



GEOLOGICAL SURVEY OF CANADA
PAPER 84-20

**REGIONAL GEOCHEMICAL RECONNAISSANCE
INTERPRETATION OF DATA FROM
THE RAINY LAKE - QUETICO AREA,
NORTHWESTERN ONTARIO**

P.W.B. FRISKE

1985

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Available in Canada through

authorized bookstore agents and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W.,
Calgary, Alberta T2L 2A7

100 West Pender Street
Vancouver, British Columbia V6B 1R8
(mainly B.C. and Yukon)

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-84/20E Canada: \$6.00
ISBN 0-660-11903-X Other countries: \$7.20

Price subject to change without notice

Critical Readers

I.R. Jonasson
J.M. Franklin

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GENERAL INTRODUCTION

Geochemical data are an essential component of the comprehensive geological description of any area or country. This paper is one of a series of overviews on the geochemistry of regions of Canada.

The Geological Survey of Canada commenced regional surveys involving systematic geophysical measurements in 1949, with an aeromagnetic survey covering 30 000 km². By 1961 such regional geophysical surveys had expanded towards national coverage through a jointly funded Federal-Provincial program.

GSC first experimented with regional geochemical surveys in the late 1950s and continued up to the early 1970s. As a result of this work, the value of such surveys was established, methods were perfected, and the importance of sample collection and analytical controls was recognized¹. The commencement of a large scale national program of regional geochemical surveys then waited upon the availability of funding. This opportunity arose with the energy crisis of 1973, which led to the Federal-Provincial Uranium Reconnaissance Program. This program was initiated with the support of the 1974 Annual Conference of the Provincial Ministers of Mines, and it commenced in 1975 with as expected life of 10 years. Costs for work within the provinces were shared between the Federal and Provincial governments, whilst the Federal government was wholly responsible for the cost of work in the Territories.

Between 1975 and 1979, when the Uranium Reconnaissance Program was terminated by the Federal government for economic reasons, work took place in seven provinces and all the Territories. During this period approximately 900 000 km² in different parts of Canada were covered by geochemical surveys. The areas covered were selected according to a variety of criteria. Work in each of the provinces was conducted through a joint Federal-Provincial management committee. Since the funds available (approximately \$1.25 million per year for geochemistry) were not large in relation to the magnitude of the task, blanket coverage was not possible. Areas for geochemical surveys were selected partly on the basis of suspected exploration potential, as indicated by existing mineral occurrence and geological information, and partly to demonstrate the applicability of geochemistry in a variety of terrains.

Following on the termination of the Uranium Reconnaissance Program in 1979 most of the participating provinces indicated their interest in continuing the surveys in their areas of jurisdiction under other financial arrangements. These have varied from year to year and from province to province. They range from mostly provincial funding in British Columbia and Ontario, to wholly federal funding as in Newfoundland. Since 1979 the Geological Survey of Canada has conducted one federally funded survey

INTRODUCTION GENERALE

Les données géochimiques sont essentielles à la description détaillée de la géologie de n'importe quel pays ou région. Le présent document fait partie d'une série d'aperçus sur la géochimie régionale du Canada.

La Commission géologique du Canada a commencé en 1949 à effectuer des levés régionaux, dont la cueillette systématique de données géophysiques, par un levé aéromagnétique couvrant 30 000 km². En 1961, ces levés géophysiques régionaux ont été étendus à tout le Canada en vertu d'un programme fédéral-provincial à frais partagés.

La CGC a exécuté ses premiers levés géochimiques régionaux à la fin des années 50 et poursuivi ses activités dans ce domaine jusqu'au début des années 70. Ces travaux ont permis d'établir la valeur de ce type de levés, de mettre au point les méthodes et de montrer l'importance de l'échantillonnage et de la vérification des résultats d'analyses¹. La mise en oeuvre d'un vaste programme national de levés géochimiques régionaux a dû attendre que les fonds requis deviennent disponibles. L'occasion attendue s'est manifestée au moment de la crise de l'énergie en 1973, phénomène responsable de la mise sur pied du Programme fédéral-provincial de recherche pour l'uranium. Ce programme a été lancé avec l'appui de la conférence de 1974 des Ministres provinciaux des mines, et mis en oeuvre en 1975 avec une durée prévue de dix ans. Les frais engagés dans les provinces ont été partagés entre les gouvernements fédéral et provinciaux, bien que le gouvernement fédéral ait assumé entièrement le coût des travaux exécutés dans les territoires.

Entre 1975 et 1979, lorsque le gouvernement fédéral a mis fin au Programme de recherche pour l'uranium pour des raisons économiques, des travaux avaient été exécutés dans sept provinces et les deux territoires. Au cours de cette période, une superficie d'environ 900 000 km² répartie dans différentes régions du Canada a fait l'objet de levés géochimiques. Les régions couvertes ont été choisies en fonction de divers critères. Dans chaque province, les travaux ont été exécutés par l'entremise d'un comité de gestion fédéral-provincial. Etant donné que les fonds disponibles (environ 1,25 million de dollars par année pour la géochimie) n'étaient pas considérables par rapport à l'ampleur de la tâche, une couverture complète n'a pas été possible. En ce qui concerne les levés géochimiques, les régions ont été choisies, d'une part, parce qu'elles étaient susceptibles de renfermer des gisements de minéraux, tel qu'indiqué par les venues minérales connues et les données géologiques disponibles et, d'autre part, afin de démontrer l'applicabilité de la géochimie à différents types de terrains.

En 1979, une fois terminé le Programme de recherche pour l'uranium, la plupart des provinces qui y avaient participé se sont dites intéressées à poursuivre les levés dans les régions placées sous leur compétence, en utilisant d'autres arrangements financiers. Ces derniers ont varié d'année en année et d'une province à l'autre. Ils vont du financement provenant surtout du gouvernement provincial, comme c'est le cas en Colombie-Britannique et en Ontario, jusqu'au financement issu entièrement du gouvernement fédéral, tel

¹ These general considerations have been described by Cameron and Hornbrook (in *Exploration for Uranium Ore Deposits*, International Atomic Energy Agency, Vienna, 1976, p. 241-264) and Coker, Hornbrook and Cameron (in *Geophysics and Geochemistry in the Search for Metallic Ores*; Geological Survey of Canada, Economic Geology Report 31, 1979, p. 435-478).

¹ Ces considérations d'ordre général ont été décrites par Cameron et Hornbrook (dans *Exploration for Uranium Ore Deposits*, Agence Internationale de l'Énergie Atomique, Vienne, 1976, p. 241-264) et par Coker, Hornbrook et Cameron (dans *Geophysics and Geochemistry in the Search for Metallic Ores*; Geological Survey of Canada, Economic Geology Report 31, 1979, p. 435-478).

in the Territories (Nahanni, Yukon). As far as possible, the areas surveyed have coincided with NTS sheets boundaries in order to facilitate eventual national compilations. Most of the regional geochemical survey work has been undertaken by contractors. Sample collection, sample preparation, and different types of analytical services have been performed by separate organizations. Twelve companies have taken part in these operations. The Geological Survey of Canada has been responsible throughout for overall co-ordination, compilation and checking of data. Commencing in 1976, all data (66 different sets) have been released on GSC Open File under the title of National Geochemical Reconnaissance, and this term has been commonly used in related published literature.

This paper is one of a series which has three main aims: to serve as a reminder of the extent to which geochemical reconnaissance data are available for various parts of the country; to make general comments upon the relationship between the observed surficial geochemistry and the general and economic geology of various regions; and to provide specific examples showing how these geochemical data may be interpreted. Although the prime purpose of the geochemical surveys is as a guide to mineral exploration, the same data are of value to environmentalists, and in populated areas to agriculturalists and health authorities.

Regional geochemistry is based either on the sampling of lakes, wherever they are sufficiently abundant to permit one sample to be taken every 13 km², or in mountainous areas on the sampling of streams, at a similar site density. In special circumstances, where additional funding has been available, more detailed sample densities have been employed. At each site both sediment and water is collected. Sediment samples have been routinely analyzed for U, Zn, Cu, Pb, Ni, Co, Mo, Ag, Mn and Fe, and loss on ignition. In some areas Ba, W, Sn, As, Sb, V and Hg have also been determined. All waters have been analyzed for U, and commonly for F. From 1976 onwards pH measurements have been made on all water samples.

For the regional surveys, sample collection and sample preparation procedures, analytical methods and repeatability of results have all been tightly specified and controlled. This has been done in order to obtain consistent data between different areas, between work undertaken in successive years, and between results from different analytical laboratories. In this way the data base contributes to the eventual completion of a national geochemical reconnaissance, providing maps which have sufficient reliability to be used as an essential component of resource assessment, mineral exploration and geological mapping.

qu'à Terre-Neuve. Depuis 1979, la Commission géologique du Canada a exécuté dans les territoires (Nahanni, au Yukon) un levé financé par le gouvernement fédéral. Dans la mesure du possible, on a fait coïncider les régions à l'étude avec les feuilles de cartes du SNRC en vue de faciliter une éventuelle compilation des données pour tout le Canada. La plupart des levés géochimiques régionaux ont été exécutés par des entrepreneurs privés. Plusieurs organismes se sont chargés du prélèvement et de la préparation des échantillons, ainsi que des différents services d'analyse. Douze sociétés ont pris part à ces activités. La Commission géologique du Canada a assumé l'entière responsabilité de la coordination, de la compilation et de la vérification de tous les résultats. À partir de 1976, toutes les données (66 séries différentes) ont été publiées dans le dossier public de la CGC intitulé «National Geochemical Reconnaissance», et cette appellation a été couramment utilisée dans les publications concernant le sujet.

Le présent document fait partie d'une série qui a trois objectifs principaux: de rappeler à quel point sont disponibles, pour diverses parties du pays, les données géochimiques de reconnaissance; de présenter des commentaires d'ordre général en ce qui concerne la relation entre la géochimie de surface et la géologie générale et la géologie économique, dans diverses régions; et de fournir des exemples précis montrant comment les données géochimiques peuvent être interprétées. Bien que le but premier des levés géochimiques soit la recherche de minéraux, ils peuvent aussi servir aux environmentalistes et, dans les régions habitées, aux agronomes et aux services d'hygiène.

Les levés géochimiques régionaux sont fondés sur l'échantillonnage des lacs, là où ceux-ci sont assez nombreux pour permettre la cueillette d'un échantillon à tous les 12 km² ou, dans les régions montagneuses, sur l'échantillonnage des cours d'eau, à intervalles semblables. Lorsque des fonds additionnels étaient disponibles par suite de circonstances spéciales, on a utilisé un réseau d'échantillonnage aux mailles plus étroites. À chaque station d'échantillonnage, on a recueilli des sédiments et de l'eau. Les échantillons de sédiments ont été systématiquement analysés afin d'évaluer la teneur en U, Zn, Cu, Pb, Ni, Co, Mo, Ag, Mn et Fe, et on a déterminé la perte au feu. Pour certaines régions, on a également dosé le Ba, le W, le Sn, l'As, le Sb, le V et le Hg. Tous les échantillons d'eau ont été analysés afin de déterminer la présence de l'uranium, et souvent, du fluor. À partir de 1976, on a déterminé le pH de chaque échantillon d'eau.

En ce qui concerne les levés régionaux, les méthodes de prélèvement et de préparation des échantillons, les méthodes d'analyse et la répétabilité des résultats, ont toutes été étroitement vérifiées et décrites en détail. Cette initiative avait pour but de s'assurer de l'uniformité des données provenant de différentes régions, de travaux s'échelonnant sur plusieurs années successives et de résultats d'analyses émanant de différents laboratoires. De cette façon les résultats pourront éventuellement s'incorporer à l'ensemble des données géochimiques de reconnaissance du Canada en fournissant des cartes ayant un degré de fiabilité suffisant pour être utilisées à titre d'éléments essentiels dans l'évaluation des ressources, la recherche de minéraux et la cartographie géologique.

It is not the intention of this series of overview papers to seek to identify every anomalous feature and determine its cause. This is only possible where there have been comprehensive follow-up investigations. Each of these must involve detailed field and laboratory work tailored to the problems presented by each anomaly. Only a very small percentage of the many anomalies which are present in the data have been investigated systematically by the Geological Survey of Canada or provincial agencies because of the limited human and material resources available to conduct such work. The major effort of examining anomalies has been undertaken by industry, but only in a small percentage of cases, where there have been discoveries of commercial interest, do such results become known and documented.

Different styles have been adopted in preparing the separate parts of this series of overview papers. This reflects upon the quantity of complementary information available, and other circumstances outside the control of individual authors. This series will achieve its aim if, by drawing attention to the wealth of data that are now available, it stimulates investigations that will lead to new discoveries of both scientific and economic importance.

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Le but de cette série d'aperçus n'est pas d'identifier toutes les anomalies ni d'en déterminer la cause. Cela ne peut se faire qu'aux endroits où l'on a procédé à des études complémentaires approfondies. Chacune de ces études doit comprendre un examen détaillé sur le terrain et en laboratoire adopté à chaque anomalie. Seul un très faible pourcentage des nombreuses anomalies qui existent dans les données a été systématiquement examiné par la Commission géologique du Canada ou par des organismes provinciaux parce que les ressources humaines et matérielles disponibles pour ce genre d'activité sont restreintes. Le secteur industriel a fourni le principal effort dans la tâche d'examiner les anomalies, mais c'est seulement dans un nombre limité de cas, c'est-à-dire, à l'occasion de découvertes présentant un intérêt commercial, que ces travaux ont été publiés et documentés.

Les diverses parties de cette série d'aperçus ne présentent pas toutes le même style. Cela tient à la quantité de renseignements complémentaires disponibles et à d'autres circonstances indépendantes de la volonté des différents auteurs. Cette série atteindra son but si, en attirant l'attention sur la quantité de données qui est actuellement disponible, elle accélère la poursuite d'études susceptibles de mener à de nouvelles découvertes présentant un intérêt scientifique et économique.

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REGIONAL GEOCHEMICAL RECONNAISSANCE: INTERPRETATION OF DATA FROM THE
RAINY LAKE-QUETICO AREA, NORTHWESTERN ONTARIO

Abstract

The Rainy Lake-Quetico area of northwestern Ontario is largely underlain by Archean bedrock from three subprovinces of the Superior Province: Wawa and Wabigoon belts (volcanic-granitoid terranes); Quetico Belt (gneiss-granitoid terrane). In the southeast corner of the survey area Archean basement rocks are unconformably overlain by Proterozoic rocks (Animikie Group) of the Southern Province.

Mineral deposits are widespread throughout the region but most of the significant mineralization is associated with the Archean greenstone belts. From an economic standpoint Au, Ni-Cu, and Fe deposits have been the most important types of mineralization, although there is potential for other deposit types.

Regional trace element patterns in the lake sediments and waters are largely controlled by, and reflect, variation in the chemical composition of the underlying bedrock. Examples include the elevated levels of U associated with migmatitic-paragneiss terranes of the Quetico Belt; elevated levels of F associated with the Rove Formation and felsic plutonic rocks. Scavenging by Fe, Mn, and organic matter do not significantly affect the regional distribution patterns, although local variation related to scavenging is likely. Other factors that may locally modify the regional distribution patterns include glacial deposits, pH of surface waters, changes in element mobility, and most notably, mineralization.

Considering the regional nature of the geochemical survey (on average one sample per 13 km²) a relatively large number of mineral occurrences and deposits are delineated by the data; e.g., elevated As values associated with areas of gold mineralization; elevated Cu values associated with Cu-mineralization along the western margin of the Wawa Belt. Geochemical data have also outlined a number of anomalous zones that are not associated with known mineralization, indicating areas of economic potential that warrant follow-up.

Résumé

La région de Rainy-Lake-Quetico dans le nord-ouest de l'Ontario est en grande partie sus-jacente au socle rocheux archéen de trois sous-provinces de la province du lac Supérieur: les zones de plissements de Wawa et de Wabigoon (terrains volcano-granitoides) et celle de Quetico (terrain gneissique-granitoides). Dans le coin sud-est de la région étudiée, les roches du socle archéen sont recouvertes en discordance par des roches protérozoïques (groupe d'Animikie) de la province du Sud.

Les gisements minéraux sont communs dans la région mais la plupart des minéralisations importantes sont associées aux zones de roches vertes de l'Archéen. Du point de vue économique, les gisements d'Au, de Ni-Cu et de Fe représentent les catégories de minéralisation les plus importantes, bien que d'autres types puissent également exister.

Les schémas produits à l'échelle régionale par la répartition des éléments à l'état de traces dans les sédiments et les eaux lacustres sont en grande partie contrôlés par la variation de la composition chimique du socle sous-jacent; ils reflètent d'ailleurs cette variation. Des exemples de ces schémas sont les teneurs élevées en U associées aux terrains migmatitiques et paragneissiques de la zone de Quetico et les fortes teneurs en F associées à la formation de Rove et aux roches plutoniques felsiques. L'épuration par le Fe, le Mn et les matériaux organiques n'influe pas énormément sur les schémas de répartition à l'échelle régionale, mais peut donner lieu à des variations locales. D'autres facteurs sont susceptibles de modifier les schémas régionaux, y compris la présence de sédiments glaciaires, le pH des eaux de surface, les variations de la mobilité des éléments et surtout la minéralisation.

Étant donné la nature régionale de l'étude géochimique (en moyenne, un échantillon par 13 km²), les données délimitent un nombre relativement important de venues et de gisements minéraux, p. ex., les teneurs élevées en As associées aux minéralisations aurifères et les teneurs élevées en Cu associées à la minéralisation cuprifère le long de la marge ouest de la zone de Wawa. Les données géochimiques ont également révélé la présence d'un certain nombre de zones anormales qui ne sont pas associées à une minéralisation connue; ces zones, qui pourraient se révéler économiquement importantes, méritent d'être examinées de façon plus détaillée.

INTRODUCTION

The Rainy Lake-Quetico program was a regional helicopter-supported lake sediment survey, undertaken by the Geological Survey of Canada in conjunction with the Ontario Ministry of Natural Resources, during the summer of 1979. The data were previously published in Open Files by the Geological Survey of Canada and the Ontario Geological Survey (see Selected References for a listing of released Open Files).

The survey area extends from 48° to 49°N and from 90° to 94°W (Fig. 1), covering parts of NTS map areas 52B and C. A total of 1641 profundal centre-lake sediments and surface lake waters were collected, average density of one sample site per 13 km². Lake sediment samples were analyzed for Cu, Pb, Zn, Co, Ni, Ag, As, Mo, Fe, Mn, LOI (loss-on-ignition), and U. Lake waters were analyzed for U, F and pH.

In the survey area and other parts of Canada, lake sediment and lake water geochemical data have been used for evaluating mineral potential, outlining natural geochemical trends, environmental studies, and as an aid to bedrock mapping. Each area, however, is unique with respect to factors (e.g., bedrock geology, mineralization, surficial geology, climate, physiography, vegetation, etc.) that control the distribution patterns of elements in lake sediments and lake waters. The objective of this report is to briefly elucidate those factors that are important in the control of the geochemical distribution patterns in this particular area.

Acknowledgments

The Rainy Lake-Quetico geochemical reconnaissance program was carried out under the direction of E.H.W. Hornbrook. Sample collection was undertaken by Marshall Macklin Monaghan Ltd. of Toronto under the supervision of E.H.W. Hornbrook and W.B. Coker. Chemical analyses were carried out by Chemex Labs Ltd. of Vancouver, Barringer Research Ltd. of Toronto and Atomic Energy of Canada Ltd. of Ottawa under the supervision of J.J. Lynch. Data monitoring and compilation were carried out by N.G. Lund. Preparation of the coloured element distribution maps was co-ordinated by W.B. Coker and D.J. Ellwood. D.J. Ellwood also prepared the computer mapping package (APPMAP) and a contouring package which facilitated data interpretation. The writer thanks J.M. Franklin and I.R. Jonasson for reviewing the manuscript and G.E.M. Hall who is co-ordinating the series of overviews on regional geochemistry.

DESCRIPTION OF THE SURVEY AREA

Bedrock geology

The survey area is located near the southern margin of the Canadian Shield. Bedrock within this region consists of lithologies of both the Superior and Southern structural provinces.

The Archean bedrock of the Superior Province is characterized by metavolcanic-metasedimentary sequences, paragneiss sequences, granitoid complexes and granitoid gneiss and granulite terranes. The distribution of these lithologies defines 13 subprovinces that are generally east-trending and differ in lithology, structural style and metamorphic grade (Stockwell et al., 1970; Goodwin, 1977; Ayres and Černý, 1982). Parts of three subprovinces occur in the survey area: Wawa and Wabigoon belts (volcanic-granitoid terranes); Quetico Belt (gneiss-granitoid terrane).

Rocks of the Quetico Subprovince, within the survey area, are part of a 800 km long sedimentary trough, set between the Wabigoon and Wawa greenstone-granitoid terranes (Fig. 1). Metasediments and migmatitic-paragneiss are the major lithologies but include tonalitic-granodioritic

orthogneiss, metavolcanic domains, and granitoid and syenitoid rocks. The metasediments are characterized by a monotonous sequence of wacke-mudstone turbidites which are restricted to the margins and western end of the belt (Fig. 2). Progressive deformation and metamorphism of these sedimentary rocks, from the margins inwards, result in the development of a central medium to high grade migmatitic-paragneiss zone. Pirie and Mackasey (1978) have described the general nature of regional metamorphism across the belt which is characterized by low grade rocks with sericite-chlorite assemblages at the margins that progressively change to medium grade rocks containing staurolite, andalusite and garnet, and in the centre, to high grade rocks with cordierite, sillimanite, and granitic melt phases.

The Wawa and Wabigoon volcanic-granitoid subprovinces are characterized by supracrustal rocks of low to medium metamorphic grade. Massive to foliated granitoid rocks are aerially the most extensive lithology. In areas of supracrustal sequences (greenstone belts) metavolcanic rocks predominate with lesser sedimentary rocks. The metavolcanics are predominantly mafic but include intermediate and felsic volcaniclastic units. In general, the mafic volcanics are concentrated in the lower portions of a given volcanic sequence with intermediate to felsic rocks increasing proportionally upwards. This sequence (cycle) may occur one or more times in a particular volcanic pile. The sedimentary rocks, mainly greywacke but including conglomerate, chert, shale and iron formation (Algoma-type), are interbedded with and/or overlie the metavolcanic rocks. Dykes, sills and plutons of mafic to felsic composition are ubiquitous, but generally minor, components throughout the greenstone belts.

The geological history of the Archean rocks of the Superior Province is somewhat enigmatic but recent publications (Morey and Sims, 1976; Sims, 1976; Goodwin, 1977; Morey, 1978; Peterman, 1979; Ayers and Černý, 1982) indicate:

1. The volcanic belts (greenstone belts) range in age from 2.90 to 2.69 Ga and are younger than the gneisses and migmatites of the gneiss-granitoid terranes, some of which are less than 3.0 Ga.
2. The greenstone belts formed on or adjacent to pre-existing sialic protocontinents represented by the gneiss-granitoid terranes, possibly in an orogenic environment analogous to recent continental borderlands or island arcs, although there is considerable doubt as to a plate-tectonic system, as known today, operative in the Archean.
3. A large proportion of the intrusive granitoid rocks prominent in both the volcanic-granitoid and gneiss-granitoid terranes, were emplaced during a late Archean (2.55-2.75 Ga) magma-producing event.

In the southeast corner of the survey area the Archean basement rocks are unconformably overlain by Proterozoic rocks (Animikie Group, unit 5, Fig. 2) of the Southern Province. The Animikie Group (Gunflint and Rove formations) is an Aphebian supracrustal sequence dominated by detrital sedimentary rocks. The Gunflint is characterized by a local basal quartzite and conglomerate (Kakabeka member), overlain by two cycles of taconite, chert, algae-chert carbonate rocks, and argillite-tuff that are capped by a discontinuous limestone member (Shegelski, 1982). The overlying Rove Formation consists of shale, argillite and greywacke. This sedimentary package has been only slightly deformed and metamorphosed by the Penokean Orogeny (1.9-1.6 Ga) even though it has intensely deformed similar rocks in Wisconsin and Michigan (Sims et al., 1981). Intruding these Aphebian rocks are Helikian rocks of the Duluth complex (unit 6, Fig. 2); a gabbroic anorthosite and troctolite body (Phinney, 1972).

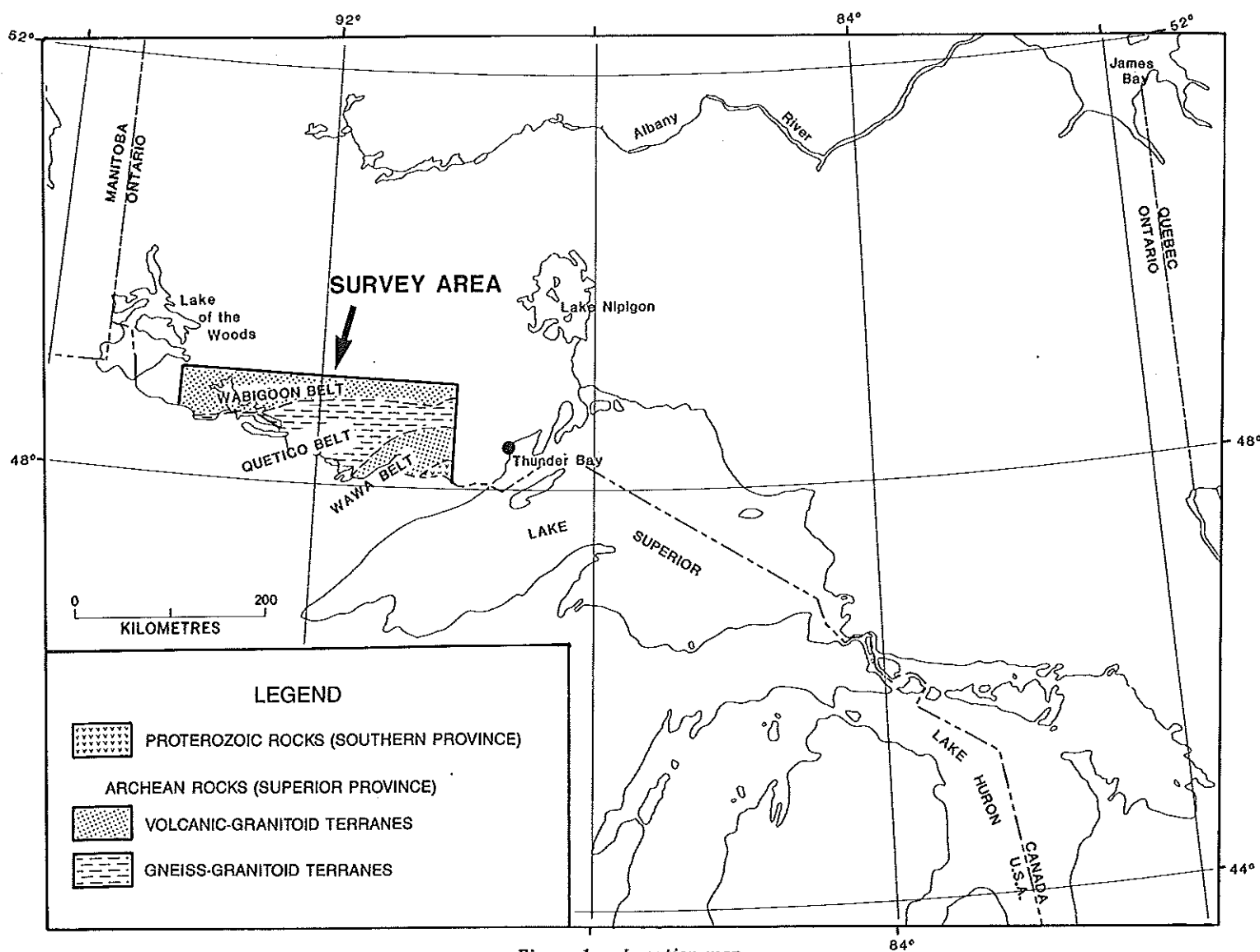


Figure 1. Location map.

Mineral deposits

Mineral deposits are widespread throughout the survey area but the different types, and their distributions, are closely related to specific lithologies. Most of the significant mineralization is associated with Archean greenstone belts (Fig. 3). A brief description of the major deposit types encountered in the region is given below with emphasis on their mineral and chemical compositions, which indicates possible element association in centre-lake sediments.

Gold deposits

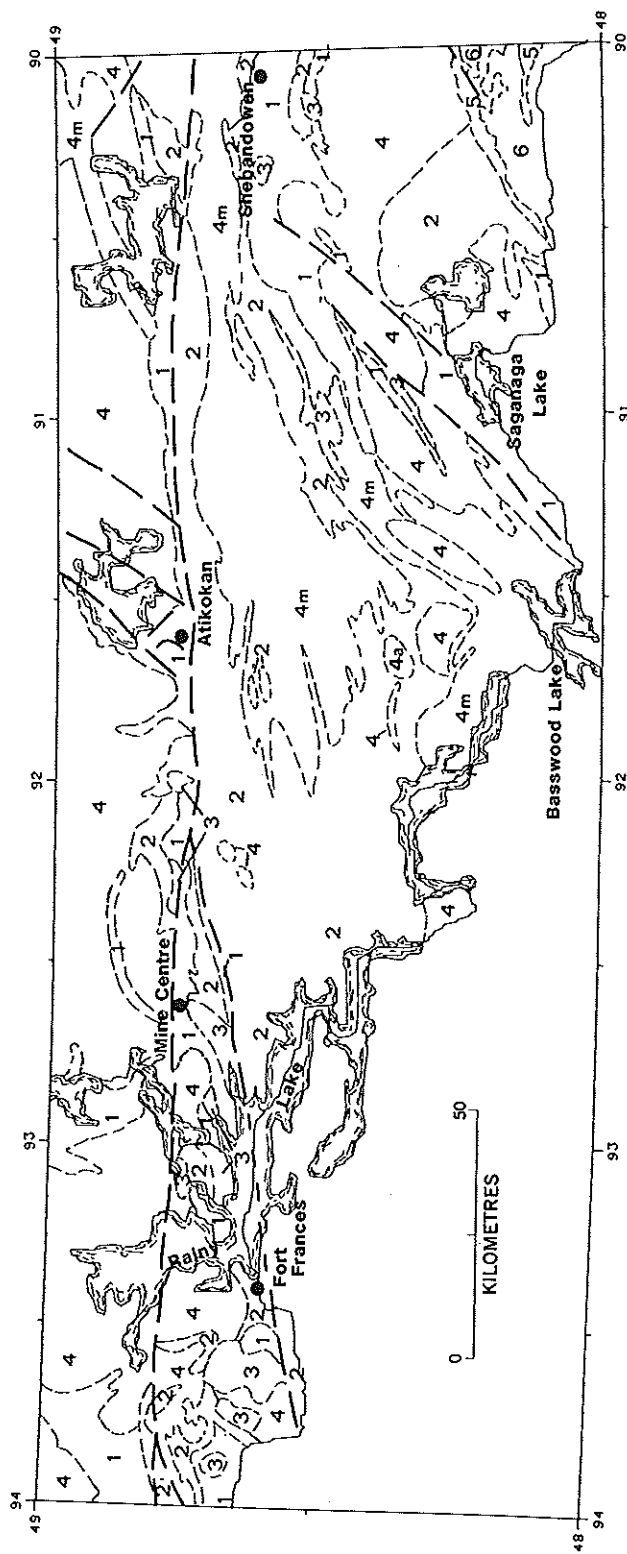
Four broad categories are recognized in rocks of the Superior Province: (1) syngenetic deposits, (2) pluton-hosted deposits, (3) volcanic-hosted vein and shear zone deposits, and (4) "porphyry gold" deposits (Franklin and Thorpe, 1982). Most gold deposits in the survey area are associated with fractures, faults, and shear zones within metavolcanic and metasedimentary rocks of the Archean greenstone belts (Type 3). The mineralization is commonly in the form of gold-bearing quartz veins accompanied by a variety of sulphides, tellurides, carbonate minerals, tourmaline and fuchsite. Extensive silicification and carbonatization of the

host rocks are common along with enrichment of Fe, S, As, CO_2 , Te, Sb, Ag, Mo, and base metals (Boyle, 1979). The majority of the deposits are closely spatially associated with the Quetico fault and, to a lesser extent, with smaller secondary faults of the area. The precise role of these structures in the mineralizing process is not known, but it is likely that they served as channelways which focused ascending, metal-rich, mineralizing solutions.

The recent discovery of extensive gold mineralization in the Hemlo area (approximately 300 km east of the survey area) has sparked extensive exploration activity in greenstone belts throughout northwestern Ontario, particularly in areas of proven potential. Within the survey area activity has focused mainly in the vicinity of Shebandowan Lake, Atikokan, and Mine Centre.

Ni-Cu-platinum group elements deposits

In northwestern Ontario, mafic and ultramafic intrusions of Archean and Proterozoic age are potential hosts for Ni-Cu sulphide mineralization. In the survey area the major deposits of this type are associated with Archean rocks; no significant occurrences are related to the mafic



LEGEND

PROTEROZOIC

HELIKIAN

6 Diabase, gabbro, diorite, ultramafic rocks

APHEBIAN

5 Sandstone, shale, argillite, iron formation, limestone, minor volcanic rocks

ANIMIKIE GROUP

5 Sandstone, shale, argillite, iron formation, limestone, minor volcanic rocks

ARCHEAN

4 Granitic rocks, syenite, pegmatite, unsubsided migmatite; (4a) Alkalic complex

4m Metasedimentary, granitic and minor metavolcanic migmatite

3 Mafic and ultramafic igneous rocks

2 Metasediments and minor metavolcanics

1 Metavolcanics and minor metasediments

Figure 2. Regional geology (after Ontario Geological Survey Map 2440).

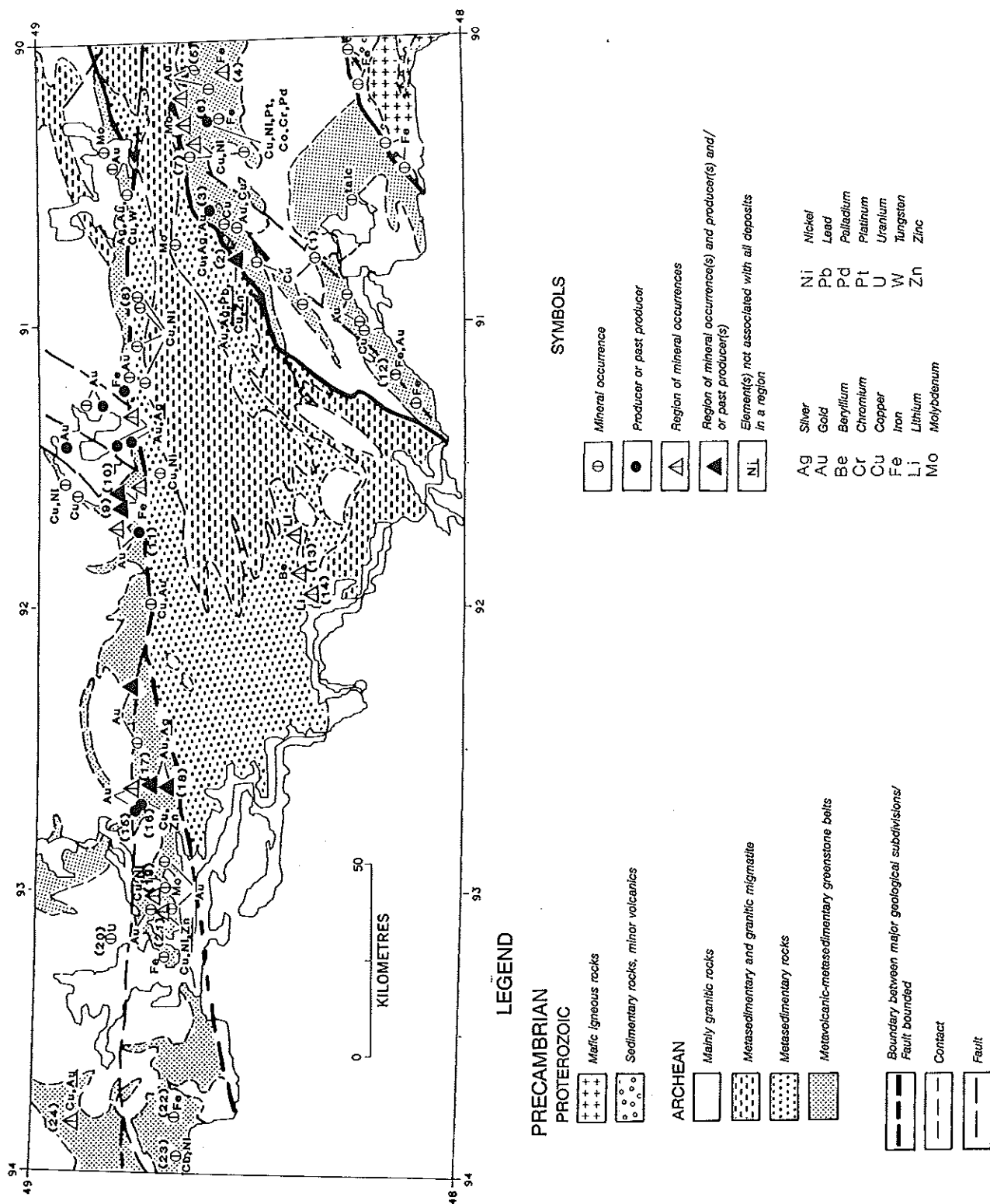


Figure 3. General geology and distribution of selected mineral deposits listed in Appendix B (after Ontario Geological Survey Map 2310; Springer, 1977a, b, c, 1978a, b, c, d, e).

Helikian intrusions, although similar rocks just east of the survey area host several major occurrences (e.g., Great Lakes Nickel).

The INCO Shebandowan mine ((6), Fig. 3) is presently the only producing Ni-Cu deposit in the area. The mineralization occurs at the top of an ultramafic intrusion (Morton, 1979) as a thin continuous zone of semi-massive sulphides that contains breccia fragments of the host intrusion as well as adjacent mafic volcanic and granitic rocks (Franklin and Thorpe, 1982).

A number of prospects are associated with small mafic and ultramafic intrusions that are located near the northern margin of Quetico Belt east of Atikokan (e.g., (8), Fig. 3). Locally, platinoid-group metals accompany the Cu-Ni mineralization of these intrusions (Irvine, 1963). Some of the other known occurrences include: Ni-Cu mineralization associated with altered gabbroic rocks in the Atikokan area (Hawley, 1929) and Cu \pm Ni mineralization associated with mafic and ultramafic intrusions in the Rainy Lake area, such as the Grassy Portage Bay prospect ((21), Fig. 3) (Harris, 1970).

In general, the Ni-Cu mineralization in the area, as is most mineralization of this type, is predominantly of magmatic origin, formed as a result of segregation of immiscible sulphides from a silicate melt. Elements that are highly enriched include Fe, Ni, Co, Cu and S. Other elements often enhanced include Pt and other platinoids, Ag, Au, As, Te, Se and Cr.

Sedimentary iron deposits

Two types of iron formation occur: Algoma and Superior. Both are commonly characterized by interbedded cherty and iron-rich layers. The Algoma-type is restricted to Archean greenstone belts. The direct-shipping goethite-hematite ore that was produced from deposits 9 and 10 (Fig. 3) of the Steep Rock iron range, was probably derived from a chert-siderite-pyrite protore (Algoma-type iron formation) by supergene enrichment processes (Lang et al., 1970). Other iron formations of the Algoma-type are concentrated in the Rainy Lake area, and along the northern and western margin of the Wawa Belt.

Superior-type iron formation is associated with Aphebian sedimentary rocks of the Animikie Group. Major deposits have been found in similar rocks in Minnesota (Mesabi and Cuyuna iron-ranges) but occurrences in the Gunflint Formation have not proved economic. Elements and oxides that may be significantly enriched in the various types and facies of iron formation include Fe, Mn, CO₂, As, and to a lesser extent Cu, Zn and Co.

Although Au, Ni-Cu, and Fe deposits have been, from an economic standpoint, the most important types of mineralization within the survey area, there are occurrences of, and potential for other deposit types including:

1. Cu-Zn volcanogenic massive sulphide deposits associated with intermediate to felsic volcanic and volcanoclastic units.
2. Cu-Au mineralization consisting of pyrite-chalcopryrite-(gold) related to intermediate and mafic volcanic rocks and associated sediments (Besshi-type massive sulphide deposits).
3. Pegmatitic deposits containing or associated with one or more of Li, Ta, Be, U, Sn and Cs. For example, in the Georgia Lake area (13, 14, Fig. 3) more than 11 million tons of potential Li-ore have been outlined in pegmatitic rocks (Riley et al., 1971). Several Be and one minor Sn occurrence are also known in this area (Pye, 1965).
4. Cu, Mo, and Au mineralization related to felsic plutons, particularly those that are within or adjacent to greenstone-belts (Ayres and Černý, 1982).
5. Ag, Pb, Zn vein mineralization primarily related to Aphebian rocks of the Rove Formation. No major prospects of this type are known in the area, however, a favourable geological environment does occur in the southeast corner.
6. Mineralization, including Nb, U-Th, REE, Cu-Fe-Ti, and Cu-Ni, related to carbonatite-alkalic complexes.

Quaternary geology

It is likely that the survey area was affected by two or more periods of glaciation during Pleistocene time; however, glacial features associated with the earlier events have been obscured by the last major glacial event, the Wisconsin Stage. Observeable glacial features indicate several different directions of ice movement during Wisconsin glaciation. As indicated by the orientation of striations, eskers, and drumlins, the direction of latest ice movement in most of the survey area was towards the southwest (Fig. 4).

The Quaternary sediments consist mainly of ground moraine which falls into two major groups. The most extensive till, often referred to as Patrician "red" drift, occurs as a discontinuous mantle over the bedrock, averaging about 1 m in thickness. In general this till is very sandy, composed of material that is mainly of local provenance. The second type of till is restricted to the southwest corner of the survey area. This till is quite different from the "red" till in that clay and silt predominate in the matrix as opposed to sand sized particles, and secondly, calcium carbonate content averages 25 weight per cent of the fine matrix (Zoltai, 1961); in the "red" till there is virtually none.

As the ice-mass retreated, much of the area was covered by proglacial Lake Agassiz. As a result, pockets of glacio-lacustrine deposits, mostly varved clays, are interspersed in the cover of till, particularly in the southern and western portions of the area. These deposits are restricted to lower lying areas of valleys, low slopes, or covering low rock knobs.

In the northeast part of the survey area, extensive loess-like material occurs as a thin veneer (averaging about 8 cm) over the till. This material is relatively uniform in texture, stone-free, and likely represents reworked moraine and outwash deposits (Zoltai, 1965c). Other less extensive types of glacial deposits encountered in the region include moraines, eskers and outwash deposits.

Physiography, climate, vegetation, soil

The survey area is part of an ancient peneplained surface which slopes gently to the west. The topography is largely bedrock controlled. Most of the area is underlain by Archean rocks and is characterized by broad rolling surfaces where relief seldom reaches 60 m. Drainage patterns are disrupted and poorly developed consisting of numerous lakes, rivers, ponds and swamps. Lakes are generally small (less than 10 hectares), relatively shallow (usually less than 9 m deep) and most frequently occur in depressions produced by glacial action (Cleugh and Hauser, 1971).

In the southeast corner, which is underlain by Proterozoic rocks, buttes and cuestas are common and terrain is much more rugged. In this area the drainage patterns are well developed, although lakes and streams are not as abundant as in the flatter regions.

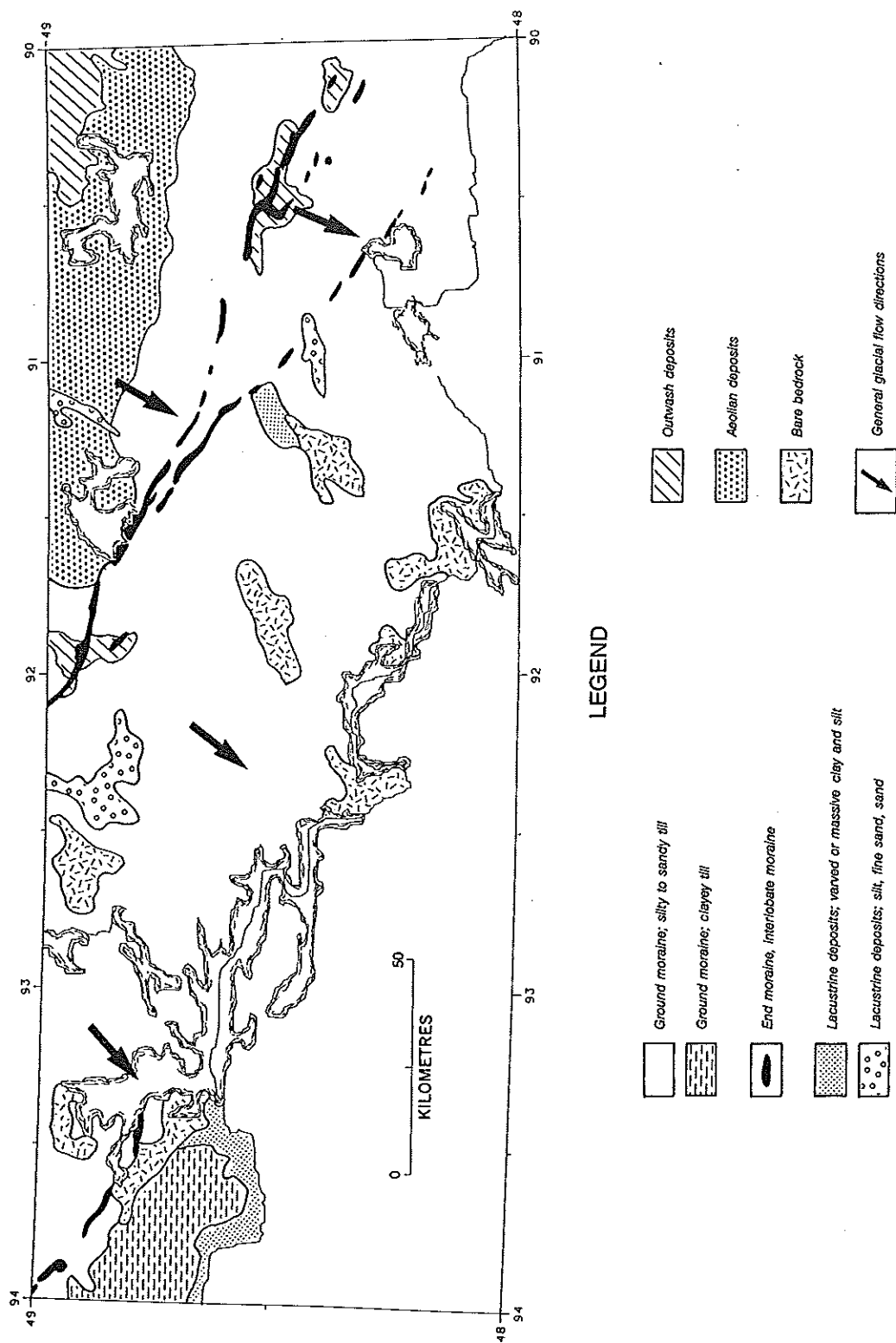


Figure 4. Surficial geology (after Zoltai, 1965a, b).

The climate of the region is characteristic of the Boreal zone; long and cold winters with relatively short and cool summers. Vegetation of both the Boreal Forest and Southeastern Mixed Forest types are encountered. Podzolic soils are the dominant product developed by weathering of the glacial deposits.

METHODOLOGY FOR LAKE SEDIMENT AND LAKE WATER SAMPLING

The lake sediment and water samples were collected by an experienced survey firm according to instructions, specifications and conditions delineated by the Geological Survey of Canada in consultation with the Ontario Geological Survey.

The area was sampled at an average density of one sample per 13 km². Only specified types of lakes were sampled. An ideal lake would be 1 to 5 km² in size, at least 3 m in depth and constitute an active part of the drainage system in a 13 km² grid cell. Lakes too small to be shown on a 1:250 000 scale topographic map were not sampled. Lake sediment samples were collected from the centre-lake profundal basin (shoreline sites were not accepted) using a GSC-developed, torpedo-shaped sampler, attached to an external winch and rope system on the fuselage of a helicopter. With the top several centimetres of sediment from the sediment-water interface being washed out of the core barrel during retrieval of the sampler, the remaining material collected is an organic-rich sediment; commonly a greenish brown to grey thixotropic gel. Samples with a dominant sand-gravel component or totally organic peat from swampland were not acceptable. High-wet-strength paper bags, approximately 10 x 15 x 15 cm with a double fold top and water resistant glue were used to contain collected sediment samples. Lake waters were routinely collected at all lake sediment sites. These samples were collected at least 20 cm below the surface using rectangular wide mouth linear polyethylene bottles, in water as free of suspended material as possible. To monitor and control sampling and analytical variance for both media, the basic sample design incorporated a field and blind duplicate and a control reference sample in every analytical block of twenty samples.

Each sampling crew consisted of a pilot, a crew member in front with the pilot who navigated, took notes and collected water samples, and a third member sitting aft who operated the winch from an outside float platform to collect the lake sediment samples. An average rate of 15 sample sites per hour was achieved while sampling on traverse. The overall survey sampling rate depended on the ferry time to and from traverses and the logistics of positioning gas caches. For detailed descriptions of sample collection and field data acquisition methods, sample preparation and analytical methods, data compilation and map production, the reader is referred to Garrett (1974), Hornbrook (1977), Coker et al. (1979), Geological Survey of Canada (1979a, b, 1981), and Appendix A.

INTERPRETATION OF THE GEOCHEMICAL DISPERSION PATTERNS IN LAKE SEDIMENTS AND LAKE WATERS

General features and considerations

Most elements are preferentially concentrated in specific rock types as a result of igneous or sedimentary processes, as is evident in Table 1. The geochemical distribution patterns of elements in lake sediment and water samples (Fig. 5-19) are to a large extent related to these variations in the chemical composition of the underlying bedrock (c.f., Hornbrook and Garrett, 1976; Jonasson, 1976; Cameron and Ballantyne, 1977; Maurice, 1977; Coker, 1981).

However, other factors contribute to the development of the observed geochemical dispersion patterns, an appreciation of which is essential to fully evaluate the geochemical data. With particular reference to the survey area some of these factors are briefly discussed below.

Variation in element source

In addition to bedrock, elements can be derived from two other major sources; mineralization and surficial material. Although the size of a given mineral deposit is small relative to the total area of a catchment basin, it can exert a tremendous influence on lake sediment and water composition because (1) trace elements such as Cu, Pb, Zn etc., can occur in mineralization in concentrations that are several orders of magnitude greater than in the surrounding bedrock, and (2) mineralization usually occurs as, or is associated with, sulphides that upon exposure, undergo rapid oxidation releasing the chemical components into the secondary environment. The types and element associations of mineralization have been outlined above and are summarized in Figure 3.

Most of the area is covered by glacial deposits of which ground moraine is the most widely distributed. In general, glacial till is composed of material that has been transported only a relatively short distance (Shilts, 1976), and hence the concentration of elements in the till is similar to that of the underlying bedrock. The coincidence of distinct trace element trends in lake sediments and waters related to underlying bedrock geology confirms that regional geochemical trends have not been significantly displaced or obscured by the cover of glacial till (e.g., elevated U values coincident with the migmatitic-paragneiss terrane of the Quetico Belt (Fig. 6), elevated As values coincident with the southern margin of the Wabigoon Belt (Fig. 16), elevated F values coincident with the Animikie Group (Fig. 18)).

The compositions of other types of glacial material including lacustrine, outwash and eolian deposits do not necessarily reflect the composition of underlying bedrock and/or mineralization. Extensive aeolian deposits occur in the northeast part of the survey area (Fig. 4) overlying granitic and gneissic rocks. This area is characterized by abnormally low concentrations of U in lake sediments and U and F in lake waters (Fig. 6, 17, 18) compared to other areas underlain by similar bedrock, suggesting that the drift cover has to some extent masked the composition of the underlying bedrock. The adverse effects on lake sediment surveys of surficial deposits whose provenance is largely unrelated to the underlying bedrock have been well documented by Gleeson and Hornbrook (1975) and needs to be considered as a possible influence on the element distribution patterns.

Mobility of elements

"Fundamentally, the response of an element to dispersion processes is governed by its mobility, i.e., the ease with which it may be moved in any given environment." (p. 13, Hawkes and Webb, 1962). In the surficial environment dispersion processes can be broadly classified into two groups; mechanical and chemical. Within the low energy environment typical of the survey area, mechanical dispersion is relatively less important than chemical (hydro-morphic) dispersion in the migration of elements into the centre-lake environment (Coker et al., 1979; Cameron, 1980). Therefore the mobility of a given element in this region is largely controlled by its ability to go into true solution (i.e., free ion or soluble complex), or to form soluble colloidal complexes.

Table 1. Concentrations of various oxides and elements in various lithologies of the survey area (Rainy Lake-Quetico area, northwestern Ontario; NTS 52B, C).

Lithologic Unit (Fig.)	Age and General Description	Group, Formation or Lithology	N*	SiO ₂ (%)	CaO (%)	Fe (%)	Mn (%)	Co (ppm)	Ni (ppm)	As (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Hg (ppb)	Ag (ppm)	Mo (ppm)	F (ppm)	U (ppm)
PROTEROZOIC																		
HEIKKAN																		
6	Diabase, gabbro, diorite ultramafic rocks	Diabase	5	49.6 47.8-50.7	0.3 0.0-1.3	10.1 7.9-12.0	0.14 0.12-0.17	58 46-66	266 42-502	1.1 0.3-2.9	229 123-341	6 1-15	123 87-177	12(4) 10-14	0.1 0.1-0.2	2 1-8	194 105-270	0.6 0.2-1.4
Abhebian																		
5	Sedimentary rocks	Aniaklia Group Rore Formation Sunflint Formation	2 7	64.2 63.3-64.4 73.7 41.9-56.1	0.1 - 3.8 0.0-7.8	3.9 3.8-4.0 5.46 0.7-16.2	0.02 0.01-0.02 0.10 0.01-0.29	10 8-12 13 1-42	64 48-79 21 1-76	2.4 2.3-2.5 12.9 3.5-30.2	32 21-43 40 3-123	10 1-18 4 1-9	154 111-197 19 2-56	100 65-135 203 44-485	0.2 - 0.2 0.1-0.3	4 3-5 8 1-18	1185 945-1225 481 41-1560	5.7 5.0-6.4 1.7 0.3-8.8
ARCHEAN																		
4, 4m	Felsic igneous and metamorphic rocks	Granite	18	73.2 70.3-75.8	0.0 0.0-0.3	0.90 0.2-2.3	0.01 0.00-0.04	3 1-8	3 1-10	0.5 0.3-1.2	11 1-61	24 10-40	20 7-55	10 5-16	0.1 0.1-0.3	2 1-5	153 55-450	3.7 1.1-11.0
		Quartz Monzonite	19	71.3 59.9-76.5	0.1 0.0-1.0	1.3 0.5-2.9	0.02 0.01-0.12	5 1-15	5 1-20	1.4 0.1-8.5	7 1-28	26 10-80	35 14-78	54 5-29	0.1 0.1-0.3	2 1-7	274 85-1065	4.2 1.0-8.2
		Granodiorite	5	72.8 70.3-74.2	0.0 0.0-0.1	0.9 0.3-1.6	0.01 0.01-0.02	3 1-5	4 1-7	0.4 0.1-0.6	6 3-10	40 24-64	24 17-35	14 5-40	0.1 0.1-0.2	4 1-6	153 90-205	6.6 2.1-17.9
		Tonalite	1	69.7 -	0.0 -	2.0 -	0.02 -	7 -	1 -	0.6 -	5 -	20 -	56 -	15 -	0.1 -	1 -	115 -	3.5 -
		Pegmatite	13	74.9 70.6-82.9	0.0 0.0-0.1	0.7 0.1-1.5	0.04 0.00-0.29	2 1-6	4 1-13	11.6 0.2-96.9	8 1-20	28 3-69	14 7-36	11 5-19	0.1 0.1-0.2	2 1-8	116 68-205	16.9 0.7-87.8
		Granite gneiss	7	71.0 63.2-74.2	0.1 0.0-0.6	1.7 0.3-3.9	0.02 0.00-0.03	8 1-22	16 1-60	0.6 0.1-1.2	8 3-18	24 1-55	40 11-72	31 5-60	0.1 0.1-0.2	2 1-5	154 45-270	14.9 0.2-76.5
		Migmatitic metasediments	2	63.3 61.4-65.2	0.3 0.0-0.6	3.2 3.1-3.3	0.04 0.03-0.04	9 -	9 7-10	0.6 0.3-0.8	5 2-7	1 -	53 43-63	10 -	0.1 -	2 1-2	250 230-270	0.8 0.3-1.3
3	Mafic and ultramafic igneous rocks	Ultramafic rocks	2	41.3 40.2-42.4	18.6 17.5-19.6	5.4 5.3-5.5	0.28 0.23-0.32	56 48-63	385 340-430	122.6 109.2-144.0	40 33-46	123 20-225	213 98-327	15 12-18	2.2 0.1-4.3	8 3-13	193 155-220	0.1 -
2	Metasediments and metavolcanics	Metasedimentary rocks	7	64.3 61.3-68.2	0.0 0.0-0.2	4.8 3.2-6.5	0.04 0.03-0.06	20 12-25	55 28-76	7.7 1.2-24.6	54 8-122	14 3-29	66 29-85	19 10-49	0.1 0.1-0.2	2 1-5	224 60-400	2.3 1.5-4.0
1	Metavolcanics and metasediments	Felsic metavolcanic Intermediate metavolcanic Mafic metavolcanic	2 8 8	65.8 64.3-67.2 43.3(1) -	1.7 0.1-3.2 0.0(1) -	2.8 2.7-2.9 7.4 4.0-14.0	0.04 - 0.12 0.07-0.23	12 - 44 23-73	40 20-59 78 37-128	0.2 0.1-0.2 3.8(1) -	15 9-21 55 24-143	7 6-7 7 1-11	58 57-59 111 69-138	26 -	0.2 -	4 3-4 3 1-5	185 125-245 400(1) -	2.9 1.4-4.3 0.5 0.2-0.7 0.6 0.1-1.8
N* = Number of samples 0.5(7) = Arithmetic mean (number of samples for an individual parameter that differs from the total) 0.2-0.4 = Range (minimum-maximum)																		

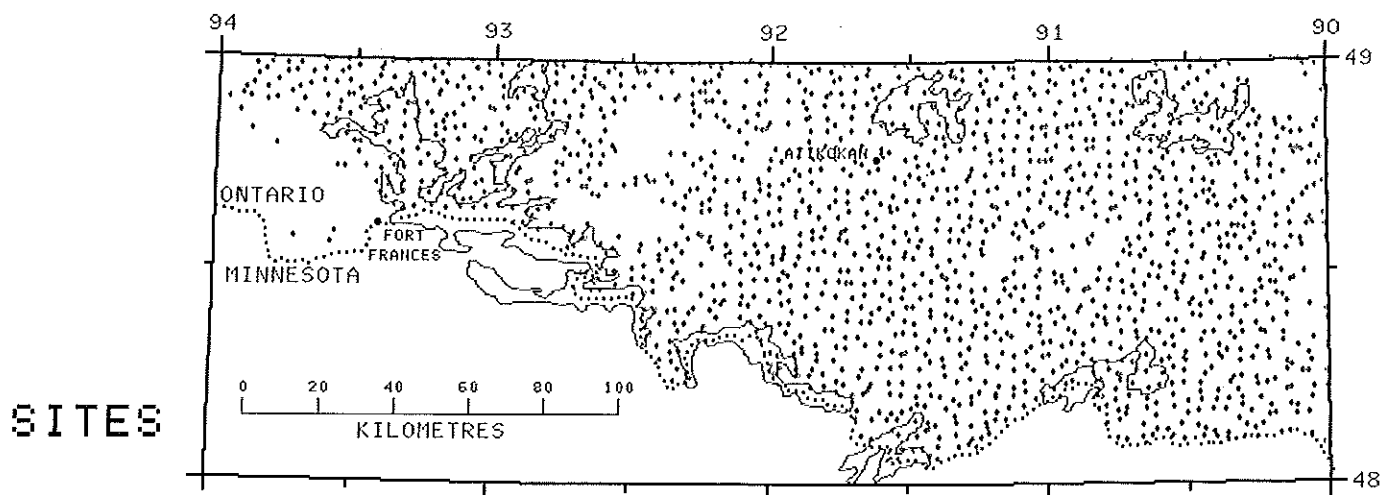


Figure 5. Sample location map.

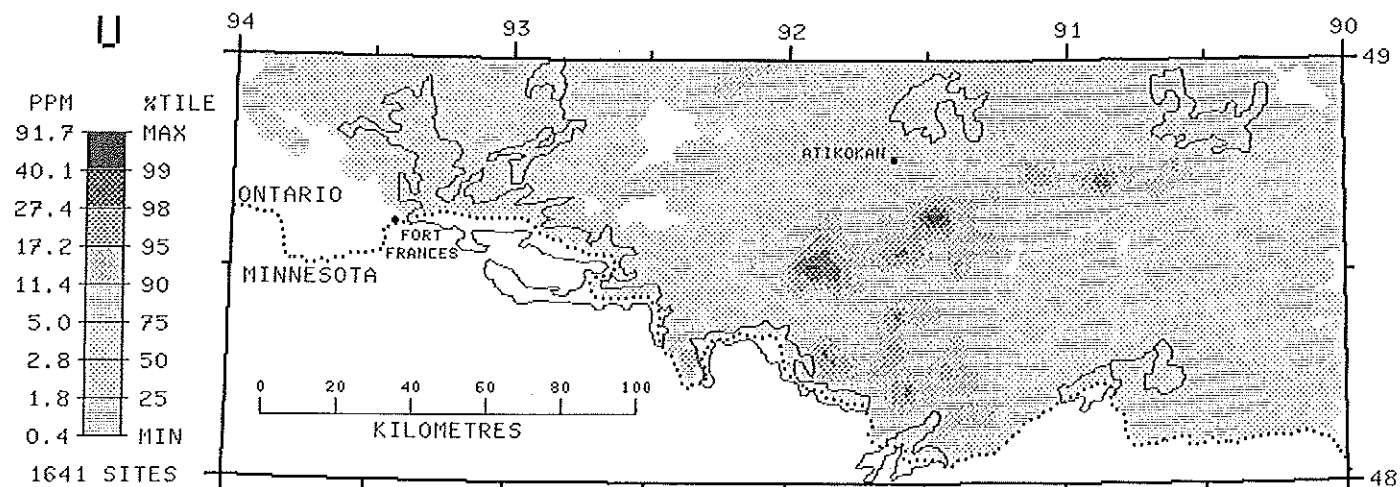


Figure 6. Distribution of U in lake sediments.

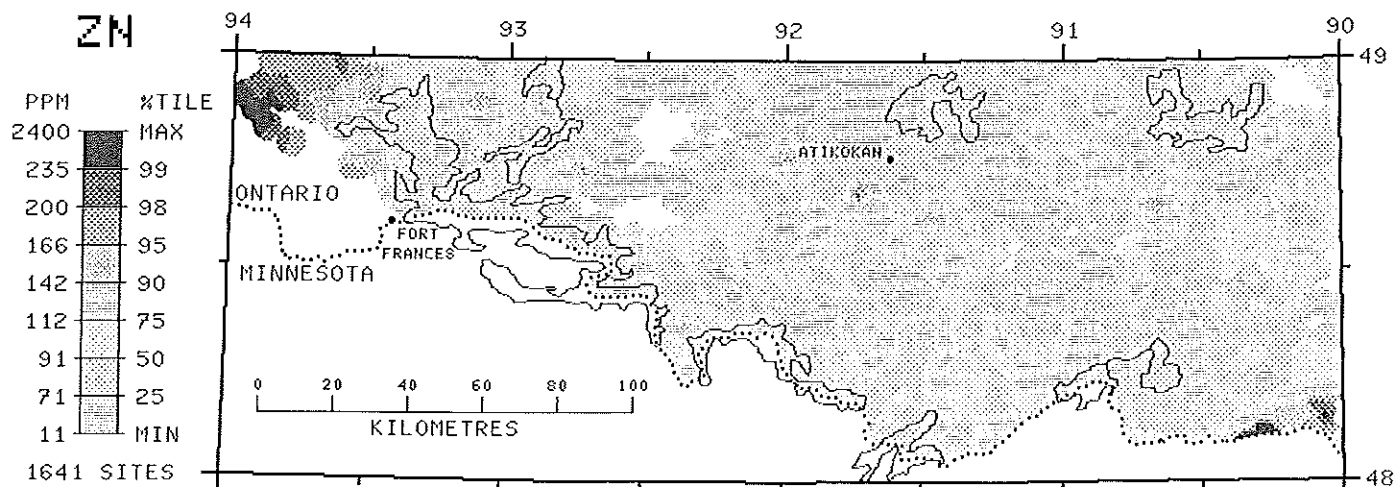


Figure 7. Distribution of Zn in lake sediments.

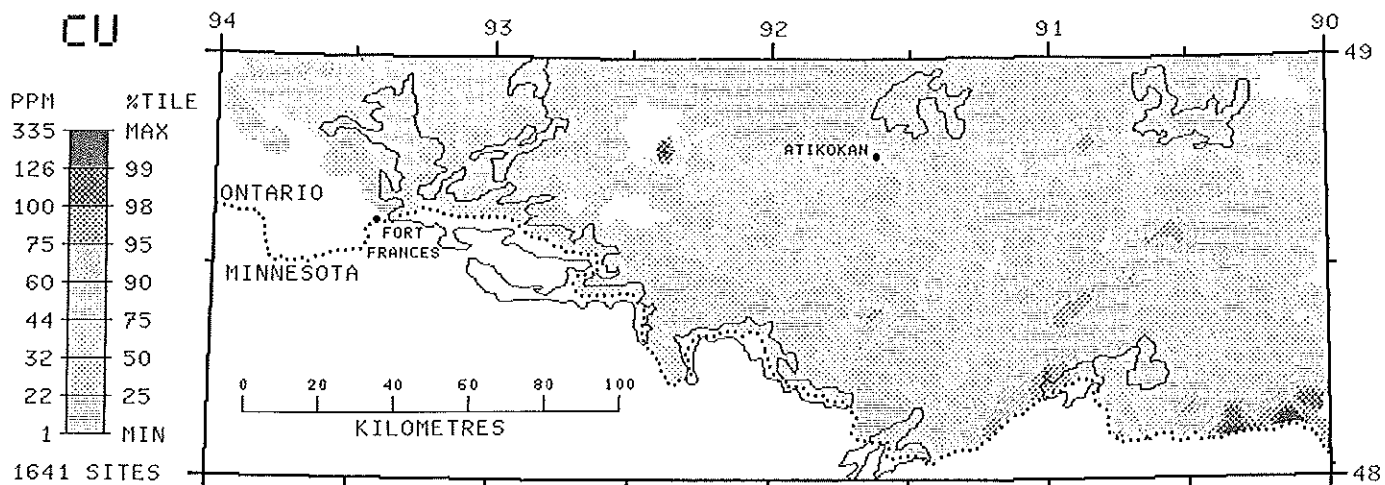


Figure 8. Distribution of Cu in lake sediments.

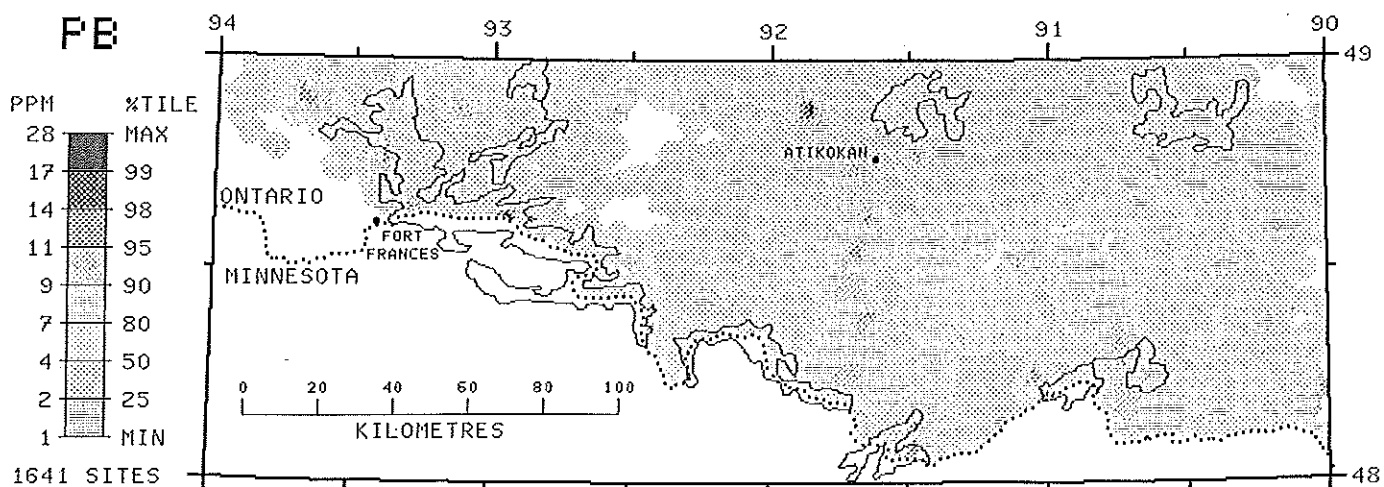


Figure 9. Distribution of Pb in lake sediments.

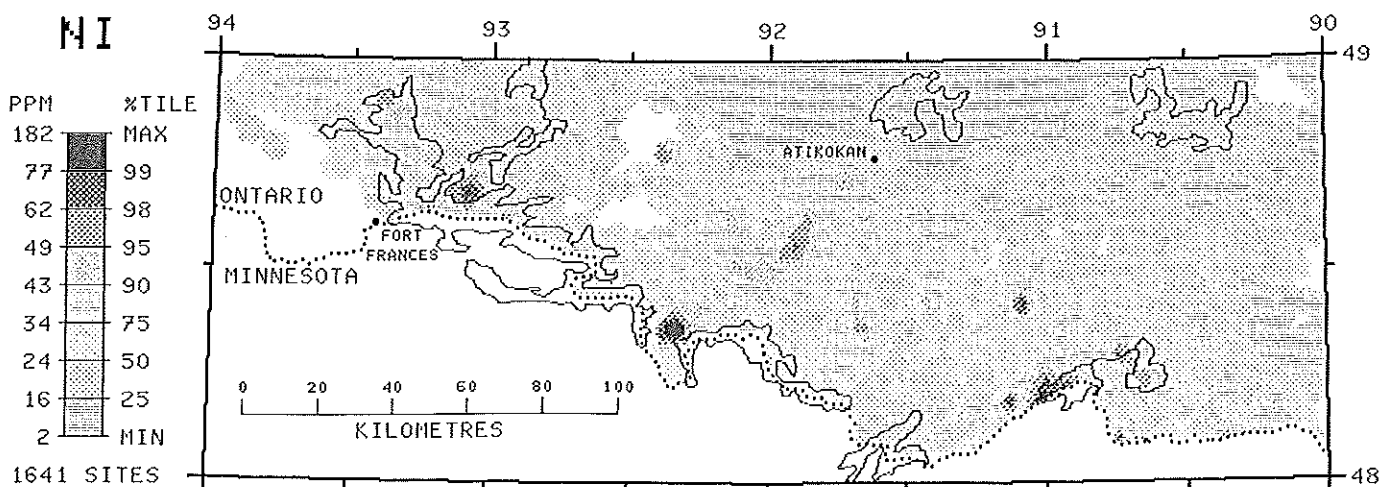


Figure 10. Distribution of Ni in lake sediments.

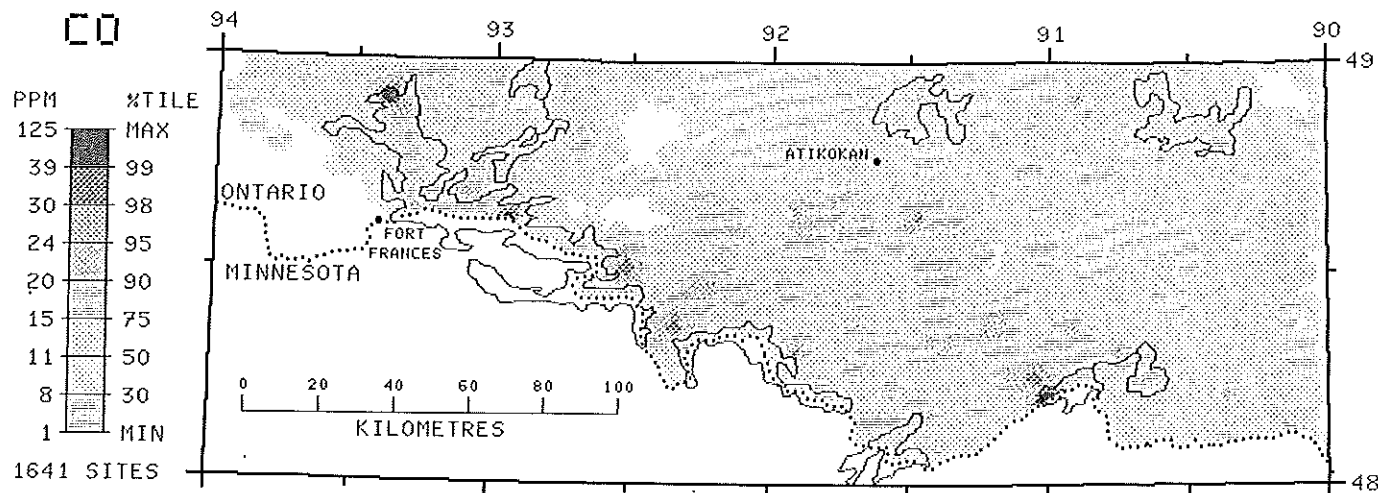


Figure 11. Distribution of Co in lake sediments.

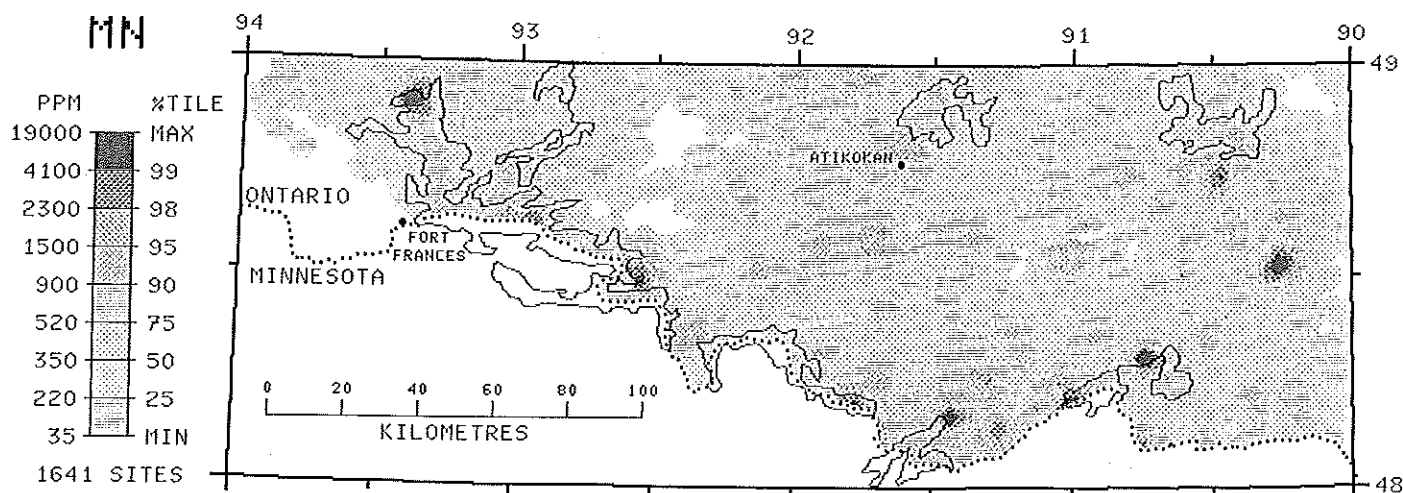


Figure 12. Distribution of Mn in lake sediments.

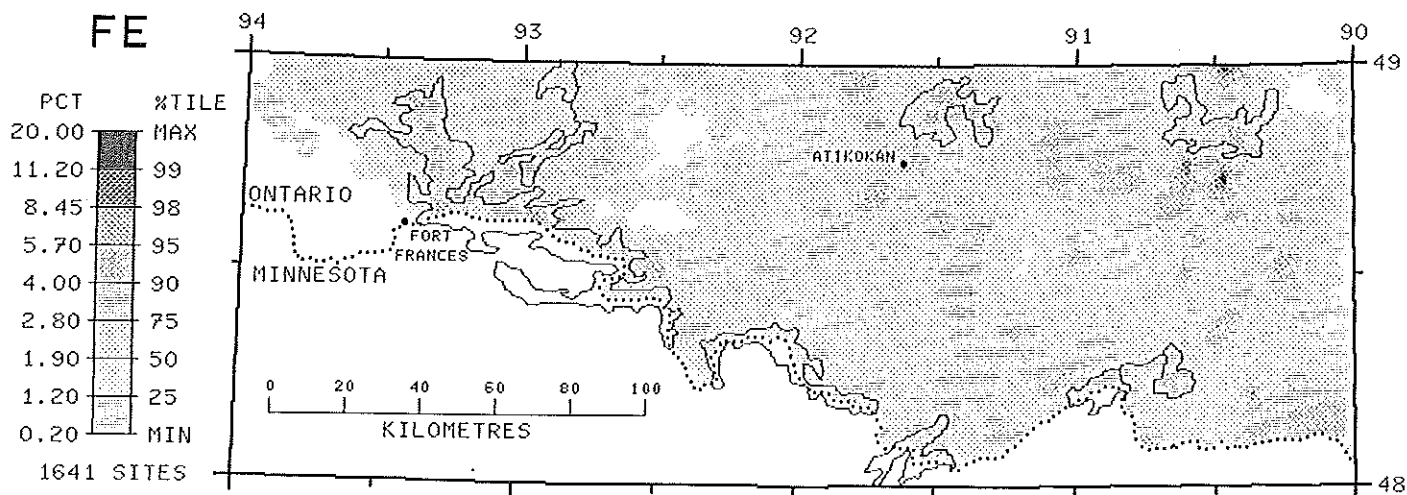


Figure 13. Distribution of Fe in lake sediments.

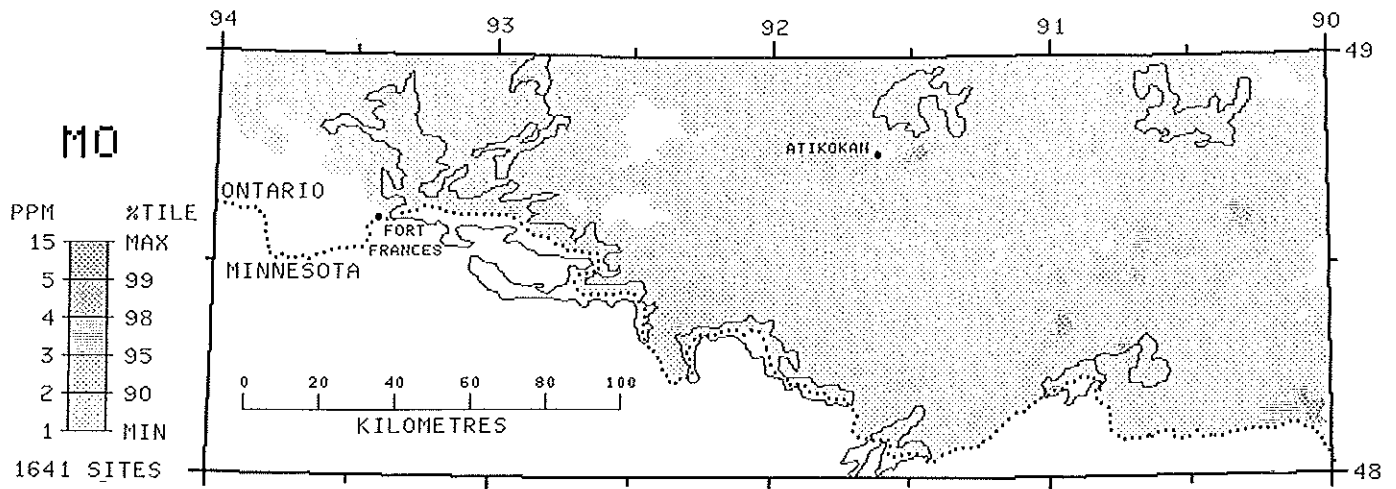


Figure 14. Distribution of Mo in lake sediments.

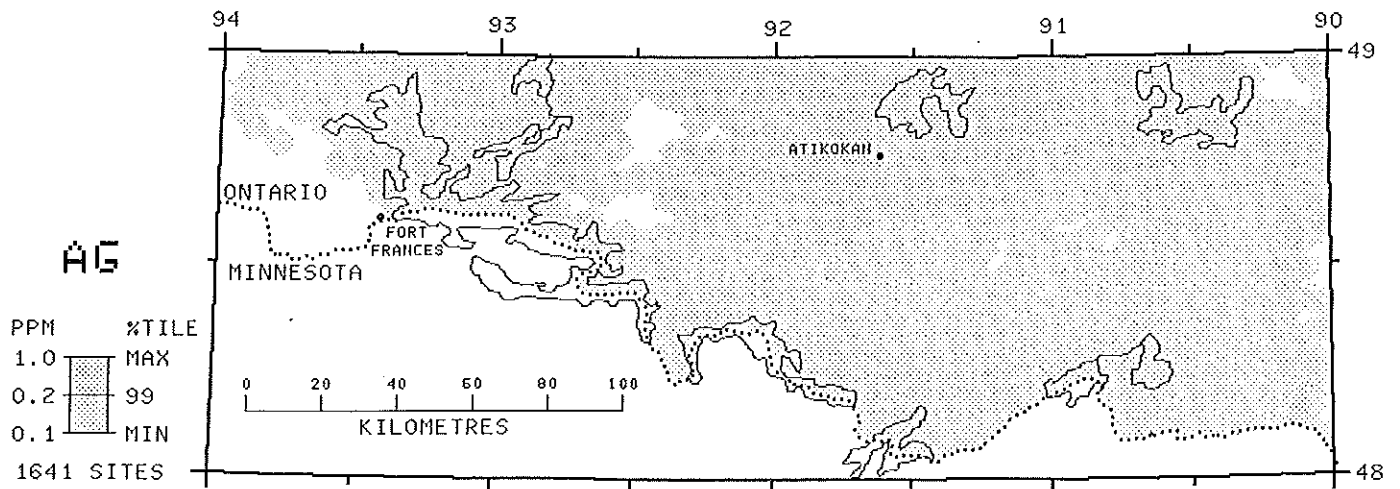


Figure 15. Distribution of Ag in lake sediments.

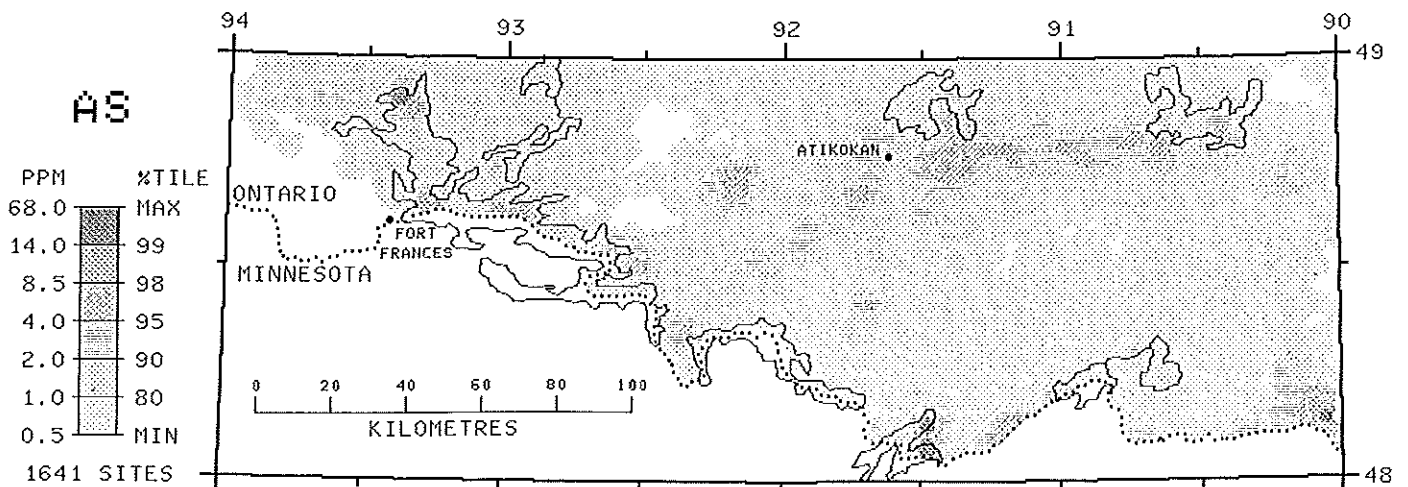


Figure 16. Distribution of As in lake sediments.

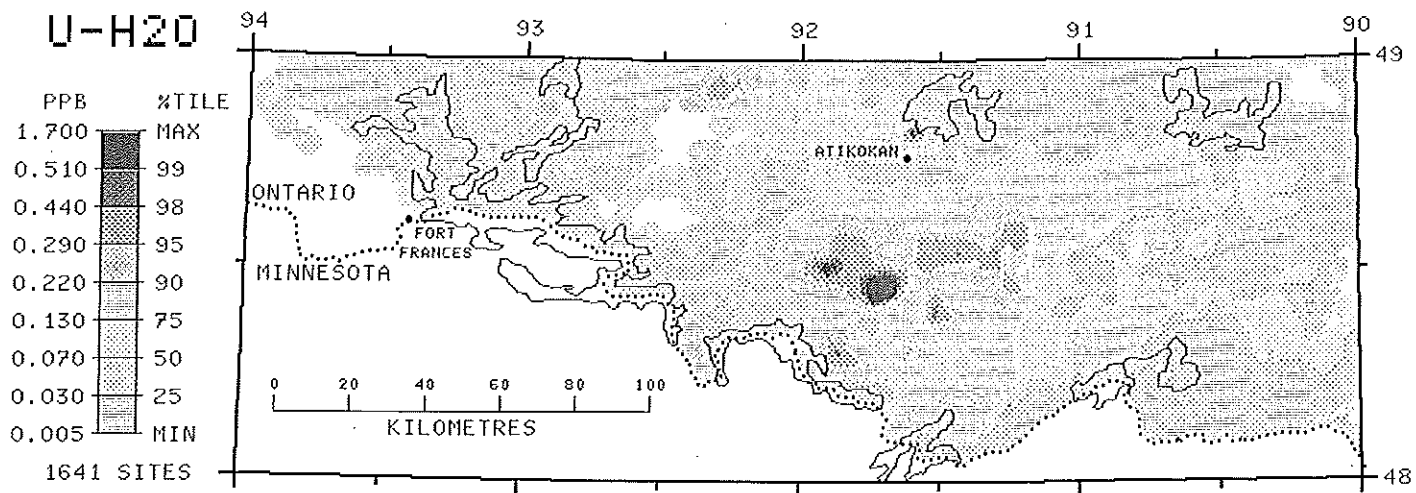


Figure 17. Distribution of U in lake waters.

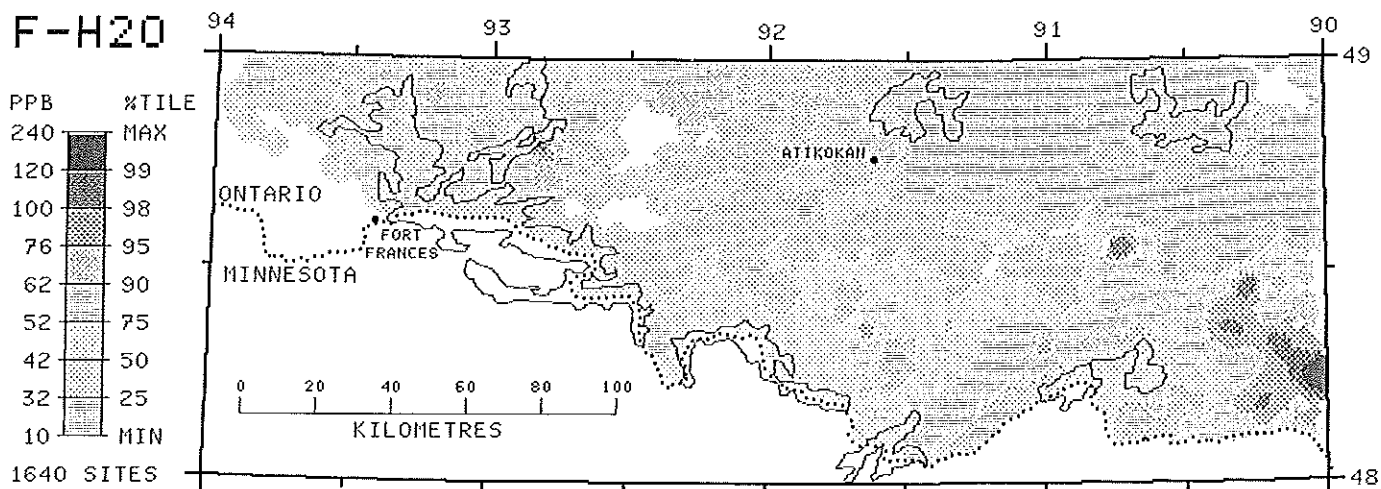


Figure 18. Distribution of F in lake waters.

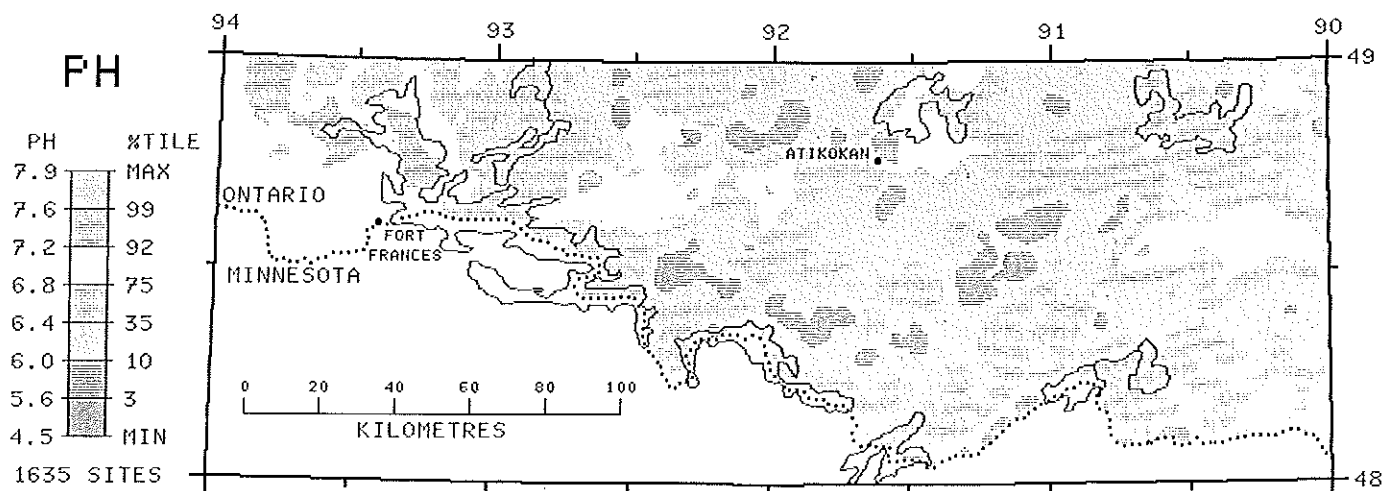


Figure 19. Lake water pH.

Whether a trace-metal remains in solution is controlled by the stability of the compounds it forms with other components that are in solution. Coker et al. (1979) have emphasized that in flat-lying tree covered terrains of the southern shield, such as the survey area, the incidence of organic matter is high and metal-organic interactions are predominant. Organic matter can enhance trace-metal mobility by forming soluble or colloidal metal-organic species, or retard it, by the precipitation of insoluble organic complexes or sulphides. Other components in solution such as carbonate, chloride, sulphate and hydrous metal oxides can also play an important role in trace-metal migration. Moreover, local factors can significantly affect the mobility of certain elements. For example, As and Mo are strongly scavenged from solution in Fe-rich environments, either by formation of Fe compounds or by adsorption in Fe-oxides (Rose et al., 1979). Because there is little quantitative data on the combined effects of all these factors, a quantitative estimate of the relative mobility of elements in this region is not possible. Qualitative estimates for several different surficial environments are given by Rose et al. (1979) based on coefficients of aqueous migration and practical experience. For a surficial environment similar to that commonly encountered in the region, i.e., oxidizing, pH 5-8, the order of relative mobility is given as: $Mo > F \approx Zn \approx Ag \approx U \approx As \approx Hg > Mn \approx Pb \approx Cu \approx Ni \approx Co > Fe$. It must be borne in mind that the order is a generalization, so that there is likely to be some variance with what actually occurs in the survey area. Moreover, the order will vary considerably in response to changes in the chemical environment. However, it serves as a general guide and illustrates the difference in the mobility of elements, which is an important consideration in evaluating any geochemical data set.

Sorption by hydrous Fe and Mn oxides and organic-matter

These substances have been noted for their ability to sorb (scavenge) trace elements, often resulting in anomalously high concentrations of elements that are unrelated to elevated source levels (false anomalies). Metal-organic interactions are likely to be of primary importance in trace element accumulation in the survey area because (1) of the characteristically high organic content in the surficial environment of the area, and (2) hydrous oxides of Fe and Mn are unstable under the reducing conditions common in the profundal basin from which the centre-lake sediments were taken (Timperley and Allan, 1974; Coker et al., 1979). Sulphide precipitation may also be an important control on element accumulation but cannot be assessed with available data.

The relation between organic content (approximated by loss on ignition (LOI), Lynch et al., 1973) and several trace elements is shown in Figure 20; two distinct trends are evident. The first is characterized by a relatively sharp increase in trace element content at the low end of LOI values, followed by a relatively consistent trace element content over a wide range of increasing LOI values, and finally a slight decrease at the upper end of LOI values (e.g., Cu and Zn in lake sediments that are coincident with mafic extrusive terranes, Zn in lake sediments that are coincident with granite terranes). A similar trend was described between zinc and LOI in centre-lake sediments from east-central Saskatchewan by Garrett and Hornbrook (1976). They interpreted the relatively flat central-portion of the curve as a range of LOI values over which there is an excess adsorption capacity in the sediment, i.e., insufficient trace element available to maintain the

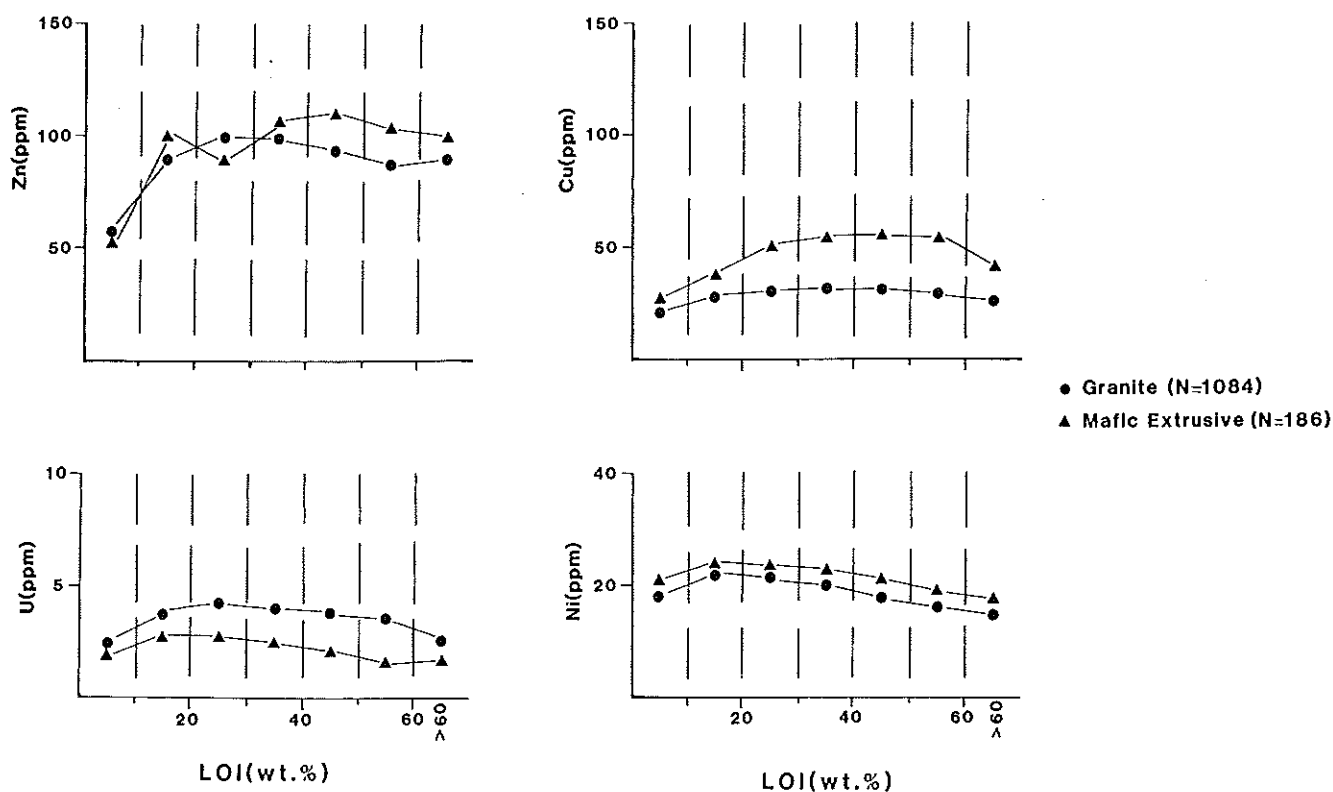


Figure 20. Variation of the U, Zn, Ni and Cu contents (geometric means) of centre-lake sediments related to loss-on-ignition and underlying bedrock composition.

sympathetic relation between LOI and trace element that occurs up to $\approx 10\%$ LOI. The decrease of trace element concentration at the upper end of LOI values may reflect a dilution effect, a disproportionately large influx of organic matter relative to trace element.

The second trend is one in which there is little or no increase in trace element with increasing LOI (e.g., Cu in lake sediments that are coincident with granite terranes, U in lake sediments that are coincident with mafic extrusive terranes). This suggests that there is always excess adsorption capacity in centre-lake sediments for those elements that have a relatively low concentration in solution. A similar trend would also be expected for trace elements, such as Ni, that do not have a particular strong affinity for organic matter.

Figure 20 clearly demonstrates that the concentrations of some elements in lake sediments are little affected by organic content, either because they lack a strong affinity for organic-matter or because they have a relatively low concentration in solution. The accumulation of other elements that do have an affinity for organic-matter and are available in sufficient quantities will vary with LOI in a manner characterized by the Type I distribution. However, even for these elements, organic content will have little effect on the regional distribution patterns because most samples collected in the survey area have LOI values between 10 and 60 weight per cent and over this range there is no sympathetic increase of an element with increasing LOI. Only samples with relatively low or high LOI contents need be considered as possibly anomalous, and these in terms of possibly suppressed responses. Distribution of LOI values less than 10 or greater than 60 weight per cent are shown in Figure 21b.

Distribution patterns of elements and surface water pH

pH of surface waters

The distribution of pH of surface waters is shown in Figure 19. In general, lakes of the Canadian Shield tend to be naturally acid unless they are underlain by calcareous bedrock or are associated with surficial deposits that have significant amounts of calcareous and/or clay-rich detritus (Shilts, 1981). Within the survey area 87% of the measured surface lake waters have a pH less than or equal to 6.9. Neutral to alkaline waters tend to be associated with areas underlain by greenstone belts and likely reflect the presence of calcareous-metasediments and/or carbonate-facies Algoma-type iron formations. Alkaline waters in the western part of the survey are likely related to the presence of the clay-rich calcareous ground moraine described above.

Solution pH is an important parameter in the dissolution, transport, and precipitation of many elements in the surficial environment; most elements are more soluble in acidic waters, although some, including U and Mo, are more soluble in alkaline solutions. Table 2 shows the variations of elements in lake sediments and waters from the Lake Superior survey area as a function of changing pH. Most of the elements are not markedly affected by the relatively limited pH range of surface waters encountered in the survey area, shown in Table 3 (a much greater variation occurs in the Lake Superior survey area); concentrations of Pb and Mo in lake sediments and U in lake waters show the greatest variations.

Uranium in lake sediments and lake waters

Elevated levels of U in lake sediments and lake waters (Fig. 21a) are for the most part coincident with migmatitic-paragneiss terranes of the Quetico Belt. Although no

significant U-bearing mineralization occurs in this environment within the survey area, it does occur in similar lithologies of the English River Subprovince located to the north (Breaks et al., 1978). Breaks et al. (1978) documented the occurrence of U mineralization associated with the "...northern supracrustal domain, being generally contained within white weathering, coarse-grained to pegmatitic, inhomogeneous and homogeneous diatexite." (p. 46). They postulated that the U initially occurred in metasedimentary rocks either detritally or absorbed by clay minerals and was subsequently concentrated in the highly fractionated residual melt phases during anatexis. The elevated U levels in both the lake sediments and lake waters, coincident with the high grade metamorphic terranes, indicate a potential for similar mineralization in the survey area. Occurrences of other lithophile elements, notably Li and Be (possibly accompanied by Ta, Sn, Cs and U) are also related to pegmatitic phases (e.g., Georgia Lake area (13), (14), Fig. 3). Although significant U concentrations are not associated with the Georgia Lake area some of the zones of elevated U may be indicators of this type of mineralization.

Two other regions of elevated U outlined in Figure 21a (areas A and B) are associated with granitoid terranes. Area A is of particular interest because it is associated with an area underlain by a massive granitic pluton (White Otter Lake Pluton, McCrank et al., 1981) and is coincident with elevated F levels which suggest the presence of relatively potassic phases which are particularly favourable hosts for U mineralization (Breaks et al., 1978).

Fluorine in lake waters

Variations of F concentrations of surface lake waters are shown in Figure 18. The most extensive and pronounced zones of elevated F values occur in the southeast corner of the survey area. These zones are correlative with bedrock characteristically enriched in F e.g., (1) the Rove Formation of the Animikie Group (see Table 1), (2) massive granitoid, syenitoid, and alkalic complexes that are particularly abundant in a northeast trending belt that extends from Shebandowan Lake to Basswood Lake, including the Hood Lake Syenite (Schwerdtner, 1976), and the Poohbah Lake alkalic complex (Riley et al., 1971).

In the north and northwest parts of the region elevated F levels are mostly associated with granitoid terranes and may reflect areas of more alkalic phases. The zone of distinctly low values in the northeast may, as described above, be the result of masking by the cover of eolian deposits in this area.

Iron, manganese, cobalt and nickel in lake sediments

The distributions of Fe and Mn in lake sediments are not as clearly related to specific bedrock lithologies as are U and F. In general however, there is a trend for the upper five percentile of the data (Fig. 21f) to be associated with greenstone belts dominated by mafic metavolcanic rocks which characteristically have relatively high Fe and Mn contents (Table 1). Elevated levels of these two elements are also coincident with (in decreasing order of prominence) metasedimentary, migmatitic-paragneiss and granitoid terranes. Enhanced levels over metasedimentary terranes likely reflect more argillaceous sections within the sedimentary packages.

The extent to which hydrous oxides of Fe and Mn scavenge trace elements (notably Co, Ni, Zn and As) and hence affect the regional distribution patterns of trace elements in the survey area is difficult to ascertain. As stated previously, hydrous oxides of Fe and Mn are not likely to be a major controlling factor because of the

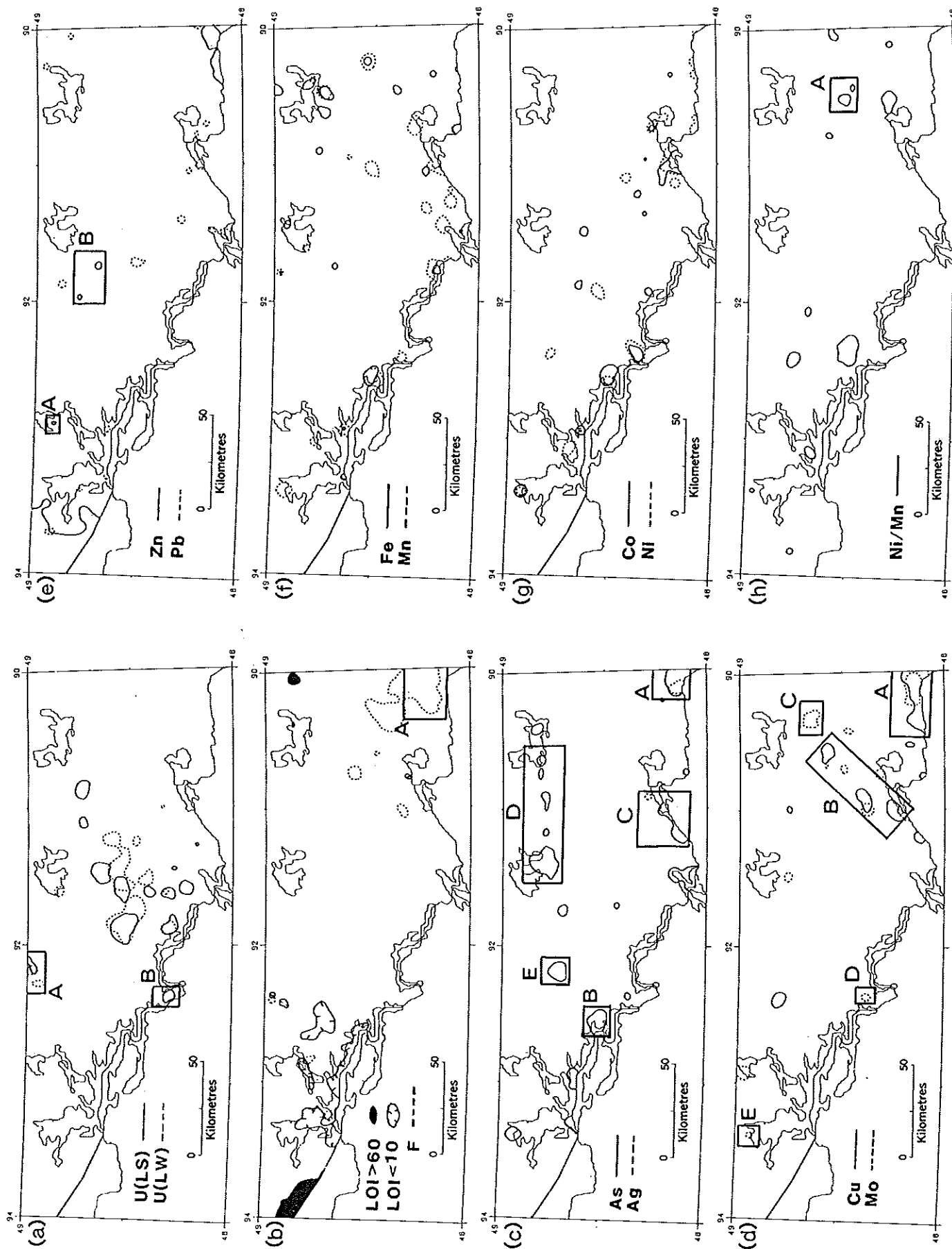


Figure 21. (a) Distribution of 95 percentile contours of U in lake sediments and lake waters. (b) Distribution of 10 and 60 weight per cent contours of F in lake waters. Distribution of 95 percentile contours of (c) As, and Ag (99 percentile) in lake sediments, (d) Cu and Mo in lake sediments, (e) Zn and Pb in lake sediments, (f) Fe and Mn in lake sediments, (g) Co and Ni in lake sediments, (h) Ni/Mn ratio in lake sediments.

Table 2. Concentrations (geometric mean) of selected elements in lake sediments and waters (Lake Superior survey area) for various intervals of surface water pH. Samples are only from catchment basins underlain by granitic bedrock.

Element		pH Intervals					
		(<6.0) (n=69)	<6.4 (n=112)	6.4-6.8 (n=140)	6.9-7.1 (n=89)	7.2-7.6 (n=111)	>7.6 (n=55) (>8.0) (n=20)
Lake sediments	Zn (ppm)	(99)	102	118	116	104	78 (59)
	Cu (ppm)	(24)	26	34	32	31	33 (29)
	Pb (ppm)	(7.7)	7.2	5.4	4.1	3.5	3.0 (2.5)
	Ni (ppm)	(14)	15	18	18	18	17 (13)
	Co (ppm)	(6.4)	8.1	10.6	9.1	7.0	6.2 (4.5)
	Ag (ppm)	(0.10)	0.10	0.11	0.11	0.11	0.10 (0.10)
	As (ppm)	(0.54)	0.54	0.57	0.56	0.54	0.62 (0.67)
	Mo (ppm)	(1.3)	1.5	2.2	1.6	1.5	2.1 (2.8)
	Hg (ppb)	(135) (54)	138 (82)	139 (120)	122 (81)	119 (106)	103 (54) (88)
Lake waters	U (ppm)	(4.1)	4.7	5.7	6.6	5.1	3.9 (2.7)
	F (ppb)	(0.05) (56)	0.05 50	0.05 49	0.08 54	0.11 54	0.24 62 (0.27) (66)

n = number of samples; for Hg, number of samples is indicated below concentration value.

Table 3. Frequency distribution of surface water pH in the Lake Superior (Friske, 1984) and the Rainy Lake-Quetico survey areas.

	pH Intervals					
	(<6.0)	<6.4	6.4-6.8	6.9-7.1	7.2-7.6	>7.6 (>8.0)
Lake Superior N = 4291 (Frequency %)	(11)	20	24	19	25	12 (1)
Rainy Lake-Quetico N = 1635 (Frequency %)	(13)	40	37	14	8	1 (0)

characteristically high organic content in lakes of the area, and also because of the instability of these complexes under the reducing conditions common in profundal basins, from which the centre-lake sediments were taken. Moreover, the distribution of the upper five percentile of the two siderophile elements, Co and Ni (Fig. 21g), more closely mimics the distribution of Fe and Mn than does the distribution of the chalcophile elements, As and Zn (Fig. 21c, e). These features suggest that the general coincidence of Co, Ni, Fe and Mn to a large extent reflects the natural association of these four siderophile elements in the same rock types, although the possibility of local scavenging cannot be entirely ruled out.

Most known Ni-Cu deposits of the area are not delineated by the distribution of the upper five percentile of Ni values (Fig. 21g). Coker and Nichol (1975) have suggested that the Ni/Mn ratio (Fig. 21h) is a better indicator of Ni-Cu mineralization than simply the Ni concentration. It is evident from Figures 21g and h that: (1) The distribution patterns of Ni and the Ni/Mn ratio are very different. (2) Neither parameter outlines the small Ni-Cu deposits along the northern margin of the Quetico belt. This may be due to characteristics of the deposits (i.e., size, grade, mineralogy) and/or regional nature of the sampling program. (3) A zone of

elevated Ni/Mn values (area A, Fig. 21h) occurs just southwest of the Shebandowan deposit ((6), Fig. 3) and may reflect down-ice dispersion of this mineralization. The deposit however, is not outlined by the Ni content of lake sediments, suggesting that the Ni/Mn ratio is indeed a better indicator of mineralization than simply the Ni concentration.

Copper, lead, zinc, molybdenum, arsenic and silver in lake sediments

Except for Mo, this suite of trace-metals are chalcophile elements and, therefore, as would be expected, their distribution patterns are significantly affected by the sulphide mineralization of the area, more so than the siderophile and lithophile elements considered above. The distributions of these chalcophile elements are however, also affected by the composition of the underlying bedrock. Examples of enhanced element concentrations in lake sediments clearly attributable to bedrock composition include: elevated Cu values related to the Helikian mafic intrusions (area A, Fig. 21d); elevated F and As levels related to sedimentary rocks of the Animikie Group (area A, Fig. 21b, c).

Other zones of enhanced As levels are concentrated along the southern margins of the Wabigoon Belt and the survey area. A number are coincident with elevated zones of one or more of Fe, Mn, Co and Ni and likely reflect bedrock lithologies that are enriched in these same elements such as argillaceous sedimentary rocks (e.g., area B, Fig. 21c), and Algoma-type iron formation (e.g., area C, Fig. 21c). Elevated levels of As that are not associated with enhanced concentrations of siderophile elements occur in areas D and E (Fig. 21c). The elevated As levels in the western portion of area D likely reflect the known As-enriched Au mineralization of this region. Area E may also reflect Au mineralization although it is slightly southeast of the known occurrences and therefore the possibility of hitherto unrecognized mineralization should also be considered. Several relatively small zones of elevated As in area D are not associated with known Au mineralization and may reflect (1) Au or other types of mineralization enriched in As, (2) lithologies enriched in As. In as much as it is evident that As can delineate areas of Au-mineralization in the region, detailed follow-up surveys are warranted in areas of elevated As particularly those near the southern margin of the Wabigoon belt, along which there is a proven potential.

Elevated zones of Cu and Mo are concentrated near the western margin of the Wawa Belt. The three zones of elevated Cu outlined in area B (Fig. 21d) are coincident with Cu-mineralization related to mafic metavolcanics. Most of the other zones of elevated Cu shown in Figure 21d are also coincident with greenstone belts and may indicate other favourable regions for this type of mineralization. A zone of enhanced Mo values (area C, Fig. 21d) is coincident with Mo-Cu mineralization related to the Loch MacDougall granite. As noted by Ayres and Černý (1982), Cu, Mo and Au mineralization of the pluton-hosted type is largely related to granitoid plutons that occur within or adjacent to greenstone belts. All of the enhanced Mo zones (except areas A, D and E) are proximal to greenstone belts and should be considered as particularly favourable areas for mineralization of Mo and associated elements of the granitoid-hosted type.

Regionally developed zones of elevated Zn values occur in the northwest and southeast corners of the survey area; the latter are coincident with sedimentary rocks of the Animikie Group, which are known to contain enhanced Zn levels (see Table 1) relative to other lithologies. The other zone coincides with the southwest portion of the Savant Lake-Crow Lake greenstone area. In the Lake Superior survey area regionally developed zones of elevated Zn values in lake sediments are associated with greenstone belts (e.g., Schreiber belt) that are known to host volcanogenic massive sulphide deposits of the Zn-Cu type (Friske, 1984). This suggests that within the survey area the greenstone terrane of the northwest corner has the greatest potential for volcanogenic massive sulphide mineralization. Several local highs (areas A and B) are also of interest as they are also closely associated with greenstone terranes.

Only about 1% of the lake sediments analyzed have a Ag content above the detection limit. Two anomalous areas are delineated (Fig. 21c). One (area C) is coincident with a gold occurrence, and the other (area A) is associated with the package of Proterozoic rocks. Similar Proterozoic rocks to the east host Ag-vein mineralization and although no significant occurrences of this type are known in the survey area the elevated silver values indicate a potential in this region. Zones of elevated Pb values are largely restricted to granitoid and migmatitic-paragneiss terranes (Fig. 21e). Since Pb is not notably enriched in any of the types of mineralization that are prominent in the area these zones likely reflect enhanced concentrations in the underlying bedrock.

It is particularly noteworthy that chalcophile elements are not significantly enhanced in lake sediments in the Mine Centre area around which there is extensive sulphide mineralization of varying types. An important factor contributing to this lack of response may be the occurrence of organic-poor lake sediments in this region (Fig. 21b), which as described above can lead to relatively suppressed trace-element contents in lake sediments.

SUMMARY

In general, the chemical composition of a lake water or lake sediment is the product of a complex system involving interplay between various physical, chemical and biological factors. Within the survey area some factors are relatively constant (e.g., climate, topography, vegetation) and hence do not contribute to the variation in element concentrations between samples. Based on available data, the factors that appear to be most important in controlling the observed chemical distribution patterns within the survey area are the distribution and chemical composition of both the bedrock lithologies and the mineralization. To a lesser extent the element variations are also a function of: sorption by hydrous Fe and Mn oxides, and organic-matter; changes in element mobility; distribution and chemical composition of surficial deposits; and pH of surface waters.

Although distribution and composition of bedrock lithologies and mineralization are the major factors controlling the chemical distribution patterns, most elements tend to be influenced to a greater extent by one of the two. Elevated levels of U and F in lake waters and U in lake sediments are correlative with bedrock terranes that are enriched in these elements (e.g., U associated with migmatitic-paragneiss terranes of the Quetico Belt; F associated with the Rove Formation and felsic plutonic rocks). In the northeast corner of the survey area abnormally low concentrations of U in lake sediments and U and F in lake waters (compared to other regions underlain by similar bedrock) likely reflect a masking effect by the cover of eolian deposits. The distribution pattern of pH of surface waters has also been affected by surficial deposits; calcareous-till occurring in the southwest part of the survey area buffers the pH of surface waters to relatively high values.

The distributions of Fe and Mn are also largely bedrock controlled, although not as distinctly as the lithophile elements. Elevated levels are generally coincident with bedrock lithologies that have enhanced concentrations of these two elements such as mafic volcanic rocks, iron formations, argillaceous sedimentary rocks, and Helikian mafic intrusions. Scavenging by hydrous oxides of Fe and Mn appears to little affect the regional distribution of elements such as Co, Ni and Zn, though local enhancements are likely to occur. The common coincidence of elevated levels of Co, Ni, Fe and Mn is considered to reflect a natural association of these four siderophile elements in the same rock types. Organic-matter (concentration approximated by loss-on-ignition (LOI)) is also a strong scavenger of trace elements, but has little effect on the regional distribution patterns because most lake sediment samples collected in the survey area have LOI values between 10 and 60 weight per cent and over this range there is no sympathetic increase of trace elements with increasing LOI. Samples with LOI levels above or below this range, however, may have suppressed trace element responses. The concentration of organic-poor lakes in the vicinity of Mine Centre may account for the absence of enhanced chalcophile element concentrations in lake sediments that are coincident with the extensive sulphide mineralization of this region.

The distribution patterns of Mo and the chalcophile elements are the best indicators of, and are strongly controlled by, sulphide mineralization, more so than the lithophile and siderophile elements. Elevated levels in lake sediments commonly reflect mineralization that is similarly enriched in one or more of these elements (e.g., elevated As values associated with areas of Au mineralization; elevated Cu values associated with Cu-mineralization along the western margin of the Wawa Belt). Some of the anomalous zones outlined by the geochemical data are not associated with known mineralization and delineate areas of economic potential that warrant follow-up (e.g., elevated Ag values in the southeast corner of the survey area, potential for Ag-vein mineralization; elevated Zn values in the northwest corner of the survey area, potential for massive sulphide mineralization; elevated As values along the southern margin of the Wabigoon Belt, potential for Au mineralization).

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APPENDIX A

Analytical Methods

Determination of Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe in lake sediments

A 1 g sample is digested in 6 mL of 1M HCl - 4M HNO₃ at 90°C for 2 hours. After cooling, the solution is diluted to 20 mL with deionised water, mixed and allowed to settle. The elements are determined by atomic absorption analysis using an air-acetylene flame with background correction for Pb, Ni, Co and Ag. Detection limits are: Zn = Cu = Pb = Ni = Co = 2 ppm; Ag = 0.2 ppm; Mn = 5 ppm; Fe = 0.02%.

Determination of Mo in lake sediments

A 0.5 g sample is digested in 1.5 mL HNO₃ at 90°C for 30 minutes. 0.5 mL 12M HCl is added and the extraction continued for 90 minutes at 90°C. After cooling, 8 mL of 1250 µg mL⁻¹ Al solution is added, diluted to 10 mL with deionised water, mixed and allowed to settle. Mo is determined by atomic absorption using a nitrous oxide-acetylene flame. Detection limit = 2 ppm.

Determination of U in lake sediments

A 1 g sample is weighed into a polyethylene vial, capped and sealed. The irradiation is provided by a Slowpoke reactor with a flux density of 10¹² neutrons cm⁻² s⁻¹. The sample is pneumatically transferred from an automatic loader to the reactor where it is irradiated for 60 s. After a 10s delay, the sample is counted for 60s with 6 BF₃ detector tubes embedded in paraffin. Calibration is carried out twice daily using natural materials of known U concentration as standards. Detection limit = 0.2 ppm.

Determination of As in lake sediments

A 0.25 g sample is leached with 10 mL of aqua regia at room temperature for 2 hours and then heated to 90°C for a further 2 hours. After cooling, a 1.0 mL aliquot is taken and diluted to 10.0 mL with 0.5 M HCl in a test tube. Arsine is generated by the addition of 2% (w/V) sodium borohydride and the gas swept into a silica tube heated to 850°C in the light path of an atomic absorption spectrophotometer. Measurement is made at 193.7 nm against known standards. N.B. The values obtained by this method are sometimes higher than those obtained by the colorimetric method (used in earlier surveys), depending upon sample type. Detection limit = 1 ppm.

Determination of LOI in lake sediments

A 0.5 g sample is weighed into a beaker, placed in a cold muffle furnace and the temperature raised to 500°C over a 2-3 hour period. The sample is maintained at 500°C for 4 hours, cooled and reweighed. Detection limit = 1.0%.

Determination of F in lake waters

An aliquot of the water sample is taken and an equal volume of TISAB (total ionic strength adjustment buffer) is added. The mV reading is measured with an ion-selective electrode combined with a reference electrode and the F concentration found from a calibration graph constructed with known standards. Detection limit = 20 ppb.

Determination of U in lake waters

After collection, the water sample (≈225 mL) is acidified with 3 mL 12 M HNO₃. Two weeks later, a 5 µL aliquot is removed and spotted on a polycarbonate tape. The tape is irradiated for 1 hour with a flux density of 10³ neutrons cm⁻² s⁻¹. The tape is then etched with 25% NaOH solution and the fission tracks counted with an optical counter fitted to a microscope. Calibration standards are subjected to the same procedure. Detection limit = 0.01 ppb.

Determination of pH

The hydrogen ion activity is measured with a combination pH electrode and a specific ion meter which has been calibrated with standard solutions at pH 4.00 and 7.00.

APPENDIX B
Listing of Selected Mineral Deposits

Deposit or region Reference number (Fig. 3)	Deposit	Commodities	Status*
1	Mowe Lake prospect	Cu	3
2	(a) Kerry, Huronian, Ardeen, Moss mines (Belore Mines Ltd.) (b) Halonen J.	Au, Ag, Pb, Cu, Zn Au	2 3
3	(a) Coldstream Mines Ltd. (b) The (Shield Development Co. Ltd.)	Cu, Ag, Au Cu, Au, Ag	2 2
4	Monpre Iron Mines Ltd.	Fe	3
5	Band-Ore Mines Ltd.	Au, As	3
6	Shebandowan mines (International Nickel Co. of Canada Ltd.)	Cu, Ni, Pt, Co, Cr, Pd	1
7	Whalen occurrence (Seemar Mines Ltd.)	Cu, Ni	3
8	Lawrence prospects	Cu, Ni	3
9	<u>STEEP ROCK LAKE IRON AREA</u> (a) Steep Rock Iron Mines Ltd. (b) Canadian Charleson mine (Mathieu, J.A., and Pattison, G.E. estate)	Fe Fe	2 2
10	<u>STEEP ROCK LAKE IRON AREA</u> (a) Caland Ore Co. Ltd. (b) Quebec Cartier Mining Co.	Fe Fe	2 2
11	Elizabeth mine	Au	2
12	That Man Lake prospect (Lakehead Mines Ltd.)	Fe, Au	3
13	Carrigan occurrence	Be	3
14	International Lithium Mining Corp. Ltd.	Li	3
15	Olive mine	Au	2
16	Port Arthur Copper mine	Cu, Zn	2
17	(a) Orelia (Golden Star) mine (b) Ferguson occurrence (c) Golden Crescent prospect (d) Isabella occurrence	Au, Ag Au Au Au, Ag	2 3 3 3
18	(a) Foley (Sante Fe) mine (b) Stagee occurrence	Au, Ag Au	2 3
19	Belacoma Mines Ltd.	Cu, Ni	3
20	Rainy Lake Mining Ltd.	U	3
21	Grassy Portage Bay prospect	Cu, Ni, Zn	3
22	West Range Iron prospect (Great West Mining and Smelting Corp. Ltd.)	Fe	3
23	Emo (Young-Corrigan) prospect	Cu, Ni	3
24	Off Lake prospect (Noranda Mines Ltd.)	Cu	3

* 1 Producer; 2 Past producer; 3 Occurrence

