32. Lake Sediment Geochemistry: Canadian Applications in the Eighties

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ABSTRACT

In the 1980s, advances in lake sediment geochemistry have been concentrated toward further development of field methods, preparation and analytical techniques, data interpretation and presentation, and an understanding of lake bottom characteristics. The most significant advances were in the study of the response of lake sediment and water to a number of different types of mineralization, principally gold, tin, tungsten, the rare earth elements, and the platinum group elements. New exploration applications in the 1980s for lake sediment geochemistry were a direct result of this work. During the 1980s there has been increased lake sediment survey coverage of Canada and increased application of these data for addressing environmental and public health concerns.

INTRODUCTION

Chemical, physical, and biological processes can interact within lakes to control the transport, accumulation, and fixation of elements into the sediments. Variations in the physicochemical–limnological conditions of a lake can effect the nature of the trace metal response of the sediments to mineralization, geographic–climatic, and geological environments. Descriptions of these processes and conditions and how they effect the mobilization, transport, and fixation of trace elements within a lake have been previously published, for example Coker *et al.* (1979), Cameron (1980, in press) and will not be discussed further.

Significant advances in the 1980s have been made in the understanding of glacial and post–glacial processes of lake formation by using acoustic subbottom profiling to map the glacial and lacustrine sediment facies (Shilts and Farrell 1982; Laroque 1985). The amount and nature of bottom fill could be of critical importance in evaluating the inflow effects of increasingly acid surface waters and groundwaters, expected to be generated by acid rain (Shilts and Farrell 1982).

Lake sediment geochemistry was originally developed for base–metal exploration where it continues to be used. In the 1970s, the use of lake sediment geochemistry for uranium exploration was widespread and successful (Coker *et al.* 1979; Cameron, in press). The application of lake sediment geochemistry for gold, tin, tungsten, platinum group elements (PGE), and rare earth elements (REE) is the quest of the 1980s. The 1980s have also seen a dramatic increase in the lake sediment geochemical coverage of Canada, amounting to over 1 million km^2. The use of these data for addressing environmental and public health concerns has also been demonstrated (Coker and Shilts 1979; Fortescue 1985; Hornbrook *et al.* 1986).

This paper highlights some recent advances in acoustic subbottom profiling of lake basins, lake sediment geochemical survey coverage of Canada, and new applications for lake sediment surveys in mineral exploration.

LAKE BASINS

Maps drawn from the interpretations of acoustic subbottom profiles of lakes in the Canadian Shield can show the distribution and physical characteristics of modern–day lake sediments and unconsolidated sediments related to glacial processes (Klassen and Shilts 1982; Shilts and Farrell 1982; Shilts 1984; Larocque 1985). At Big Turkey Lake, Environment Canada's test site north of Sault Ste. Marie, subbottom characteristics (Figure 32.1) and the distribution of bottom sediments have been outlined by Shilts and Farrell (1982). Modern–day organic lake sediment or gyttja is not uniformly distributed throughout the lake, but is concentrated in thicker layers in the profundal basin where it constitutes an ideal sample site location. The sediment is usually greenish grey to brownish coloured with a variable organic content and consists of diatoms, pollen, algae, spore cases, and fibrous organic material all in a mush of organics and clay minerals frequently with oxides and hydroxides of Mn and Fe (Dunn 1980). Fluvial deltaic sands were found only at the southeast inlet of Big Turkey Lake but can also be found elsewhere in many other lakes. The gyttja may be underlain by till, proglacial laminated sediments, fluvial deltaic sand, or be in direct contact with bedrock. An acoustic subbottom profile of the lake (Figure 32.2) shows the shadow of deep bedrock depressions filled with glacial sediments, probably under proglacial conditions (Klassen and Shilts 1982). The whitish area, marked gyttja (*see* Figure 32.2), is the modern surface lake sediment. With this much clastic sediment within a lake basin and groundwater flow through these and adjacent clastic sediments at

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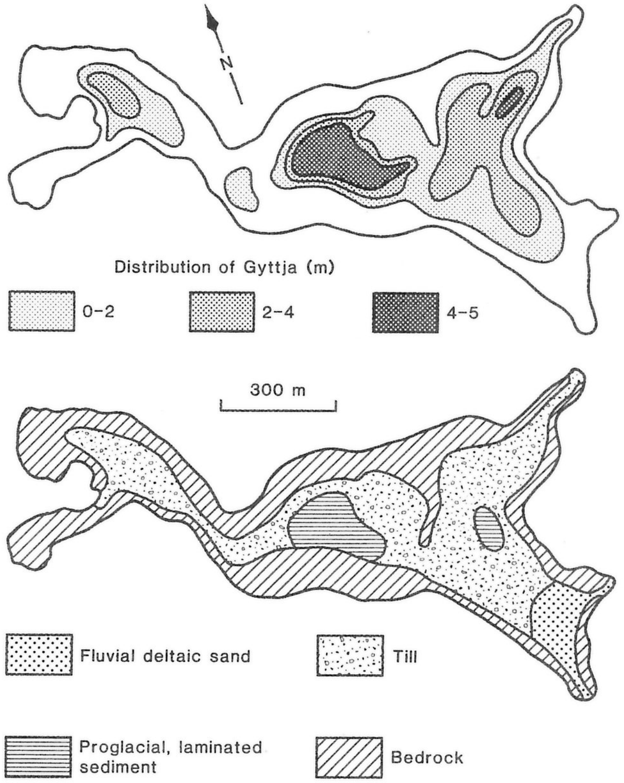

Figure 32.1. *Thickness and distribution of modern-day lake sediments and the distribution of bedrock and, glacial or proglacial sediments at Big Turkey Lake, Ontario (after Shilts and Farrell 1982).*

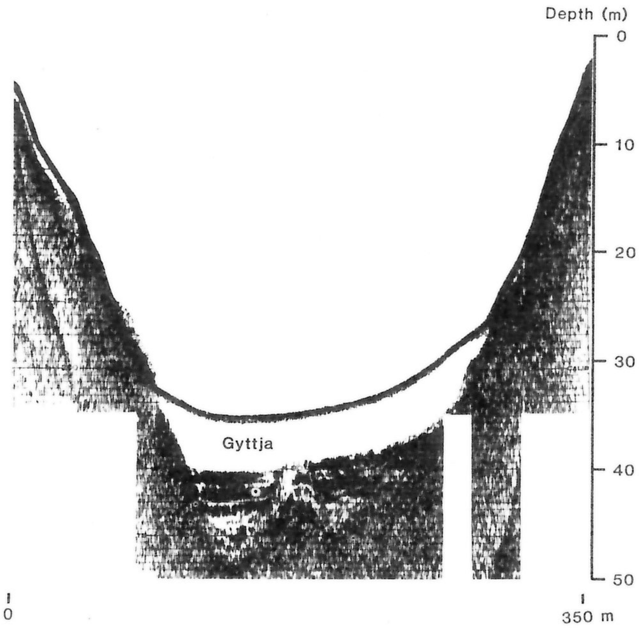

Figure 32.2. *Acoustic subbottom profile across Big Turkey Lake, Ontario (after Klassen and Shilts 1982).*

the surface, either of which may not be locally derived, the chemistry of the lake could be significantly influenced by their chemistry. This is dramatically evident where Paleozoic carbonate rocks from the Hudson Bay area have been glacially transported to the southwest and deposited on the granitic gneiss terrain along the north shore of Lake Superior, resulting in buffered alkaline lakes rather than the usual acidic lakes of the Canadian Shield (Figure 32.3) (Coker and Shilts 1979). It is necessary to understand the provenance and sediment characteristics of modern–day lake basins to know which factors play a dominant role that could effect the interpretation of lake sediment geochemical data.

REGIONAL GEOCHEMICAL SURVEYS

National Geochemical Reconnaissance (NGR) lake sediment surveys at the Geological Survey of Canada (GSC) began in the early 1970s (Hornbrook and Gleeson 1972; Davenport *et al.* 1974), expanded considerably under the Uranium Reconnaissance Program from 1975 to 1979 (Darnley *et al.* 1975) and after a slow period of a few years in the early 1980s were again nationally applied in 1984 under various Mineral Development Agreements with the Provinces.

These surveys, carried out by the Geological Survey of Canada, by the Provinces or jointly under various agreements, have covered significant areas of Canada (Figure 32.4) amounting to over 1.1 million km^2. The coverage of Canada by other types of NGR surveys totaling about 0.8 million km^2 is also shown in Figure 32.4. Some Cordilleran stream survey areas contain minor areas of lake surveys. Lake sediment coverage in Québec (Figure 32.5) (M. Beaumier, Geochemist, Ministère de l'Energie et des Ressources (MER), Québec, personal communication, 1987) has been undertaken by the Provincial Ministry since 1983, generally at a sample density of 1 sample per 13 km^2. Other large surveys were carried out by the Sociétés de Développement de la Baie James (SDBJ) in 1973 and 1974, at an average density of 1 sample per 7 km^2, and by Soquem in 1976 and 1977 at an average density of 1 sample per 2 km^2.

The NGR lake sediment work in Canada is part of a national systematic methodology with specifications for collection, preparation, analysis, and publication, all of which are quality controlled. For 18 years, the Geological Survey of Canada has played the major role in developing the technology and carrying out NGR survey programs to provide a systematic high–quality geochemical data base across Canada.

The data base is used by industry for mineral exploration, by governments for assessment of resources, and as an aid to geological mapping. It is also relevant to environmental and public health programs.

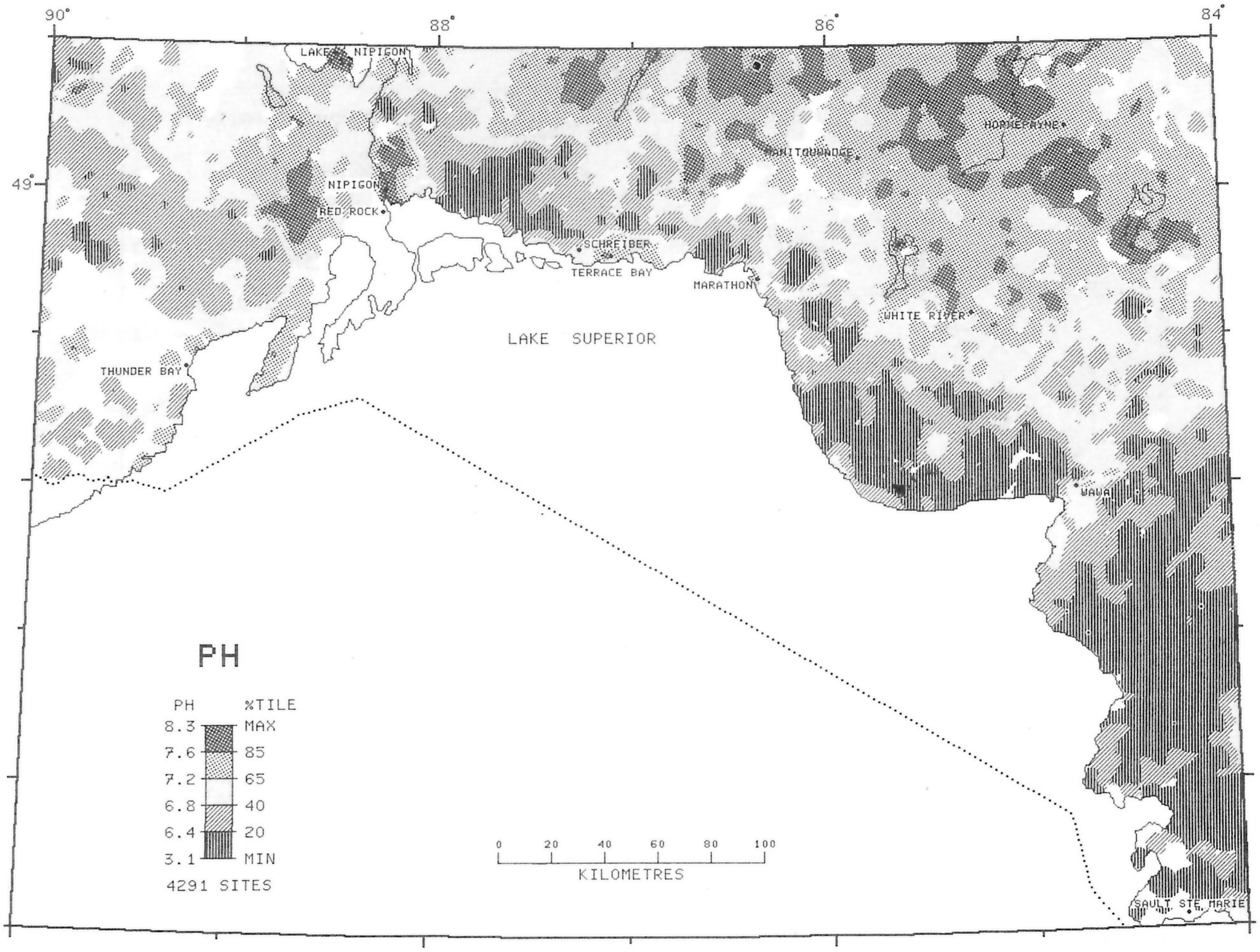

Figure 32.3. *Distribution of acid to alkaline lakes based on lake water pH, north shore Lake Superior, Ontario (after Coker and Shilts 1979).*

NEW EXPLORATION APPLICATIONS

TIN

In 1985, the effectiveness of using lithophile elements in regional lake bottom sediment surveys was tested over the East Kemptville tin deposit area of Nova Scotia (Rogers and MacDonald 1985; Rogers and Garrett 1987). The deposit is located on a topographic high of granitoid rocks surrounded by low–lying till plains on which most of the regions' lakes have been developed. The tin mineralization, with traces of tungsten, is found in a greisen zone along the contact of the Davis Lake Granitoid Complex with metasedimentary rocks of the Meguma Group (Chatterjee and Strong 1984). A subset of 55 archived regional samples was selected from the deposit area and analyzed for Sn, Rb, F, and Cl. Anomalous values of Sn, Rb, and F were found to be related to the tin deposit and showed no relationship to the organic content (LOI) of the samples.

Following the preliminary test, a more comprehensive study was carried out using Sn, W, Au, U, and other element data from 167 sites located in the tin deposit area. Anomalous Sn–bearing lakes (Figure 32.6), found in the major study, are radially distributed south, southeast, and southwest of the deposit. The W pattern (Figure 32.7) is similar but not as strong a regional anomaly as Sn (Rogers 1986). The less intense W anomalies may simply be a reflection of the less extensive wolframite mineralization. The radial down–ice pattern of Sn and W distribution has probably been controlled by topography, relief, and the polyphase glacial movements in the area (Stea and Grant 1982). The anomaly at South Horseshoe Lake (*see* Figures 32.6 and 32.7) indicates a translation distance of up to 17 km from the deposit. This significant distance of transport has almost certainly involved some glacial transport of Sn and W in the till. Evidence of mechanical transport in till is revealed at Moosefly Lake where the lake sediment was found to contain discrete grains of clean, sharp angular cassiterite in addition to numerous grains of zircon, monazite, and magnetite. Therefore, the 32 ppm Sn anomaly in Moosefly Lake is probably due to the presence of cassiterite

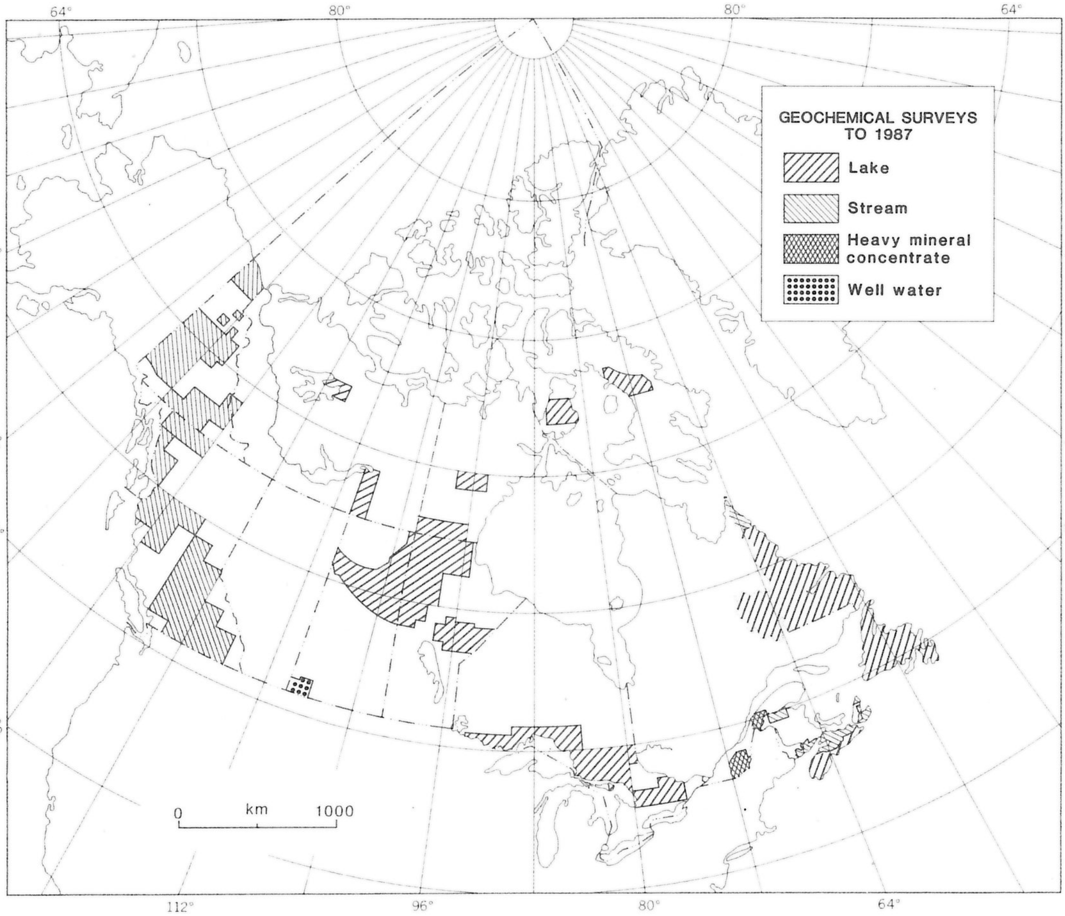

Figure 32.4. *National Geochemical Reconnaissance (NGR) survey coverage of Canada, 1973 to 1987.*

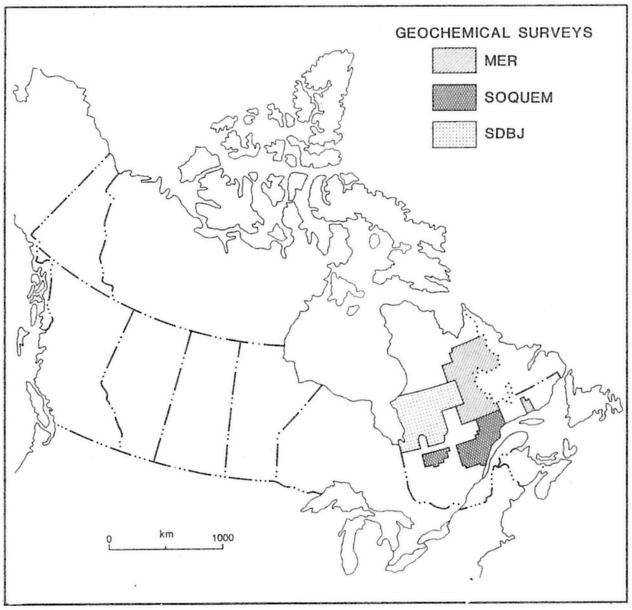

Figure 32.5. *Lake sediment geochemical survey coverage of Québec, 1973 to 1987.*

grains in the sample (Rogers and Garrett 1987). Further, the cassiterite grains in the Moosefly Lake sediment have a clean angular nature indicating minimal abrasion and waterborne transport. The cassiterite grains could have been moved from the deposit several kilometres to the immediate catchment basin of the lake by glacial transport. The common dispersal model of glacial clastic dispersion followed by hydromorphic dispersion into lake basins (Timperley and Allan 1974; Coker and Nichol 1975; Coker *et al.* 1979) must be reconsidered for lithophile elements present as refractory grains with more emphasis on mechanical dispersion. In contrast, for a test set of lake sediment samples collected from the tin-mineralized Ackley Granite area, Newfoundland, Davenport found no response for Sn (Davenport 1981).

TUNGSTEN

A good example of the effective use of W in lake sediment surveys was described by Davenport and Butler (1982, 1983). Their survey covered over 2000 km^2 of granitoid rocks in south-central Newfoundland defining several areas anomalous in W, particularly in the Granite–Meelpeag Lakes area

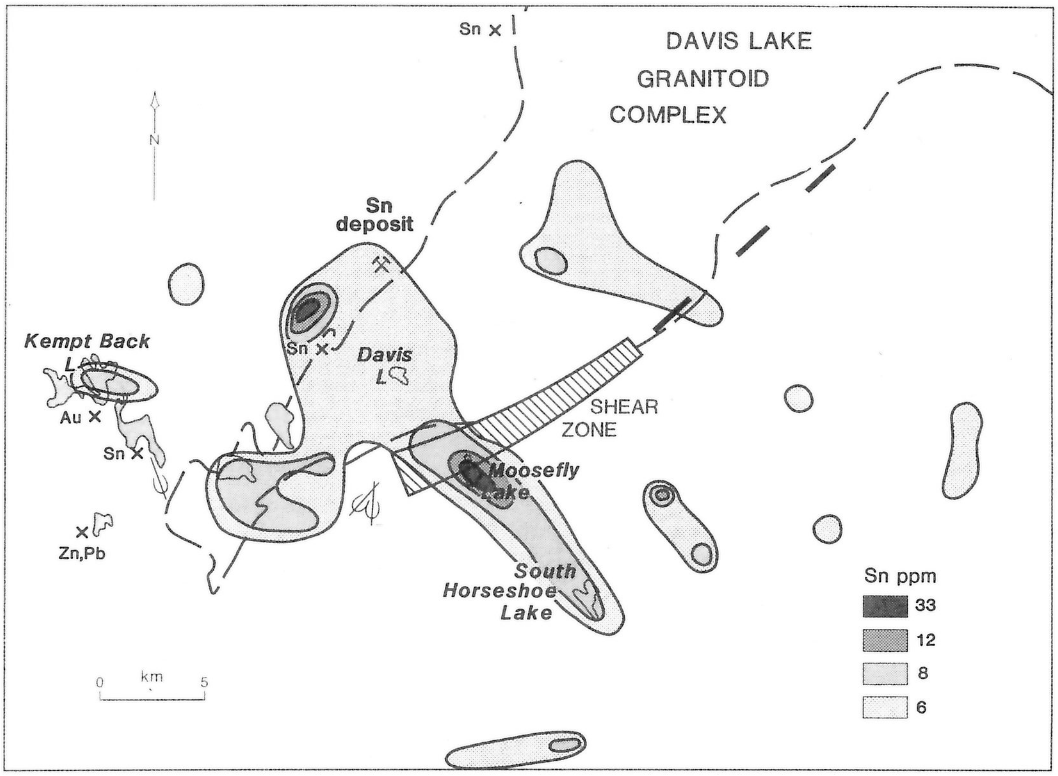

Figure 32.6. *Distribution of Sn in lake sediments; East Kemptville tin deposit area, Nova Scotia (modified after Rogers 1986).*

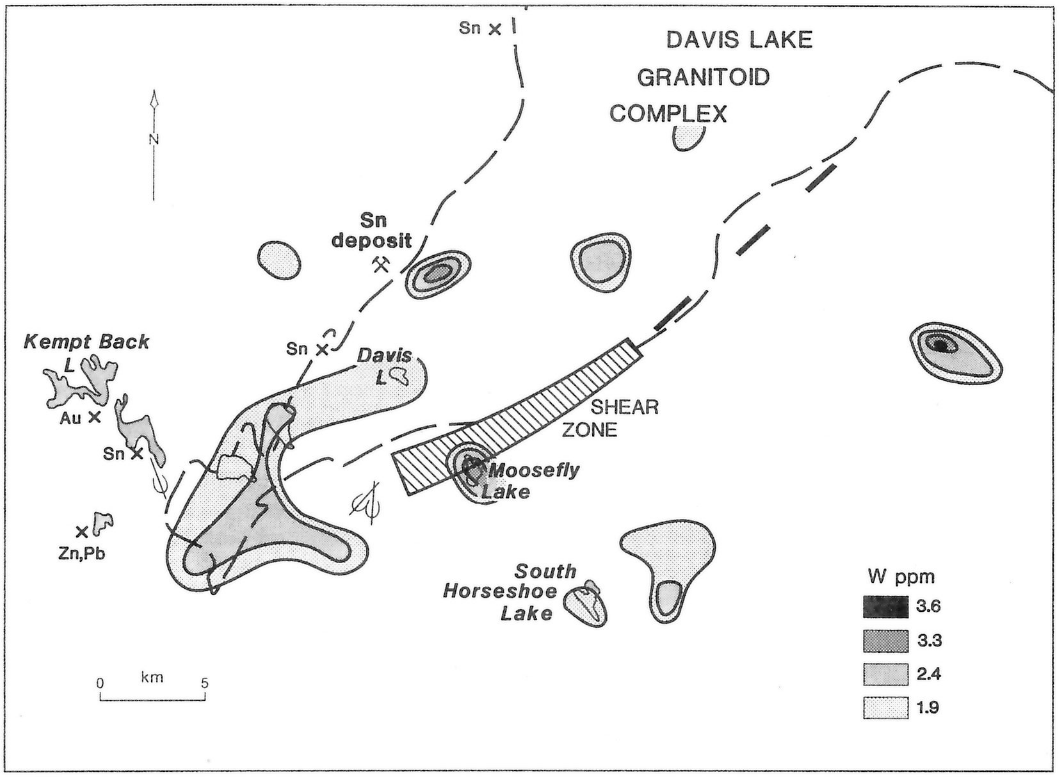

Figure 32.7. *Distribution of W in lake sediments; East Kemptville tin deposit area, Nova Scotia (modified after Rogers 1986).*

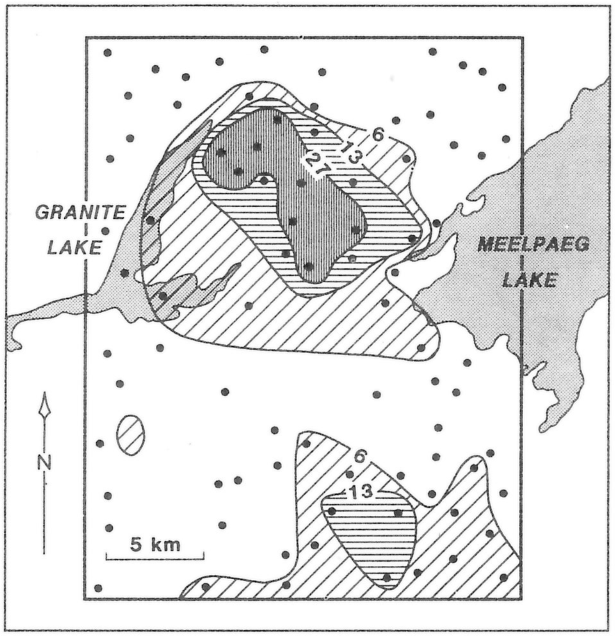

Figure 32.8. *Distribution of W (ppm) in lake sediments at Granite – Meelpaeg Lakes, south-central Newfoundland (after Davenport and Butler 1982).*

(Figure 32.8) (Davenport and Butler 1982). The 25 km^2 area of mainly wolframite and molybdenite mineralization between Granite and Meelpeag Lakes is within and external to a massive pink biotite–muscovite granite and is also related to north–northwest– and northeast–trending fractures (Tuach and Delaney 1987).

As shown in Figure 32.8, at a regional sampling density of about one sample per 4 km^2, the central target and general areas of W mineralization are clearly defined by the 27 ppm W contour and a background cut–off contour of 6 ppm W. According to Davenport and Butler (1982), W does appear to be mobile in surface waters, dispersing in the drainage system and then concentrating in the lake sediments of the area. The source of the anomalous W is likely to be the tungsten mineralization, but some portion of the W may also be derived from the tungsten–rich (5 to 50 ppm) micas in the granitoid rocks (Davenport and Butler 1982). Therefore, W in lake sediments have effectively located an area of known tungsten mineralization. As a result, W analysis was added to some NGR lake sediment surveys beginning in 1984.

RARE EARTH ELEMENTS

Data for La and REEs were compiled from 136 analytical pairs of lake sediment samples and lake sediment reference standards to determine ranges, means, and to establish detection limits (P.H. Davenport, Senior Geochemist, Newfoundland Department of Mines and Energy, St. John's, Newfoundland, Canada, personal communication, 1987). These data, which are summarized in Table 32.1, were produced by multi–element neutron activation analysis. The data indicate sufficient range for geochemical contrast in lake sediments was found and, except for Eu, the ranges are readily detectable. There is some difference in the detection limits quoted and those actually acceptable.

An example of the effective use of REEs in lake sediment geochemical exploration is described at the Strange Lake Zr–Y–Nb–Be–REE deposit (J.W. McConnell, Geochemist, Newfoundland Department of Mines and Energy, St. John's, Newfoundland, Canada, personal communication, 1987). The deposit is in a peralkaline granite complex on the provincial border with Québec, 145 km west of Nain, Labrador.

The deposit was discovered in 1979 by the Iron Ore Company of Canada during an exploration program following up U and F anomalies in lake sediments and waters shown on geochemical maps released under the Canada—Newfoundland Uranium Reconnaissance Program (Geological Survey of Canada 1979).

Samples of till, stream and lake sediment, and water were collected over 800 km^2 of the granite hosting the deposit (McConnell and Batterson 1987). Glacial erosion forms an eastward dispersal pattern up to 40 km in length in the various sample media. Dispersal patterns in till are strong, linear, and narrow, relative to the somewhat wider pattern found in the streams for a number of indicator elements including Be, Pb, Nb, La, and Y. Lakes, which provide the widest dispersal pattern, were initially proven useful for Be and Pb in the sediment and F in the water. Additional data for La and REEs in lake sediment (J.W. McConnell, Geochemist, Newfoundland Department of Mines and Energy, St. John's, Newfoundland, Canada, personal communication,1987) have produced very long broad down–ice direction anomalies as illustrated by Yb (Figure 32.9). The heavier REEs provide a stronger dispersal pattern. The spatial distribution and contrast of the La and REE anomalies in lake sediment are as effective as related elements in other sample media for delineating a strong regional geochemical target. Lake bottom sediment surveys including La and REE data have a high potential for successful application in other areas of Canada.

PLATINUM GROUP ELEMENTS

There is very little published data on the content and distribution of PGEs in lake sediments of the Canadian Shield. The author has acquired a limited data set for 165 lake sediment samples from five mafic/ultramafic areas of PGE mineralization in northwestern Ontario (P.W.B. Friske, Head, Regional Studies Section, Geological Survey of Canada, Ottawa, personal communication, 1987). Archived samples from regional geochemical surveys in this area were

TABLE 32.1. DATA FOR La AND REE'S PRODUCED BY MULTI-ELEMENT NEUTRON ACTIVATION ANALYSIS.

ELEMENT	DETECTION LIMIT PPM		ABUNDANCE IN LAKE SEDIMENT PPM	
	QUOTED	ACTUAL	RANGE	GEOMETRIC MEAN
Ce	3	3	4.8 - 608	102
Eu	0.2	≈0.5	<0.2 - 5.3	1.2
La	1	1	5.7 - 304	44
Lu	0.05	≈0.05	<0.05 - 3.5	0.4
Sm	0.1	≈0.1	0.34 - 53	7.3
Tb	0.5	0.5	<0.5 - 9.3	1.1
Yb	0.1	≈0.5	<0.1 - 27.3	2.1

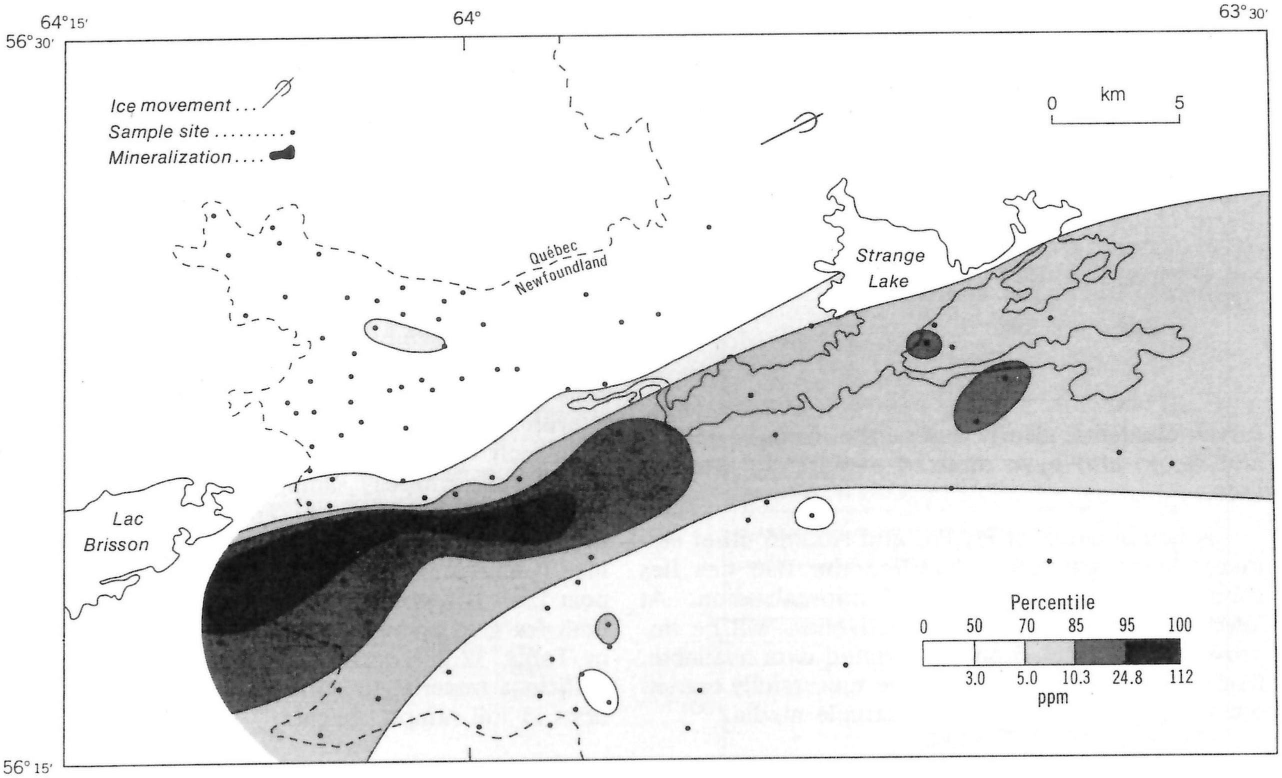

Figure 32.9. *Distribution of Yb in lake sediments; Strange Lake REE deposit, Labrador (J.W. McConnell, Geochemist, Newfoundland Department of Mines and Energy, St. John's, Newfoundland, Canada, personal communication, 1987).*

retrieved and analyzed for Pt, Pd, and Au by a Pb fire assay–inductively coupled plasma–mass spectrometer method. Results from the Lac des Iles area are shown in Figure 32.10 The Roby Zone, the largest showing of several PGE occurrences in the area, is located about 1 km south of Lac des Iles at the "X" within the Lac des Iles gabbro.

Anomalous levels of Au, Pt, and Pd occur in the vicinity of the mineralization (*see* Figure 32.10) and show evidence of down–ice displacement of the anomaly. The highest Pt value of 15 ppb was found in the sample from Camp Lake which is the focal point for the drainage system around the Roby zone. The median Pd value for samples from the area is 6 ppb compared to 2 ppb for the total data set. This is evidence of some enrichment of Pd levels in the lakes reflecting the mineralization and/or the ultramafic complex.

Although detection limits of 1 or 2 ppb have since become available, work is still in progress (G. Hall, Head, Analytical Method Development, Geological Survey of Canada, Ottawa, personal communication, 1987) to further lower these to 0.1 ppb for Pt and Pd to better define background levels of Pt and Pd distribution. Additional data for Cu, Ni, Co, Cr, and Mg, as well as other routine regional

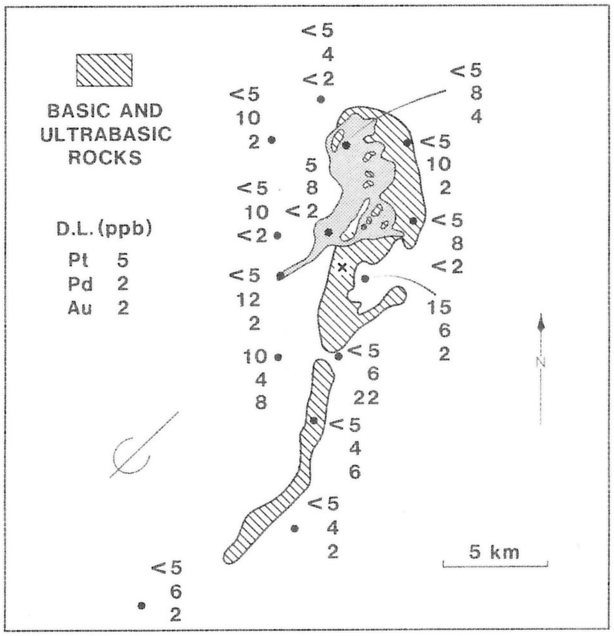

Figure 32.10. *Distribution of Pt, Pd, and Au in lake sediments, Lac des Iles Area, northern Ontario (Roby zone X) (P.W.B. Friske, Head, Regional Studies Section, Geological Survey of Canada, Ottawa, personal communication, 1987).*

survey elements, clearly outline the intrusive gabbro and would also have directed exploration into the area.

A combination of Pt, Pd, and Au and other elements have regionally identified the Lac des Iles gabbro and targeted areas of mineralization. At lower detection limits, the effectiveness will be improved. It appears, from the limited data available, that exploration for PGEs can be successfully carried out using lake sediments as a sample media.

GOLD

Currently, much exploration is focused on the search for gold in Canada and worldwide. Centre–lake bottom sediments have been employed as a geochemical sample media in exploring for gold. The interpretation of lake sediment gold data can be difficult, as illustrated below, because of its nature and distribution—a feature commonly referred to as the nugget effect or particle sparsity effect (Harris 1982). As described by Harris, gold only needs to be present as microscopic dust to randomly cause the problem of unacceptable precision in repeat analysis. The work of Coker *et al.* (1982) and Gregoire (1985) have demonstrated that particulate gold as well as organically or chemically bound forms commonly occur together in lake sediments. Fortunately, many of the commonly associated pathfinder elements for gold such as As, Mo, Sb, Hg, W, and, U do not have this problem.

The table of gold values (Table 32.2) illustrates the best and the worst situations that may occur with gold data from lake sediments. These data were selected from thousands of pairs of gold determinations from 1987 Ontario and Manitoba data sets. In most cases, the repeats were close or similar in the sense that the site was still considered anomalous. For example, 8 to 9 ppb or 3 to 2 ppb are similar and 32 to 17 ppm is still anomalous. However, 394 to <2 ppb and 172 to <2 are a problem and likely reflect the nugget effect. In some ways <1 to 17 ppb is even a worse situation, because in most cases, values such as 394 or 172 would be routinely reanalyzed, whereas samples with below detection limit values would not be. This situation may result in non–detection of anomalous sites. In rare cases, insufficient sample material was available for a repeat (i.e. 125 ppb value on 2.8 gm). The detection limit for gold changes with sample weight, as shown in Table 32.2, confirming the necessity to collect sufficient material to allow at least two determinations at full sample weight.

TABLE 32.2. GOLD VALUES FROM LAKE SEDIMENTS.

Au-1 (ppb)	Au-2 (ppb)	Wt-1 (gms)	DL-1 (ppb)	Wt-2 (gms)	DL-1 (ppb)
8	9	10.0	1	10.0	1
2	5	10.0	1	10.0	1
6	<1	10.0	1	10.0	1
394	<2	10.0	1	5.0	2
172	<2	10.0	1	5.0	2
<1	17	10.0	1	10.0	1
32	17	10.0	1	10.0	1
11	3	10.0	1	2.5	4
125	–	2.8	4	–	–
4	14	10.0	1	1.0	10
3	2	10.0	1	10.0	1
4	2	10.0	1	7.5	1

It appears that the gold reproducibility problem is less evident in lake sediments as the organic content increases. This is illustrated by a modified plot of 50 duplicate gold analyses on lake sediments from northwestern Ontario (Figure 32.11). Gold repeat values are more variable in samples with lower loss on ignition (LOI) values. Of the 22 samples with less than 11 percent LOI, five had repeat gold values where the gold changed from background to anomalous or the reverse. In the range of 11 to 19 percent LOI, two pairs changed and where LOI values exceeded 20 percent, no pairs changed. This is not a guarantee that samples with high LOI values over 20 percent will never have a nugget effect problem, but is an indication that they have a significantly better chance of acceptable repeatability. The geometric mean for Canadian Shield, Boreal Forest lake bottom sediments exceeds 20 percent LOI (Coker *et al.* 1979). The increased variability in the low LOI range probably reflects the largely clastic character of the sediment and the greater possibility of containing detrital gold.

Unlike many other elements, one of the benefits of using gold is that it is not influenced by organics, Mn, or Fe in lake sediments. This is demonstrated in Figure 32.12 where the X–Y plots of Au versus Fe, Mn, and LOI, using data from northern Ontario, show no demonstration of a sympathetic relationship (P.W.B. Friske, Head, Regional Studies Section, Geological Survey of Canada, personal communication, 1987). Gold values will, therefore, most often be reflecting enhanced bedrock concentrations and/or gold–bearing mineralization rather than false anomalies generated by the scavenging action of Fe and Mn oxides and hydroxides or organics.

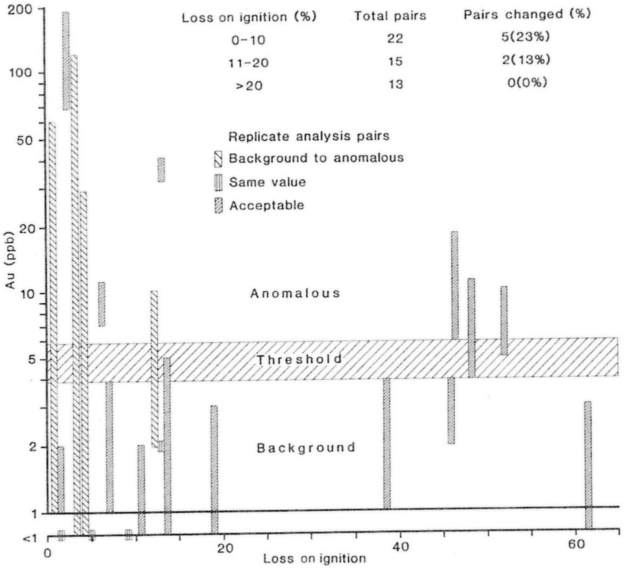

Figure 32.11. *Replicate pair Au analyses in relation to the organic content of the lake sediment samples. The ends of the vertical bars represent the two gold values.*

Evidence of successful regional gold exploration using lake sediments is provided in the East Kemptville, Nova Scotia area previously described. The Kempt Back Lake gold mineralization (Figure 32.13) was detected (Rogers 1986) and a new

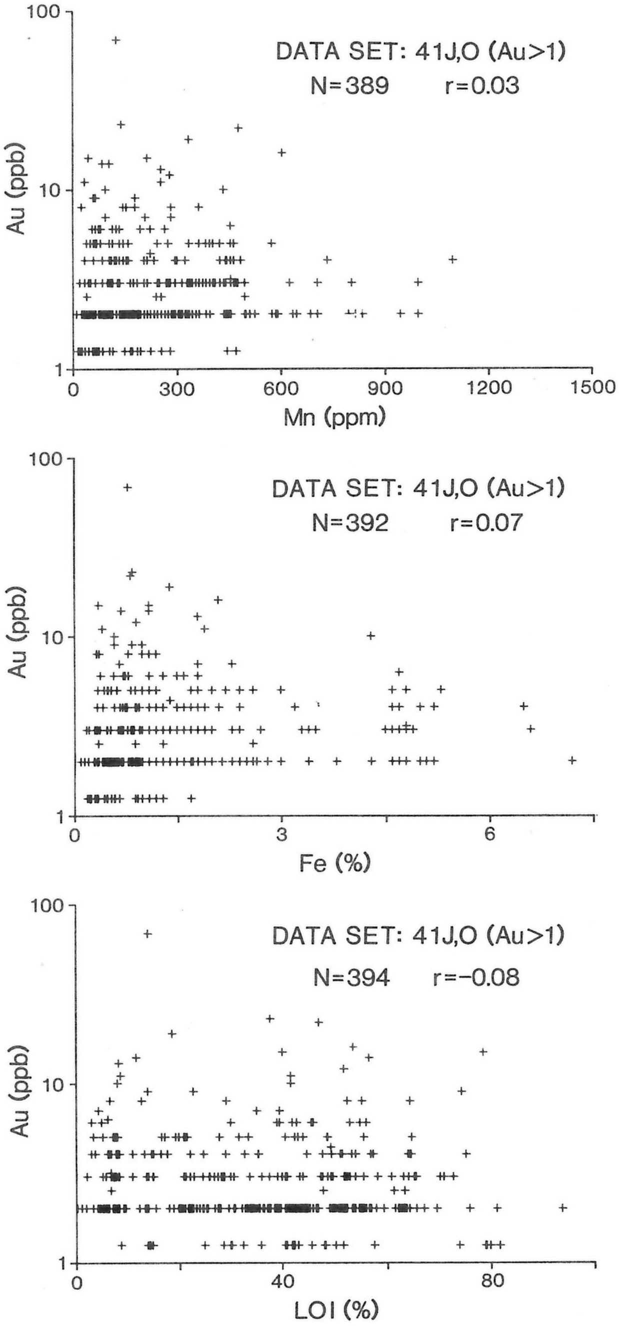

Figure 32.12. *The relationship of gold to the organic content (LOI) of and Fe and Mn in lake bottom sediments (P.W.B. Friske, Head, Regional Studies Section, Geological Survey of Canada, Ottawa, personal communication, 1987).*

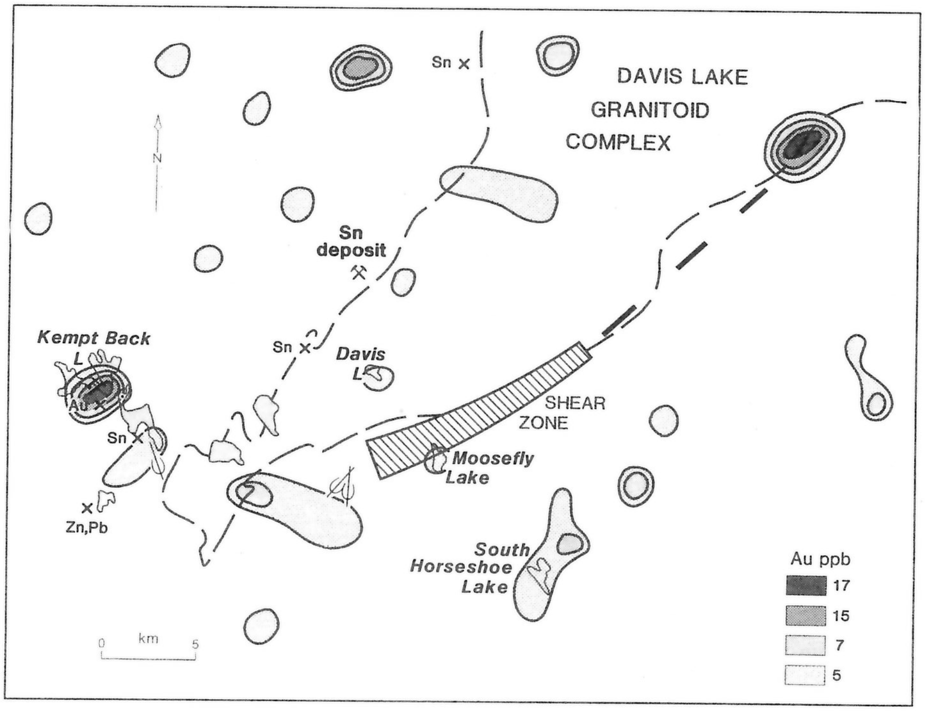

Figure 32.13. *Distribution of gold in lake sediments; East Kemptville tin deposit area, Nova Scotia (modified after Rogers 1986).*

anomalous area was discovered and later staked along the granitoid–metasediment contact on the northeastern extension of a shear zone (P.J. Rogers, Geochemist, Nova Scotia Department of Mines and Energy, Halifax, Nova Scotia, Canada, personal communication, 1987).

Another example is from the Hemlo gold camp of northwestern Ontario before the landscape was geochemically contaminated. Figure 32.14 shows the Au, Mo, and As values for some of the 150 samples collected in the area. Lake sediments from Moose Lake, the focal point for drainage in the vicinity of the Hemlo deposits are definitely anomalous for all three elements. The Au concentration in Moose Lake of 6 ppb and that of nearby lakes contrasts well with the less than 1 ppb local background. Not shown is an Sb value of 8 ppm in Moose Lake that also is in high contrast to a background value of less than 0.2 ppm.

The work of Coker *et al.* (1982), Thomas (1986), and Schmitt and Friske (1987) in Saskatchewan and McConnell (1987) in Newfoundland have also demonstrated the effectiveness and problems of gold data in lake sediment exploration. The use of centre–lake bottom sediments for gold and related pathfinder element exploration has become an established method with appropriate consideration for the problems of repeating gold analyses.

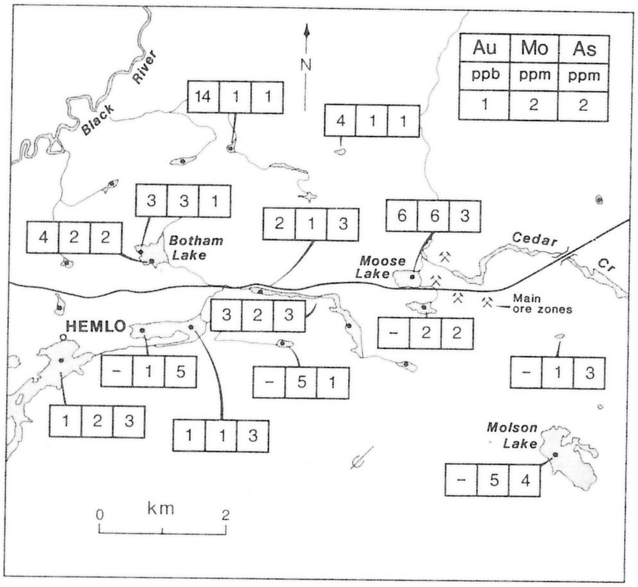

Figure 32.14. *Distribution of Au, Mo, and As in lake bottom sediments, Hemlo gold camp area, Ontario, (– Au value below the <1 ppb detection limit).*

CONCLUSIONS

Subbottom acoustic profiling can be used to map glacial and lacustrine sediment facies in lakes of the Canadian Shield and significantly aid in the geochemical interpretation of lake sediment survey data. Regional geochemical lake sediment survey coverage of Canada amounts to 1.1 million km^2. Together with other geoscientific data, it provides a valuable data base for governments, the mineral industry, and environmental and public health concerns. The 1980s have seen new and potential applications for lake sediment geochemistry for Au–, Sn–, W–, PGE–, and REE–bearing mineralization.

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