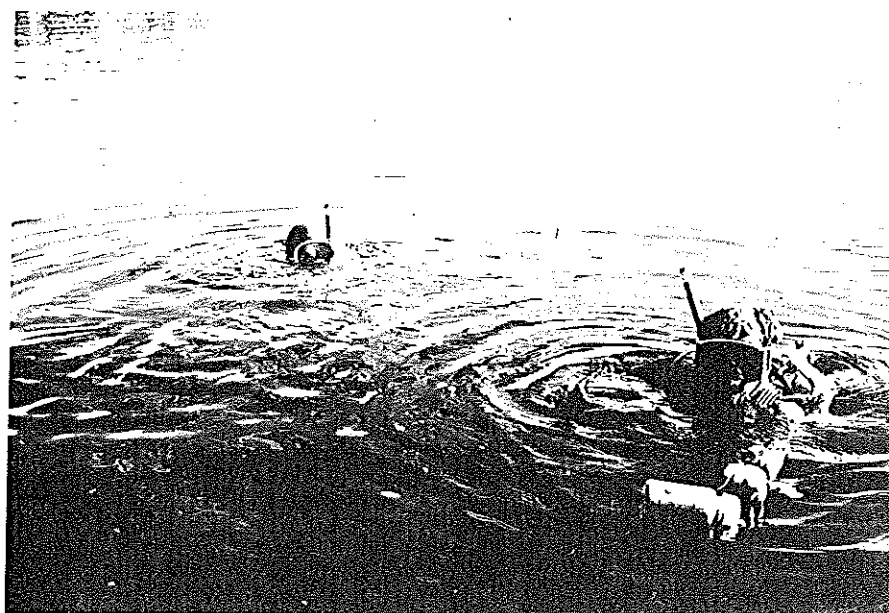


Figure 6
Sampling techniques by scuba divers.

molybdenum, tungsten (Na_2CO_3 fusion; colorimetry); for uranium (4M HNO_3 ; 0.1M HCl ; fluorimetry); and for mercury (4M HCl ; 0.2M HCl ; flameless atomic absorption). For all organic sediments and gels, the metals released by these attacks represented close to 100 per cent of total metal according to preliminary studies. These observations support the contention, that most metal is loosely bound in the form of labile organic complexes, secondary sulphides, or is adsorbed in some way.

Combustion-titrimetric methods were utilized for the determination of organic carbon, carbonate and sulphur.

Geology and Economic Geology

The geology of the study area is presented in generalized form in Figure 4 which was compiled using previous studies of Peach (1956) who produced a map covering parts of Lanark and Frontenac counties (Clarendon-Dalhousie-Darling area, O.D.M. Map 1956-4) and Nikols (1972) who mapped in some detail a small area to the south of Lavant Long Lake, and from the author's observations.

Perch Lake lies almost entirely within granite gneiss units which are intruded in places by pegmatite sills and commonly interbedded with amphibolites.

Small outcrops of Grenville marble can be seen along the eastern shoreline, but they are relatively minor by comparison. The geology of the Lavant Long Lake area is variable. The north and west arms lie within the same gneissic units as does Perch Lake but there are proportionately more interbedded amphibolites at the western end. Radioactive pegmatites have been observed along the south shoreline of the western arm near the lake narrows. Some crystalline limestones (marble) outcrop along the eastern shore of the north arm. The rest of the lake, herein referred to as the east arm and main body (south arm) lie almost entirely within crystalline limestone and dolomite units.

The major structural feature in the area described by Nikols (1972), as the Long Lake fault of possible Cretaceous age. It cuts and offsets a number of gneiss and marble units along its strike which is marked by the north shore of the east and west arms of the lake. The deep trench referred to earlier lies at the foot of the steep fault scarp and is probably part of its structure. The scarp itself is faced with quartz-rich carbonate rocks containing minor amounts of graphite and pyrite.

Little sulphide mineralization is to be found around either lake, but small amounts of pyrite-magnetite have been observed in the gneisses, and specks of

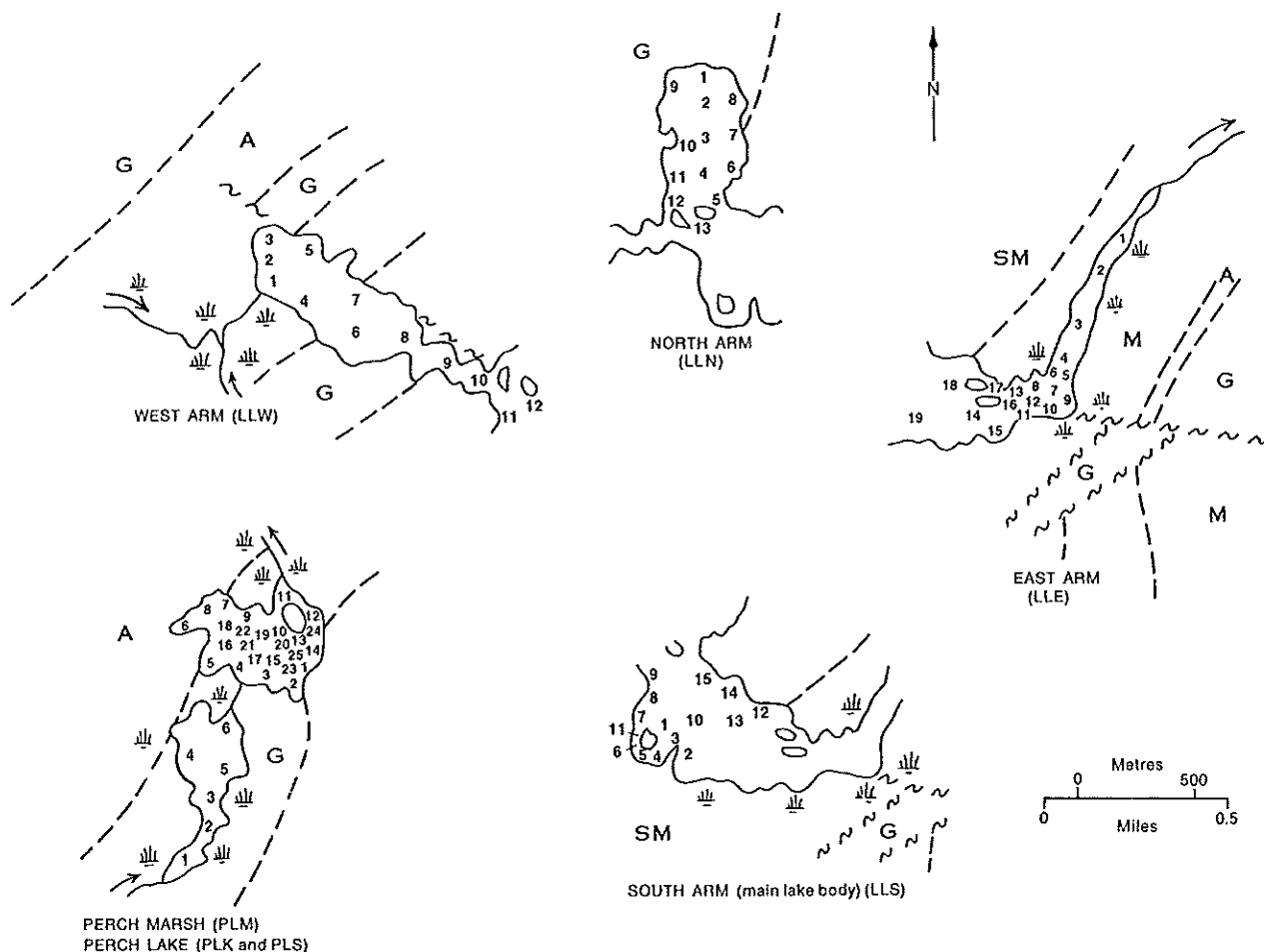


Figure 7. Localities for all sediments and water samples.

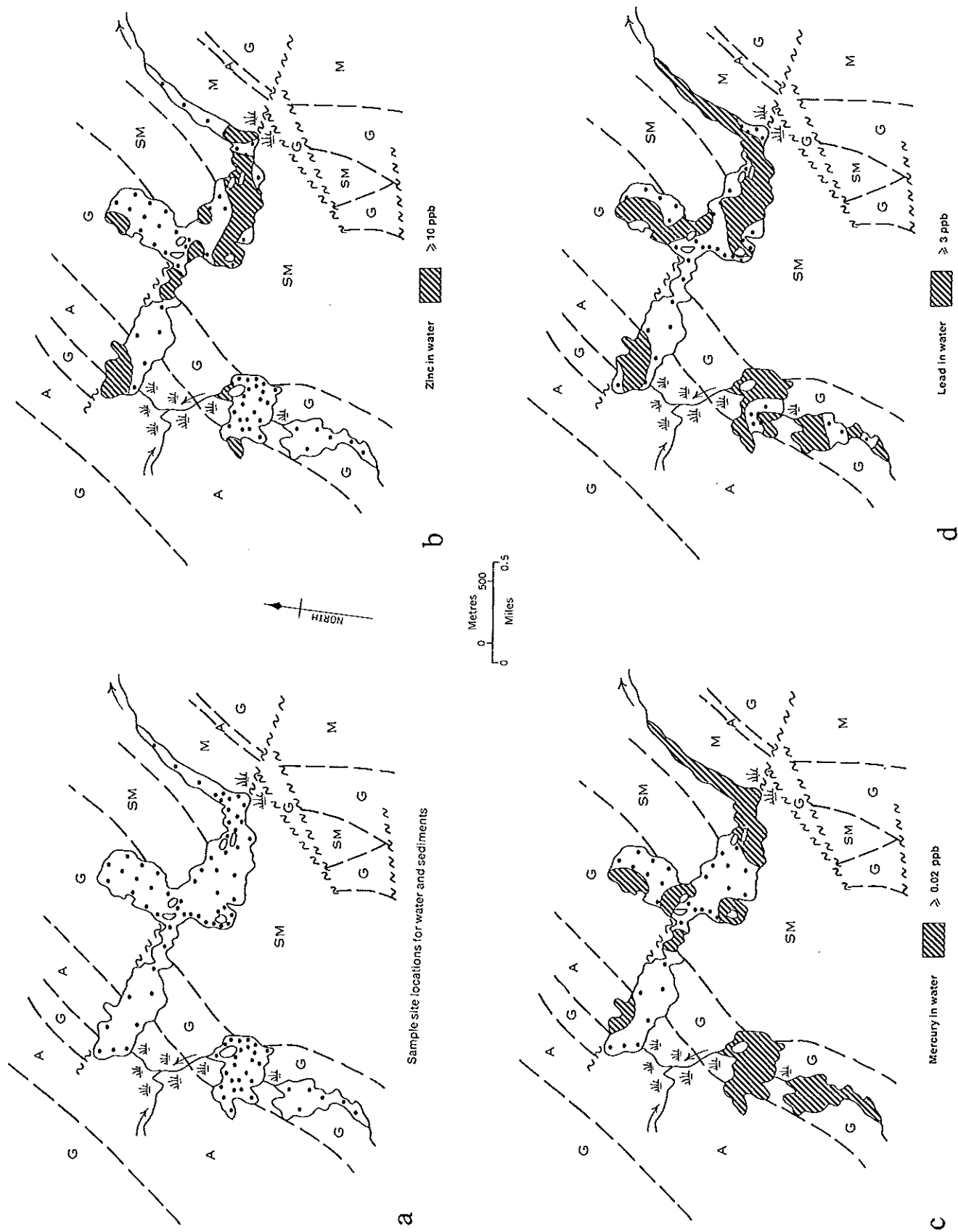


Figure 8. Zinc, mercury, and lead in lake waters.

Table 1
Surface and bottom waters: Summary data (ppb)

Lake Basin	PLK Perch Lake		LLN		Lavant Long Lake				LLE	
	X _s	X _b	X _s	X _b	X _s	X _b	X _s	X _b	X _s	X _b
Zn	3.8	-	1.8	4.2	7.2	16	7.9	9.0	10.4	9.3
Co	1.2	-	1.0	0	0	0	1.4	1.0	0.9	0
Hg	0.05	-	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Cu	0.6	-	0.5	0	0.5	1.0	1.0	1.0	1.1	0
Ni	1.1	-	1.8	1.1	8.5	21	4.5	5.0	4.8	3.7
Pb	4.3	-	2.0	0	0	1.4	1.7	1.8	2.6	2.0
U	0	-	0	0	0	0	0	0	0.2	0
No. of samples	14	-	12	11	11	10	15	5	20	9

X_s = mean value surface water

X_b = mean value bottom water

tetrahedrite are visible in places in the marbles at the east end of Lavant Long Lake.

To the south of Lavant Long Lake, lies an abandoned silver-mercury prospect once known as the Lanark Silver Mines. Some pitting and trenching has taken place and an adit 100 feet (30 m) has been driven into the hillside. Mineralization consists of pyrite-chalcopryrite with minor sphalerite, tetrahedrite and cinnabar in carbonate rich skarns and marbles cut by veins of barite containing tetrahedrite with minor cinnabar. Although drainage from the vicinity of this occurrence moves into swamps to the south rather than into Lavant Long Lake, it is important in view of the fact that similar rock types outcrop in Lavant Long Lake.

Sulphide samples from this zone are generally enriched in copper, silver, zinc, mercury, nickel, iron, arsenic, and antimony. There is little lead, gold, cadmium, cobalt, uranium, molybdenum, or tungsten. Pegmatites are enriched in uranium in places; gneisses contain some nickel and cobalt, mainly in magnetite granules.

Geochemistry of Lake Waters

Water samples were collected from Perch Marsh (PLM), Perch Lake (PLK) and from Lavant Long Lake. For the purposes of sample classification and subsequent discussion, the samples from Lavant Long Lake are subdivided into four groups: west arm samples (LLW), north arm samples (LLN), the east arm samples (LLE), and the samples from the main body of the lake (LLS). Samples were collected only from the surface in the Perch system, but from the bottom and the surface in Lavant Long Lake. In the tables, surface waters have the suffix S, bottom waters, the suffix B. Depths are given for bottom waters. In general, bottom water samples were collected with sufficient care to avoid

disturbance of the first tenuous sediment layer. Afterwards sediment samples were taken beneath the diffuse film which commonly was observed to cover the gel-like sediments found at depth in Lavant Long Lake and Perch Lake.

There is some correlation between surrounding geology and different areas of Lavant Long Lake: samples from the west and north arms correspond fairly closely to areas of gneissic group rocks, whereas those from the east arm and main body are generally from within lakewaters surrounded by carbonate-rich rocks, mostly marbles and siliceous marbles.

Sample sites for all waters are shown in Figure 7. The sample localities also apply to bottom sediments and nearshore sediments; there is some overlap in sampling sites from the different arms of Lavant Long Lake. The density of sampling in Perch Lake is greater than elsewhere, so these may be regarded as the most detailed sample sites from within the study area with regard to replicate water sampling. In many instances water samples were taken no more than 100 feet (30 m) apart. Figure 8a shows the sample sites on a composite map. These points reappear on all subsequent elemental distribution maps depicted in Figures 8 and 9. Surface and bottom water samples are included. In most instances there was little difference between surface and bottom waters in terms of their metal values. Where areas in which exceptional differences existed will be discussed later. Table 1 presents summary data for all waters from Lavant Long and Perch lakes.

Data summarized in Table 1 and displayed in Figures 8 and 9 are derived from the elemental analysis presented in Appendices 1, 2 and 3.

The concentration limits chosen for any given element for figure presentation are somewhat arbitrary, but are generally close to the arithmetic means for all samples. The information is presented in this manner

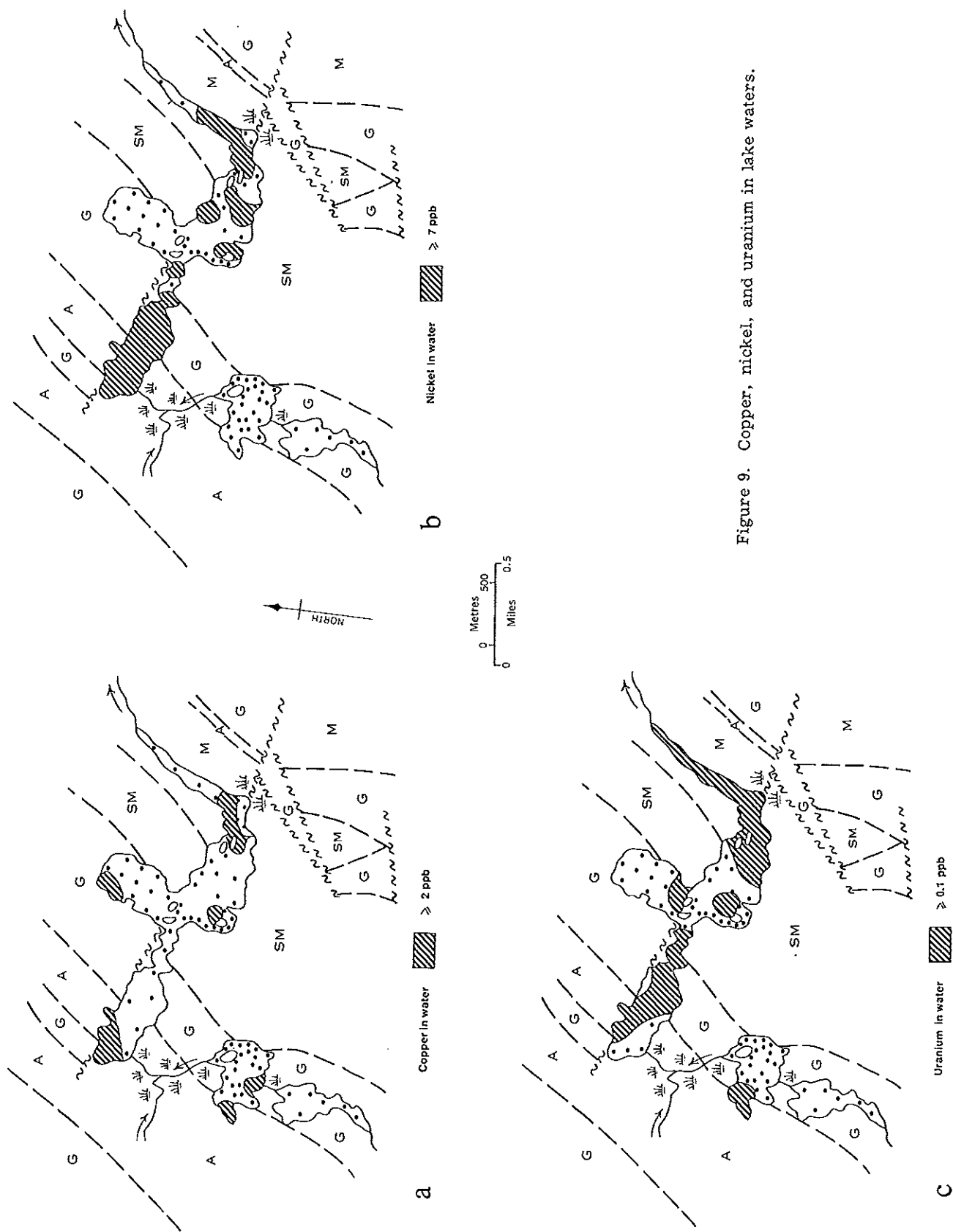


Figure 9. Copper, nickel, and uranium in lake waters.

solely to facilitate the discussion on elemental levels and dispersion patterns.

The distribution patterns for lead, zinc and mercury (Fig. 8b, c, d) are fairly similar. The actual values found for lead and zinc are relatively high in certain zones of the lakes. Those for mercury may be regarded as being typical of natural lake waters in uncontaminated regions (Jonasson and Boyle, 1972), although levels in Perch Lake are higher than those in Lavant Long Lake. The zinc values in the west arm and main body of Lavant Long Lake are relatively high; those in the bottom waters of the deepest parts of the west arm are the highest of all. The highest values for nickel (Fig. 9b) are also found in this area. Copper and uranium values are uniformly low throughout the lakes' system (Fig. 9a, c); uranium, however, does show a coherent distribution pattern.

The patterns for all these elements are not readily interpretable in terms of local geology, mineralogy and dispersion mechanisms in their own right. But meaningful discussion of these factors is possible when the sediment data are viewed comparatively.

Geochemistry of Organic Lake Sediments

General Principles

It is necessary to define what is meant by the term lake sediment. The author and co-workers have made some attempt at classifying and categorizing these types in a descriptive sense (Timperley *et al.*, 1973). Briefly, it was considered that lake sediments could be grouped: as organic gels, organic sediments, or inorganic sediments. For a simple analogy, these three groups can be regarded as being similar to A, B and C horizons of soils. But, within each category, the broad chemical, physical and mineralogical characteristics, are relatively uniform. The end members are organic gels and inorganic sediments. Organic sediments are intermediate and incorporate all of the problems and complications, usually in varying degrees, of both end members.

Organic gels are materials commonly found in the deeper waters of organic-rich lakes and are abundant in most parts of the Shield where there is a deciduous-coniferous forest cover. These gels, which should be regarded as mature sediments, commonly extend to 30 feet (10 m) or more above the inorganic sediment base of a lake. Almost completely organic in origin, they smell strongly of reducing conditions (H_2S) and are thixotropic. As their coherence often is very low the gels may disperse freely into the lake waters if the sediment-water interface is unduly disturbed. They usually have a low density, perhaps 1.5 to 2 times that of water. Their origin probably lies in the sedimentation of fine, dispersed particles of vegetation debris (spores etc.), and of coagulating colloids of dissolved organic matter (organic acids such as humates, fulvates, etc.). Relatively little coarse organic debris or mull is present in these samples of organic gels which occur in the deepest parts of a lake. Each dries into a hard,

dark, lustreless, homogeneous organic cake which is difficult to break and does so conchoidally.

Organic sediments are widespread throughout most lakes of the Canadian Shield, especially in shallow waters either near shores or near inflows. They are also the most abundant material to be found in swamps and marshes, and may be regarded as mixtures of organic gels, organic debris, and inorganic sediments (silts and clays). In comparison with organic gels, these represent immature sediments.

Inorganic sediments are materials which commonly occur in lakes in areas of the Canadian Shield which are sparsely forested, for example above the northern limit of tree growth. However they are found elsewhere in shallow waters in most lakes, especially near the shores of a lake, and near inflows and outflows. They may originate from the winnowing action of waves on shoreline sediments and soils, or may occur as silty deposits in deeper waters. The term "inorganic sediment" is used herein to imply various combinations of sand, silt, marl and clay with inorganic oxides and hydroxides (precipitates and colloids) with virtually no organic matter, and with little or no regard paid to mode of formation. Trace elements are usually held in silicate-aluminate or sulphide lattices, as adsorbed or occluded species, or as coprecipitates in oxides. Concentrations of trace elements are usually higher in the finer fractions (silt and clay size).

The forms in which trace metals may be held (particularly transition metals) in organic gels has been discussed at length by Timperley and Allan (1974). In summary, it is sufficient to say that competition for metal ions exists between sulphide ions and complexing organic ligands in varying degrees according to the chemical nature of the metal ion and to its relative stabilities in complexes with each type of binding ligand. But in general, the higher the concentration of free sulphide ions (in equilibrium with H_2S), the more likely it is that trace heavy metal elements are tied up as sulphides. This particular conclusion will be shown later to be most important in determining nature of dispersion mechanisms for metals in lake waters and sediments.

Nature of the Sediments in the Study Area

Organic gels were observed exclusively in the deepest waters but were mixed, in patches, with organic sediments and sands in shallower waters. All sediment samples were organic-rich (i.e., arbitrarily defined as greater than or equal to 10 per cent carbon by weight) in all parts of the lakes except in the open shallows along shorelines where depths were less than 3 feet (1 m) and where inorganic soils and sands predominated. As a general observation (often found too general) organic sediments grade through mull-like chaffs and gel mixtures to true gels as depth increases although organic-rich sediments sometimes were observed near shorelines, particularly near swampy inflows. True inorganic sediments were never found at depth,

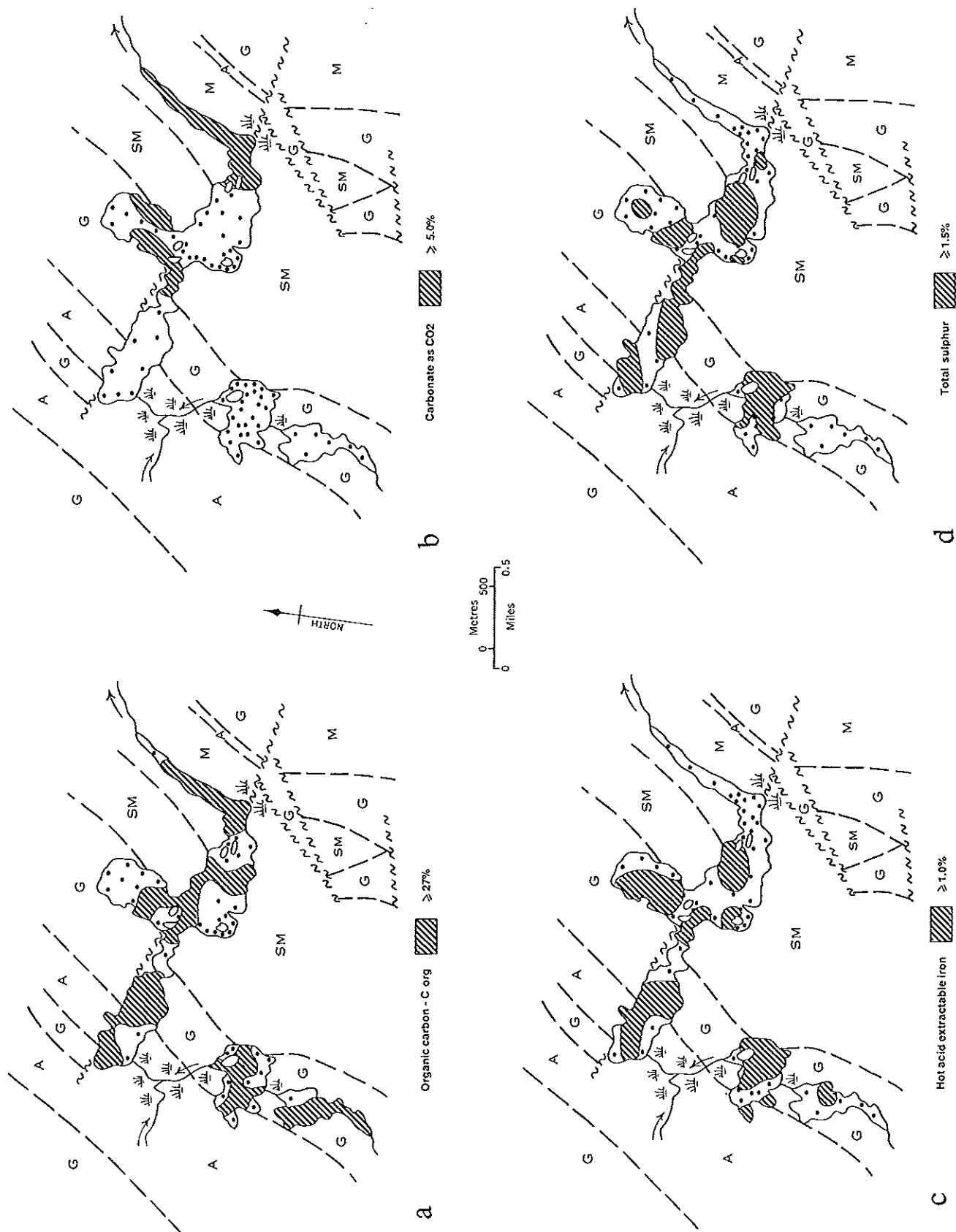


Figure 10. Sulphur, iron, organic carbon, and carbonate in organic lake sediments.

Table 2
Deepwater organic rich sediments: Summary data (ppm except where noted)

Enclosing Rock	Granite gneiss			Granite gneiss			Grenville marble			Probability of Significance
Lake Basin	PLK Perch Lake			LLN & LLW Lavant Long Lake			LLE & LLS Lavant Long Lake			
Element	X _a	Sa	Cv%	X _a	Sa	Cv%	X _a	Sa	Cv%	p%
Zn -	106	35	33	100	38	38	126	34	27	96
Cd	0.9	0.5	60	0.7	0.5	79	1.4	0.6	45	99
Hg -	0.32	0.33	103	0.08	0.03	34	0.11	0.03	24	99
Cu -	24	9.5	40	30	10	33	25	6.9	27	90
Ag -	-	-	-	-	-	-	0.30	0.14	41	-
Ni -	12	2.7	23	12	4.7	39	10	4.5	46	78
Co -	7.8	2.0	26	5.0	2.7	52	5.0	2.1	43	-
Mn -	236	128	54	217	104	48	337	205	61	97
Pb -	33	26	79	32	26	81	41	26	65	69
As -	4.8	1.8	38	4.8	1.5	31	4.9	1.3	26	17
Sb	-	-	-	-	-	-	-	-	-	-
U -	5.1	2.0	39	4.8	1.9	39	1.9	1.2	66	99
Mo -	3.4	0.8	23	5.2	2.9	56	3.6	1.2	33	96
W	-	-	-	1.6	-	-	1.7	0.5	27	-
Fe% -	1.20	0.35	29	1.06	0.36	33	0.92	0.39	42	72
S%	1.58	0.56	35	1.58	0.54	34	1.39	0.40	29	75
Corg% -	24.7	7.6	31	27.5	7.6	28	27.0	5.9	22	17
CO ₂ %	0.1	-	-	0.1	-	-	0.80	1.19	157	-
No. of samples	25			18			17			
Mean depth of sample site (ft.)	15			13			9			

X_a = arithmetic mean; Sa = std. deviation; Cv% = coefficient of variation

excluding carbonate marls which were rarely found, however, these were comprised mainly of micro-skeleta and shells indicating an organic origin.

Heavy Metal Distribution

Table 2 presents summary data for some trace element and some major element contents of organic gels and sediments collected from the Perch Lake and Lavant Long Lake systems. The table is subdivided into three groups, Perch Lake (PLK), north and west arms of Lavant Long Lake (LLN, LLW) and east arm and main body of Lavant Long Lake (LLE, LLS). The division into such "basins" is made on the basis of broad geological differences and thereby assuming that local chemical effects of different enclosing rock units will be significant when comparing mean values for each basin. Comparisons were made between the two separate lake basins within gneissic rocks and the two basins of the same lake within different rock types - gneiss and marble. Table 2 also gives average depth of each basin along with means, standard deviations and coefficients of variance for each element

considered. The probability of significance (p per cent) estimates whether the differences in means for each element in each basin of Lavant Long Lake are or are not significant. The function was calculated using the Students' "t" test where this could be applied legitimately to the data. Probability values in excess of 95 per cent indicate high significance; those less than 90 per cent indicate near-zero significance of data.

Figure 10 displays distribution maps for certain major elements in organic lake sediment; organic carbon (Fig. 10a), carbonate carbon as CO₂ (Fig. 10b), acid extractable iron (Fig. 10c), and total sulphur (Fig. 10d). A comparison with Figure 4, shows that organic carbon, iron and total sulphide are definitely higher in sediments collected from the deeper parts of the lakes' system. Sulphur and iron exhibit a close relationship throughout both lakes; organic carbon matches both but is also high in the outflow of east arm of Lavant Long Lake. In this sense it corresponds with carbonate carbon, as CO₂, in the outflow arm. These distributions will be shown to exert a strong influence in certain minor and trace elements described below.

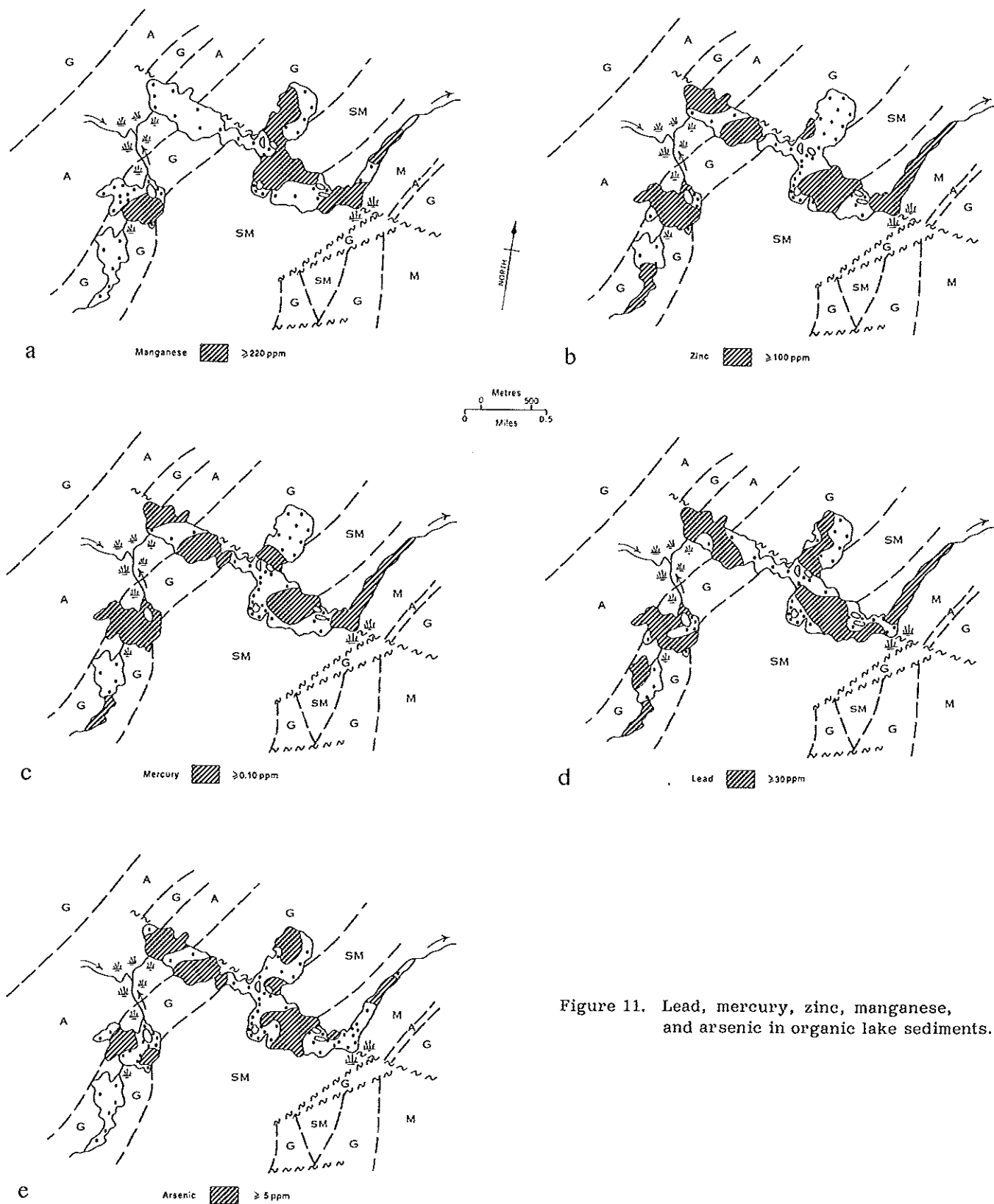


Figure 11. Lead, mercury, zinc, manganese, and arsenic in organic lake sediments.

Table 3
Geochemical analyses for rock chips: Perch Lake

Sample No.	Rock Type	Zn	Cu	Hg	Ag	Ni	Co	Mn	Pb	As	Sb	U	Fe%
1-01	QBFG	7	5	.007	0	8	8	53	0	0.6	1	0	0.33
1-02	QBFG	6	5	.004	0	8	7	53	0	0.3	0	0	0.27
1-03	QBFG	7	5	.007	0	8	8	53	0	0.3	0	0.1	0.33
1-04	QBCH	40	46	.013	0	25	18	232	0	0.3	0	0.5	1.89
1-05	QBFG	72	2	.004	0	2	5	80	0	0.3	0	0.6	1.82
1-06	BSCH	44	43	.011	0	27	22	352	0	0.3	0	0.2	2.85
1-07	BSCH	31	8	.007	0	7	14	352	0	0.3	0	0.2	2.56
1-08	QBFG	112	5	.007	0	3	4	328	0	0.3	0	1.0	2.85
1-09	QBFG	91	8	.004	0	3	2	256	0	0.3	0	2.0	2.26
1-10	QBFG	101	5	.007	0	2	3	352	0	0.3	0	0.8	2.71
1-11	QBGN	99	15	.013	0	26	26	486	0	0.3	0	2.0	5.53
1-12	QBFG	102	4	.010	0	2	3	352	0	0.3	0	0.7	2.63
1-13	QBFG	110	8	.011	0	2	3	352	0	1.7	0	1.7	3.00
1-14	MRBL	13	3	.011	0	8	6	232	0	0.3	0	0.1	0.33
1-15	QBGN	83	3	.007	0	9	12	304	0	0.3	1	0.2	3.33

All values are in ppm, unless otherwise indicated.

Key to rock types: QBFG -- quartz biotite feldspar gneiss;
BSCH -- biotite schist;
QBGN -- quartz biotite gneiss;
MRBL -- marble or crystalline dolomite.

Figure 11 presents distribution maps for the trace elements in sediments; manganese in excess of 220 ppm (Fig. 11a), zinc 100 ppm (Fig. 11b), mercury 0.10 ppm (Fig. 11c), lead 30 ppm (Fig. 11d), and arsenic 5 ppm (Fig. 11e). The primary analytical data from which these maps and Table 2 were derived are recorded in Appendices 4 and 5. It must be emphasized that all trace element data represent hot acid extractable forms. In the case of gels and most deep water organic samples this amounts to better than 90 per cent of all trace metals present.

Manganese tends to concentrate in the deeper parts of the system especially in Perch Lake, but is low in the west arm of Lavant Long Lake. It is also high in marly sediments of the east arm of Lavant Long Lake.

Zinc, mercury, arsenic, and lead produce virtually the same distribution pattern, but only the level of mercury is significantly higher in Perch Lake than elsewhere. Significant differences between the two basins of Lavant Long Lake are observed for manganese, zinc, and mercury but not for arsenic and lead.

Figure 12 presents distribution maps for trace elements in sediments; copper in excess of 27 ppm (Fig. 12a), nickel 12 ppm (Fig. 12b), uranium 5 ppm (Fig. 12c), and molybdenum 4 ppm (Fig. 12d). Molybdenum and copper are distributed similarly to iron and sulphur (Fig. 10a,b). Nickel, whilst occurring at low levels, resembles copper in its gross features, however, only copper tends to be higher in Lavant Long Lake than in Perch Lake. Uranium produces a distribution map different from all others, a point which is worthy of discussion later.

Hydrogeochemical Relationships in the Sediments of Perch Lake

Before a general discussion of trace metal distributions in the lakes' system, it is necessary to establish some correlative relationships between the major elements studied and the trace heavy metals. Perch Lake was chosen for detailed studies for several reasons. Firstly it is small (57 acres, 23 ha) and symmetrical. Figure 5 shows that Perch Lake has a bottom profile similar to that of a saucer and that except for an underwater ridge of granite gneiss, the deepest parts of the lake are near to its geometric centre. Secondly, it has very limited inflow and outflow, especially in the month of August. Thus the waters and bottom sediments remain relatively undisturbed at that time in mid-summer. Thirdly, it lies essentially within banks of one rock type, granite gneiss, although minor outcrops of amphibolite and marble are present (Fig. 4, Table 3).

The difficulty of making a similar study in any of the major basins of Lavant Long Lake is apparent in view of the above criteria, none of which apply (Fig. 4; Table 4). As will be shown, inter-element relationships are nowhere near so clear-cut in Lavant Long Lake as in Perch Lake where a model system seems to be operative.

Consequently, some 26 samples of sediment were taken in the deeper waters of Perch Lake in August 1972. Only the highest values of trace metal contents are represented in Figures 10, 11, and 12. More interesting relationships become apparent when all data are plotted at five times scale (Figs. 13, 14 and 15).

Although there are probably sufficient individual data for each element considered to permit calculation

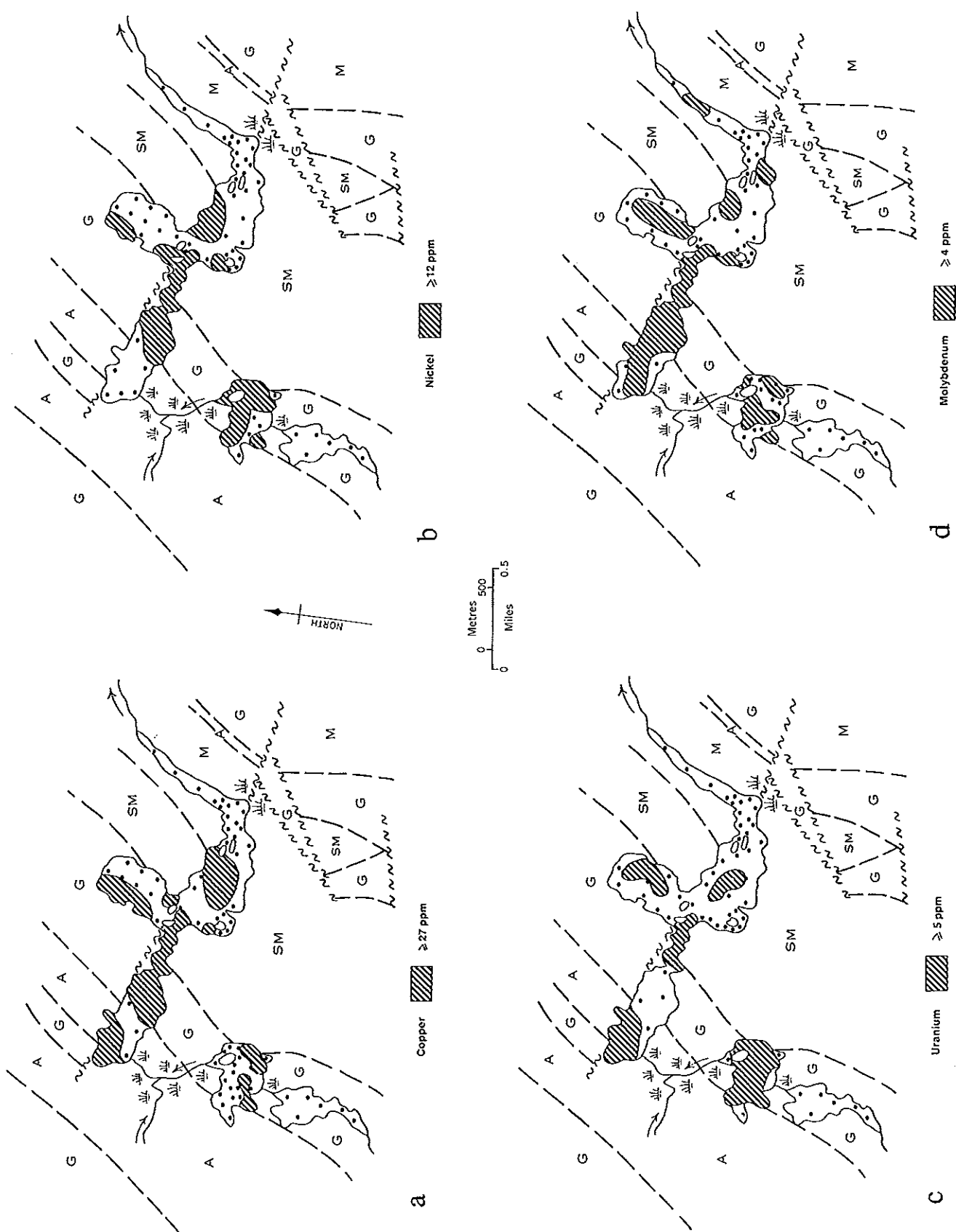


Figure 12. Copper, nickel, uranium, and molybdenum in organic lake sediments.

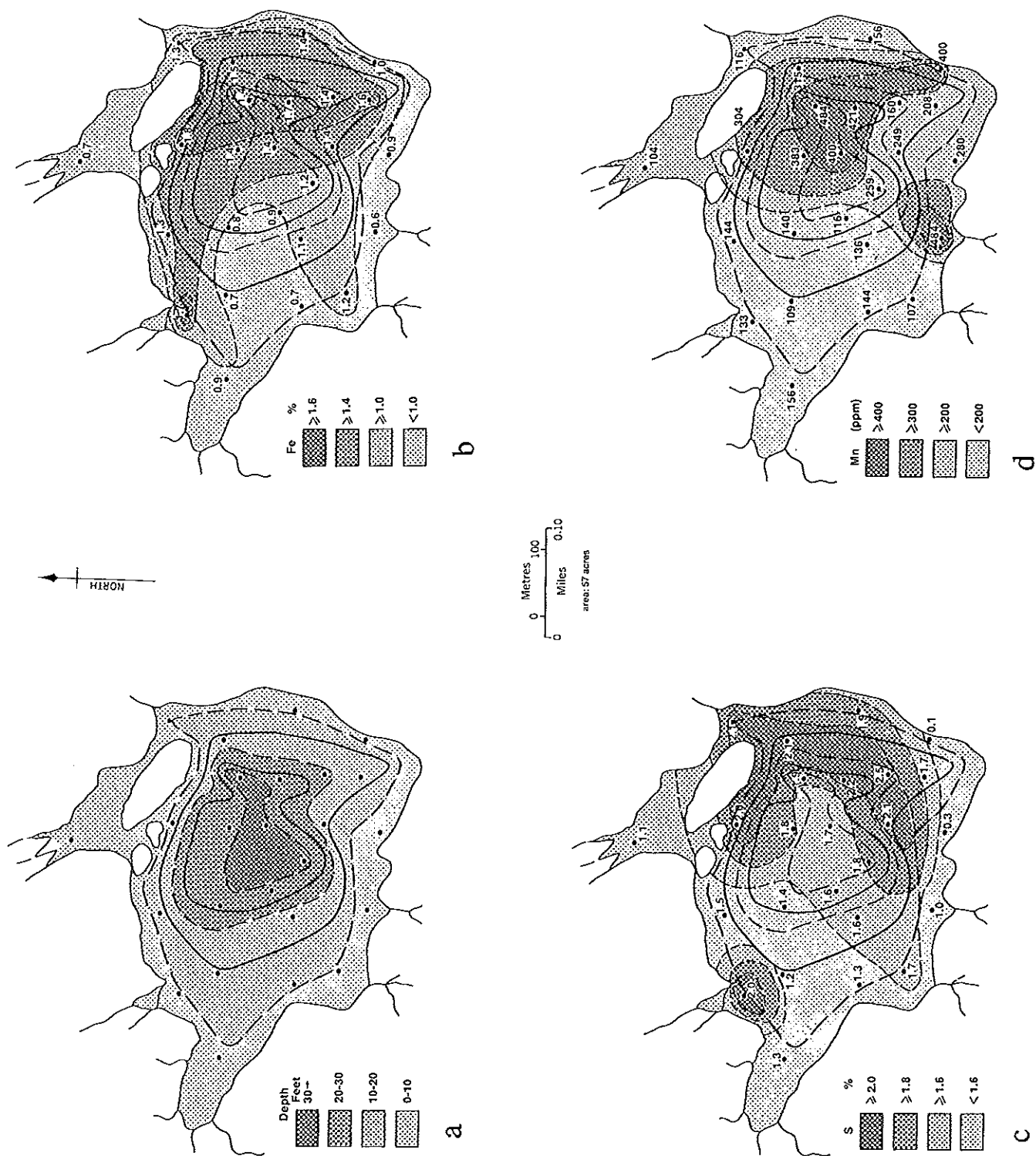


Figure 13. Water depth, iron, sulphur, and manganese distribution in organic sediments of Perch Lake.

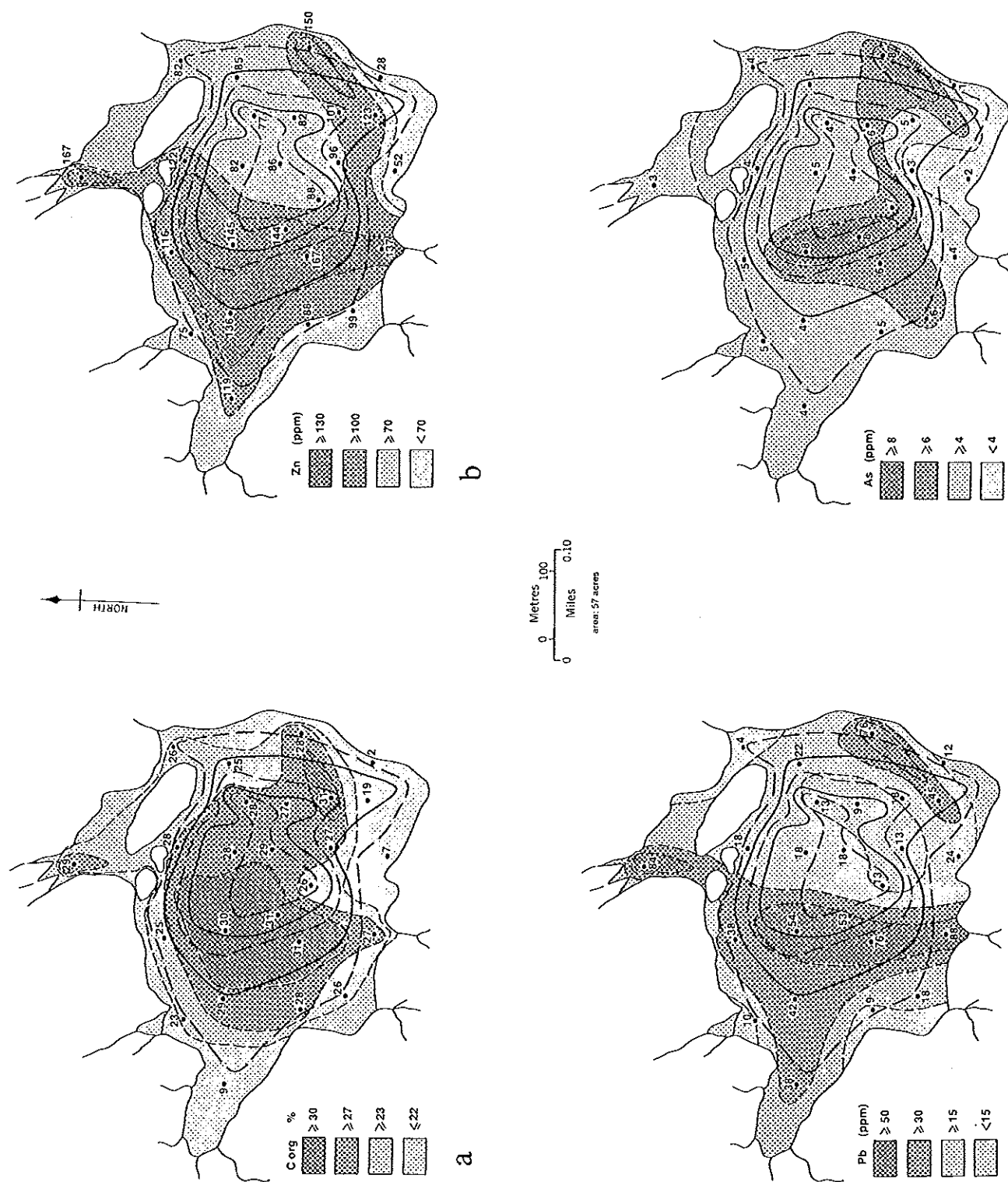


Figure 14. Organic carbon, zinc, lead, and arsenic distribution in organic sediments of Perch Lake.

Table 4
Geochemical analyses for rock chips: Lavant Long Lake

Sample No.	Rock Type	Zn	Cu	Hg	Ag	Ni	Co	Mn	Pb	As	Sb	U	Fe%
L-06-W	MGNT	76	53	.012	0	30	21	594	28	3	1	40	72.2
L-09-W	QBFG	8	22	.014	0	8	4	42	28	3	1	26	0.84
L-05-W	PGMT	5	2	.006	0	1	2	184	0	0	0	0	0.33
L-06-S	MRBL	11	143	.006	0	9	5	-	5	1	1	0	0.0
L-05-E	MRBL	22	68	.006	0	8	5	-	5	1	1	0	0.0
L-12-S	BSCH	15	31	.009	0	11	7	-	5	1	1	0	-
L-12-S	QRTZ	59	19	.011	0	11	10	-	5	1	1	0	0.0
L-14-S	QRTZ	5	19	.005	0	7	5	-	5	1	1	0	0.0
L-15-S	QRTZ	5	13	.006	0	3	2	-	5	1	1	0	0.0
L-04-W	QBFG	10	20	.007	0	7	2	-	15	1	1	22	-
L-05-N	BSCH	21	15	.011	0	16	7	-	13	4	1	0	-
L-10-N	QBFG	128	15	.007	0	47	25	-	11	1	1	0	-
L-07-N	MRBL	18	14	.007	0	7	2	-	8	1	1	0	0.0
L-18-E	QRTZ	9	80	.011	0	1	5	-	5	1	1	0	-

All values are in ppm, unless otherwise indicated.

Key to rock types: BSCH - biotite schist;
MGNT - magnetite;
MRBL - marble;
PGMT - pegmatite;
QBFG - quartz feldspar biotite gneiss;
QRTZ - quartz (some carbonate).

of correlation coefficients between elements, results are presented pictorially because correlation coefficients would not reflect the hydrodynamic imprints apparent in the distribution maps. Rather, these would disappear into average relationships between elements, calculated for the lake as an entity. The meaning of such averages becomes difficult to interpret in terms of chemistry alone. The interplay of both chemical and physical controls on elemental distributions effectively renders the system a heterogeneous one and makes the application of simple statistical treatment to the data a somewhat dubious exercise. There is little extra to be gained, in terms of chemical interpretation, by using statistical presentations but much to be gained by the visual, alternate means of presentation as will be demonstrated.

Figure 13 illustrates depth contours for Perch Lake at 10 foot (3 m) intervals (Fig. 13a) and the elements dependent on lake depth, iron (Fig. 13b), total sulphur (Fig. 13c), and manganese (Fig. 13d). Iron, sulphur, and manganese, which display very similar patterns are concentrated in organic gels at depth in the lake. Sulphur is almost certainly the principal fixer for both iron and manganese, rendering them immobile. These results are not unexpected; the deeper placed sediments in the lake, in particular in the more stagnant zones, are usually richest in H_2S and probably remain undisturbed by epilimnion-hypolimnion turnover and especially by increased flow through the lake, relative to shallower shelf or nearshore sediments. Nor would they be subjected to shifts in redox potential E_h mixing with oxygenated waters which would remove sulphide ion and promote the release of iron, and manganese in particular. Such redox processes are particularly

important in controlling sediment levels of sulphur, iron, and manganese in zones affected by lake water turnover. In regions of the country where manganese is greatly enriched in rocks and subsequently, in sediments, those processes would, in part, control generation and disintegration of ferromanganese nodules and crusts and their hydrolytic gel precursors.

The heavy metals, zinc, lead and perhaps arsenic are grouped in Figure 14 with organic carbon rather than with iron, manganese and sulphur. These elements appear to be closely related to organic carbon in terms of distribution across the lake. Organic carbon is clearly not related to increase of depth as were iron, manganese and sulphur, but rather to some dynamic function such as water flow through the lake. Figures 14a through d display very similar patterns. The waters of Perch Marsh, although not analyzed for organic carbon, were observed to be pale brown in colour, indicating high dissolved organic content. The marsh is relatively young because it was created by a high beaver dam which was estimated to be no more than a few years old from the appearance of its construction. Consequently, the marsh waters were still interacting with and dissolving organic matter from drowned reed and grass vegetation at the time of sampling, particularly near shoreline. The low sulphur contents of the marsh sediments (really bog soils) are indicative of the juvenility of those sediments. When the waters of the marsh passed through the beaver dam they were rapidly clarified; perhaps causing organic colloids to flocculate and sedimentation to occur along the direction of flow through Perch Lake. These processes seem to be more apparent in Perch than in Lavant Long Lake.

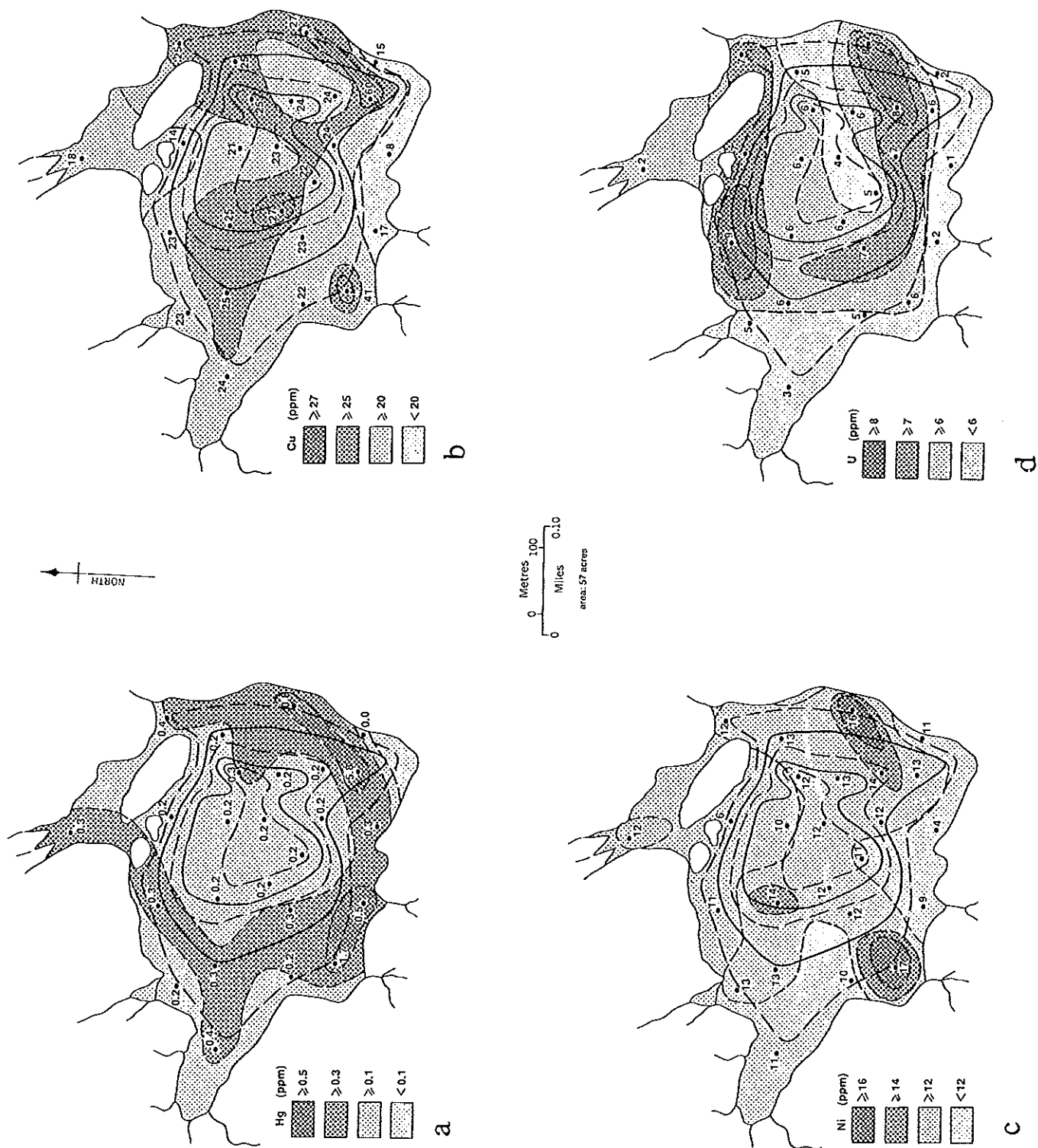


Figure 15. Mercury, copper, nickel, and uranium distribution in organic lake sediments.

It is postulated, therefore, that the patterns for organic carbon, zinc and lead, and to a lesser extent, arsenic in Figure 14, reflect these depositional processes and produce the strong correlative relationships now observed in the Perch Lake sediments. Thus it is proposed that these heavy metals are controlled in their dispersion by strong complexation with relatively insoluble organic chelates probably humates, and after precipitation into a reducing sediment, are firmly fixed by interaction with sulphide ions generated within the sediments, although organic binding probably remains of considerable importance. The absence of accumulations of iron and manganese in the same zones of the lake reflects the known weak binding of humic acids for these metal ions which escape to the quieter, deeper waters where hydrolysis eventually leads to their precipitation and subsequently, their immobilization by H_2S .

The fact that the relative degrees of dispersion are seemingly in the order $Zn \geq Pb > As$, probably reflects the increasing stability of binding of these elements by organic matter and sulphide ion. The lower the stability of the metal sulphide, the more likely it is to creep by adsorption-desorption processes towards the outflow of Perch Lake, or to disperse in eddy patterns around it, settling in stagnant zones. This seems to be the case in Perch Lake where water flow patterns are readily apparent in metal distribution maps for zinc and lead which display strong linear configurations considered here to be characteristic of combined chemical-mechanical dispersion processes.

The heavy metals mercury, copper, nickel and uranium (Fig. 15) cannot be fitted readily into either of the two other groups as they do not obviously relate to either water depth in the lake (i.e., sulphur content) or to organic carbon content of the sediments. However, this may be a function of poor precision data rather than a real effect. In fact, there may well be an inverse relationship with depth. The mercury content is quite low in the deepest parts of the lake with its highs closest to the inflow from Perch Marsh. Mercury may be slightly dependent on organic carbon. Some forms of mercury possibly are removed from waters as they enter Perch Lake when organic complexes precipitate other metals such as zinc, and the remainder disperse to the stagnant, sheltered parts of the lake. Copper resembles the organic carbon dependent group but like mercury its distribution is very even and no realistic patterns emerge. The pattern for nickel is much the same as for copper. The levels of both copper and nickel are very low. As a result the precision of the data is relatively poor and may not be adequate to properly reflect real distribution patterns. Uranium is very evenly dispersed with high levels in all sediments. Perhaps the one common feature of these elements, relevant to processes which might influence their dispersion behaviour, is that they can form very stable soluble organic chelate compounds and therefore are likely to disperse in solution in the lake water before settling out into sediments presumably as adsorbed or coprecipitated species in fine organic precipitates.

Thus it is suggested that at least three chemical groups of metals are present in Perch Lake sediments, classified according to their dispersion behaviour:

1. those which readily hydrolyze, precipitate and are fixed and accumulated by sulphur rich sediments and which do not form strong organic complexes: iron, manganese.
2. those which form mainly stable insoluble organic chelates and are subsequently fixed by sulphide ion in sediments: zinc, lead, arsenic, (mercury?).
3. those which tend to form mainly stable, soluble organic chelates and settle into sediments by coprecipitation-adsorption mechanisms and are finally fixed by sulphide or, for uranium, reduced to an immobile species: copper, nickel, uranium (mercury?).

The distribution of elements in Lavant Long Lake is considerably more obscure than in Perch Lake. While similar dispersion processes probably are operative for the same metals in each lake, these are not so clearly separated or zoned, if at all, to permit recognition of individual mechanisms in Lavant Long Lake. For example, in Perch Lake zinc and manganese (or iron) display a strong negative relationship but in Lavant Long Lake there is no apparent correlation.

It is considered that the unusual seasonal flow-through patterns observed for organic carbon, lead and zinc in Perch Lake have led to a separation of these metals from iron and manganese in such a manner that lead and zinc are effectively scavenged by organic matter in different zones from where iron and manganese eventually hydrolyze and precipitate. In Lavant Long Lake the absence of strong flow directions leaves all metals mixed together where hydrolyzing iron and manganese ions can effectively compete in the scavenging processes for lead and zinc. In the absence of considerable organic matter, as in lakes of the Canadian sub-arctic or tundra regions, strong positive correlations between zinc and manganese commonly are observed (Jackson and Nichol, 1974). In this system, however, the common operative effects are competing processes between organic carbon-zinc, and manganese-zinc but not organic carbon-manganese.

Comparison of Water and Organic Sediment Data

Armed with some possible controls on and mechanisms of heavy metal dispersion in lake sediments, it is now practicable to reassess all the data for the lakes' system as a whole.

As already noted, iron and sulphur definitely tend to accumulate in deeper parts of both lakes (Figs. 10 and 13). This pattern appears consistent. The relationship between organic carbon, lead, and zinc (Figs. 10 and 11) seems to hold firm in Lavant Long Lake and in Perch Lake, but mercury (Fig. 11), however, more closely resembles this group in Lavant Long Lake than in Perch Lake (Fig. 15). Molybdenum,

copper, and nickel (Fig. 12) retain dispersed patterns in Lavant Long Lake. The main difference in waters entering Lavant Long Lake when compared with those entering Perch Lake is that the former are not visibly organic enriched (discoloured) and therefore may not carry such a high proportion of their metals in the highly mobile form of soluble organic chelates as may occur in Perch Marsh.

Further clues towards the elucidation of dispersion mechanisms for metals in these lakes may be obtained from comparisons of water and organic sediment data.

Similar distribution maps are observed for zinc, mercury, and lead (Fig. 8) i.e., locations of highs and lows coincide broadly for each of these metals in water and sediments. On the other hand, patterns for nickel and uranium are different between sediment and water in each case, although the water patterns are alike for the two metals (Fig. 9).

The presence of coincident patterns for zinc, mercury, and lead strongly suggests that there remains some space restricted to dynamic interaction between water and sediment. Moreover, it is interesting to note that where waters are likely to be more organic enriched, viz; in Perch Lake and Perch Marsh, zinc is depleted relative to mercury and lead. It would appear likely that zinc has a greater tendency to disperse through the system as soluble organic complexes than mercury or lead. The relative degrees of dispersion noted for the detailed Perch Lake study (Fig. 14) support this contention.

The comparisons between respective water and sediment patterns for uranium and nickel are of great interest. Uranium is the only trace metal studied for which some definite source rocks were located (Tables 3 and 4). Although the organic sediments in Perch Lake are uniformly enriched in uranium, no anomalously radioactive rocks were located along the shoreline, so it seems likely that the values measured (Appendix 4) represent background values for sediments derived from that terrain. However, in sediments from the west arm of Lavant Long Lake some very high local values were recorded. Investigation of the shoreline revealed three occurrences of radioactive pegmatites and granite gneiss on the south shore with up to 30 ppm uranium present, commonly in magnetite granules (Table 4). One occurrence outcrops in the lake. Sediments derived from these sources contain uranium in mineral form rather than in adsorbed or complexed forms.

The water-borne highs of uranium, however, are displaced a considerable distance downstream. Perch Lake waters are depleted as are waters of the west arm of Lavant Long Lake. Most uranium is located in the stagnant waters of the shallow outflow (east) arm of Lavant Long Lake where the presence of carbonate-rich sediments may well enhance retention of the elevated solution levels.

Nickel behaves similarly with water-borne metal strongly displaced from nickel-rich sediments. The proposal, drawn from the Perch Lake detailed study, that uranium and nickel form very stable soluble organic chelates and are readily dispersed as such, seems to

hold true for the entire lakes' system. It is widely accepted that uranium (Dyck, 1974) and nickel (Bugelskii, 1965) are transported in natural waters in these forms. The situation with regard to copper is more ambiguous and the quality of data does not justify drawing any conclusions as to its mode of dispersion, although soluble organics are likely involved.

It would seem from the preceding discussion that uranium might not be expected to accumulate in deep water lake sediments in view of its high mobility in soluble or colloidal form. From experience, this is obviously not true. Mobilization and dispersion of aqueous uranium is clearly an efficient process but it is likely the nature of the drainage system is the controlling influence on its subsequent precipitation and accumulation in bottom sediments. Although uranium can occur in particulate mineral form close to its sources, these mechanical dispersion trains do not persist, the uranium being quickly leached into waters which carry it through a lake system. If the system is open-ended, uranium moves considerable distances and flow-through lakes accumulate relatively little in sediments. Ultimately uranium is precipitated into dead-end lakes or swamps where it can accumulate. Thus it might be anticipated that these transportation processes will result in some lakes showing a greater accumulation of uranium than others, given the same quantity at source.

One further point to note with regard to nickel in waters (Fig. 9) is that the very high values recorded in bottom water samples in the west arm of Lavant Long Lake (Appendix 3) were also matched by highs in surface waters in the same zone (Appendix 2). According to the dispersion mechanisms proposed herein for nickel, much of the metal may be derived from the Perch Lake area and the Middle Branch Creek marshes; the alternative is that groundwater is feeding the metal in locally, although divers collecting samples did not observe any springs in the vicinity. The fact that sediments from the west arm of Lavant Long Lake do not have a high nickel content lends support to the idea that the nickel has been transported rather than locally derived or remobilized from bottom sediments. A couple of high zinc values were also noted in these bottom waters (Appendix 3).

One check which could be made, would be to determine dissolved organic matter of not only these water samples, but all others in the lakes' system as well. The absence of such data severely limits interpretive discussion of geochemical mechanisms of dispersion.

In the data for waters from Perch Lake (Appendix 1), two samples PKL-206 and PKL-211 are designated swamp waters. These came from stagnant, shallow parts of the lake and from their physical appearance as yellowish waters, were considered organic enriched. Values for zinc, lead and copper, and perhaps mercury, in these samples are well above lake averages while nickel and uranium are low and about average. These two samples represent extreme organic enrichment and data from them should only be taken to illustrate the ability of certain types of dissolved organics to

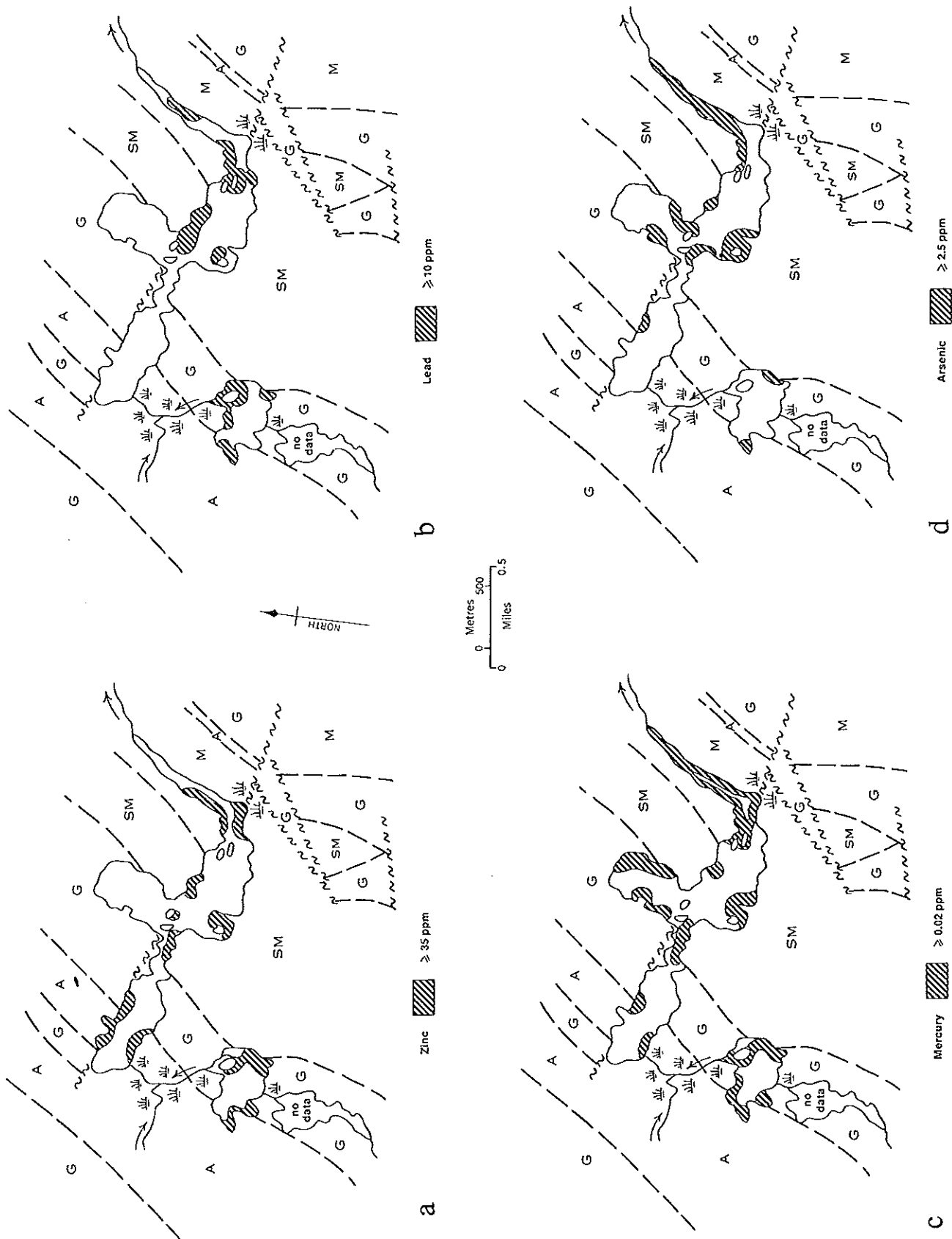


Figure 16. Zinc, lead, mercury, and arsenic in silty shoreline lake sediments.

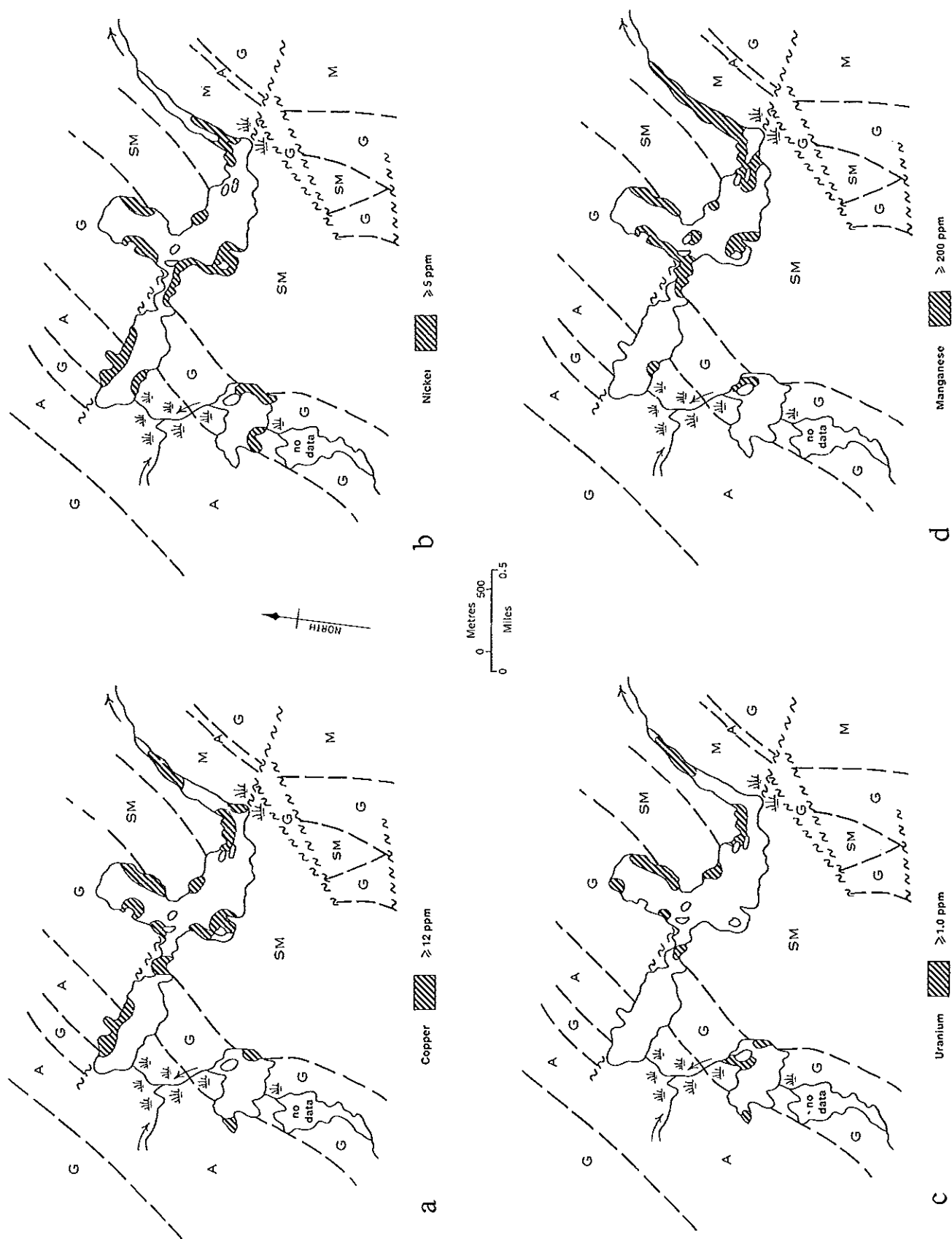


Figure 17. Copper, nickel, uranium, and manganese in silty, shoreline lake sediments.

Table 5
Shoreline inorganic (silty) sediments: Summary data (ppm)

Enclosing Rock	Granite gneiss			Granite gneiss			Grenville marble			Probability of Significance
Lake Basin	PLK Perch Lake			LLN & LLW Lavant Long Lake			LLE & LLS Lavant Long Lake			
Element	X _a	S _a	Cv%	X _a	S _a	Cv%	X _a	S _a	Cv%	p%
Zn	44	23	52	34	22	65	37	23	63	30
Cd	-	-	-	-	-	-	-	-	-	-
Hg	0.04	0.05	119	0.02	0.01	47	0.02	0.01	49	-
Cu	5.5	4.6	83	12	5.2	45	12	5.1	44	-
Ag	-	-	-	0.20	-	-	0.20	0.13	72	-
Ni	5.0	3.6	73	5.6	3.4	60	6.2	4.9	79	-
Co	-	-	-	4.6	3.0	66	4.4	2.1	49	-
Mn	103	62	60	264	213	81	248	142	57	25
Pb	16	12	71	6.1	2.8	46	12	14	116	93
As	0.8	-	-	2.3	0.7	32	3.0	1.2	38	98
Sb	2	-	-	-	-	-	-	-	-	-
U	1.0	1.2	113	1.1	1.6	139	0.6	0.5	84	88
Mo	-	-	-	1.2	1.3	104	1.1	0.8	72	-
W	-	-	-	1.7	-	-	1.3	-	-	-
Fe%	0.71	0.61	86	0.74	0.51	68	0.86	0.53	62	50
S%	0.16	0.16	98	0.27	0.25	93	0.24	0.22	92	30
Corg%	8.4	11.1	132	2.3	1.4	61	3.4	2.5	74	92
CO ₂ %	0.2	-	-	10	14	140	11	15	133	-
No. of samples	13			20			29			
Mean depth of sample sites (ft.)	1.0			3.6			2.8			

X_a = arithmetic mean; Sa = std. deviation; Cv% = coefficient of variation.

complex and mobilize certain metal ions into solution. They are not typical lake water samples but may be typical of the waters which are purged from swamps and stagnant marshes into Perch Lake when water flow is high. The metal load of the waters is then deposited in sediments when the organic matter precipitates, perhaps due to oxygenation of those waters on passing through the dam.

Zinc, lead, copper and perhaps mercury, therefore, can become enriched along flow channels but nickel and uranium are not expected to become so enriched. Nickel, like uranium, could also be useful in water sampling of lakes such as these.

Geochemistry of Inorganic Lake Sediments

The third important phase of the study of Perch and Lavant Long lakes was to compare the distribution of metals in inorganic shoreline sediments, with deep-water organic sediments. Some knowledge of local sources of heavy metals derived from soil or soil slump materials may also be accrued from this program.

However, the results in Table 5 and in Figures 16 and 17 derived from Appendices 6 and 7, show few differences in distribution patterns between the metals.

Zinc, lead, mercury, and arsenic are presented as distribution maps (Fig. 16) with contents exceeding 35 ppm, 10 ppm, 0.02 ppm and 2.5 ppm, respectively. Zinc and mercury may be chemically related, but firm conclusions could not be drawn. Copper, nickel, uranium and manganese are presented in Figure 17 where metal contents in excess of 12 ppm, 5 ppm, 1.0 ppm and 200 ppm are displayed, respectively. The low quantity of uranium in samples from the west arm of Lavant Long Lake is the only significant feature.

The physical nature of the sample, whether silty, sandy, marly or rarely, organic-stained sand, makes little difference to measured levels of all metals. The levels, however, do rise in areas where organic carbon reaches a few per cent. For reasons already noted "organic-rich" sediments were presumed to contain more than 10 per cent organic carbon, so conversely it follows that "inorganic" sediments will contain less than 10 per cent organic carbon. Fortunately, only 15 per cent of the shoreline samples contained more than 5 per cent organic carbon, so the "arbitrary" division of the types based on this particular parameter remains a reasonably useful one.

Comparisons between Perch Lake and north and west arms of Lavant Long Lake, all of which lie in

Table 6
Geochemical comparisons of silty shoreline and organic deep water sediment samples
(values in ppm unless otherwise indicated)

Perch Lake	Shoreline silts		Organic gels		Organic enrichment factor		
Element	X_s	Cv%	X_o	Cv%	$\frac{GEL}{SILT}$	$\frac{X_o}{X_s}$	= R
Zn	44	52	106	33		2.41	
Cd	-	-	0.9	60		-	
Hg	0.04	119	0.32	103		8.00	
Cu	5.5	83	24	40		4.36	
Ag	-	-	-	-		-	
Ni	5.0	73	12	23		2.40	
Co	-	-	7.8	26		-	
Mn	103	60	236	54		2.29	
Pb	16	71	33	79		2.06	
As	0.8	-	4.8	38		6.00	
Sb	2	-	-	-		-	
U	1.0	113	5.1	39		5.10	
Mo	-	-	3.4	23		-	
W	-	-	-	-		-	
Fe%	0.71	86	1.20	29		1.69	
S%	0.16	98	1.58	35		9.88	
Corg%	8.4	132	24.7	31		2.94	
CO ₂ %	0.2	-	0.1	-		0.50	

X_s = arithmetic mean for shoreline silts

X_o = arithmetic mean for organic gels

Cv% = coefficient of variation.

gneissic rocks, can be made from Table 5 which shows that mercury and lead are relatively enriched and that copper, manganese, and arsenic are lower in content in Perch Lake. These relationships tend to be reflected in organic-rich sediments as well, except for a reversal in the case of manganese.

When making comparisons between the two "basins" of Lavant Long Lake, the function ρ is again used to quantitate differences between means for each element. Because of the much higher coefficients of variation found for elemental means of shoreline samples, Students' "t" test is not applicable in so many instances as for the organic-rich types of sediments. This is a chemical reflection of the greater differences in physical homogeneity observed in silty sediments over organic gels and mulls. Thus only arsenic and perhaps lead show significant differences between means. The level of these elements in sediments from the "marble basin" (east arm and main body of Lavant Long Lake) exceed those from the "gneissic basin" (west and north arms of Lavant Long Lake). The presence of some carbonate-rich sediments in samples from the north and east arms of Lavant Long Lake does not appear to greatly influence shoreline metal values.

From the viewpoint of assigning definite source areas for metals in the banks of the lakes, the analytical data are so varied from point to point that it would be an exercise of dubious value to attempt to do so.

When all sediment data are considered, however, it is apparent that mercury is definitely enriched in Perch Lake, uranium values are higher in Perch Lake, and that copper values are lower in Perch Lake relative to the remainder of the study area.

Influences of Local Geology on Hydrogeochemistry

Throughout previous sections of this paper, analytical results for water and sediment samples have been described in terms of distribution maps for each element considered and then related to proposed geochemical processes of dispersion dealing with organic matter both particulate and dissolved, with dissolved and complexes metal ions, and latterly with the gross physical-chemical nature of the sediments.

The chemical differences affecting heavy metals distributed in inorganic silty sediments and organic gel-like sediments now will be considered but, first, the gross effects of organic matter must be elucidated before discussing the geological influences on metal levels (Tables 6, 7, 8).

Table 6 summarizes Perch Lake sediment data. Arithmetic means and standard deviations are represented for all elements considered and an organic

Table 7

Geochemical comparisons of silty shoreline and organic deep water sediment samples
(values in ppm unless otherwise indicated)

Lavant Long Lake LLW & LLN	Shoreline silts		Organic gels		Organic enrichment factor		
Element	X _S	Cv%	X _O	Cv%	$\frac{\text{GEL}}{\text{SILT}}$	$\frac{X_O}{X_S}$	= R
Zn	34	65	100	38		2.94	
Cd	-	-	0.7	79		-	
Hg	0.02	47	0.08	34		4.00	
Cu	12	45	30	33		2.50	
Ag	0.20	-	-	-		-	
Ni	5.6	60	12	39		2.14	
Co	4.6	66	5.0	52		1.09	
Mn	264	81	217	48		0.82	
Pb	6.1	46	32	81		5.25	
As	2.3	32	4.8	31		2.09	
Sb	-	-	-	-		-	
U	1.1	139	4.8	39		4.35	
Mo	1.2	104	5.2	56		4.33	
W	17	-	1.6	-		0.94	
Fe%	0.74	68	1.06	33		1.43	
S%	0.27	93	1.58	34		5.85	
Corg%	2.3	61	27.5	28		11.96	
CO ₂ %	10	140	0.1	-		0.01	

(X_S, X_O, Cv% have the same meanings as in Table 6)

enrichment factor, R, is given which indicates the degree of enrichment of heavy metal in organic sediments.

Tables 7 and 8 present similar data for the "gneissic basin" and "marble basin" of Lavant Long Lake, respectively. All metals tend to be enriched in organic sediments to a greater or lesser extent — a factor which is most probably a function of the nature of metal-organic binding strength and perhaps increased ion-exchange capacity of organic sediments over inorganic types. Those elements greatly enriched are the heavy metals: mercury, zinc, copper, lead, arsenic, uranium, and molybdenum. Those slightly enriched are the iron group: nickel, cobalt, manganese, tungsten, and iron(?). The R values further show that sulphur and organic carbon are greatly enriched, the latter by definition; while on average CO₂ is greatly depleted in organic-rich sediments.

Thus organic matter has a very strong influence on measurable heavy metal levels in the sediments from a lake system of the type studied. In the case of this particular study, organic carbon content has been shown to range from 0 to 40 per cent carbon, with dramatic effects on certain heavy metals levels.

It also is obvious that certain metals are contributed primarily from sources within gneissic-amphibolite rock units, whereas others originate from within marble and crystalline dolomite units (Fig. 4).

On the basis of data from Tables 2 and 5, wherein metal levels in samples from the north and west arms

of Lavant Long Lake are compared with those from the east arm and main body using the significance factor ρ , it is possible to decide which of these metals are probably derived from which broad rock unit. These may be grouped as follows: from gneiss-amphibolite sources: uranium, molybdenum, and iron; from marble sources: zinc, cadmium, mercury, manganese, arsenic, and lead; and from both sources: copper, nickel, cobalt, and tungsten(?). Thus there is a tendency for detailed sampling of sediments, organic-rich sediments in particular, to reflect gross geological changes. When the known sulphide mineralogy of certain parts of the marble units in which Lavant Long Lake lies is reconsidered, it can be shown that zinc, lead, mercury and arsenic probably would be reflected in lake sediments derived from those rock units. Likewise, the presence of uranium in the granite gneisses and amphibolite units is consistent with the higher level of uranium found in sediments derived from rocks around the north and west arms of Lavant Long Lake. Moreover it can be postulated that some sources of uranium ought to be found near Perch Lake on the basis of the hydrogeochemical data presented. In general the sediments of Perch Lake are similar to those of the west and north arms of Lavant Long Lake for all metals except mercury (and perhaps copper and lead) for which no obvious explanation is available.

Some relevant analytical data for rock chips around both lakes are given in Tables 3 and 4. Sample numbers

Table 8
Geochemical comparisons of silty shoreline and organic deep water sediment samples
(values in ppm unless otherwise indicated)

Lavant Long Lake LLE & LLS	Shoreline silts		Organic gels		Organic enrichment factor		
Element	X _S	Cv%	X _O	Cv%	$\frac{GEL}{SILT}$	$\frac{X_O}{X_S}$	= R
Zn	37	63	126	27		3.41	
Cd	-	-	1.4	45		-	
Hg	0.02	49	0.11	24		5.50	
Cu	12	44	25	27		2.08	
Ag	0.20	72	0.30	41		1.50	
Ni	6.2	79	10	46		1.61	
Co	4.4	49	5.0	43		1.14	
Mn	248	57	337	61		1.36	
Pb	12	116	41	65		3.42	
As	3.0	38	4.9	26		1.63	
Sb	-	-	-	-		-	
U	0.6	84	1.9	66		3.17	
Mo	1.1	72	3.6	33		3.37	
W	1.3	-	1.7	27		1.31	
Fe%	0.86	62	0.92	42		1.07	
S%	0.24	92	1.39	29		5.79	
Corg%	3.4	74	27.0	22		7.94	
CO ₂ %	11	132	0.80	157		0.07	

(X_S, X_O, Cv% have the same meanings as in Table 6)

refer to the outcrop nearest the sediment sample site location with the corresponding sample number.

Implications for Regional Geochemical Reconnaissance Surveys

One final point of discussion of these data concerns the question, often posed but rarely answered satisfactorily; "if one sample of water or sediment were to be taken from a lake as part of a regional survey, what are the chances of getting a sample which will provide trace element data characteristic of that lake?"

Answers to the question inevitably involve a discussion of the relative merits of sampling deep water organic sediments (usually centre-lake sediments) or silty shoreline sediments. Water samples usually are considered to be safe from any "edge" effects provided they are taken from the deeper water zones of the lake.

The information in the Tables and Appendices herein provides some insight into this problem, and for these lakes, located in forested areas of the Grenville Province, a reasonably meaningful answer is possible.

From the information in Tables 2 and 5 the following observations can be made:

1) means for all metals in organic sediments are higher than those in inorganic sediments for all samples. (See also Tables 6, 7 and 8).

2) coefficients of variance (Cv) of those means are much lower for organic sediments than inorganic sediments for most metals; exceptions are manganese, lead and arsenic for which the coefficient of variance is much the same in each case.

3) organic material in deep water sediments probably has its origin in coagulating colloids as precipitates of aging dissolved organic acids, spores, pollen, and very finely dispersed vegetation debris, producing a homogeneous, mature, gel-like substance considerably different from the parent plant material which generated it, and acting as a trap for certain migrating metal ions.

4) one of the major influential variables, organic carbon content, is virtually independent of local geological influences, thus providing a chemically homogeneous sample medium in organic sediments.

5) the presence of organic carbon in relatively highly variable quantities in shoreline sediments strongly influences metal values found. Organic materials in these samples often consist of organic coatings on sand, or unmaturation vegetation debris, rather than mature organic gels and mulls.

6) although detection limits for analyses are not quoted for the metals studied, it is fair to say that the enrichment of metals by organic matter places analytical data farther from these limits than in the case for silty sediments. The net result is that the analytical variance, which is included along with sampling

variance in the values for the coefficient of variance quoted, is less for organic samples.

7) shallow water sediment samples are subject to redox (E_h) shifts over a seasonal cycle. Because sulphide ion, which can be lost from the sediment by oxidation, is an important fixer of heavy metals, it is advisable to avoid collecting samples from shallower zones of the lake bottom which represent a chemically less-stable environment.

Thus, the coefficients of variance in the tables are in reality a measure of the "chances of getting a characteristic sample". In particular, for Perch Lake, a sample of sediment collected in deep water near to its geometric centre will provide a characteristic sample; moreover it can be readily "duplicated" if extra samples are taken nearby, at that time or later. Organic samples collected in shallow waters are less dependable particularly if collected near inflows, outflows, or very stagnant areas. Silty sediments were difficult to find in Perch Lake, a feature which is probably typical of many lakes in heavily forested regions of the Canadian Shield. Such samples were often organic stained sands and silts which were difficult to "duplicate" in replicate sampling. Deep water organic sediments are clearly superior samples for regional surveys. Lavant Long Lake, which has been treated as two separate lake basins has been shown to yield data, for organic sediments, which do reflect, in instances with some subtlety, differences in local geology and therefore in the gross primary origins of the metals in question. Such differences are generally not apparent in the more variable data derived from assorted shoreline sediments. Thus for best results two samples should be taken from a lake with similar peculiar arm-like features — one in the many main bodies of the lake, and the other in either of the west or north arms, once again taking care to go to deep water zones where possible. One sample would be less reliable in a broad regional survey.

The homogeneity of deep water organic sediments is the best feature of this type of sample in terms of matrix constituents and trace metal levels. It would appear that once a certain level of organic content is exceeded (i. e., 10 per cent carbon) further increases have relatively little impact on trace metal variations.

It is worth noting that spotty occurrences of elements (e. g. uranium) probably would be missed with a single deep water sediment sample from the main body of Lavant Long Lake because of its inability to migrate in sediments far from the source rocks. The same argument may well apply to other very mobile metals (e. g. nickel), although this could not be tested in these lakes because of the virtual absence of intense sources of such metals along the shoreline drainage.

Under these circumstances, the possibility of missing a potential metal source may be avoided by also collecting a single water sample, and the best place to do this seems to be in the body of the lake close to the outflow especially if the water is stagnant. Inspection of relevant Figures for both lakes will lend

support to this contention. A knowledge of the hydro-geochemical dispersion mechanisms for the specific metals sought is clearly very helpful in determining from where a sample ought to be taken. Thus chances of detecting the presence of mobile metals are maximal near outflows. Follow-up sampling should then go to inflows. In the specific example quoted, the presence of uranium would be detected although it is far from its source rocks and derived sediments.

Conclusions and Suggestions for Further Work

The conclusions drawn here on the relative virtues of sampling lake centre sediments rather than those from shorelines do not necessarily apply in regions of different degrees of forestation, climate or hydrogeochemical landscape.

However it is considered that the general chemical rationale for taking a deep water sample will hold true in most circumstances. The fine sediments in deep water are more likely to be independent of local shoreline influences both organic and mineral, but at the same time will continue to reflect gross chemical, geological and mineralogical features where these occur. If the objective is to get a typical sample of sediment this is clearly the best place to go. However if ground waters are thought to play a significant role in the local hydrogeochemical dispersion processes (as for example in the permafrost arctic barren lands), carefully chosen nearshore (inflow-outflow) sediments will possibly better reflect these influences. One sample, however, may not be adequate to do so.

This study was primarily concerned with influences of organic matter which exert a dominant control over the local hydrogeochemistry; its controls on dispersion, precipitation and metal level have been clearly demonstrated. Metal ions are almost certainly never free aquo- or hydroxyaquio-ions but rather are bound to some organic moiety as a complex ion or absorbed species of varying stability depending on the nature of species involved and on a number of physical and chemical factors.

In the absence of such gross organic matter control, as in arctic barrens, dispersion processes for metal ions are very different, much less restricted in extent, and probably more predictable in terms of simple ionic chemical behaviour under the influences of such factors as acidity and hydrolysis.

This study clearly has some shortcomings. For example it would have been most useful to have had some data on organic carbon content which could be related to amount of complexing species present of the lake waters to better enable some qualitative chemical interpretation to be made of the peculiar hydrodynamic dispersion patterns observed, and of the abnormally high values found in certain zones of Lavant Long Lake for zinc and nickel.

Measurement of dissolved and suspended load metals in spring flood waters would be most useful in delineating flow and sedimentation patterns as deduced from sediment metal data in Perch Lake.

Moreover, detailed soil analyses from the edges of the lakes would have been useful in determining very local contributions of metal contents of nearshore sediments; and in determining degrees of depletion or enhancement of soil-slump metal loads.

An obvious gap in knowledge exists in the absence of geochemical data for the half mile of the swampy stream, Middle Branch Creek, which runs between the two lakes. Nothing is presently known of the contributions of metals from this region to Lavant Long Lake, or of the fate of metals leaving Perch Lake.

Finally, although the qualitative approach taken herein towards postulating mechanisms for hydrogeochemical dispersion of heavy metal ions has proved adequate from the viewpoint of partially explaining observed behaviour in the lakes' system, it would indeed have been most useful to have had quantitative chemical data on relative strengths of metal-organic moiety stability constants and on adsorption characteristics of the sediments, to confirm them.

At present, stability constant data which are available for fulvic acid complexes of copper and zinc for example are not particularly useful. Data are usually only available for water pH of less than 6. Measurement of stability constants at pH more commonly observed in lakes and streams, pH 7-9, would be grossly complicated by competing hydrolytic reactions, a situation usually avoided by inorganic chemists where possible. Thus the problem remains and only extrapolations, of dubious validity, of stability data derived at acid pH's, can be made. The best that can be hoped for is that relative trends between different metals remain the same when pH values range from 4 to 9.

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APPENDIX 1

Surface waters: Perch Lake and Marsh

Number	Type	Zn	Cu	Pb	Ni	Cd	U	Hg
PLK201	LKWT	3	1	5	1	5	0.0	0.02
202	LKWT	2	1	5	1	0	0.0	0.03
203	LKWT	1	0	1	0	1	0.0	0.06
204	LKWT	5	3	5	1	0	0.0	0.06
205	LKWT	1	0	5	0	0	0.0	0.02
206	SWWT	16	32	69	1	1	0.0	0.05
207	LKWT	1	0	3	1	0	0.0	0.06
208	LKWT	2	1	3	2	1	0.1	0.05
209	LKWT	3	0	5	3	1	0.0	0.06
210	LKWT	2	1	10	2	5	0.0	0.05
211	SWWT	14	0	52	1	1	0.0	0.11
212	LKWT	2	0	3	0	1	0.1	0.07
213	LKWT	2	0	5	0	1	0.0	0.04
214	LKWT	2	0	4	0	1	0.0	0.07
215	LKWT	2	0	3	2	0	0.0	0.05
216	LKWT	2	1	3	2	1	0.0	0.09
PLM201	LKWT	4	1	3	3	1	0.0	0.07
202	LKWT	1	1	0	2	1	0.0	0.08
203	LKWT	2	1	3	2	1	0.0	0.11
204	LKWT	2	0	3	2	1	0.0	0.09
205	LKWT	1	0	0	2	1	0.0	0.07
206	LKWT	1	0	3	1	1	0.0	0.08

NOTES: 1. all values in ug/l (ppb).

2. LKWT: unfiltered lake water; SWWT: unfiltered swamp water.

APPENDIX 2

Surface waters: Lavant Long Lake, east and north arms

Number	Type	Zn	Cu	Pb	Ni	Co	U	Hg
LLE01S	LKWT	4	1	3	4	2	0.2	0.03
02S	LKWT	2	1	3	2	3	0.1	0.03
03S	LKWT	4	1	6	8	1	0.2	0.03
04S	LKWT	6	1	0	4	1	0.0	0.03
05S	LKWT	17	2	1	4	1	0.0	0.01
06S	LKWT	3	1	6	1	0	0.0	0.01
07S	LKWT	9	2	3	7	1	0.2	0.01
08S	LKWT	5	0	3	2	1	0.2	0.03
09S	LKWT	27	1	0	5	1	0.2	0.02
10S	LKWT	2	1	0	1	1	0.4	0.03
11S	LKWT	3	1	6	2	1	0.2	0.02
12S	LKWT	23	3	6	12	1	0.1	0.02
13S	LKWT	2	0	0	3	1	0.0	0.02
14S	LKWT	32	2	0	6	1	0.2	0.02
15S	LKWT	3	1	6	2	1	0.1	0.02
16S	LKWT	7	0	0	2	1	0.1	0.01
17S	LKWT	3	0	0	2	0	0.2	0.01
18S	LKWT	23	1	3	14	1	0.2	0.01
19S	LKWT	25	1	3	7	0	0.1	0.01
20S	LKWT	8	2	3	7	1	0.3	0.01
LLN01S	LKWT	1	0	0	3	1	0.0	0.01
02S	LKWT	1	0	4	3	0	0.0	0.01
03S	LKWT	2	1	4	1	1	0.0	0.01
04S	LKWT	1	1	0	1	2	0.0	0.01
05S	LKWT	2	1	4	2	1	0.1	0.01
06S	LKWT	2	0	0	1	0	0.0	0.01
07S	LKWT	3	0	0	1	1	0.0	0.01
08S	LKWT	2	1	0	3	1	0.0	0.01
09S	LKWT	3	1	0	1	1	0.0	0.03
10S	LKWT	2	1	4	2	1	0.0	0.02
11S	LKWT	1	0	4	2	1	0.0	0.01
12S	LKWT	1	0	0	1	2	0.0	0.02
LLS01S	LKWT	6	0	4	3	1	0.0	0.02
02S	LKWT	7	0	1	4	1	0.0	0.01
03S	LKWT	4	0	1	4	1	0.0	0.01
04S	LKWT	7	1	1	7	0	0.0	0.01
05S	LKWT	10	1	4	5	1	0.0	0.02
06S	LKWT	5	0	0	2	0	0.0	0.01
07S	LKWT	4	1	1	3	2	0.0	0.01
08S	LKWT	6	0	1	4	1	0.0	0.01
09S	LKWT	10	1	0	5	2	0.0	0.01
10S	LKWT	5	1	6	4	0	0.0	0.01
11S	LKWT	24	0	1	5	3	0.0	0.01
12S	LKWT	9	1	1	5	3	0.0	0.01
13S	LKWT	8	1	0	5	2	0.0	0.01
14S	LKWT	6	1	1	5	3	0.0	0.01
15S	LKWT	7	1	4	6	1	0.0	0.02
LLW01S	LKWT	9	1	0	17	0	0.0	0.01
02S	LKWT	7	0	4	5	0	0.0	0.01
03S	LKWT	10	3	0	11	1	0.0	0.01
04S	LKWT	6	0	0	10	0	0.0	0.01
05S	LKWT	11	1	0	20	1	0.1	0.02
06S	LKWT	4	0	0	4	0	0.1	0.01
07S	LKWT	4	0	0	7	0	0.0	0.01
08S	LKWT	6	0	2	10	1	0.1	0.01
09S	LKWT	10	0	0	3	0	0.2	0.01
10S	LKWT	6	1	0	2	0	0.0	0.01
11S	LKWT	6	0	0	4	0	0.0	0.01

NOTES: 1. all values in ug/l (ppb).
2. LKWT: unfiltered lake waters.

APPENDIX 3

Bottom Water: Lavant Long Lake, all arms

Number	Type	Zn	Cu	Pb	Ni	Co	U	Hg	depth (ft.)
LLE12B	LKWT	4	0	0	2	0	0.0	0.02	10
13B	LKWT	3	0	6	4	0	0.0	0.01	10
14B	LKWT	6	1	6	2	1	0.2	0.02	15
15B	LKWT	6	0	0	2	3	0.0	0.01	5
16B	LKWT	37	1	1	12	0	0.1	0.01	10
17B	LKWT	8	0	0	2	0	0.0	0.01	20
18B	LKWT	4	0	3	2	0	0.0	0.01	20
19B	LKWT	4	0	0	3	0	0.2	0.01	20
20B	LKWT	12	1	0	4	0	0.0	0.02	10
LLN02B	LKWT	7	0	0	1	1	0.0	0.01	20
03B	LKWT	2	0	0	3	0	0.0	0.01	25
04B	LKWT	2	0	0	1	0	0.0	0.02	20
05B	LKWT	4	1	0	2	0	0.0	0.01	25
06B	LKWT	1	1	0	1	0	0.0	0.01	5
07B	LKWT	2	1	0	1	0	0.0	0.01	20
08B	LKWT	3	0	0	0	0	0.0	0.01	8
09B	LKWT	15	2	9	1	1	0.0	0.03	20
10B	LKWT	4	0	0	0	1	0.0	0.02	20
11B	LKWT	2	0	0	1	1	0.0	0.01	10
12B	LKWT	4	0	0	1	0	0.0	0.01	5
LLS10B	LKWT	19	0	0	6	1	0.0	0.01	30
11B	LKWT	4	1	1	2	3	0.0	0.01	5
12B	LKWT	5	0	1	5	0	0.0	0.01	20
13B	LKWT	7	1	6	9	1	0.0	0.01	50
14B	LKWT	10	1	1	6	0	0.0	0.01	25
LLW02B	LKWT	73	4	4	90	1	0.0	0.01	25
03B	LKWT	7	0	0	20	0	0.0	0.01	10
04B	LKWT	6	0	2	7	1	0.0	0.01	10
05B	LKWT	28	3	4	49	2	0.0	0.03	5
06B	LKWT	9	0	0	7	1	0.0	0.01	15
07B	LKWT	8	0	0	5	0	0.0	0.01	15
08B	LKWT	7	0	0	15	0	0.0	0.01	10
09B	LKWT	6	0	2	5	0	0.1	0.03	5
10B	LKWT	4	1	0	7	0	0.0	0.01	5
11B	LKWT	10	0	2	5	0	0.0	0.01	5

- NOTES: 1. all values in ug/l (ppb).
 2. LKWT: unfiltered lake water.

APPENDIX 4

Deepwater sediments: Perch Lake and Marsh

Number	Type	Mn	Pb	As	Sb	U	Fe%	S%	Corg%	CO ₂ %	Mo
PLK001	CLAY	400	12	0.6	2	1.7	1.02	0.07	2.0	0.4	2.9
002	CHFF	208	45	6.6	10	5.8	1.60	1.67	18.9	0.6	4.0
003	CLAY	280	24	1.7	2	1.1	0.87	0.31	6.9	0.1	2.5
004	GELL	484	88	3.8	2	2.4	0.60	0.95	26.7	0.1	1.9
005	GELL	107	18	6.3	2	5.5	1.16	1.68	25.7	0.1	6.1
006	CHFF	156	38	3.9	2	3.3	0.90	1.33	9.4	0.1	3.0
007	GELL	133	10	4.8	2	4.5	1.67	2.03	23.4	0.1	3.6
008	GELL	107	42	4.1	2	6.3	0.74	1.15	28.8	0.1	3.2
009	GELL	144	38	5.4	2	8.8	1.30	1.49	24.8	0.1	3.8
010	GELL	304	18	3.9	2	6.5	1.82	1.97	28.1	0.1	3.6
011	CHFF	104	84	2.8	2	1.7	0.70	1.10	29.0	0.1	1.9
012	GELL	116	4	3.6	2	6.5	1.30	2.08	26.3	0.6	3.6
013	GELL	484	13	3.9	2	5.5	1.40	1.86	27.8	0.1	3.0
014	GELL	156	76	7.5	2	7.8	1.40	1.88	28.1	0.1	3.8
015	GELL	249	13	3.1	2	7.3	1.40	2.06	26.6	0.1	3.4
016	GELL	136	76	6.1	2	5.3	1.10	1.60	31.1	0.1	3.3
017	GELL	259	13	6.6	2	5.0	1.20	1.76	25.9	0.1	4.0
018	GELL	144	9	4.9	2	4.5	0.70	1.32	27.7	0.1	3.6
019	GELL	383	18	5.4	2	5.5	1.40	1.79	28.1	0.1	3.0
020	GELL	400	18	3.9	2	4.0	1.43	1.68	29.1	0.1	4.1
021	GELL	116	53	7.6	2	5.5	0.90	1.56	31.1	0.1	3.8
022	GELL	140	54	8.2	2	5.5	0.80	1.44	30.0	0.1	3.6
023	GELL	160	18	5.2	2	8.3	1.40	2.54	30.9	0.1	3.6
024	GELL	315	22	4.9	2	4.5	1.50	2.08	24.8	0.1	2.8
025	GELL	421	9	6.3	2	5.5	1.70	2.18	27.0	0.1	3.3
PLM001	CHFF	175	65	3.5	1	1.1	0.43	0.34	22.0	0.2	2.9
002	CHFF	71	63	2.1	1	1.5	0.54	0.41	29.0	0.2	3.0
003	GELL	27	11	0.3	1	3.2	0.18	0.66	43.0	0.1	1.0
004	CHFF	109	43	0.3	1	1.5	0.31	0.32	27.0	0.1	2.4
005	CLAY	184	16	0.3	2	1.1	2.75	0.14	7.0	0.1	3.3
006	CLAY	100	3	0.3	1	1.0	0.88	0.10	2.0	0.1	0.5

Number	Type	depth	Zn	Cd	Hg	Cu	Ag	Ni	Co
PLK001	CLAY	10	28	0.2	0.02	15	0.3	11	10
002	CHFF	20	123	0.7	5.84	60	0.3	13	9
003	CLAY	5	52	0.3	0.33	8	0.3	4	5
004	GELL	5	137	1.3	0.45	17	0.3	9	5
005	GELL	8	99	0.8	1.72	41	0.3	17	5
006	CHFF	8	119	0.7	0.35	24	0.3	11	9
007	GELL	10	75	0.3	0.17	23	0.3	13	7
008	GELL	15	136	0.7	0.31	25	0.3	13	5
009	GELL	20	116	0.9	0.28	23	0.3	11	9
010	GELL	20	122	0.2	0.18	14	0.3	6	6
011	CHFF	5	167	2.3	0.32	18	0.3	12	6
012	GELL	10	82	0.9	0.40	25	0.3	12	7
013	GELL	35	77	0.3	0.28	25	0.3	12	7
014	GELL	10	150	1.1	0.78	29	0.3	16	11
015	GELL	20	96	0.7	0.19	24	0.3	12	9
016	GELL	20	167	1.9	0.26	23	0.3	12	7
017	GELL	35	88	0.7	0.19	22	0.3	11	7
018	GELL	10	88	0.7	0.16	22	0.3	10	7
019	GELL	25	82	0.7	0.17	21	0.3	10	8
020	GELL	30	86	1.1	0.15	23	0.3	12	6
021	GELL	25	144	1.3	0.22	27	0.3	12	12
022	GELL	20	145	1.5	0.22	25	0.3	14	8
023	GELL	25	101	0.7	0.18	24	0.3	14	11
024	GELL	20	85	0.7	0.16	25	0.3	13	10
025	GELL	25	82	0.6	0.15	24	0.3	13	9
PLM001	CHFF	5	128	-	0.11	15	0.1	5	-
002	CHFF	5	116	-	0.13	13	0.1	8	-
003	GELL	5	18	-	0.07	13	0.1	3	-
004	CHFF	5	39	-	0.09	19	0.1	4	-
005	CLAY	5	107	-	0.01	5	0.1	2	-
006	CLAY	5	40	-	0.02	6	0.1	9	-

NOTES: 1. all values in ppm unless otherwise indicated.

2. CLAY: clay;

CHFF: organic mull or chaff;

GELL: organic gel.

APPENDIX 5

Deepwater sediments: Lavant Long Lake, north and west arms

Number	Type	depth	Zn	Cd	Hg	Cu	As	Ni	Co	Mn
LLN020	GELL	20	68	0.6	0.09	26	0.1	10	2	185
030	GELL	25	79	1.3	0.09	26	0.2	8	4	266
040	GELL	20	60	-	0.06	26	0.2	8	-	129
050	GELL	25	86	0.8	0.10	27	0.2	10	2	298
090	GELL	20	91	0.2	0.08	42	0.2	13	8	292
102	GELL	25	62	0.2	0.08	27	0.3	8	7	221
110	GELL	10	119	0.2	0.10	38	0.3	20	10	279
LLW010	GELL	25	47	0.6	0.03	13	0.0	8	2	64
020	OSLT	25	86	1.6	0.05	13	0.0	7	2	214
023	GELL	25	177	0.2	0.14	31	0.2	11	2	539
030	CHFF	10	152	-	0.10	28	0.2	10	-	194
050	OSND	5	155	1.6	0.11	34	0.2	11	7	178
060	GELL	15	149	1.3	0.12	30	0.3	12	8	173
070	GELL	15	77	0.6	0.07	25	0.3	10	7	121
080	GELL	12	126	0.2	0.10	28	0.3	13	6	126
090	OSND	5	84	0.2	0.05	54	0.3	25	6	164
100	OSND	5	83	0.2	0.06	38	0.3	15	3	177
110	OSND	5	96	1.2	0.06	41	0.1	17	6	289

Number	Type	Pb	As	Sb	U	Fe%	S%	Corg%	CO ₂ %	Mo	W
LLN020	GELL	21	7.0	0.2	6.6	0.94	1.56	25.0	0.2	7.0	1
030	GELL	41	4.6	0.2	4.0	0.98	1.40	24.0	0.2	4.0	1
040	GELL	8	-	-	6.4	0.64	1.32	32.	0.1	-	-
050	GELL	34	6.5	0.2	3.2	1.06	1.60	28.	0.2	5.0	1
090	GELL	40	5.9	0.2	4.0	1.48	1.64	19.	0.1	3.0	1
102	GELL	5	3.4	0.2	4.4	0.92	1.32	21.	0.2	3.0	1
110	GELL	40	4.2	0.2	4.4	1.64	1.88	27.	0.2	3.0	4
LLW010	GELL	30	5.8	0.2	1.1	0.77	0.28	11.	0.1	1.0	2
020	OSLT	17	6.4	0.2	3.2	0.71	0.64	14.	0.1	8.0	1
022	GELL	111	1.9	0.2	5.7	1.33	1.84	28.	0.1	1.0	1
030	CHFF	35	-	-	5.6	0.69	1.38	34.	0.2	-	-
050	OSND	45	6.6	0.2	6.0	1.08	1.68	29.	0.1	4.0	2
060	GELL	61	5.5	0.2	3.6	1.21	1.68	28.	0.1	8.0	2
070	GELL	8	3.9	0.2	3.6	0.94	1.60	32.	0.1	5.0	2
080	GELL	25	5.1	0.2	3.6	0.73	1.52	37.	0.1	8.0	2
090	OSND	5	3.7	0.2	9.2	0.70	2.10	35.	0.7	6.0	1
100	OSND	5	3.2	0.2	50.0	1.54	2.56	39.	0.1	12.0	2
110	OSND	41	3.5	0.2	6.6	1.76	2.48	32.	0.1	5.0	2

- NOTES: 1. all values in ppm unless otherwise indicated.
 2. GELL: organic gel;
 OSLT: organic stained silt;
 CHFF: organic chaff or mull;
 OSND: organic stained sand.

APPENDIX 5 (cont'd.)

Deepwater sediments: Lavant Long Lake, south and east arms

Number	Type	Depth	Zn	Cd	Hg	Cu	Ag	Ni	Co	Mn
LLS100	GELL	32	140	2.5	0.13	34	0.3	11	7	432
110	OSND	5	80	0.2	0.06	29	0.5	20	7	233
120	GELL	22	174	1.3	0.12	38	0.0	18	8	329
130	GELL	50	153	1.4	0.11	28	0.3	13	6	881
150	OSND	10	67	-	0.06	14	0.2	14	-	264
LLE012	GELL	5	158	1.7	0.14	25	0.5	6	2	316
022	GELL	5	155	1.8	0.14	23	0.4	9	2	228
040	GELL	6	171	-	0.15	26	0.5	9	-	188
072	GELL	4	138	-	0.11	18	0.4	3	-	834
100	GELL	4	103	1.1	0.10	19	0.2	6	2	282
110	OSND	3	84	0.4	0.09	20	0.2	8	6	303
120	GELL	10	158	-	0.14	26	0.4	10	-	217
130	GELL	6	123	1.8	0.11	24	0.3	8	6	258
150	OMRL	4	92	1.3	0.07	19	0.2	3	4	286
180	GELL	20	133	1.5	0.13	28	0.4	10	6	193
190	GELL	18	116	1.8	0.13	28	0.4	10	4	188
200	CHFF	10	98	-	0.09	20	0.4	10	-	303

Number	Type	Pb	As	Sb	U	Fe%	S%	Corg%	CO ₂ %	Mo	W
LLS100	GELL	89	4.8	0.2	1.8	1.14	1.56	26.	0.1	3.0	16
110	OSND	5	4.0	0.2	2.8	1.58	1.72	20.	0.1	4.0	1
120	GELL	67	6.0	0.2	2.4	1.57	1.92	29.	0.1	4.0	1
130	GELL	78	6.2	0.2	2.0	1.47	1.52	26.	0.5	5.0	2
150	OSND	8	-	-	0.1	0.58	0.24	30.	0.3	-	-
LLE012	GELL	63	3.8	0.2	0.8	0.63	1.17	26.	0.3	3.0	1
022	GELL	59	6.0	0.2	1.0	0.68	1.23	30.	0.2	6.0	2
040	GELL	47	-	-	1.5	0.65	1.40	36.	0.2	-	-
072	GELL	61	-	-	0.6	0.51	1.01	28.	0.6	-	-
100	GELL	21	3.4	0.2	1.5	0.61	1.44	32.	3.9	2.0	2
110	OSND	5	3.6	0.2	1.7	0.46	1.68	12.	3.4	4.0	2
120	GELL	45	-	-	2.2	0.69	1.38	35.	0.3	-	-
130	GELL	8	4.5	0.2	1.7	0.82	1.34	27.	1.7	2.0	2
150	OMRL	41	3.5	0.2	0.9	0.68	1.18	22.	10.0	4.0	2
180	GELL	41	6.9	0.2	2.8	1.24	1.84	25.	0.1	3.0	2
190	GELL	30	6.2	0.2	5.6	1.06	1.80	33.	0.2	3.0	2
200	CHFF	25	-	-	2.4	1.30	1.20	22.	0.2	-	-

NOTES: 1. all values in ppm unless otherwise indicated.

2. GELL: organic gel;
 OSND: organic stained sand;
 OMRL: organic marl or limey gel;
 CHFF: organic chaff or mull.

APPENDIX 6
Shoreline sediments: Perch Lake

Number	Type	depth(ft.)	Zn	Hg	Cu	Ag	Ni	Mn	Pb	As
PLS010	OSND	1	53	0.01	11	0.1	9	75	11	4.0
020	OSND		46	0.04	1	0.1	2	149	11	0.3
030	OSND	1	14	0.01	1	0.1	4	58	3	0.2
040	OSND	1	36	0.01	3	0.1	10	144	3	0.2
050	OSND	1	70	0.02	2	0.1	5	27	3	0.2
060	OSND	1	67	0.12	15	0.1	4	50	43	4.0
070	OSND	1	30	0.03	8	0.1	3	104	22	0.3
080	-	-	-	-	-	-	-	-	-	-
090	OSND	1	24	0.02	6	0.1	3	62	16	0.2
100	OSND	1	44	0.04	10	0.1	3	127	16	0.2
110	OSND	1	22	0.02	2	0.1	2	83	22	0.2
120	OSND	1	30	0.01	5	0.1	2	208	22	0.2
130	OSND	1	96	0.02	2	0.1	13	219	548	0.2
140	OSND	1	40	0.16	65	0.1	56	38	27	0.2

Number	Type	Sb	U	Fe%	S%	Corg%	CO ₂ %
PLS010	OSND	3	0.7	0.92	0.20	4.4	0.4
020	OSND	3	0.9	0.96	0.14	8.0	0.6
030	OSND	10	0.4	0.53	0.04	1.7	0.1
040	OSND	1	0.7	0.19	0.05	4.0	0.1
050	OSND	1	0.1	0.39	0.02	0.8	0.1
060	OSND	1	1.5	0.23	0.56	39.0	0.4
070	OSND	1	0.3	0.81	0.16	9.0	0.2
080	-	-	-	-	-	-	-
090	OSND	1	0.7	0.46	0.11	2.7	0.1
100	OSND	1	1.2	0.77	0.18	10.0	0.1
110	OSND	1	1.0	0.64	0.09	3.8	0.1
120	OSND	1	0.6	0.33	0.11	0.9	10.3
130	OSND	1	0.6	2.58	0.02	1.2	0.1
140	OSND	1	4.7	0.47	0.42	24.0	0.1

- NOTES: 1. all values in ppm unless otherwise indicated.
2. Sample PLS-130: corroded Pb shot found in coarse (+100 mesh) fraction.
3. OSND: organic stained sand.

APPENDIX 7

Shoreline sediments: Lavant Long Lake, south and east arms

Number	Type	depth	Zn	Cd	Hg	Cu	Ag	Ni	Co
LLS013	SAND	2	43	0.2	0.02	16	0.0	5	7
023	SAND	2	28	0.2	0.01	6	0.0	5	4
033	SAND	1	33	0.2	0.02	12	0.0	10	3
043	SAND	1	45	0.6	0.02	13	0.2	12	8
053	SAND	1	38	0.2	0.03	8	0.1	8	4
063	SAND	1	19	0.2	0.01	7	0.2	6	3
073	SAND	4	18	0.2	0.01	7	0.2	7	3
083	SAND	1	29	0.2	0.01	25	0.3	7	2
093	SAND	10	16	0.2	0.01	7	0.3	8	2
143	SAND	2	52	0.2	0.02	13	0.3	12	2
140	OSND	25	109	0.8	0.05	16	0.3	5	7
153	SAND	1	17	0.2	0.01	6	0.0	1	2
LLE011	MARL	1	20	0.2	0.05	17	0.1	1	2
021	MARL	1	20	0.2	0.03	16	0.2	1	2
033	SAND	2	53	0.2	0.04	10	0.5	9	7
053	SAND	1	33	0.2	0.03	8	0.3	13	3
063	SAND	1	99	0.2	0.03	12	0.4	5	6
071	MARL	1	17	0.2	0.02	12	0.3	5	2
083	SAND	3	56	0.2	0.03	22	0.1	9	6
093	SAND	1	64	0.2	0.02	18	0.0	4	6
113	SAND	3	41	0.2	0.02	9	0.0	4	8
133	SAND	6	17	0.2	0.02	5	0.2	3	2
140	MARL	4	15	0.2	0.02	11	0.1	1	3
153	SAND	4	16	0.2	0.01	7	0.2	1	3
163	MARL	10	34	0.2	0.02	9	0.3	1	6
160	SAND	10	29	0.2	0.04	11	0.2	1	6
173	SAND	20	33	0.2	0.02	19	0.1	1	6
170	SAND	20	57	0.2	0.03	9	0.2	1	7
203	SAND	10	31	0.2	0.03	8	0.4	3	6

Number	Type	Mn	Pb	As	Sb	U	Fe%	S%	Corg%	CO ₂ %	Mo	W
LLS013	SAND	208	25	2.5	0.2	0.2	1.53	0.12	2.3	0.1	0.5	2
023	SAND	239	8	3.3	0.2	0.2	1.25	0.22	1.2	0.1	0.5	1
033	SAND	200	5	3.1	0.2	0.2	0.93	0.20	1.2	0.1	1.0	1
043	SAND	184	8	3.5	0.2	0.4	1.53	0.17	3.1	0.1	1.0	2
053	SAND	176	8	3.6	0.2	0.4	1.21	0.24	3.2	0.1	1.0	2
063	SAND	45	5	2.8	0.2	0.5	0.54	0.12	1.5	0.1	1.0	2
073	SAND	101	5	2.1	0.2	0.1	0.69	0.07	0.7	0.1	0.5	2
083	SAND	69	5	2.5	0.2	0.6	0.81	0.28	3.0	0.1	3.0	40
093	SAND	85	5	2.0	0.2	0.1	0.07	0.07	1.6	0.1	0.5	1
143	SAND	297	5	3.6	0.2	0.8	2.26	0.36	4.6	0.1	3.0	1
140	OSND	257	45	5.5	0.2	1.2	1.06	0.68	9.0	0.5	1.0	1
153	SAND	84	72	1.3	0.2	0.1	0.36	0.06	0.7	0.2	0.5	2
LLE011	MARL	384	5	3.8	0.2	1.6	0.22	0.48	8.0	35.0	2.0	1
021	MARL	333	10	3.3	0.2	1.2	0.13	0.36	7.0	36.0	1.0	1
033	SAND	390	17	6.3	0.2	0.4	1.71	0.11	2.3	11.0	2.0	1
053	SAND	406	5	2.9	0.2	0.2	0.81	0.08	1.5	17.0	0.5	1
063	SAND	157	5	2.5	0.2	2.0	1.23	0.33	7.0	0.2	2.0	1
071	MARL	519	10	3.5	0.2	0.5	0.09	0.24	6.0	38.0	0.5	1
083	SAND	266	10	3.9	0.2	1.3	1.33	0.36	7.0	2.9	2.0	1
093	SAND	70	8	3.9	0.2	0.2	0.59	0.09	1.2	0.2	2.0	1
113	SAND	303	5	2.1	0.2	0.4	0.46	0.12	1.1	21.0	1.0	1
133	SAND	155	12	1.8	0.2	0.4	0.50	0.04	1.2	5.0	0.2	1
140	MARL	539	12	2.2	0.2	0.9	0.03	0.10	1.1	41.0	0.2	1
153	SAND	105	12	0.9	0.2	0.4	0.26	0.06	0.7	5.0	0.5	2
163	MARL	370	12	2.0	0.2	0.2	0.39	0.04	1.9	30.0	0.5	2
160	SAND	277	5	2.1	0.2	0.7	0.89	1.06	6.0	29.0	1.0	2
173	SAND	486	12	3.1	0.2	1.4	0.89	0.34	2.2	27.0	0.5	1
170	SAND	365	10	3.7	0.2	0.6	0.97	0.48	3.3	20.0	2.0	1
203	SAND	127	5	4.2	0.2	0.2	1.23	0.13	3.2	0.1	0.5	1

- NOTES: 1. all values in ppm unless otherwise indicated
2. SAND: sand;
OSND: organic stained sand;
MARL: marl or limey clay.

APPENDIX 7 (cont'd.)

Shoreline sediments: Lavant Long Lake, west and north arms

Number	Type	Depth	Zn	Cd	Hg	Cu	Ag	Ni	Co
LLW040	SAND	12	62	-	0.02	9	0.2	7	-
053	SAND	1	82	0.2	0.01	16	0.2	11	7
073	SAND	1	38	0.2	0.02	16	0.2	14	11
093	MARL	3	44	0.2	0.02	18	0.2	5	2
103	SAND	1	59	0.2	0.02	9	0.3	6	8
113	SAND	2	27	0.2	0.01	7	0.1	6	3
123	SAND	1	78	0.2	0.01	10	0.2	7	6
120	SAND	1	29	0.2	0.01	6	0.2	2	3
LLN013	SAND	2	10	0.2	0.02	5	0.4	4	2
053	SAND	2	9	0.2	0.01	5	0.1	1	2
060	MARL	3	12	0.2	0.01	12	0.2	3	2
070	SAND	8	27	0.2	0.02	22	0.2	10	11
081	MARL	8	16	0.2	0.02	18	0.2	3	2
082	SAND	8	32	0.2	0.02	14	0.2	8	6
093	SAND	20	26	0.2	0.01	5	0.1	3	2
103	SAND	25	24	0.2	0.03	14	0.2	5	3
101	SAND	25	47	0.2	0.04	14	0.2	7	7
113	SAND	10	32	0.2	0.03	7	0.2	6	4
120	MARL	3	12	0.2	0.01	17	0.0	2	2
133	SAND	1	11	0.2	0.01	7	0.0	2	4

Number	Type	Fe%	S%	Corg%	CO ₂ %	Mo	W	Mn	Pb	As	Sb	U
LLW040	SAND	0.79	0.40	5.0	0.4	-	-	210	5	-	-	0.8
053	SAND	1.98	0.19	2.8	0.1	1.0	2	97	5	2.4	0.2	0.3
073	SAND	1.45	0.12	1.3	0.4	1.0	2	155	8	3.9	0.2	0.1
093	MARL	0.99	0.74	4.0	29.0	5.0	1	382	5	2.2	0.2	32.0
103	SAND	1.24	0.18	2.9	8.0	0.5	2	334	5	2.5	0.2	0.1
113	SAND	0.43	0.11	3.2	0.2	1.0	1	91	5	1.7	0.2	0.1
123	SAND	1.19	0.16	2.3	2.3	0.5	8	496	17	2.5	0.2	0.8
120	SAND	0.31	0.10	2.2	0.1	0.5	2	34	5	3.0	0.2	0.3
LLN013	SAND	0.19	0.09	0.3	0.2	1.0	2	28	5	0.7	0.2	0.4
053	SAND	0.31	0.03	0.3	0.1	0.5	2	36	5	2.5	0.2	0.3
060	MARL	0.17	0.28	3.2	39.0	0.2	1	623	5	2.5	0.2	1.2
070	SAND	0.81	0.53	0.4	4.4	0.2	1	249	5	1.9	0.2	0.4
081	MARL	0.50	0.52	2.3	38.0	2.0	1	562	5	2.2	0.2	4.8
082	SAND	1.23	0.96	1.7	2.2	0.2	1	152	5	2.1	0.2	4.4
093	SAND	0.26	0.17	1.3	0.1	4.0	2	80	8	2.3	0.2	4.0
103	SAND	0.67	0.11	1.5	11.0	0.5	1	287	5	2.2	0.2	0.2
101	SAND	1.19	0.17	2.9	8.0	1.0	1	359	5	3.4	0.2	0.2
113	SAND	0.47	0.13	4.6	25.0	1.0	1	442	5	2.5	0.2	0.3
120	MARL	0.18	0.30	3.4	37.0	2.0	1	723	8	2.1	0.2	2.8
133	SAND	0.37	0.03	0.4	0.1	1.0	1	38	5	0.8	0.2	0.1

- NOTES: 1. all values in ppm unless otherwise indicated.
2. SAND: sand;
MARL: marl or limey clay.