RESULTS OF GEOCHEMICAL MAPPING EMPLOYING HIGH-DENSITY LAKE-SEDIMENT AND WATER SAMPLING IN CENTRAL LABRADOR

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ABSTRACT

During 1996, a high-density lake-sediment and water geochemical-mapping program was conducted in central Labrador in NTS map areas 13N/2, 3, 6 and 7. A previous reconnaissance-scale geochemical survey had yielded localized high values of Au and base metals in sediment. The area is underlain, predominantly, by Archean gneiss and granitoid rocks and parts of two Archean greenstone belts. Although most of the area outside the volcanic terrain has received little or no exploration attention, several mineral occurrences are known. Altogether, 619 sediment and water samples were collected. The sediment samples were analyzed for loss-on-ignition and 49 elements. The water samples were analyzed for pH, conductivity, sulphate and 22 elements.

The results from the geochemical mapping survey are effective in delineating mineralized areas as evidenced by anomalously high levels of Au, Cu and Ni in sediment, from sites in proximity to several known mineral occurrences. Prospective areas, remote from known mineralization, which have lake sediments with anomalous levels of Cu, Ni, and to a lesser extent, Au have been identified. The significance of the Au in sediment analyses appears compromised by the nugget effect, as evidenced by the lack of reproducible results in site-duplicate samples, in which one of the pair had detectible Au. Arsenic may act as a gold pathfinder, in the two greenstone belts, as evidenced by its high levels in samples near greenstone-hosted gold mineralization.

INTRODUCTION

The study area has potential for gold and base-metal mineralization and at least 12 occurrences of mineralization are known presently. The area is underlain predominantly by Archean gneiss and granitoid rocks, and parts of two Archean greenstone belts. Aside from some work in the volcanic terrain (McLean, 1991), the area has not been extensively explored. In addition to encouraging geological features, an earlier reconnaissance-scale lake-sediment survey indicated anomalous levels of Au, Cu and Ni in several lakes. The present high-density survey is designed to provide a sufficient level of detail to focus follow-up exploration. In addition, a large suite of water analyses, including base metals, gives a second level of data. This report describes the geology, sampling and analytical methods used, provides a variety of statistical summaries and tools, and presents several maps of element distribution in sediment and water with an accompanying interpretation. For a more complete discussion and presentation, as well as the data in digital format, the reader is referred to McConnell (1999).

LOCATION, ACCESS AND PHYSIOGRAPHY

The lake survey was conducted over NTS map areas 13N/2, 13N/3 and most of 13N/6 and 13N/7 (Figure 1). The closest town to the area is Hopedale, located on the coast, about 30 km to the east. Hopedale is connected to Goose Bay by year round scheduled air service and by coastal boat service during the summer months. Access to the survey area is practical only by float plane or helicopter. Charter services are available in Goose Bay.

Except for portions of the Adlatok River valley, the terrain is moderately rugged with relief in excess of 500 m. Forest cover is widespread with only the higher hills and areas near the coast remaining unvegetated. Lake density is quite high, affording relatively uniform sampling coverage in most of the survey area. Notable exceptions include areas underlain by large sand plains adjacent to the Adlatok River.
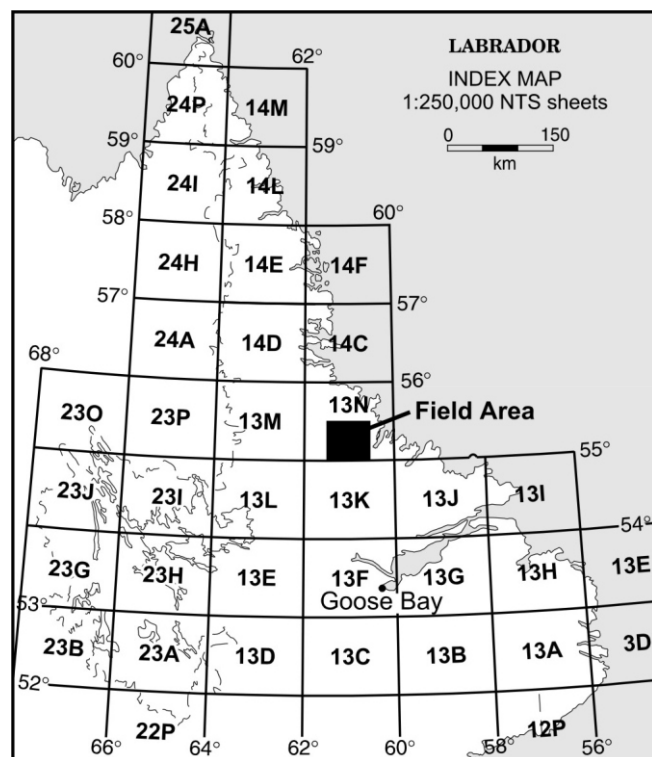
Figure 1. *Location of field area.*

PREVIOUS GEOCHEMICAL SURVEYS

Lake-sediment and water sampling was undertaken over this area in 1978 as part of a larger regional survey by the Geological Survey of Canada (GSC) in conjunction with the Newfoundland Department of Mines and Energy. Samples were collected at an average density of 1 per 13 km^2 in the survey. Data listings and distribution maps of 16 elements in sediment and of uranium, fluoride and pH in water were first published by Hornbrook and Lund (1978). Subsequently, the archived sediment samples were re-analyzed by instrumental neutron activation for gold and 25 other elements. These data, together with the original, were published as a report that included a data listing, analytical procedures, sample location and gold distribution maps (Friske *et al.,* 1993).

GEOLOGY AND MINERALIZATION

The area is underlain by Archean rocks of the Nain Province and some younger gabbroid and granitoid intrusive rocks in the southwest. The oldest rocks are those of the 3100 Ma Maggo gneiss. These are infolded with volcanic rocks of the Hunt River and Florence Lake greenstone belts and tonalitic plutons of the 2800 Ma Kanairiktok Intrusive Suite (Wardle, 1993). The Nain Province was deformed during the ca. 3000 Ma Hopedalian event and the ca. 2800 Ma Fiordian event.

In the Nain Province, six rock groupings are shown on Figure 2; the following descriptions are taken from Wardle (1993). The Maggo gneiss is a strongly banded, migmatitic, tonalite gneiss. The Weekes amphibolite is derived, in part, from rocks of the Hunt River and Florence Lake greenstone belts. The Hunt River greenstone belt consists of metagabbroic to metaleucogabbroic rocks, partly layered and intercalated with pelitic schist, ultramafic rocks and amphibolite. The Florence Lake greenstone belt is composed of mafic volcanic and volcaniclastic rocks at greenschist to amphibolite facies. The Kanairiktok Intrusive Suite includes granodiorite, tonalite and minor granite; it is variably foliated to massive. The migmatite gneiss is derived, at least in part, from Kanairiktok Intrusive Suite and Maggo gneiss protoliths.

The eastern rim of the Harp Lake Intrusive Suite underlies the southwest part of the area. The complex includes layered to massive anorthosite, leuconorite, leucotroctolite, minor leucogabbro and a border zone of rusty gabbro and minor troctolite. Associated granitic rocks include biotite–hornblende-bearing quartz monzonite.

Twelve occurrences of gold, copper and nickel mineralization are known in the area (Figure 2). Six of these are just outside survey study area. Data about the gold occurrence that occurs in NTS map area 13N/6 are obtained from the provincial Geological Survey's Mineral Occurrence Data System (MODS) and are classified as either "indications" or "showings".

The gold occurrence in NTS map area 13N/6 is on claims owned by Ascot Resources and was tested by trenching and diamond drilling in 1996. Some results included, "7 of 8 drill holes intersecting discontinuous but highly anomalous gold mineralization over thicknesses of 15 to 35 m in chlorite–ankerite altered quartz veins, diorite and alkali granite host rocks. Significant intersections included 5 m of 4.55 g/t gold in DDH AR96-02, and 3.4 m of 3.69 g/t gold in DDH AR96-05" (Ascot Resources Ltd., 1996). During a visit to the property, pyrite and galena were noted in the quartz veins. The other two gold occurrences are sulphide-bearing gossans hosted by carbonatized ultramafic rocks of the Florence Lake greenstone belt. Mineralized grab samples from these also contained anomalous amounts of arsenic and copper.

The five copper occurrences in NTS map areas 13N/2 and 13N/1 are hosted by volcanic rocks of the Florence Lake greenstone belt. The northern ones have associated gold ± nickel whereas only copper is reported from the southern one. The remaining two copper occurrences are in NTS map area 13N/4. They consist of magnetite-bearing lenses within leucogabbro of the Harp Lake Intrusive Suite and contain disseminated to semi-massive chalcopyrite and pyrrhotite with anomalous nickel.
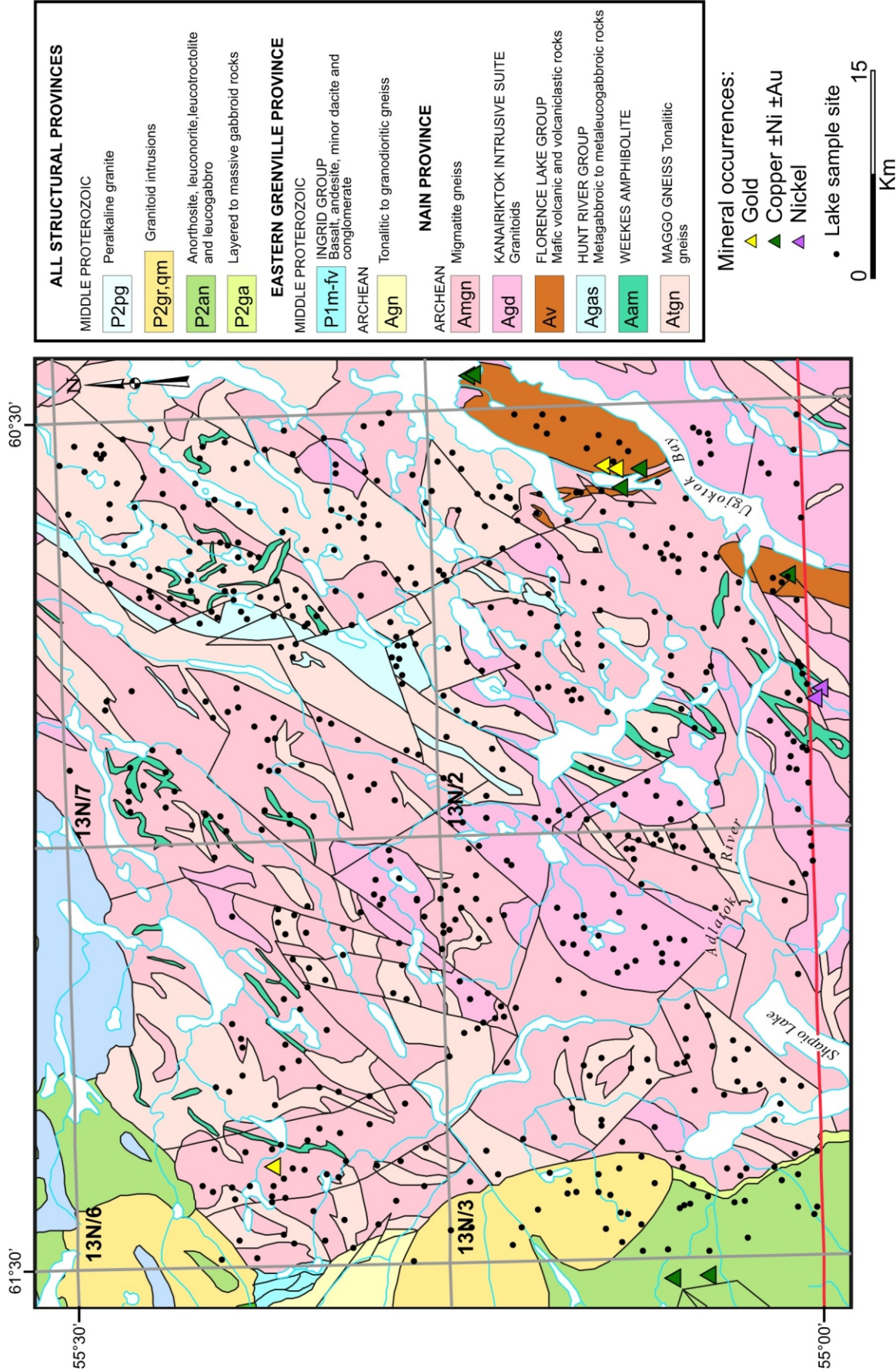
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Figure 2. *Geology and sample locations.*

ALL STRUCTURAL PROVINCES

MIDDLE PROTEROZOIC

P2pg — Peralkaline granite

P2gr,qm — Granitoid intrusions

P2an — Anorthosite, leuconorite,leucotroctolite and leucogabbro

P2ga — Layered to massive gabbroid rocks

EASTERN GRENVILLE PROVINCE

MIDDLE PROTEROZOIC

P1m-fv — INGRID GROUP Basalt, andesite, minor dacite and conglomerate

ARCHEAN

Agn — Tonalitic to granodioritic gneiss

NAIN PROVINCE

ARCHEAN

Amgn — Migmatite gneiss

Agd — KANAIRIKTOK INTRUSIVE SUITE Granitoids

Av — FLORENCE LAKE GROUP Mafic volcanic and volcaniclastic rocks

Agas — HUNT RIVER GROUP Metagabbroic to metaleucogabbroic rocks

Aam — WEEKES AMPHIBOLITE

Atgn — MAGGO GNEISS Tonalitic gneiss

Mineral occurrences:
- ▽ Gold
- ▲ Copper ±Ni ±Au
- ▲ Nickel
- • Lake sample site

0 ——— Km ——— 15

Little is known of the two nickel occurrences ("indications") in NTS map area 13K/15. One is reported to be hosted by the Maggo gneiss and the other, oddly, by granitoid rocks.

SURFICIAL GEOLOGY

The surficial geology in the southern part of the study area has been mapped recently by Batterson (1996). The NTS map areas 13N/2 and 13N/3 were described from aerial-photograph interpretation and some ground checking in 1995, but the NTS map areas 13N/6 and 13N/7 were mapped using aerial photograph interpretation exclusively (M. Batterson, personal communication, 1998).

The entire area was glaciated during the late Wisconsinan. Batterson (1996) describes paleo ice-flow as being generally northeastward toward the coast, approximately parallel to the bedrock structure. Marine limit in the area is estimated at 120 m asl, based on comparison with areas to the south (Batterson, 1996). The distribution of sediment types across the area reflects both the glacial and postglacial history. Areas below the marine limit commonly show marine and fluvial sediments deposited during periods of higher sea level and subsequent sea-level fall. A stratigraphy of marine muds overlain by fluvial sand and gravel is common in valleys below marine limit. Areas above the marine limit are dominated by exposed bedrock and thin veneers of till, except in the larger valleys (e.g., Adlatok River and associated tributaries) that contain glaciofluvial sand and gravel deposited by meltwater from waning glaciers farther inland. Geochemical data (particularly soil or stream-sediment) from areas underlain by till will much more closely reflect underlying bedrock than data obtained from areas underlain by waterlain sediment (sand, gravel or mud).

SAMPLE COLLECTION

A total of 619 lake sediment and water samples were collected from 579 sites. As a check on sample representivity, duplicate samples were collected about 50 to 100 m apart at 40 of these sites. Generally, smaller lakes were sampled in this survey than was the case for the reconnaissance survey, in which the objective had been to obtain a more regional geochemical perspective. Normally, the centre of the lake (or if apparent from the air, the central basinal portion of the lake) was sampled. On some deep lakes (>25 m), no sample was retrieved in lake centres and a sample from a shallower site closer to shore was obtained. The collection procedure involves landing a float-equipped 206-B Jet Ranger helicopter on the lake surface and first obtaining a sample of near-surface water by immersing and filling a

purified, 250 mL Nalgene bottle. Prior to sampling, the bottles are acid leached in the laboratory, and washed with distilled and deionized water. Then a sediment sample is obtained by dropping a weighted tubular sample fitted with a nylon rope for retrieval. A butterfly valve in the bottom of the tube opens upon impact with the sediment and closes upon retrieval trapping the contained sediment. Samples are stored in water-resistant Kraft paper bags. Markings on the rope permit determination of the sample depth. Other observations made during sampling include GPS coordinates of site, elevation, the nature of vegetation surrounding the lake, sediment colour, composition and water colour.

SAMPLE PREPARATION AND ANALYSES

PREPARATION

Lake sediments were partially air-dried in the field prior to shipping to the department's laboratory for final oven-drying at 40°C. The samples were then disaggregated by mortar and pestle before being screened through a 180 micron stainless-steel sieve; the fine fraction was retained for chemical analyses. To monitor analytical precision, five percent of the samples were randomly selected, split and included as blind duplicates in all analytical procedures. Water samples were stored in a cool environment prior to shipping to St. John's. At the laboratory, waters were filtered using a 0.45 µm millipore filtration apparatus.

ANALYSES

Lake sediment was analyzed by several methods for 49 different elements plus loss-on-ignition for a total of 72 separate determinations. These elements and methods of analyses are tabulated in Table 1. Note that several elements (e.g., Cu, Co, Fe, Pb, etc.) have been analyzed by two or three methods. The reader should note whether the method is "partial" or "total" and then select the element/method combination desired. To enable the user to readily distinguish the method of analysis for a given element, a suffix is attached to the element symbol when used in tables and figures. All analyses except INAA were conducted in the geochemical laboratory of the Department of Mines and Energy. INAA analyses were done by Becquerel Laboratories. The key to the suffixes is as follows:

1. Neutron activation analysis (INAA).
2. ICP-ES (or AA) after $HF-HClO_4-HCl$ digestion.
3. AA after HNO_3-HCl digestion.
6. AA after HNO_3 digestion.
9. Fluoride-ion selective electrode.

In the foregoing, "ICP-ES" refers to inductively coupled plasma-emission spectrometry; "AA" is atomic absorption spectrophotometry. Thus, Zn2 is zinc analyzed by ICP-ES/$HF-HClO_4-HCl$ whereas Zn1 is zinc analysed by INAA.

Table 1. Analytical methods for lake-sediment samples

ELEMENTS	METHOD	DIGESTION/ PREPARATION
(Ag), As, Au, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Mo, Na, Ni, Rb, Sb, Sc, Sm, Ta, Tb, Th, U, W, Yb, (Zn), (Zr)	Neutron Activation Analysis (INAA)	5 to 10 g in shrink-wrapped vial. (total analysis)
Al, Ba, Be, Ca, Cd, Ce, Co, Cr, Cu, Dy, Fe, Ga, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, Pb, Rb, Sc, Sr, Ti, V, Y, Zn, Zr*	Inductively Coupled Plasma Emission Spectroscopy (ICP-ES)[1]	$HF-HClO_4-HCl$ (total digestion)
Cr, Mo	Atomic Absorption Spectroscopy (AA)[1]	$HF-HClO_4-HCl$ (total digestion)
Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn*	Atomic Absorption Spectroscopy (AA)[2]	HNO_3-HCl (3:1) (partial digestion)
Ag*	Atomic Absorption Spectroscopy (AA)[2]	HNO_3
F	Flluoride-ion specific electrode with digital ion analyser[2]	2:1 Na_2CO_3:KNO_3 flux, fusion
Loss-on-ignition (LOI)	Gravimetric using muffle furnace raised to 500° C	

* Indicates preferred method of analysis.
( ) indicates less favoured method of analysis; use alternative.

[1] Finch (1998)
[2] Wagenbauer *et al.* (1983)

Lake water was analyzed for conductivity, pH, SO_4 and 22 elements using the methods noted in Table 2.

DATA QUALITY

To ensure the reliability of the analytical data, three means of determining data accuracy and precision were employed. During sample collection, 40 pairs of site dupli-cates were obtained to give an appreciation of within-lake data variation. At the analytical stage, a standard of known composition was inserted within every batch of 20 samples and a sample split, or laboratory duplicate, was similarly included. For sediment, international reference standards composed of lake sediment material were used, notably LKSD-1, LKSD-2, LKSD-3 and LKSD-4. For water, stan-dards used were both naturally occurring water and synthet-ic standards created in the laboratory to predetermined com-positions. The results of these standards were monitored and found generally to be satisfactory (McConnell, 1999).

Site duplicates are useful because they give an appreci-ation of overall data variance occurring at both the sampling and analytical stages. Since they consist of samples from the survey itself, they may reveal limitations in the data that are specific to the area and which may not show up in the refer-ence standards. Scatterplots of nine types of analyses in lake sediment are shown in Figure 3. One can see there is a range of reproducibility in the site duplicates from quite good for Ni2, Pb3, Cr2 to apparently poor for Au1. The quality of the Au data is difficult to assess. Of the 80 samples, only 3 had detectible Au and none of these 3 pairs had detectible Au in both samples. This may suggest that the gold present is rel-atively coarse grained giving a "nugget effect", however, there are too few sites sampled having detectible Au to reach a statistically valid conclusion.

Scatterplots of site duplicates in water are shown in Figure 4. The correlations are stronger between duplicate pairs that is the case of sediment. This is not surprising in the fact that water is a more homogeneous medium than sedi-

Table 2. Analytical methods for lake-water samples

ANALYSIS	METHOD	PREPARATION
pH	Corning combination pH electrode	None
Conductivity	Corning conductivity sensor	None
Ca, Fe, K, Mg, Mn, Na, Si, SO$_4$	ICP-emission spectroscopy[1]	Filtration (0.45 µm) and HNO$_3$ acidification
Al, Ba, Be, Co, Cr, Cu, Li, Mo, Ni, P, Sr, Ti, Y, Zn	ICP ultrasonic nebulizer[1]	Filtration (0.45 µm) and HNO$_3$ acidification
F	Fluoride-ion specific electrode with digital ion analyser[2]	

[1] Finch (1998)

ment and, unlike sediment, is not prone to compositional modifications within a lake due to variations in depth, LOI, Fe/Mn oxide scavenging and bottom currents. Correlations for the more abundant elements, Mg, F and SO$_4$ are particularly strong. Elements like Ni, and particularly Cu , are present in levels near or below their analytical detection limits even with nebulizer ICP techniques and hence are "noisy". Lower detection levels, such as that offered by ICP-mass spectrometric methods, might overcome this problem.

DESCRIPTION AND DISCUSSION OF RESULTS

STATISTICAL ANALYSIS

Summary Statistics

To quantify the range and distribution characteristics of the element populations, summary statistics have been calculated for the sediment and water data and a selection of these are tabulated in Tables 4 and 5 respectively. Because most element populations are more nearly log-normal than normal, the geometric means as well as arithmetic means are given.

Histograms of Analytical Data

Histograms for several elements analyzed in sediment and water are shown in Figures 5 and 6. These provide a quick graphical view of the shape of an element's population distribution and, in particular, show the relationship of extremely high values to the main population. Note that the X axis in each case is a log scale as most element popula-

tions more closely approximate a log distribution than an arithmetic one.

Correlation Analysis

Correlation coefficients show the strength of inter-element associations; i.e., the tendency for pairs of elements to vary sympathetically (positive correlations) or inversely (negative correlations) with each other in a given sample population. For example, if gold is associated with arsenopyrite in an area, this relationship may show as a positive correlation between Au and As. Iron and manganese (hydr)oxides frequently act as significant scavenging agents for many metals in lake sediments. For some elements, this may be so extreme as to require normalizing, or even outright rejection, of the data involved. Table 6 lists Spearman correlation coefficients of most elements analyzed in sediment and water with a selection of elements in sediment and the variables depth and LOI. Spearman correlations make no assumptions about the nature or shape of the component populations. For statistical purposes, correlations $>|0.09|$ (i.e., absolute value of 0.09) are significant at the 99 percent confidence level. For practical purposes, however, correlations of $<|0.6|$ generally do not call for adjustment of values when dealing with scavenging agents like Fe and Mn. That is, enough of the element signal is present that satisfactory results may be obtained by treating only the raw values. For elements with coefficients $>|0.6|$, procedures such as regression analysis may be employed to minimize the component of the signal due to scavenging.

A visual appreciation of the affect of scavenging of Co, Ni and Zn by Fe, as well as the correlation of Cu content with depth, can be gained by inspection of scatterplots (Figure 7). Note the logarithmic axes.

Table 3. Summary statistics of selected lake-sediment data; element values in ppm unless otherwise indicated (N=578)

Element	Median	Mean (Arithmetic)	Mean (Geometric)	Standard Deviation (Arithmetic)	Standard Deviation (Logarithmic)	Minimum	Maximum
Ag6	0.1	0.1	0.1	0.1	0.27	<0.1	1
Al2	4.51	4.77	3.89	2.68	0.31	0.27	13.06
As1	0.6	1.5	0.6	6.3	0.47	<0.5	126
Au1, ppb	<1.0	0.7	0.6	0.7	0.18	<1.0	10
Ba2	218	268	209	185	0.31	26	1044
Be2	0.5	0.5	0.4	0.3	0.3	0.1	2.5
Ca2	1.06	1.28	1.07	0.81	0.26	0.21	5.21
Cd2	0.3	0.4	0.3	0.2	0.25	<0.2	3.4
Ce2	55	60	51	35	0.28	2	344
Co2	8	11.8	8.3	11.2	0.37	1	92
Cr1	28	30	24	24	0.33	<10	380
Cs1	<0.5	0.4	0.3	0.3	0.26	<0.5	2.7
Cu2	20	26	20	30	0.27	3	378
F9	110	134	107	93	0.29	21	519
Fe1, wt.%	1.6	2.2	1.4	2.0	0.43	0.1	14
Fe2, wt.%	1.84	2.34	1.62	2.06	0.4	0.13	15.9
Hf1	1	2.0	1.3	2.4	0.37	<1	23
K2, wt.%	0.33	0.48	0.31	0.44	0.43	0.02	2.43
La2	31	34	28	20	0.29	1	192
Li2	5.5	7.2	5.2	5.8	0.38	0.1	31.1
LOI, wt.%	31.3	32.1	28.8	13.2	0.22	2.8	94.7
Mg2, wt.%	0.26	0.36	0.25	0.30	0.37	0.03	1.95
Mn2	227	410	219	1353	0.43	17	29904
Mo2	3	5.5	3.0	9.6	0.46	<1	127
Na2, wt.%	0.51	0.72	0.49	0.60	0.43	0.01	2.44
Nb2	3	3.8	3.0	2.9	0.31	<2	16
Ni2	15	17	15	10	0.22	2	115
P2	751	962	776	645	0.28	155	3538
Pb2	4	5.0	3.8	4.9	0.32	<1	87
Pb3	1	2.3	1.7	3.9	0.3	<1	78
Rb2	9	13.2	8.7	12.6	0.41	<5	83
Sb1	<0.1	0.0	0.0	0.1	0.22	<0.1	0.5
Sc2	4.2	4.7	3.9	2.6	0.27	0.3	14.1
Sr2	103	134	105	94	0.3	21	686
Ta1	<0.2	0.2	0.2	0.2	0.29	<0.2	1.3
Th1	2.6	3.1	2.5	2.1	0.3	0.3	17
Ti2	1300	1571	1202	1109	0.34	96	10073
U1	2.1	6.6	3.1	11.3	0.53	0.1	117
W1	<1	0.2	0.2	0.2	0.12	<1	4
Y2	12	14	11	9	0.27	1	86
Zn2	59	66	56	40	0.27	9	311
Zr1	<100	91	69	95	0.27	<100	820

ELEMENT DISTRIBUTION IN LAKE SEDIMENT

Distributions of Cu, Ni, Au and As are shown as symbol plots. The intervals used in the symbol maps of Cu, Ni and As were chosen by examining the respective cumulative frequency plots (shown on the symbol plots) and selecting suitable inflection points. The inflection points separate natural groupings or subpopulations within the overall distribution. For example Cu, shows a distinct break at about 74 ppm. Inflections were chosen that emphasize the upper por-
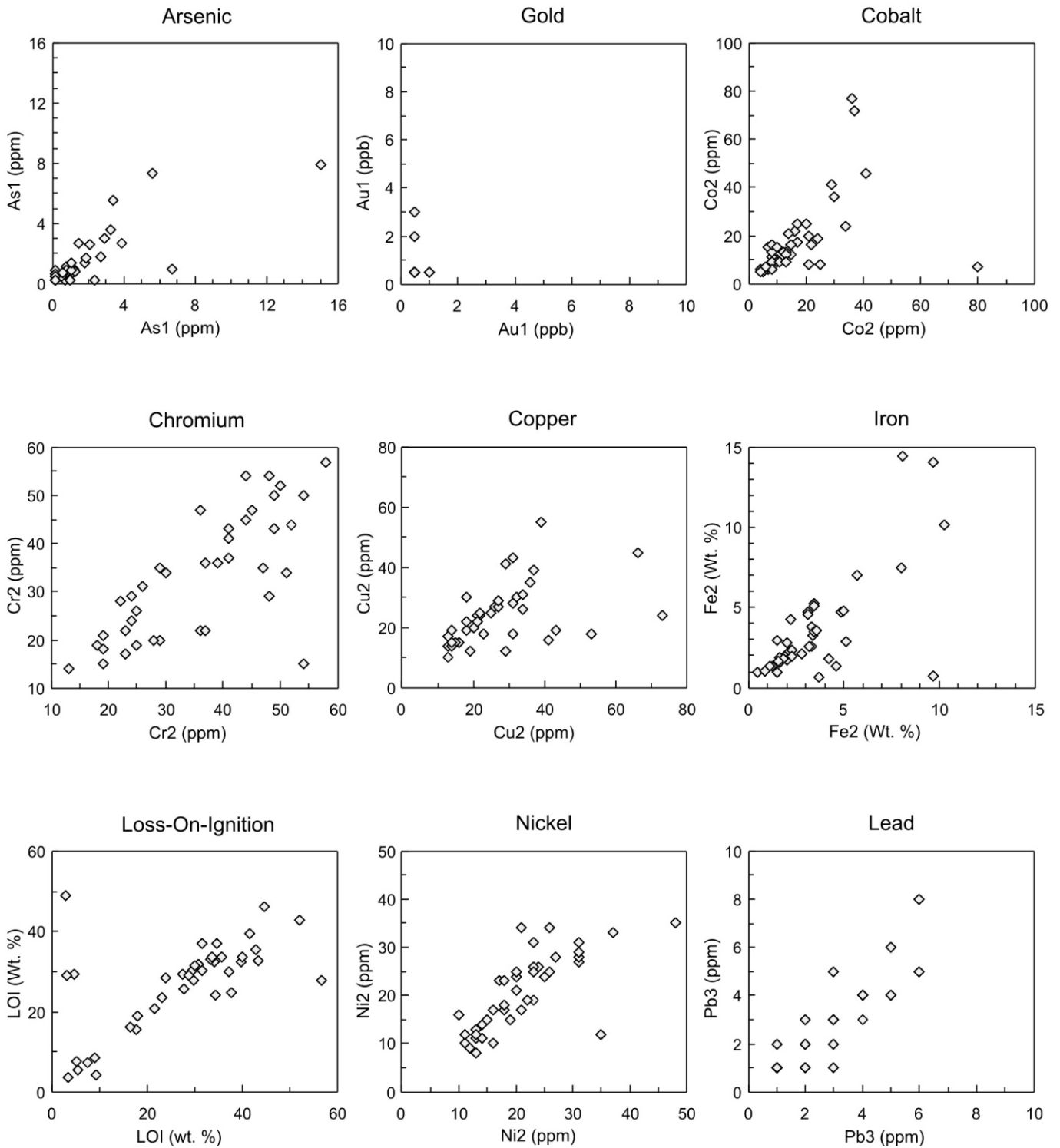
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Figure 3. *Scatterplots of As1, Au1, Co2, Cr2, Cu2, Fe2, LOI, Ni2 and Pb3 in site duplicates of lake sediment (N = 40).*
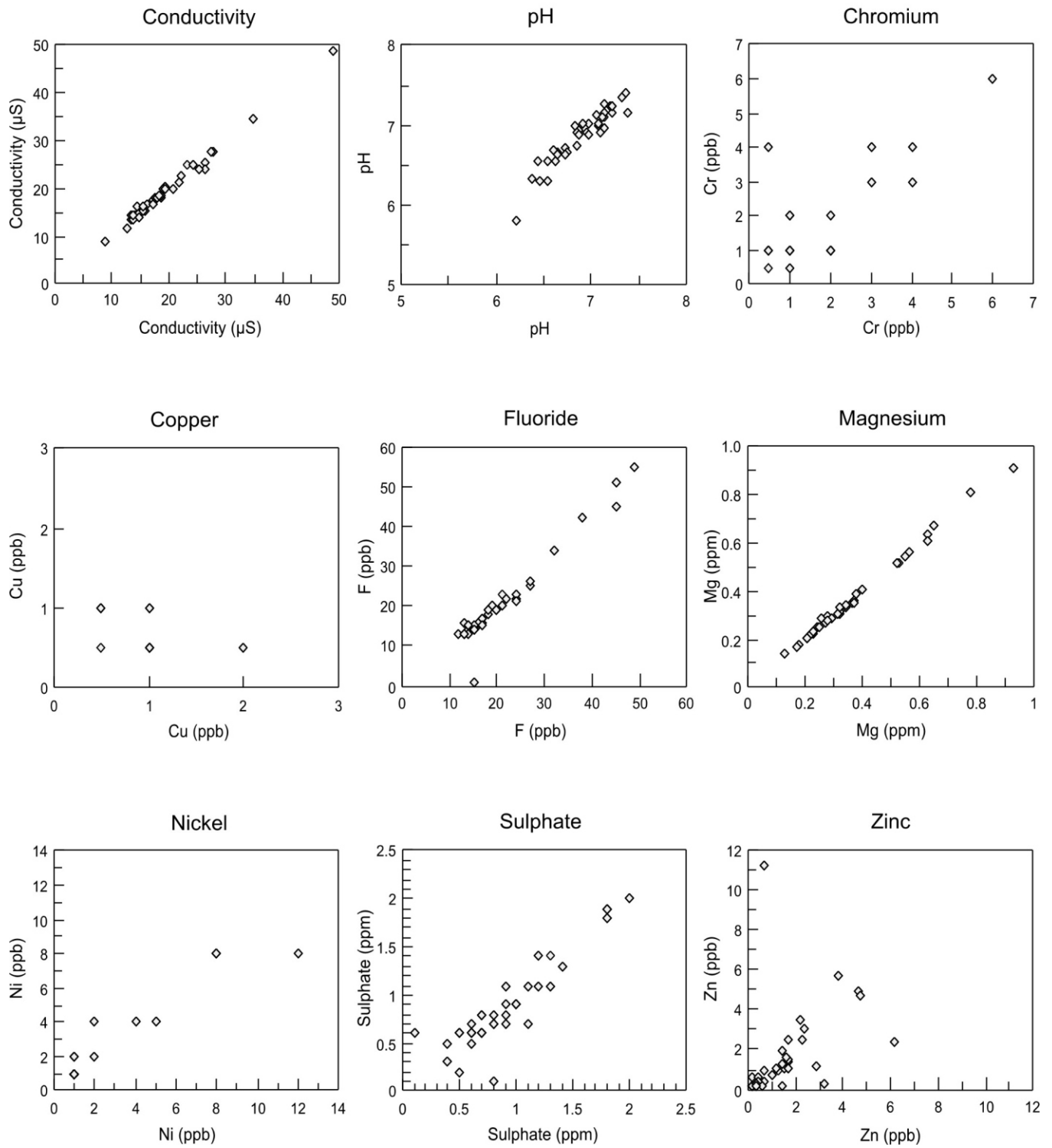
Site duplicates: lake water

Figure 4. *Scatterplots of conductivity, pH, Cr, Cu, F, Mg, Ni, SO₄ and Zn in site duplicates of lake water (N = 38).*

Table 4. Summary statistics of lake-water data; element values in ppb unless otherwise indicated (N=578)

Element	Median	Mean (Arithmetic)	Mean (Geometric)	Standard Deviation (Arithmetic)	Standard Deviation (Logarithmic)	Minimum	Maximum
Al	91	109	91	75.0	0.25	1	939
Ba	1	2.1	1.6	3.05	0.26	<1	46
Be	<0.1	0.05	0.05	0.01	0.03	<0.1	0.1
Ca	1.54	1.72	1.48	0.94	0.24	0.2	6.22
Co	<1	0.5	0.5	0.05	0.03	<1	1
Cr	<1	1.1	0.8	1	0.29	<1	6
Cu	<1	0.6	0.5	0.41	0.12	<1	9
F	18	20.4	19.1	9.66	0.15	1	143
Fe	44	56.7	40.7	52.5	0.37	5	564
K, ppm	<0.2	0.2	0.2	0.12	0.24	<0.2	0.7
Li	<1	0.5	0.5	0.06	0.04	<1	1
Mg, ppm	0.30	0.34	0.31	0.19	0.19	0.10	2.32
Mn	<2	1.7	1.4	1.37	0.24	<2	13
Mo	<1	0.6	0.6	0.18	0.11	<1	1
Na, ppm	0.91	0.97	0.91	0.37	0.15	0.25	4.15
Ni	<2	1.8	1.4	1.95	0.27	<2	15
P	<5	3.2	2.7	2.54	0.23	<5	24
Si, ppm	1.1	1.2	1.0	0.76	0.31	0.1	6
SO$_4$, ppm	0.8	0.8	0.7	0.43	0.25	0.1	3.5
Sr	6.6	8.2	6.6	12.09	0.25	0.1	215
Ti	<1	1.0	0.9	0.92	0.24	<1	10
Y	<0.3	0.2	0.2	0.02	0.03	<0.3	0.4
Zn	1.0	3.6	1.0	42.29	0.51	<0.3	1014
Conductivity (μS)	17.8	19.0	17.8	6.67	0.15	6.41	48.9
pH	6.84	**	6.78	**	0.37	4.92	7.73

** pH is defined as a logarithmic value.

tion of the distributions. Too few samples had detectable Au to create a meaningful cumulative frequency plot, hence intervals were selected more subjectively.

Copper

The distribution of Cu is shown in Figure 8. Six areas are identified as being very anomalous (>74 ppm Cu2). Of these, two are underlain by the Hunt River and Florence Lake greenstone belts. The latter, in the south of NTS map area 13N/2, has three anomalous samples in proximity to known Cu mineralization. The northern segment of this belt also has two samples having high Cu (>59 ppm). The Hunt River belt in NTS map area 13N/7 has high Cu values throughout the central portion but a cluster of 3 samples toward the south is particularly interesting. These samples are also anomalous in Ni and Pb as well as Cu in water; it is likely these reflect mineralization. At the time of writing, this area (exempt mineral lands or EML) remains under a

staking moratorium. A single site anomaly in NTS map area 13N/2 at the extreme southern boundary of the EML is also anomalous in As. Copper and As are sometimes associated with gold mineralization. In southern NTS map area 13N/3, a high Cu sample also is anomalous in Ni and Pb; a second site a few kilometres to the east is also high in Cu. Finally, a high Cu site is found near the margin of the Harp Lake Complex in NTS map area 13N/3; it is also high in Ni.

Nickel

The distribution of Ni2 in sediment is shown in Figure 9. Most of the very high values (>38 ppm Ni2) are in proximity to mafic rocks. The Hunt River greenstone belt has higher values than does the surveyed portion of the Florence Lake belt with one anomalous area in the south of NTS map area 13N/7 that is also anomalous in Cu and Pb. Most of the other high sites in NTS map area 13N/7 are in proximity to areas of Weekes amphibolite; the only anomalous sample in

Table 5. Spearman correlation coefficients for selected elements and variables in lake sediment and water (N=578)

	As1	Au1	Cr1	Cu2	F9	Fe1	La1	Mg2	Mn2	Ni2	Pb2	Sb1	U1	Zn2	Depth	LOI
SEDIMENT:																
Ag6	0.48	0.02	0.30	0.44	0.11	0.34	0.27	0.02	0.28	0.21	0.35	0.02	0.40	0.43	0.41	0.32
As1	**1.00**	0.06	0.53	0.51	0.36	0.55	0.44	0.30	0.49	0.47	0.46	0.21	0.34	0.54	0.47	0.14
Au1	0.06	**1.00**	0.00	0.08	-0.00	0.02	0.06	-0.02	0.04	-0.04	-0.00	0.09	-0.03	0.05	0.06	0.02
Br1	0.44	0.03	0.09	0.59	-0.13	0.28	0.25	-0.24	0.14	0.07	0.04	0.03	0.36	0.35	0.62	0.67
Ca2	0.27	0.03	0.75	0.15	0.79	0.61	0.38	0.93	0.71	0.66	0.59	0.03	0.04	0.50	0.15	-0.55
Cd2	0.39	0.10	0.27	0.62	0.20	0.50	0.51	0.05	0.42	0.26	0.29	0.00	0.36	0.60	0.49	0.34
Co2	0.48	0.02	0.70	0.55	0.65	0.90	0.58	0.66	0.89	0.73	0.50	0.04	0.18	0.74	0.49	-0.29
Cr1	0.53	0.00	**1.00**	0.41	0.74	0.73	0.58	0.78	0.77	0.71	0.70	0.14	0.19	0.63	0.34	-0.32
Cu2	0.51	0.08	0.41	**1.00**	0.19	0.56	0.55	0.12	0.47	0.48	0.29	0.11	0.35	0.55	0.64	0.32
F9	0.36	-0.00	0.74	0.19	**1.00**	0.68	0.62	0.83	0.74	0.56	0.70	0.02	0.10	0.57	0.23	-0.49
Fe1	0.55	0.02	0.73	0.56	0.68	**1.00**	0.67	0.62	0.91	0.61	0.58	0.08	0.23	0.78	0.57	-0.20
Fe2	0.51	0.01	0.70	0.55	0.67	0.98	0.67	0.61	0.91	0.60	0.57	0.04	0.22	0.77	0.56	-0.22
Fe3	0.54	0.02	0.64	0.58	0.61	0.97	0.65	0.53	0.85	0.57	0.50	0.04	0.24	0.77	0.60	-0.15
K2	0.31	0.01	0.76	0.08	0.84	0.56	0.45	0.94	0.70	0.60	0.78	0.03	0.08	0.48	0.07	-0.59
La1	0.44	0.06	0.58	0.55	0.62	0.67	**1.00**	0.39	0.63	0.38	0.57	0.02	0.25	0.62	0.40	-0.09
LOI	0.14	0.02	-0.32	0.32	-0.49	-0.20	-0.09	-0.61	-0.33	-0.28	-0.27	0.06	0.17	-0.09	0.21	1.00
Mg2	0.30	-0.02	0.78	0.12	0.83	0.62	0.39	**1.00**	0.74	0.72	0.66	0.03	0.00	0.53	0.12	-0.61
Mn2	0.49	0.04	0.77	0.47	0.74	0.91	0.63	0.74	**1.00**	0.65	0.66	0.06	0.18	0.75	0.46	-0.33
Mo2	0.23	0.06	0.06	0.41	0.07	0.35	0.42	-0.16	0.20	-0.02	0.06	-0.13	0.46	0.31	0.44	0.18
Na2	0.24	-0.01	0.74	0.06	0.80	0.56	0.37	0.96	0.70	0.63	0.69	0.01	0.04	0.46	0.05	-0.64
Nb2	0.32	0.03	0.75	0.11	0.83	0.54	0.51	0.87	0.68	0.55	0.80	0.05	0.09	0.49	0.09	-0.52
Ni2	0.47	-0.04	0.71	0.48	0.56	0.61	0.38	0.72	0.65	**1.00**	0.52	0.09	0.14	0.65	0.27	-0.28
Pb2	0.46	-0.00	0.70	0.29	0.70	0.58	0.57	0.66	0.66	0.52	**1.00**	0.06	0.29	0.56	0.17	-0.27
Sb1	0.21	0.09	0.14	0.11	0.02	0.08	0.02	0.03	0.06	0.09	0.06	**1.00**	-0.09	0.04	0.05	0.06
Sr2	0.23	0.00	0.73	0.07	0.82	0.57	0.40	0.95	0.70	0.62	0.67	-0.02	0.04	0.47	0.07	-0.60
Ta1	0.33	0.01	0.63	0.11	0.68	0.51	0.42	0.70	0.60	0.45	0.69	0.09	0.04	0.41	0.10	-0.45
Th1	0.51	0.04	0.76	0.40	0.79	0.71	0.84	0.67	0.74	0.55	0.78	0.07	0.21	0.68	0.31	-0.28
Ti2	0.33	-0.02	0.81	0.17	0.83	0.64	0.48	0.94	0.77	0.64	0.78	0.01	0.11	0.55	0.13	-0.54
U1	0.34	-0.03	0.19	0.35	0.10	0.23	0.25	0.00	0.18	0.14	0.29	-0.09	**1.00**	0.26	0.27	0.17
W1	0.15	0.08	0.11	0.04	0.10	0.14	0.08	0.10	0.12	0.10	0.06	-0.04	0.05	0.15	0.10	-0.06
Y2	0.41	0.05	0.61	0.52	0.66	0.73	0.88	0.49	0.72	0.43	0.57	0.04	0.15	0.65	0.38	-0.18
Zn2	0.54	0.05	0.63	0.55	0.57	0.78	0.62	0.53	0.75	0.65	0.56	0.04	0.26	**1.00**	0.45	-0.09
Zr2	0.29	0.02	0.74	0.10	0.80	0.56	0.46	0.89	0.70	0.55	0.78	0.04	0.13	0.47	0.05	-0.55
WATER:																
Conductivity	0.02	0.14	0.12	-0.07	0.16	0.04	0.02	0.18	0.07	0.13	-0.03	0.18	-0.08	-0.03	-0.13	-0.33
pH	-0.05	0.16	0.10	0.01	0.15	0.10	0.08	0.16	0.12	0.10	-0.12	0.13	-0.16	-0.04	0.00	-0.29
AlW2	-0.14	0.03	-0.16	-0.19	-0.04	-0.26	-0.15	-0.04	-0.22	-0.13	0.04	0.06	-0.00	-0.30	-0.24	-0.03
BaW2	-0.19	0.07	-0.00	-0.05	0.14	-0.00	0.24	-0.00	0.02	-0.19	0.07	0.05	-0.05	-0.11	-0.13	-0.13
CaW1	-0.09	0.16	0.01	-0.07	0.07	-0.03	-0.03	0.08	-0.00	0.02	-0.15	0.17	-0.13	-0.16	-0.14	-0.28
CrW2	-0.08	-0.03	-0.02	-0.04	-0.01	-0.02	-0.06	-0.02	-0.01	-0.07	-0.04	0.13	-0.12	-0.07	0.01	0.02
CuW2	0.05	0.03	0.07	0.17	-0.03	0.00	0.02	0.01	0.02	0.10	0.05	0.11	-0.01	0.07	-0.01	0.08
F_W	-0.25	0.02	-0.09	-0.29	0.24	-0.10	0.16	0.04	-0.07	-0.22	-0.04	-0.05	-0.11	-0.20	-0.20	-0.32
FeW1	-0.22	0.02	-0.17	-0.42	0.04	-0.29	-0.17	0.00	-0.25	-0.19	-0.00	0.04	-0.24	-0.32	-0.49	-0.16
KW1	0.06	0.12	0.05	-0.08	0.14	0.02	0.06	0.09	0.04	0.02	0.03	0.04	-0.11	-0.04	-0.03	-0.09
MgW1	-0.04	0.08	0.13	-0.12	0.17	0.07	-0.10	0.28	0.10	0.23	-0.07	0.17	-0.27	-0.05	-0.12	-0.36
MnW1	0.16	-0.01	0.16	0.09	0.20	0.23	0.23	0.14	0.21	0.11	0.17	0.12	-0.17	0.21	0.02	0.02
NaW1	0.08	-0.03	0.10	-0.26	0.15	-0.00	-0.10	0.20	0.01	0.11	0.11	0.01	0.08	0.03	-0.18	-0.28
NiW2	-0.12	-0.07	-0.05	-0.02	-0.05	-0.05	-0.07	-0.03	-0.05	-0.02	-0.08	0.11	-0.17	-0.15	0.00	0.02
PW2	-0.07	0.03	-0.17	-0.27	-0.07	-0.25	-0.11	-0.08	-0.21	-0.15	-0.04	0.01	-0.21	-0.21	-0.30	-0.08
SiW1	-0.25	0.03	-0.00	-0.15	0.20	0.06	0.03	0.20	0.08	-0.03	-0.09	-0.04	-0.16	-0.18	-0.04	-0.42
SO4W1	0.16	0.08	0.22	0.20	0.19	0.16	0.19	0.14	0.16	0.23	0.18	0.11	0.10	0.18	0.03	-0.10
SrW2	-0.27	0.12	-0.09	-0.23	0.13	-0.08	0.00	0.09	-0.05	-0.12	-0.15	0.02	-0.17	-0.24	-0.20	-0.37
TiW2	0.01	0.06	-0.02	-0.20	0.08	-0.18	-0.09	0.03	-0.12	-0.08	0.14	0.07	-0.05	-0.25	-0.17	-0.07
ZnW2	0.11	-0.06	0.04	-0.01	-0.01	0.01	-0.04	0.00	0.00	0.07	0.15	0.01	0.15	0.21	0.03	0.09

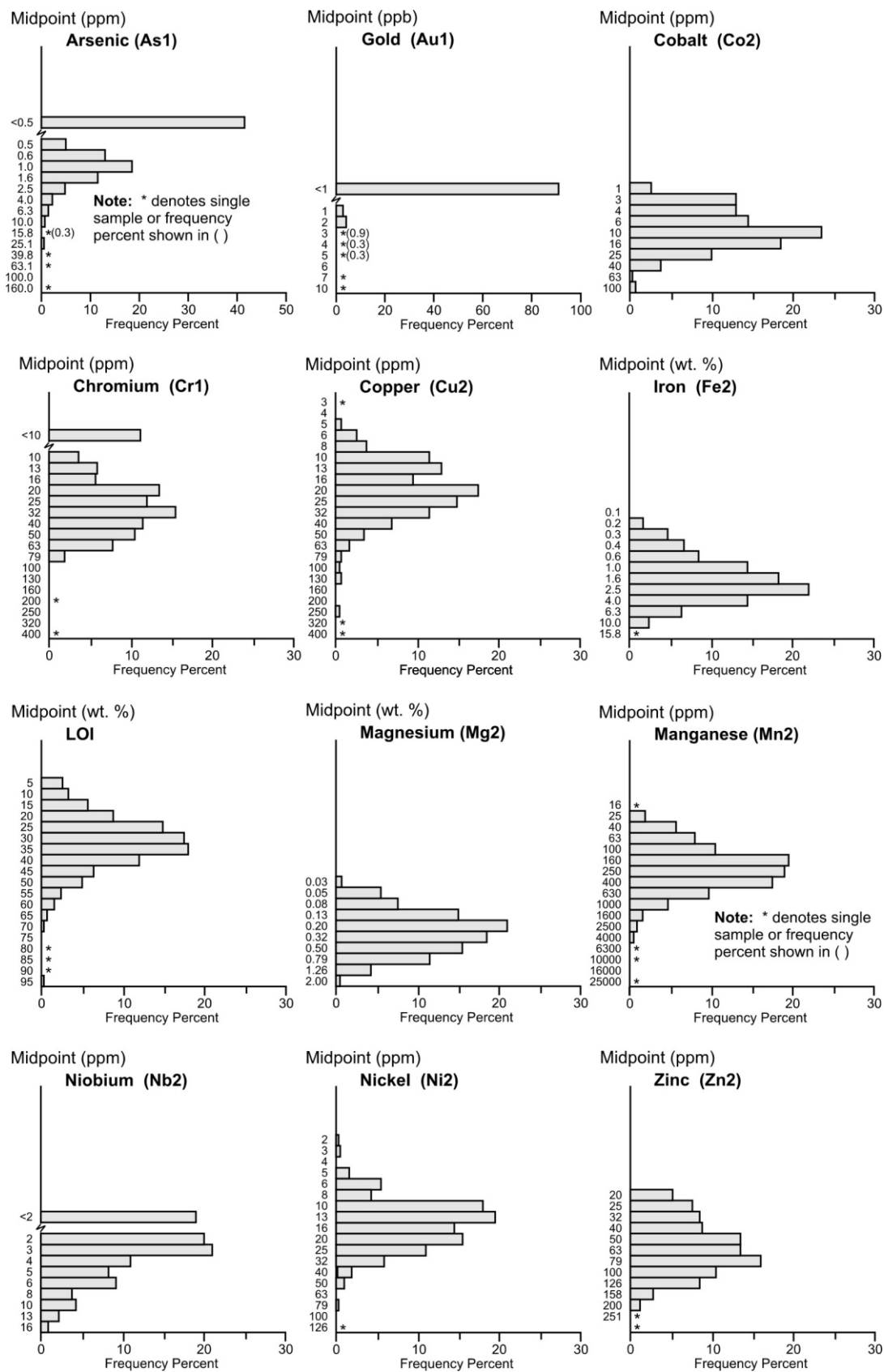Note: Correlations >|0.09| are significant at the 99% confidence level.

Figure 5. *Histograms of As1, Au1, Co2, Cr1, Cu2, Fe2, LOI, Mg2, Mn2, Nb2, Ni2 and Zn2 in lake sediment (N = 578).*
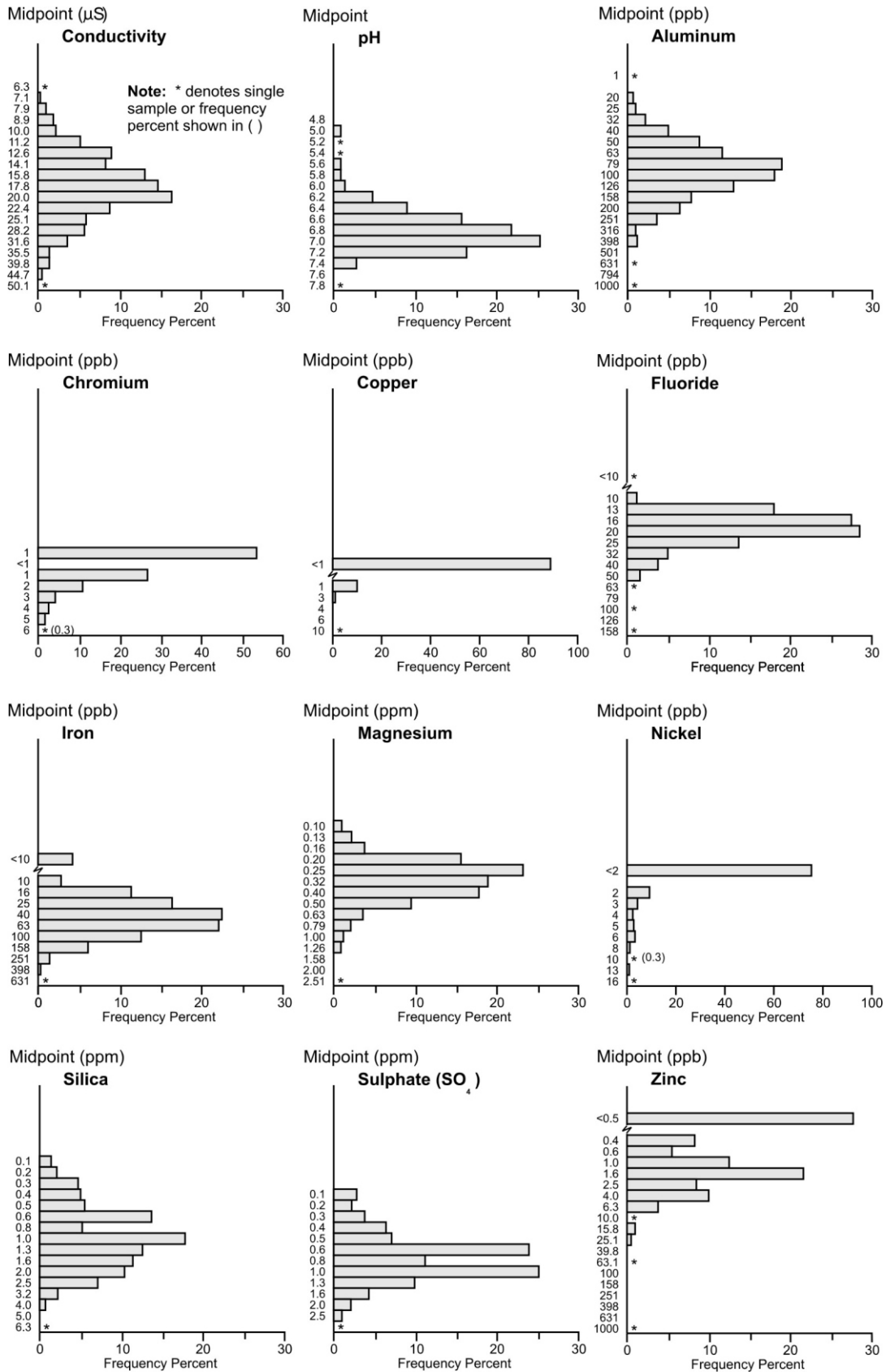
Figure 6. *Histograms of conductivity, pH, Al, Cr, Cu, F, Fe, Mg, Ni, Si, SO₄ and Zn in lake water (N = 578).*

Table 6. Spearman correlation coefficients for lake-water data (N=578)

	Al	Ba	Ca	Cr	Cu	F	Fe	K	Mg	Mn	Na	Ni	P	Si	SO₄	Sr	Ti	Zn	pH	Conductivity
Al	**1.00**																			
Ba	0.20	**1.00**																		
Ca	-0.01	0.38	**1.00**																	
Cr	0.20	0.02	-0.07	**1.00**																
Cu	0.05	0.05	0.12	-0.03	**1.00**															
F	0.13	0.46	0.53	0.01	-0.05	**1.00**														
Fe	0.59	0.35	0.23	0.11	0.02	0.39	**1.00**													
K	-0.07	0.15	0.31	-0.13	0.01	0.25	0.16	**1.00**												
Mg	0.11	0.18	0.77	0.03	0.07	0.41	0.34	0.36	**1.00**											
Mn	0.03	0.19	-0.02	-0.01	0.00	0.07	0.29	0.11	0.08	**1.00**										
Na	0.23	-0.06	0.27	-0.05	-0.01	0.19	0.34	0.25	0.52	-0.01	**1.00**									
Ni	0.15	0.06	0.04	0.63	0.02	0.08	0.12	-0.11	0.07	-0.00	-0.11	**1.00**								
P	0.37	0.15	0.11	-0.02	0.06	0.20	0.45	0.21	0.19	0.19	0.23	-0.00	**1.00**							
S	0.23	0.35	0.63	-0.01	0.00	0.57	0.26	0.10	0.59	-0.02	0.18	0.17	0.01	**1.00**						
SO₄	-0.02	0.33	0.49	-0.08	0.10	0.28	0.14	0.32	0.43	0.14	0.29	-0.08	0.03	0.23	**1.00**					
Sr	0.14	0.50	0.85	-0.02	-0.01	0.69	0.35	0.31	0.71	-0.02	0.31	0.07	0.16	0.74	0.40	**1.00**				
Ti	0.68	0.17	0.07	0.17	0.01	0.19	0.59	0.11	0.18	0.09	0.22	0.17	0.43	0.16	0.08	0.15	**1.00**			
Zn	0.21	-0.20	-0.36	0.17	0.17	-0.30	0.03	-0.11	-0.18	0.00	0.25	0.01	0.09	-0.31	-0.02	-0.31	0.18	**1.00**		
pH	-0.18	0.27	0.89	-0.08	0.07	0.47	0.04	0.28	0.72	-0.04	0.16	0.03	-0.01	0.61	0.39	0.76	-0.06	-0.44	**1.00**	
Conductivity	-0.00	0.30	0.90	-0.10	0.14	0.49	0.25	0.38	0.82	0.01	0.52	-0.04	0.14	0.52	0.56	0.78	0.10	-0.22	0.80	**1.00**
Depth	-0.24	-0.13	-0.14	0.01	-0.01	-0.20	-0.49	-0.03	-0.12	0.02	-0.18	0.00	-0.30	-0.04	0.03	-0.20	-0.17	0.03	0.00	-0.13

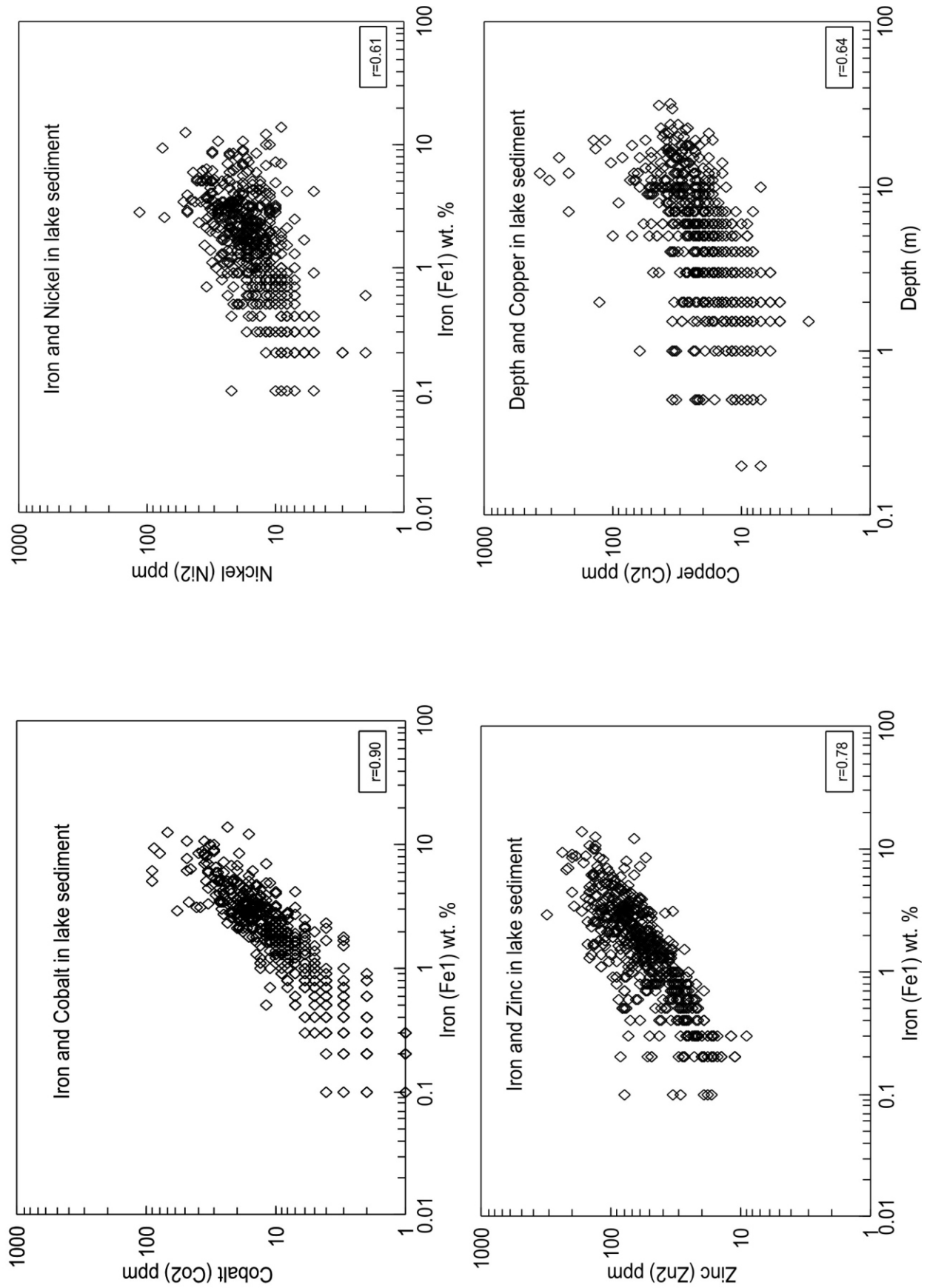Note: Correlations >|0.09| are significant at the 99% confidence level.

Figure 7. *Scatterplots of iron with cobalt, nickel and zinc and of depth with copper (N = 578).*
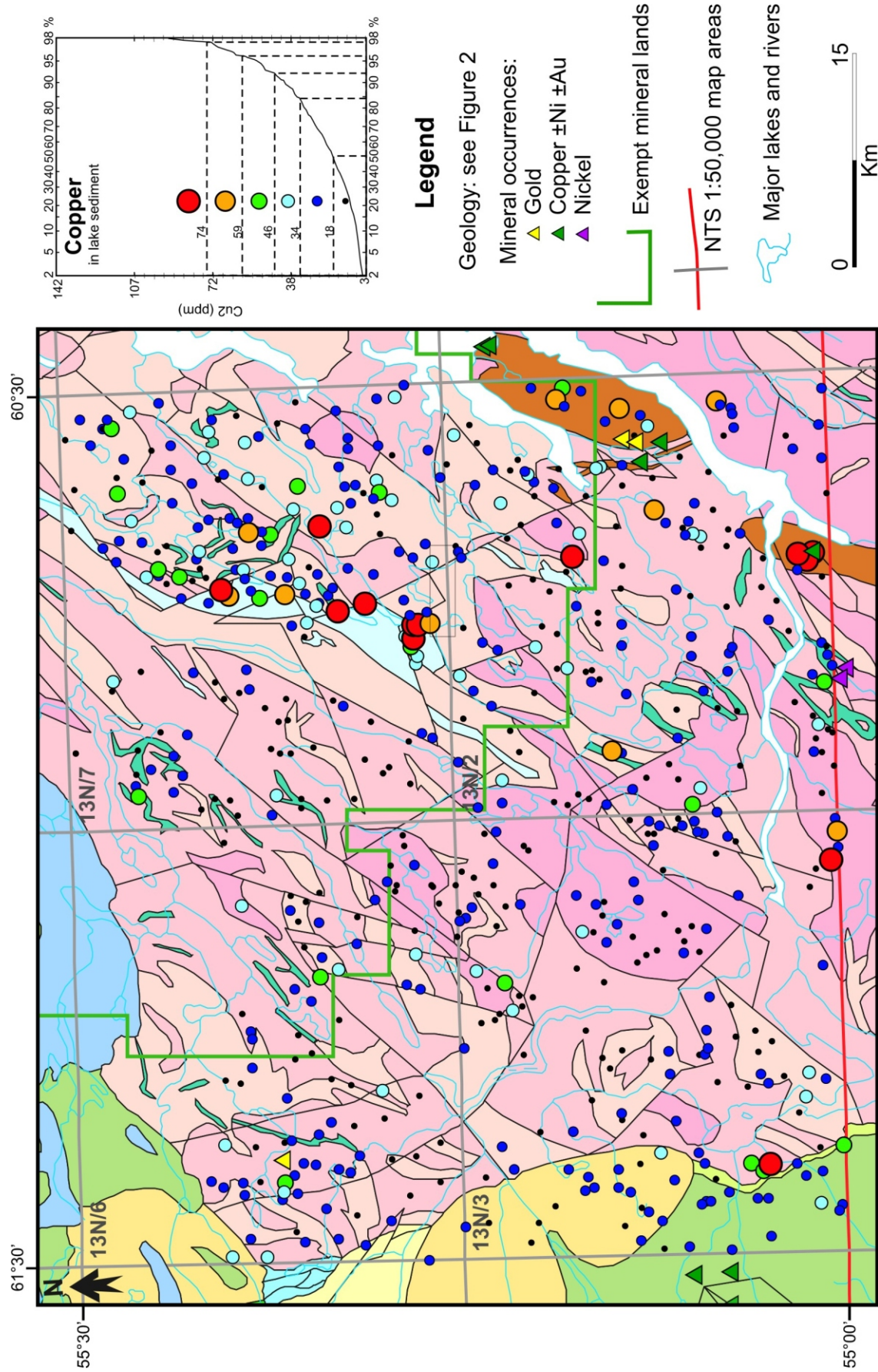
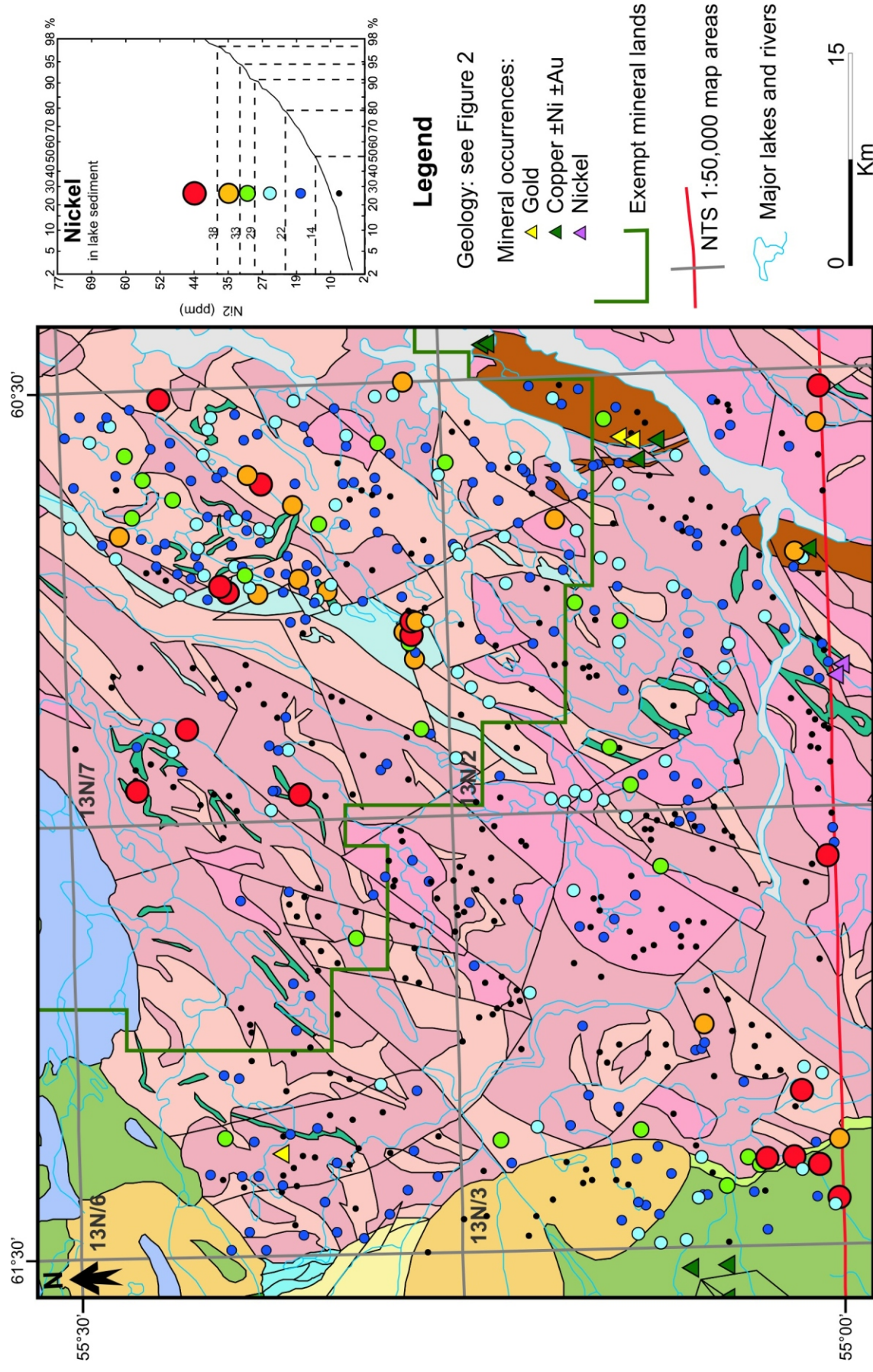**Figure 8.** *Copper (Cu2) in lake sediment.*

Figure 9. *Nickel (Ni2) in lake sediment.*

NTS map area 13N/2 is also near amphibolite. In southwest NTS map area 13N/3, a group of 4 anomalous Ni sites overlie, or are immediately down-ice of, the Harp Lake Complex. Nickel mineralization occurs about 10 km to the northeast but these sites appear to reflect either a new mineralized area or abnormally nickeliferous rocks. Two other isolated anomalous samples are found in NTS map area 13N/3, one of which is also anomalous in Cu and Pb.

Gold

The distribution of Au in sediment is shown in Figure 10. The significance of the Au pattern is problematical for two reasons. First is the fact that nearly all samples (91 percent) have Au contents below the 1 ppb detection limit and analyses near the detection limit are often unreliable. Secondly, Au in lake sediment may suffer from the 'nugget effect'. In this area, the nugget effect appears to be a factor because of the 40 pairs of site-duplicate samples, none has detectible Au in both samples (*see* Figure 3). Overall, the levels of Au in the area are disappointing and generally lower than expected in view of the earlier reconnaissance survey. In the previous survey, seven lakes had Au values in the range of 8 to 14 ppb. All of these lakes were resampled and none had detectible Au. Despite this, the results of the present work appear to be geologically meaningful. The two highest sites are in close proximity to known Au or Cu–Au mineralization in NTS map area 13N/2. As well, a lake close to a recent gold discovery by Ascot Resources in NTS map area 13N/6 is anomalous in Au (>99 percentile). Two other lakes in NTS map area 13N/7 have comparable gold values (4 to 6 ppb). An interesting cluster of 8 lakes having detectable gold (1 ppb) is located in central NTS map area 13N/3 to the east of the Adlatok River.

Arsenic

The distribution of arsenic in sediment is shown in Figure 11. Arsenic is sometimes associated with gold mineralization and can be used as a pathfinder element. The two highest gold samples are also anomalous in As (>8.1 ppm). Both of these sites occur within the Florence Lake greenstone belt. All but one of the twelve highest As sites fall within either the Hunt River or Florence Lake greenstone belts. Due the apparent nugget effect with Au analyses in this area, As may well be useful here as a gold proxy, particularly in the volcanic terrains.

GEOCHEMISTRY OF LAKE WATER

Acidity (pH)

The pH of lake water is shown in Figure 12. Five equal percentile intervals are used to group the distribution. The pH distribution is included here primarily to reflect the lithochemical nature of bedrock that may not be apparent from geology maps alone; most patterns are as would be expected. For example, the dominantly mafic Florence Lake greenstone belt and the Harp Lake Complex have alkaline signatures relative to most granitoid areas. However, some patterns within the gneisses are not explained by geological mapping. The eastern portions of the gneissic areas (NTS map areas 13N/2 and 13N/7) are more acidic than their western counterparts, perhaps suggesting that the protoliths were more felsic in the east and more mafic in the west.

Copper

The distribution of Cu in lake water is not shown. The usefulness of analyses of Cu in water suffers from the high detection limit of the ICP method. More than 89 percent of the samples are below the detection limit of 1 ppb. Two samples are highly anomalous (>99 percentile) in the southern part of NTS map area 13/N7 and two others have detectable Cu. These sites also have anomalous values of several elements in sediment. Four other anomalous sites occur in NTS map area 13N/2, 3 and 7; one of these is adjacent to known Cu mineralization. A 6-sample cluster of sites having detectable Cu is located in northeast NTS map area 13N/3. Four sites having detectable Cu are found adjacent to the Au mineralization in NTS map area 13N/6.

Nickel

The distribution of Ni in water is not shown. The analytical detection limit is also a problem with Ni but less so than with Cu; 75 percent of the samples are <DL compared to 89 percent for Cu. The distribution of the high Ni samples forms distinct but puzzling patterns. The highest values do not show a strong association with either mafic bedrock or Ni mineralization. Two samples near the Ni mineralization are elevated (>91 percentile), however, all but one of the highest samples occur in the southeast quadrant of NTS map area 13N/2, an area mapped as being underlain by granitoid and gneissic rocks. Twelve of 14 samples from the Harp Lake Complex have detectable Ni suggesting that the higher bedrock Ni values in that area are being reflected in the water.

Sulphate

The distribution of sulphate is shown in Figure 13. Intervals were chosen to depict the entire distribution with some emphasis on the highest values. Some strong spatial patterns are apparent. Most of the highest values are found in a swath across the central part of NTS map area 13N/6. No geological explanation is readily apparent for this anomaly. It includes the gold–sulphide occurrence of Ascot Resources. Another five-sample cluster of the highest group of values is located over the southern end of the Hunt River greenstone belt in NTS map area 13N/7. The area is also
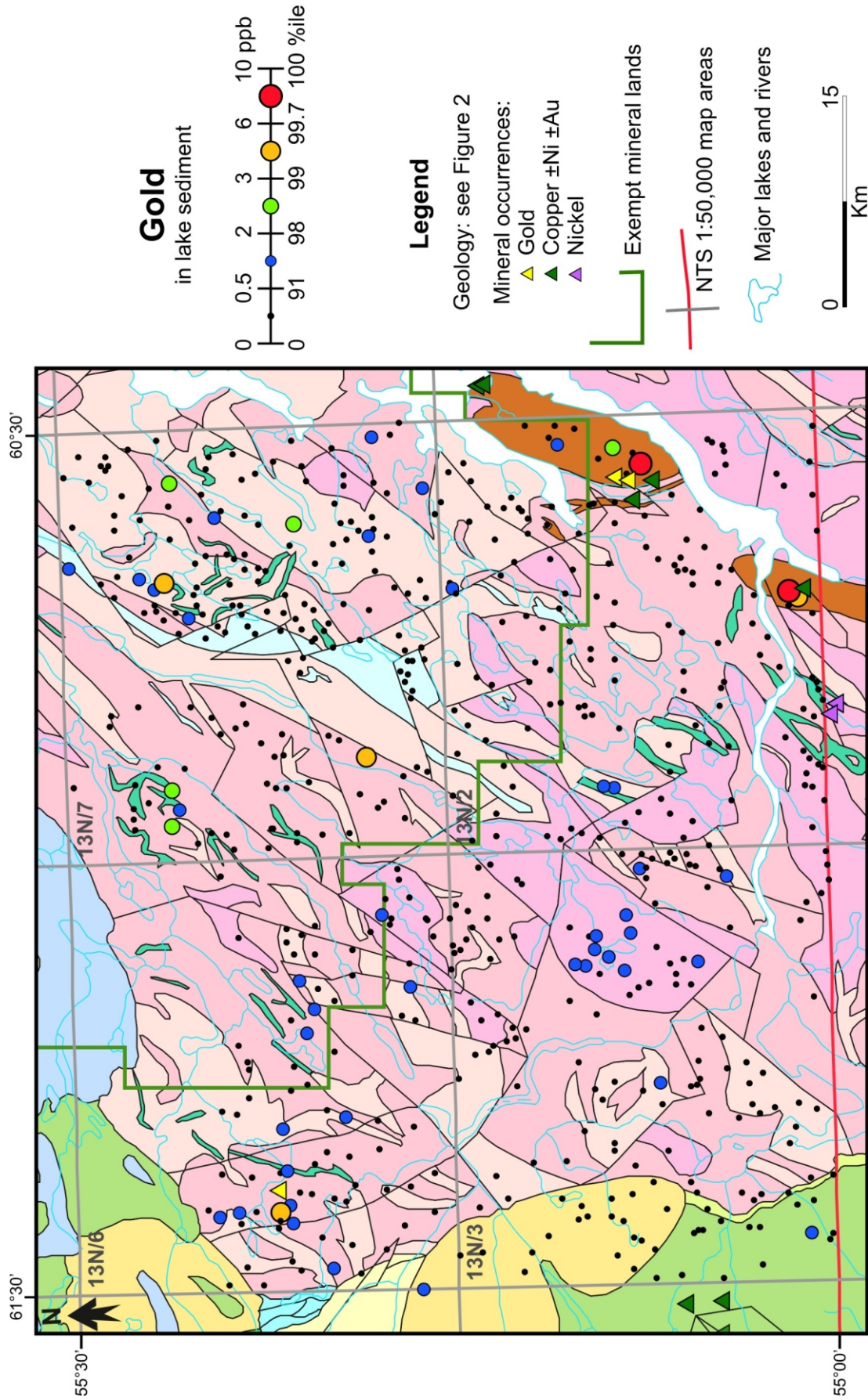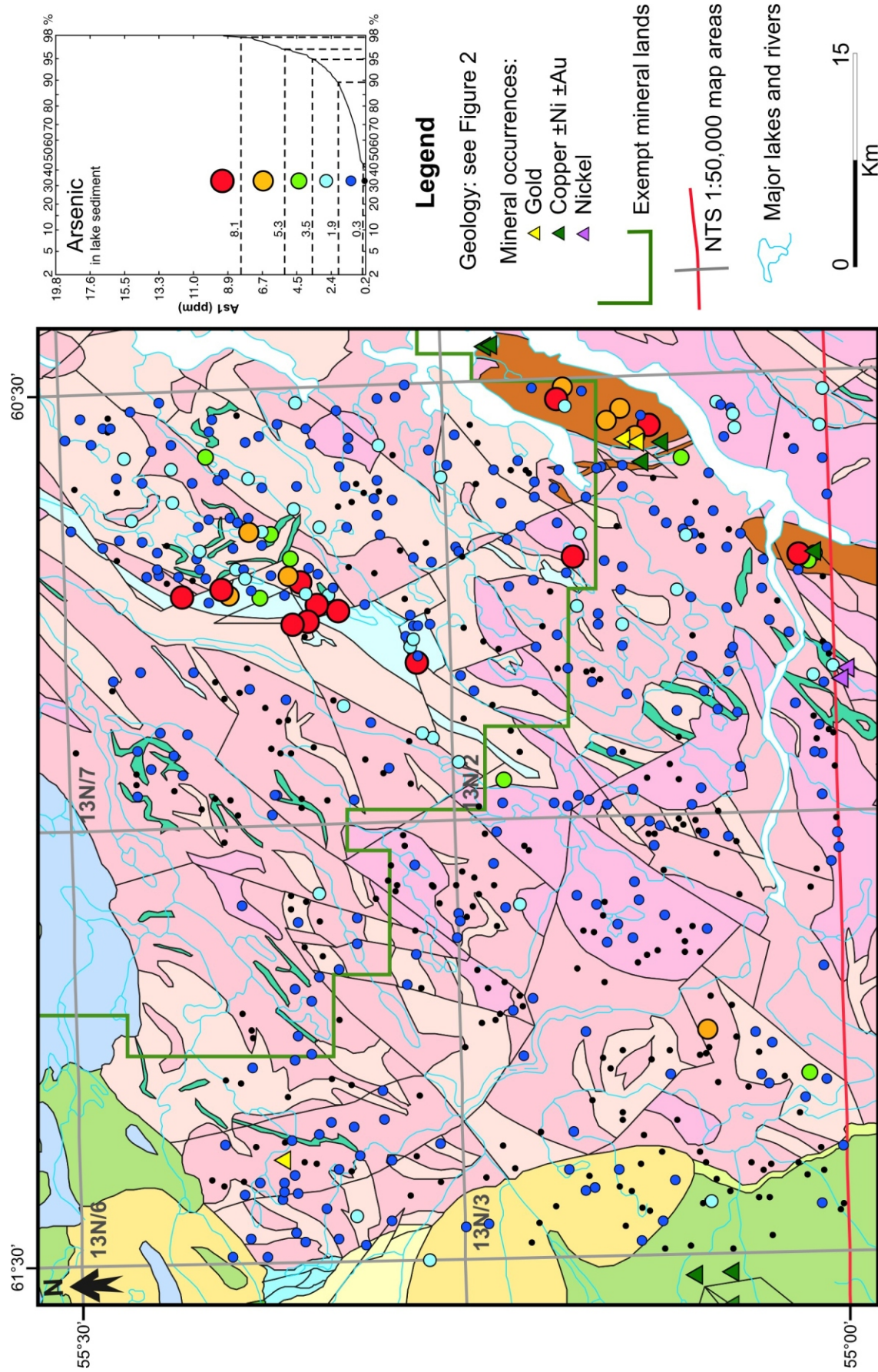
Figure 10. *Gold (Au) in lake sediment.*

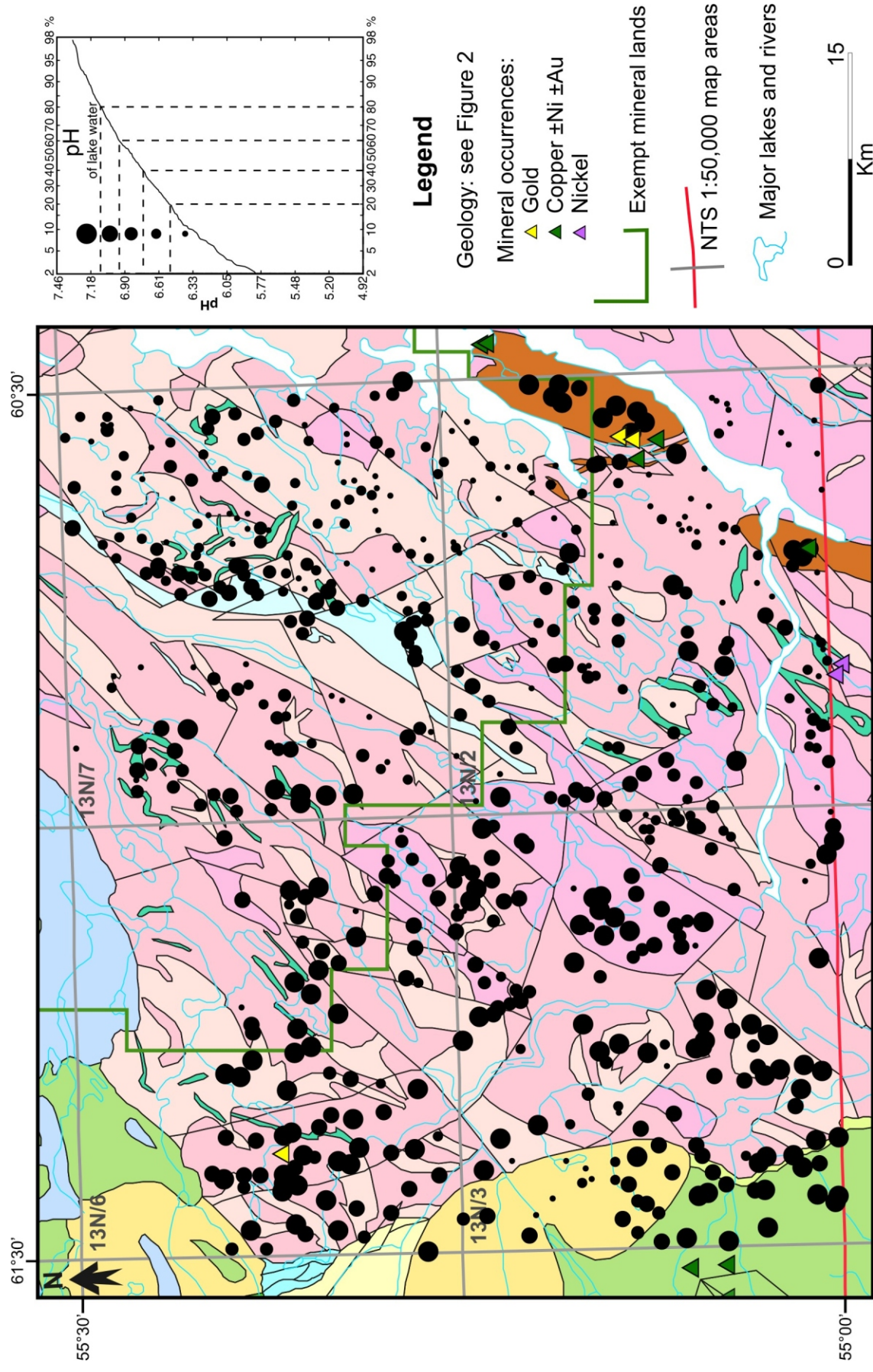**Figure 11.** *Arsenic (As1) in lake sediment.*
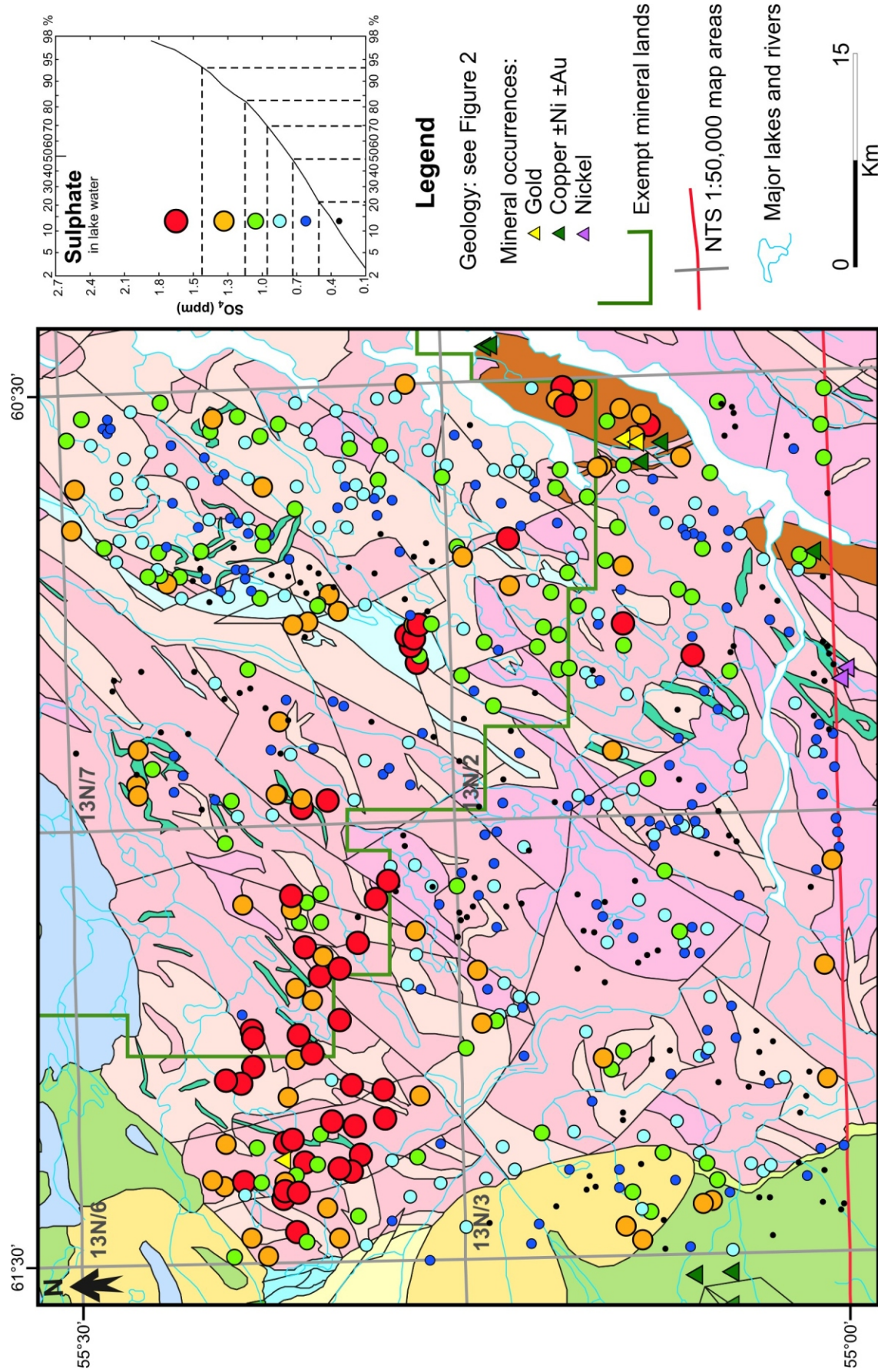
Figure 12. *pH of lake water.*

Figure 13. *Sulphate (SO₄) in lake water.*

anomalous in several elements in sediment and Cu in water. Finally, three samples from the northern segment of the Florence Lake greenstone belt in NTS map area 13N/2 are anomalous – one of these is adjacent to Cu–Au mineralization.

CONCLUSIONS

The results of geochemical mapping using high-density lake sampling include the following:

1. The method is effective in delineating mineralized areas as evidenced by anomalously high levels of Au, Cu and Ni in sediment from sites in proximity to several known mineral occurrences.

2. Prospective areas, remote from known mineralization, are identified that have lake sediments containing anomalous levels of Cu, Ni, and to a lesser extent, Au.

3. Analyses of Au in sediment are somewhat lower in this survey than the previous reconnaissance survey had suggested.

4. The significance of Au in sediment analyses in this area appears compromised by the nugget effect as evidenced by the lack of reproducible results in site-duplicate samples in which one of the pair had detectible Au.

5. Arsenic may act as a gold pathfinder in the Hunt River and Florence Lake greenstone belts as evidenced by high levels in samples near greenstone-hosted gold mineralization.

6. Analyses of pH in lake water suggest that the protoliths of gneiss and granitoid rocks were more mafic in the western part of the area than in the east.

7. The significance of Cu and Ni analyses in lake water is problematical, in part, due to high detection limits. However, the presence of contiguous watersheds having high values suggests that the data reflect real geological conditions. The highest Cu value is coincident with a cluster of high values in sediment.

ACKNOWLEDGMENTS

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