

Canada's National Geochemical Reconnaissance programme

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Synopsis

National Geochemical Reconnaissance (NGR) stream- and lake-sediment and water surveys have been carried out by the Geological Survey of Canada both independently and with the provinces under various federal-provincial programmes since the early 1970s. These surveys, which use established methods and specifications for the collection, preparation, analysis and publication of the data, provide a systematic coast-to-coast geochemical database. Areal coverage to 1990 amounted to approximately 2 100 000 km², representing 180 000 sites.

Although the data have applications in resource evaluation, environmental studies, etc., their prime utilization is in aiding and stimulating mineral exploration. Excess sediment material that is not required for the initial analytical determinations has been stored for future use. Reanalysis of these samples by instrumental neutron activation analysis (INAA) provides usable data for a large number of elements (up to 20 new elements).

The NGR surveys and the programme of archive reanalysis are supported by orientation and follow-up studies on specific geochemical problems and interpretative work on the existing geochemical database. These often have a direct impact on the regional surveys.

The objective of Canada's National Geochemical Reconnaissance (NGR) programme is to establish and maintain a nationally consistent geochemical drainage-survey database. The programme began in 1973 and by 1990 more than 200 surveys, representing 180 000 sites spread over approximately 2 100 000 km², had been completed to NGR standards. The data, in conjunction with other related geoscience or social science data, are used in support of mineral exploration programmes, mineral resource assessment, geological mapping and in investigations of environmental or public health concerns.

The programme has three components: conducting and publishing the results of regional geochemical drainage surveys; selective reanalysis of samples from previous surveys; and related orientation, methodology development, follow-up and interpretative studies.

NGR surveys

Introduction

Geochemical stream and/or lake surveys have been undertaken by the Geological Survey of Canada (GSC) for more than three decades.² Work in the late 1960s and early 1970s^{6,8,9} provided the basic framework for the NGR survey methodology. In 1973 the first large-scale NGR centre-lake bottom survey was carried out in insular Newfoundland

under the Canada-Newfoundland Mineral Development Subsidiary Agreement.⁴ A similar survey was conducted in Saskatchewan^{7,10} in 1974. From 1975 to 1979, when the Federal-Provincial Uranium Reconnaissance Program (URP) was active,³ stream (Cordillera only) and lake surveys were conducted in seven provinces and in the Yukon and Northwest Territories. During this period an area of approximately 900 000 km² was covered by geochemical drainage surveys.

From 1979 to 1983 provincial governments that expressed an interest in continuing the surveys with the GSC proceeded under other funding and/or managerial arrangements. Meanwhile the GSC continued to carry out wholly federally funded geochemical surveys. Since 1984 Mineral Development Agreements with the provinces and territories have provided the funding for a significant increase in NGR drainage surveys.

Sample collection, sample preparation and chemical analysis for most of the NGR surveys have been contracted out to private companies across Canada. The role of the GSC has been to develop and provide the technology, to monitor the work to ensure quality control of all aspects of the surveys and to compile and release the data to the public. The tight specifications and control maintained by the GSC throughout the NGR programme have ensured that the data are consistent regardless of the survey year, area, contractor collecting the samples, analytical laboratory or other factors. This has provided reliable data for a systematic, coast-to-coast geochemical database.

Extent and type of NGR regional survey coverage

The NGR regional survey coverage of Canada is shown in Fig. 1. The total area covered is about 2 000 000 km², representing approximately 180 000 sites. Most of this coverage is by stream-sediment (39%), lake-sediment (58%) and water surveys, with only limited coverage by well-water surveys (3%). Table 1 provides a regional breakdown of the

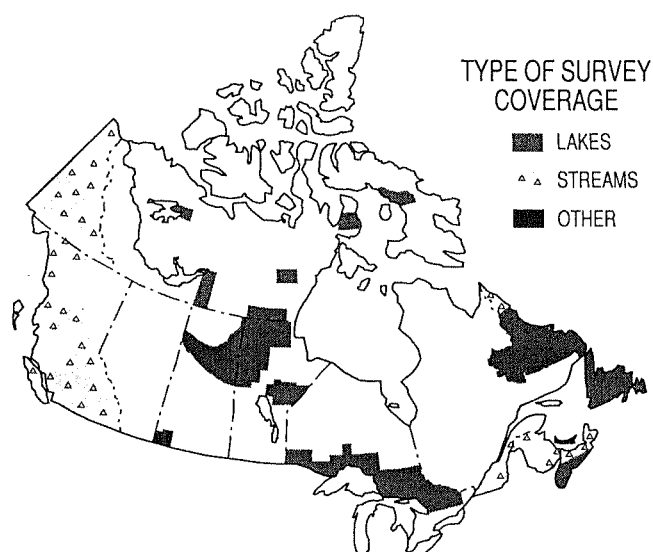


Fig. 1 National Geochemical Reconnaissance (NGR) survey coverage of Canada

Originally presented at the 28th International Geological Congress, Washington D.C., U.S.A., in July, 1989; revised manuscript received by the Institution on 7 June, 1991. Paper published in *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, 100, May-August 1991. © The Institution of Mining and Metallurgy 1991.

coverage and the corresponding number of sample sites.

Since the beginning of the programme the most common types of survey have been relatively low-density (one sample per 13 km²), helicopter-supported lake and/or stream surveys. Higher-density (up to one sample/2 km²), detailed surveys of new areas and infill surveys of areas previously sampled have also been undertaken and are becoming increasingly important. Data from a limited number of well-water surveys are also included as part of the NGR database. Because the latter are restricted in scope (<3% of total NGR coverage) and are not at present part of the programme, they are not discussed further.

Table 1 Breakdown, by region, of National Geochemical Reconnaissance survey coverage of Canada

Province/ territory	Lake survey		Stream survey	
	Sites	Area, km ²	Sites	Area, km ²
Newfoundland				
Labrador	19 029	280 900	1 377	17 200
Island	16 603	110 600	—	—
Prince Edward Island	—	—	380	5700
Nova Scotia	6952	32 900	4673	21 700
New Brunswick	339	4300	3 682	13 860
Quebec	—	—	2 021	23 850
Ontario	17 945	253 685	200	1 000
Manitoba	16 966	233 000	—	—
Saskatchewan	10 372	130 700	—	—
British Columbia	735	54 430	34 602	456 411
Yukon Territory	—	—	24 525	308 185
Northwest Territories	11 596	165 400	773	9 400
Total	100 537	1 265 915	72 233	857 306

Not all geochemical surveys carried out by the GSC or provincial agencies are included as NGR surveys. The surveys shown in Fig. 1 fulfill the criteria that: surveys are regional in extent (>1000 km²) and have been conducted between 1973 and 1990; samples are collected from lakes, streams, springs or wells; a uniform sample density is maintained by gridding site-selection maps to produce grid squares (cells) of appropriate size, e.g. 13 km²; specifications for sample collection, sample preparation and chemical analysis are consistent with those developed and employed by the Exploration Geochemistry Subdivision of the GSC; and all geochemical data have been, or will be, made available as open-file reports published by the GSC and/or equivalent provincial ministry or department.

Survey methodology

Introduction

A very important feature of the NGR regional survey methodology is its consistency over time. Although changes have been made to data-management techniques and to some of the analytical procedures, aspects such as sample collection, sample preparation and analytical monitoring procedures have not altered significantly. For example, with few exceptions the following observations apply to all the NGR surveys: analysis of stream sediments is carried out on the -80-mesh fraction (not necessarily ball-milled); lake-

sediment samples are collected from the centre-of-lake profundal basin and are prepared for analysis by ball-milling and sieving; a core suite of elements (Cu, Pb, Zn, Co, Ni, Ag, Fe, Mn, ...) is determined for all samples by a standard analytical procedure; quality control and field sampling variance are monitored by means of a blind duplicate, control reference and a field duplicate sample in every block of 20 samples; and a proportion of the control reference material used in any survey is carried over from previous surveys.

Consistency in these and in other fundamental parameters of the surveys has ensured the compatibility of data between different years and areas. Below is a brief description of selected aspects of the surveys.

Sample collection procedures

Stream surveys

In general, sampling in remote areas is totally helicopter-supported and is performed by one or more two-man crews, plus the pilot. The senior sampling crew member (navigator) is responsible for recording all pertinent field data, determining the actual sample site on the traverse maps and, with the pilot, for navigation. The junior crew member is responsible for sample collection and noting various field observations, which he relays to the senior member. In regions of good road access crews using trucks and all-terrain vehicles are often employed.

Proposed sample locations are provided by the GSC on National Topographic System (NTS) map sheets of appropriate scale (usually 1:250 000). Generally, locations are selected on first- or second-order streams in a drainage system where widths of less than 5 m are common. These locations are later transferred by the contractor to maps at convenient scales for use by crews sampling in assigned areas. However, after identifying a sample location from the traverse map the sampling crew chooses the actual field site.

Site-selection considerations The following factors are assessed in choosing a field site during sample collection. If the intended location does not provide a safe landing area for the helicopter but one can be found by an adjacent stream, the location is changed and the sample is taken from the stream rather than leave the area totally unsampled. Appropriate changes are made on the field traverse map and office copy map.

Contamination is avoided whenever possible. If the sampler has been in contact with gas, fuel or oil, hands are thoroughly washed before sampling. This is extremely important after assisting in fuelling of the helicopter. Contamination from residential and/or agricultural areas is avoided by collecting samples only at sites upstream from dams, water reservoirs, pumping stations, etc. At bridges or railway crossings samples are collected at least 50 m upstream to avoid contamination from culverts, road dust, exhaust, etc. Contamination from mining activity (wind-blown dust, placer deposits, tailings material) is avoided by moving a site as far as possible from the identified source. At stream confluences samples are collected at least 50 m above the juncture to avoid cross-contamination caused by spring flood overflow or back-up from one stream branch into the other.

At each location a sediment and water sample must both be collected if a site is to be considered as successfully sampled. If the stream is dry, and no acceptable alternative site is available, the collection of only a sediment sample is acceptable. However, under no circumstance is a water sample alone collected.

The sampler first collects the stream-water sample in a 250-cm³ Nalgene bottle after rinsing out the bottle and cap.

The sample should as far as possible be devoid of suspended materials, particularly organic matter and glacial rock flour. The sediment sample is collected from within a radius of 2.5 m from the centre of the sampling site. A composite, consisting of material from several places within the circle, is preferred to a sample taken from only one spot. Ideally, silt and clay-rich sediments from the active stream bed are favoured. Sediment with a dominantly sand-gravel composition is avoided. Pebble-size fragments are excluded from the sample. If organic-rich samples are collected, they must contain a high proportion of silt-clay material.

At sites where there are not enough fines in the active stream bed moss is collected from along the stream banks. In flood conditions streams can carry a high suspended load of silt-clay that becomes trapped in such moss. A hand-packed bag full of carefully collected moss constitutes an acceptable source of fines. Ideally, a suitable stream-sediment sample consists of sufficient fines that, after drying and sieving, there is enough -80-mesh fraction to fill two 16-dram vials (approximately 60 g). Field observations, such as the depth and flow rate of the stream, are recorded on standard field cards⁵ before the site is left.

Lake surveys

Sample collection in lake surveys is accomplished by two-person sampling crews using float-equipped helicopters. Proposed sample locations are provided by the GSC on NTS map sheets of appropriate scale (usually 1:250 000). An ideal sample comes from a lake that is less than 5 km² in size and more than 3 m deep, with a single, central basin that is the focus of drainage in the area adjacent to the sample site and contains organic-rich sediment. In general, in a given cell a lake with active inflow-outflow drainage is sampled in preference to a stagnant lake. Round lakes with one central basin are preferable to lakes with several arms and deep bays. If only long, narrow lakes are available, they are judiciously sampled more than once to provide a consistent sampling density. Large lakes are not sampled in their central basins where grid cells are entirely over water; along smooth shorelines or amongst islands in the middle of the lake. However, the deep bays of such large lakes can be sampled if carefully chosen. Small peat-bog or string-bog ponds are not sampled.

Lake-sediment samples are collected from the centre-of-lake profundal basin by means of a hollow-pipe, bottom-valved sampler that has been developed at the GSC (Fig. 2); the apparatus is lowered by an external winch and rope system on the fuselage of a helicopter. Once the helicopter has landed on the lake and come to rest the

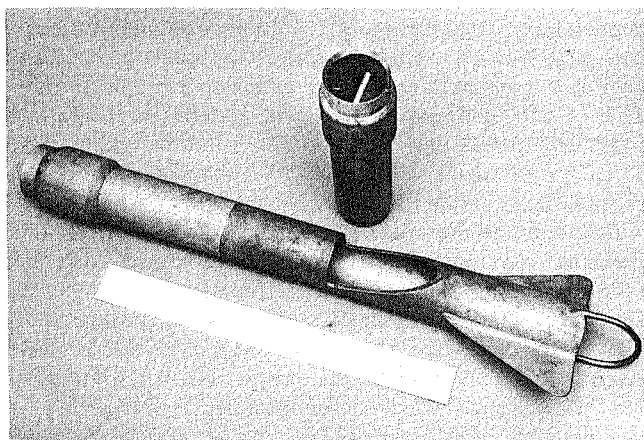


Fig. 2 Geological Survey of Canada lake-sediment sampler (length of bar, 46 cm)

sampling apparatus is released and allowed to sink unimpeded to the lake bottom. During retrieval the top few centimetres of sediment are washed out of the core barrel; the remaining material collected is an organic-rich sediment (*gyttja*)—commonly a greenish brown to grey thixotropic gel. The sediment samples are then placed in high wet-strength paper bags with dimensions when filled of approximately 10 cm × 15 cm × 15 cm and with a double-fold top; the bags are then stored in a partitioned aluminium box that is specially designed to fit in the back of the helicopter. Before the sampling crew leave the site they record field observations, such as the size and depth of the lake and local relief, on standard field cards.

Lake waters are routinely collected at all lake-sediment sites before the sediment sampler is raised. The samples are collected in rectangular, wide-mouthed polyethylene bottles from at least 20 cm below the surface in water that is as free of suspended material as possible.

Sampling procedures

For all NGR surveys samples are collected according to a basic sampling design. This incorporates—as detailed below and outlined in Fig. 3—field and blind duplicate and control

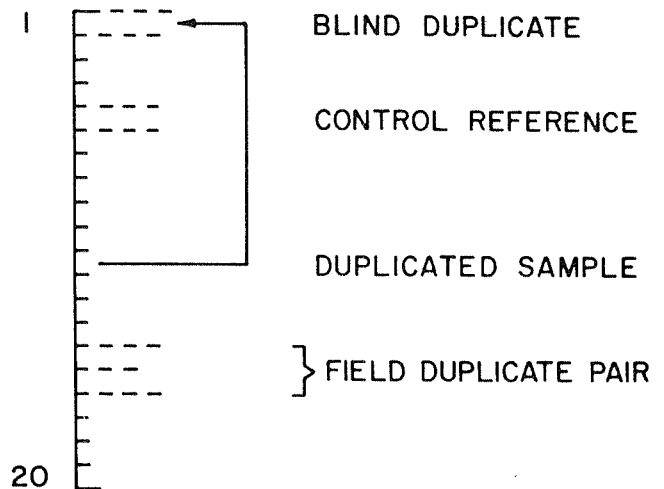


Fig. 3 Basic sample collection design used for quality control in NGR surveys (see text for explanation)

reference samples that are used to monitor and control sampling and analytical variance.

Each sample is identified by a unique 12-character alphanumeric, e.g. 105G_891176. The first group, 105G, refers to the 1:250 000 NTS map sheet (two blanks are left after the 1:250 000 map sheet number for identification of the 1:50 000 map sheets); 89 is the year of collection; the 1 identifies the crew and sample medium; and 176 is the incremental sample number. The use of a number to identify the crew allows up to four to sample simultaneously, as well as indicating the sample medium: 1, 3, 5, and 7 indicate sediment samples and the consecutive even numbers indicate water samples.

Every block of 20 consecutive field numbers (e.g. 001–020, 041–060) consists of 17 routine field samples, a control reference sample, a blind (analytical) duplicate sample and a field duplicate sample. The field duplicate sample is a separate sample collected at one of the 17 routine sites. The choice of which routine site to duplicate in a block of 20 is random and is left to the judgement of the sampling team.

One number—always the first in a block of 20 (i.e. 021, 121, 181, 541, ...)—is reserved for the blind duplicate. The sample-preparation laboratory selects a sample in the block, preferably one of the field duplicate samples, to duplicate and place in this reserved slot. Another number in each block of 20 is reserved for the control reference sample. A list of control reference numbers, which are produced by a random-number generating program, is supplied by the GSC to the field-sampling and sample-preparation contractors. GSC standard reference materials (usually three different ones with a matrix similar to the material being analysed) are later inserted by the sample-preparation laboratory. Use of this sampling design enables site and analytical variability to be monitored.

Sample preparation and analysis

Sample preparation

When field-dried survey samples are received from a contractor they are initially checked individually against the field cards for errors or omissions. Sample preparation is then carried out, preferably on large numbers of sequential samples. A minimum requirement is that all the samples from a given block of 20 be prepared at the same time.

Once drying is complete lake-sediment samples are crushed or broken down to pieces less than 0.5 cm in diameter, which are then loaded into ceramic ball-mills. When properly loaded (about half full for efficient particle reduction) each ball-mill holds approximately 10–15 g sediment. The mills are then clamped into wooden holders, which, in turn, are mounted on paint-pot shakers.

After the samples have been shaken for 45 min they are emptied on to clean, folded sheets of kraft paper. The –80-mesh fraction is placed into a 16-dram vial and weighed. For samples weighing less than 10 g additional sample material is prepared. Between the grinding of different samples the mills and balls are cleaned with ground quartz. The +80-mesh fraction, along with any excess material not ball-milled, is placed in 0.5-l polyethylene containers and stored in an archive.

The general procedure for the preparation of stream-sediment material is similar to that for lake sediment. However, a sieved –80-mesh fraction is used for milling instead of disaggregated bulk material. Sieves are cleaned between samples by brushing with a paint brush and blowing with a jet of compressed air. As with the lake sediment, vials of prepared samples are loaded into 40-hole trays and excess material is retained in polyethylene containers.

No special preparation is used for the water samples before they are sent to a laboratory for analysis apart from the care taken during collection to ensure that samples are as free as possible from visible suspended materials.

Sediment analysis

The analytical procedures used on NGR sediment samples can be conveniently divided into three categories: analysis of the 'core' element suite; analysis by specific techniques; and instrumental neutron activation (INA) analysis. These are summarized in Table 2 and are discussed below.

Since the beginning of the NGR programme a number of elements have been determined in most surveys by a standard dissolution procedure followed by atomic absorption spectroscopic (AAS) analysis. This group of elements, which is referred to as the 'core element suite', includes Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe, Cd and As.

The dissolution procedures used for lake and stream sediment differ slightly. For lake sediment a 1-g sample is reacted with 6 cm³ of a mixture of 4 M HNO₃ and 1 M HCl in

a test tube overnight at room temperature. After digestion the test tube is immersed in a hot-water bath at room temperature, brought to 90°C and held at this temperature for 2 h with periodic shaking. This sample solution is diluted to 20 cm³ with metal-free water. Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe and Cd are determined by AAS using an air-acetylene flame. Background corrections are made for Pb, Ni, Co, Ag and Cd.

Table 2 Generalized summary of elements determined during course of NGR programme

Year	Medium	Variables determined and methods used
1976	Lake sediment	Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe (AAS1); As (COL1); Mo (AAS2); LOI (GRAVI); U (NADNC)
	Stream sediment	Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe (AAS1); Mo (AAS2); U (NADNC); W (COL2)
1985	Lake sediment	Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe, Cd (AAS1); Mo, V (AAS2); As, Sb (AAS3); Hg (AAS4); LOI (GRAVI); U (NADNC); F (ISE); Au (FANA)
	Stream sediment	As lake sediment, plus W (COL2); Ba, Sn (AAS2)
1990	Lake sediment	Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe, Cd (AAS1); V (AAS2); Hg (AAS4); LOI (GRAVI); F (ISE); Na, Sc, Cr, Fe, Co, Ni, As, Br, Rb, Mo, Sb, Cs, Ba, La, Ce, Sm, Eu, Tb, Yb, Lu, Hf, Ta, W, Th, U, Au (INA)
	Stream sediment	As lake sediment, plus Sn (AAS2)

AAS1, atomic absorption spectroscopy (AAS) with air-acetylene flame; AAS2, AAS with nitrous oxide-acetylene flame; AAS3, AAS with hydride evolution; AAS4, cold-vapour AAS; COL1, colorimetry with use of diethyldithiocarbamate; COL2, colorimetry with use of dithiol or zinc dithiol; FANA, fire assay preconcentration with neutron activation analysis of doré bead; GRAVI, gravimetric determination at approximately 500°C; ISE, ion selective electrode; INA, instrumental neutron activation; NADNC, neutron activation analysis by delayed neutron counting.

Arsenic is determined on the same solution by means of a hydride-generation method wherein the hydride (AsH₃) is evolved and passed through a heated quartz tube in the light path of an atomic absorption spectrophotometer.¹

In the case of stream sediment a 1-g sample is reacted with 3 cm³ concentrated HNO₃ in a test tube overnight at room temperature. After digestion the test tube is immersed in a hot-water bath at room temperature, brought to 90°C and held at this temperature for 30 min with periodic shaking. Then 1 cm³ concentrated HCl is added and heating is continued for another 30 min. This solution is diluted to 20 cm³ with metal-free water. The analysis continues as outlined above for lake sediment.

In addition to the suite of core elements a number of other elements were routinely determined (up to and including 1988 survey samples) by specific techniques. These included Sb, Ba, Au, Hg, Mo, V, Sn, W and U; loss on ignition (LOI) was also determined. Of these, Mo, V and U were determined on all samples. The others—Ba, Au, Hg, Sn, W and LOI (Sn and W on stream-sediment samples only)—were gradually added up to 1985.

Since the 1989 surveys (inclusive), the results of which were released in 1990, INA has been the main method of

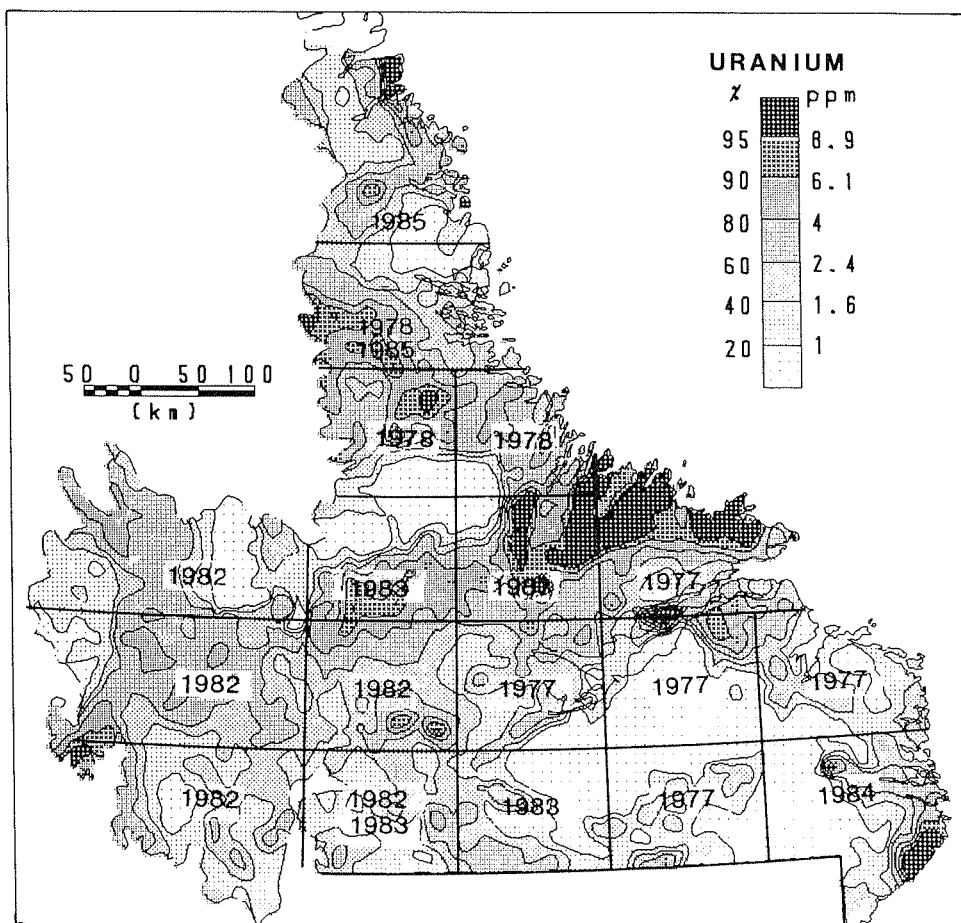


Fig. 4 Distribution of uranium in lake sediments throughout Labrador

analysis for lake and stream sediments. Additionally, a number of elements are determined by AAS and other specific techniques. In total, data for about 40 elements will be available for lake and stream sediments (Table 2).

The INA analytical procedure begins with the weighing of the sample material into plastic vials that hold 15–30 g, depending on the specific gravity of the sample. The vials are then irradiated for 20 min in a neutron flux with a density of about 5.3×10^{11} neutrons/cm²/s. Counting begins seven days after irradiation. The counting time is somewhat variable (6–11 min) and is matrix-dependent. Counting is performed with a germanium–lithium coaxial counter; the raw count data are accumulated on a computer and subsequently converted to concentrations.

This INA analytical package provides data on 34 elements (Table 2). The data for Zn, Se, Zr, Ag, Cd, Sn, Te, and Ir will not, however, be published because of inadequate detection limits and/or precision.

Water analysis

Determinations of U, F and pH are routinely carried out on all lake and stream waters. Since 1986 Ca, Mg and alkalinity (expressed as equivalent ppm CaCO₃) have also been determined on about 13 000 lake waters, representing an area of 18 000 km², collected in the provinces of Ontario and Manitoba.

Quality control

Quality control of all analytical data is maintained by monitoring control reference and blind duplicate data (field duplicate data are not used for this purpose). Within the sediment data each type is evenly distributed at a frequency of 5% (one each per block of 20 samples). For the water samples, however, only control reference samples are inserted

for quality control.

Once the sediment data have been received from the laboratory they are processed with a PC-based software program, Deval. Deval calculates a mean and standard deviation for all of the elements for each unique control reference sample (usually three per survey). For the data from a block of 20 samples to be acceptable the control reference and blind duplicate values for an element must be within calculated, predefined limits. The program then produces a listing of all cases that fail to meet the criteria. The block of 20 samples containing the unacceptable control reference and/or blind duplicate data sample numbers is then submitted for reanalysis. The data control procedure for water samples is similar but is based on control reference sample data only.

The results of the analytical quality-control programme and the consistency of the analytical methods over time are evident from Fig. 4, which shows the distribution of U in lake sediments throughout Labrador, an area of 280 000 km². More than 16 000 samples were collected over a 12-year period by six different contractors and analysed by four different laboratories. Despite this, broad regional trends are evident that reflect the known bedrock geology and are independent of survey boundaries (shown as solid lines). Although this is a very generalized plot, at a local scale there is the same absence of boundary effects. A 10-ppm U value determined in 1975 is directly comparable with the same value determined in 1989—not only from Labrador but from any other NGR lake-sediment survey across Canada.

Data management and release

The data collected and generated by each survey are initially released to the public in open-file form. Open files are also

prepared for the data that are generated as part of the reanalysis programme. At present a typical open file has three components.

(1) Text, which contains introductory information, a description of collection and analytical procedures, listings of field and analytical data and various summary statistics for each analytical variable.

(2) A set (one for each analytical variable) of 11 in × 14 in (28 cm × 35.5 cm) symbol-trend maps (Fig. 5). These are accompanied by clear plastic overlays of geology and the locations of sampling sites. Together they provide a rapid means of evaluating the survey area for anomalous zones and other areas of interest.

The key to the system is a small data-definition file that contains the list of permissible inputs for each open file, such as NTS map sheets, geological units in the study area, the variables measured, units, detection limits and the method used, as well as the control reference materials used. Other information includes the measurements to be listed or not listed, their order of listing and so on. This file is consistently used at every step of the process. It is open-ended and may be expanded in scope, but before any operation starts it must be established.

The first data entered into the system are the field observations. The monitor displays a form—similar to the field card—with designated areas for each item of data. When

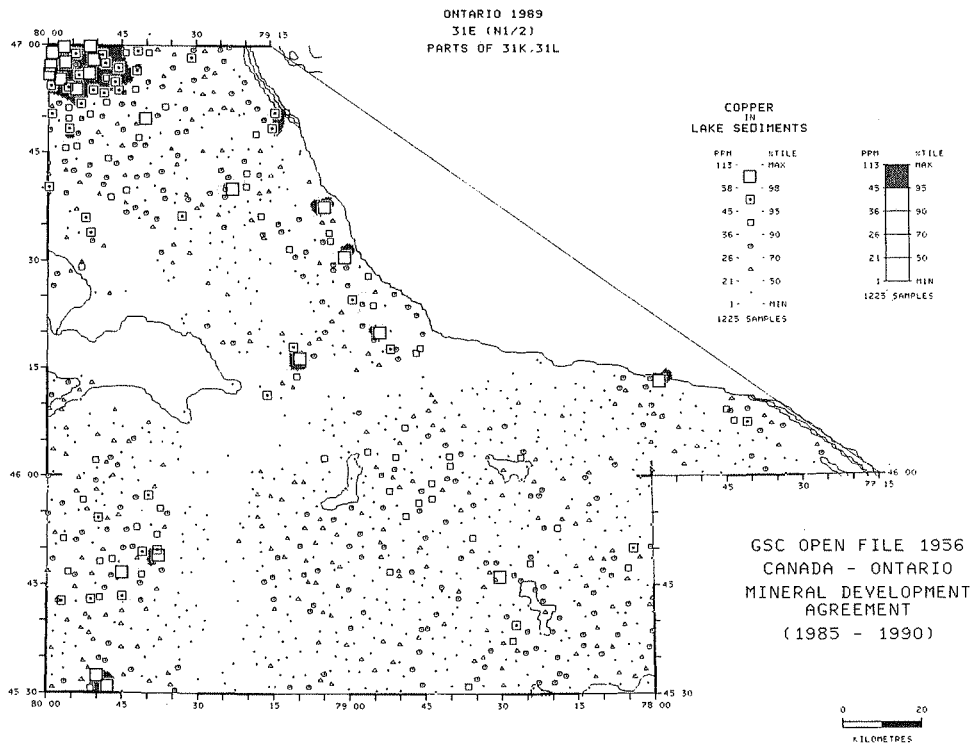


Fig. 5 Example of symbol-trend map from GSC Open File 1956

(3) A map showing sampling sites and gold values at the scale on which locations were originally recorded—usually 1:250 000. The sample locations and gold values are superimposed on NTS base maps and provide information on site locations, bedrock and surficial geology, drainage, culture, etc.

The process of managing the survey data to generate the open files has evolved significantly since the beginning of the programme. Most important has been the migration from a mainframe (CDC Cyber) to a personal computer environment. Almost all phases of open-file production are now accomplished on PC equipment (286- and 386-based IBM compatibles) instead of the mainframe, and the remaining mainframe-based programs are in the process of being adapted and transferred.

Associated with the change of hardware and software have been important gains in economy, speed of production and flexibility. Data are now checked for errors and internal consistency by the computer while being entered from source documents, not days later from printed listings.

A set of programs has been developed in-house with a consistent interface that is designed to allow the control of any step in the production process by the person responsible, rather than depending on a batch system and operator. All files being worked on are catalogued and displayed and may be selected via menus and roll bars, as may be all operations on the files.

the data for each field site are entered the program checks the entries; if an error is found, it will prompt the operator for a correction. An entry may be recalled for editing at any time. On completion a listing is produced and the program ensures that all sample sites are accounted for and that each block of samples has the correct number of control reference, blind duplicate and field duplicate samples. The operator is notified of any samples that may have been entered twice or more and of gaps in the site sequence.

The locations of sample sites are digitized from the field maps. When digitizing is complete the program plots, via a Hewlett-Packard LaserJet printer, a tiled series of 8.5 in × 11 in (21.6 cm × 27.9 cm) printouts on paper or transparent film. The operator then overlays each on the source map and checks for missing or incorrect points and edits the data as necessary.

The chemical analyses are received from the laboratory on floppy disks in a specified format that allows direct input into the system. The blind duplicate and control reference data are then processed as described above and, if necessary, the laboratory is advised which samples should be re-run.

After the repeat analyses have been received and inserted the clean field, spatial location and analytical data files are merged into one processed file. This file is used to produce all the open-file maps and text. At present production of the text, including data listings, statistics, histograms, etc., is part

of the system. The integration of map production with the system is currently under way.

Utilization of survey data

The traditional and, currently, the prime use of regional geochemical survey data is to aid and stimulate mineral exploration. The release of regional data—particularly gold data—frequently sets off a staking rush. Table 3 shows post-release date claim-staking activities in a number of provinces in 1986 and 1987 over a period of about three months from the release date. Large acreages have been staked as a result of data release, usually concentrated in areas of anomalous gold responses and/or associated pathfinder elements such as As and Sb.

Table 3 Summary of post-release claim staking for 1986 and 1987

Province/territory	Acreage staked following 1986 releases	Acreage staked following 1987 releases
Labrador	*	124 241
New Brunswick	4 703	4 626
Ontario	†	4 742
Manitoba	43 161	8 233
Saskatchewan	14 027	20 600
British Columbia	30 887	129 726
Yukon	141 037	36 988
Total	233 815	329 156

*No data available.

†No data released.

If, despite the increased costs, major elements were to be included in the analytical data, the data would be even more useful for supporting the geological mapping of bedrock and surficial materials. In areas of thick overburden geochemical data can be very useful in extending geological contacts, etc. Certain resource evaluations can be supported by new anomalies on the basis of similarities to known anomalies and their related deposit environments. The regional survey data include elements that are considered to be toxic or contaminants, such as Cd, As, Pb and Hg, and which are of importance in environmental studies. Obviously, older regional data provide reference levels for current work and all

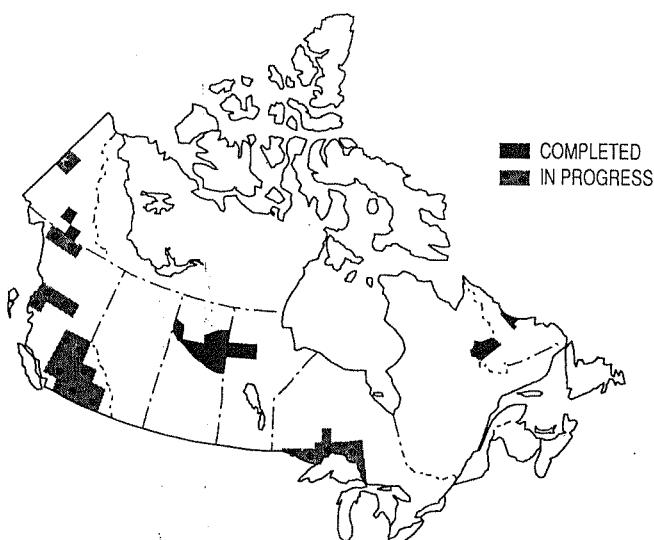


Fig. 6 Status of NGR reanalysis programme

survey data define the naturally occurring levels of those toxic/non-toxic elements which are of environmental and public health concern. There is still a need to make further additions, as has been done in the past. A number of variables that are environmentally relevant would—even if not of direct benefit to mineral exploration—be useful additions to the present analytical suite.

A large NGR database containing all regional geochemical data collected from 1973 to the present is being constructed. This database will facilitate the use, and publication in digital form, of millions of elemental determinations from more than 150 geochemical surveys that are held on open file. For the first time all or part of the data set for a province or territory can easily be retrieved for exploratory data analysis and map display. Such data, together with other geoscience data and in combination with currently available software for geographical information systems, provide an extremely powerful means of evaluating complex data for mineral exploration and other purposes.

Reanalysis programme

The second component of the NGR programme is the reanalysis of archived stream- or lake-sediment material. From the outset sediment samples not required for analysis have been catalogued and stored. At present the GSC has about 140 000 such samples, and additional samples are stored by several provincial surveys.

Reanalysis of this material, particularly of pre-1984 samples, is becoming an increasingly important aspect of the NGR programme—largely because of recent advances in INA analysis. The INA analytical method has several important advantages for the reanalysis programme. The most important is that it is a non-destructive analytical method, so after a 'cooling down' period the analysed material can be returned to storage. This ensures that there

Table 4 Selected related studies recently undertaken as part of NGR programme

Title	Objective(s)
Gold in lake-sediment study	Evaluate effectiveness of lake-sediment surveys for gold exploration
Evaluation of INA and ICP methods	Evaluate feasibility of using other analytical techniques to provide core element data for NGR surveys
NGR database development	Create consistent database in microcomputer environment to facilitate access to all NGR data
Microcomputer development	Develop microcomputer-based system to handle all aspects of data management from initial acquisition to open-file production
Geographical information systems (GIS) evaluation	Evaluate GIS with regard to potential applications in production of second-generation geochemical releases
Kirkland Lake silver study	Follow-up and evaluate extensive Ag anomaly defined by lake-sediment <i>Open File</i> 1640
Contwoyto Lake orientation study	Evaluate usefulness of lake-sediment geochemistry for gold exploration in northern tundra areas

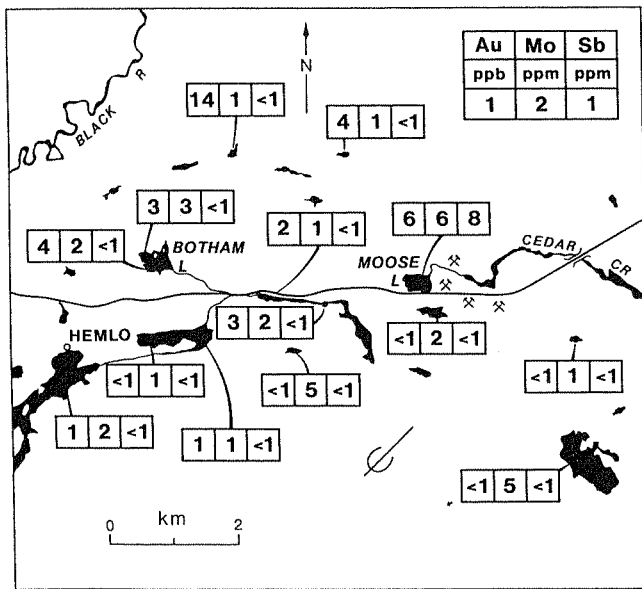


Fig. 7 Distribution of Au, Mo and Sb in selected lake sediments from Hemlo area, northwestern Ontario

will be material available for future programmes of reanalysis. Second, it is cost-effective; and, finally, it provides usable data for a large number of elements. In general, the reanalysis produces new data for about 20 elements that were not available in the original open-file release (refer to Table 2).

The present status of the reanalysis programme is summarized in Fig. 6. When all current work has been completed and the results released (tentatively, in 1992) approximately 35 000 samples will have been reanalysed from an area of about 455 000 km².

Related studies

Related studies form the third major component of the NGR programme. Although such work often has general application to the field of applied geochemistry, it was originally designed to address particular problems encountered by the NGR programme. This is a very important aspect of the programme as it is the mechanism by which the methodology evolves.

Table 4 lists some of the projects that have been undertaken over the last few years as part of the NGR programme. Below, to illustrate the impact of this kind of work, is a brief description of a study of Au in lake sediment.

The project to study Au in lake sediment started in 1985 and still continues. Over this period observations have been made on the basis of data acquired from several orientation studies. The most important of these is that anomalous concentrations of Au and/or other related elements can occur with known gold mineralization. For example, Fig. 7 shows the results for Au, Mo and Sb obtained from some of the 150 lake-sediment samples taken in the Hemlo gold area of northern Ontario. Sediments from Moose Lake, adjacent to the mineralization, are distinctly anomalous in these three elements. The Au concentration of 6 ppb compares to a local background level of <1 ppb. Sb exhibits an even more pronounced enhancement—8 ppm in Moose Lake, compared to a background of <0.2 ppm.

A second observation is that reproducing Au values is a problem—although less so as the organic content of the lake sediment increases. This is illustrated in Fig. 8, which is a generalized plot of 50 replicate Au analyses of lake sediments from northern Ontario. Along the y-axis are Au values, which, for a given sample, are joined by a bar if different or shown as a hatched square if both values are the same. The x-

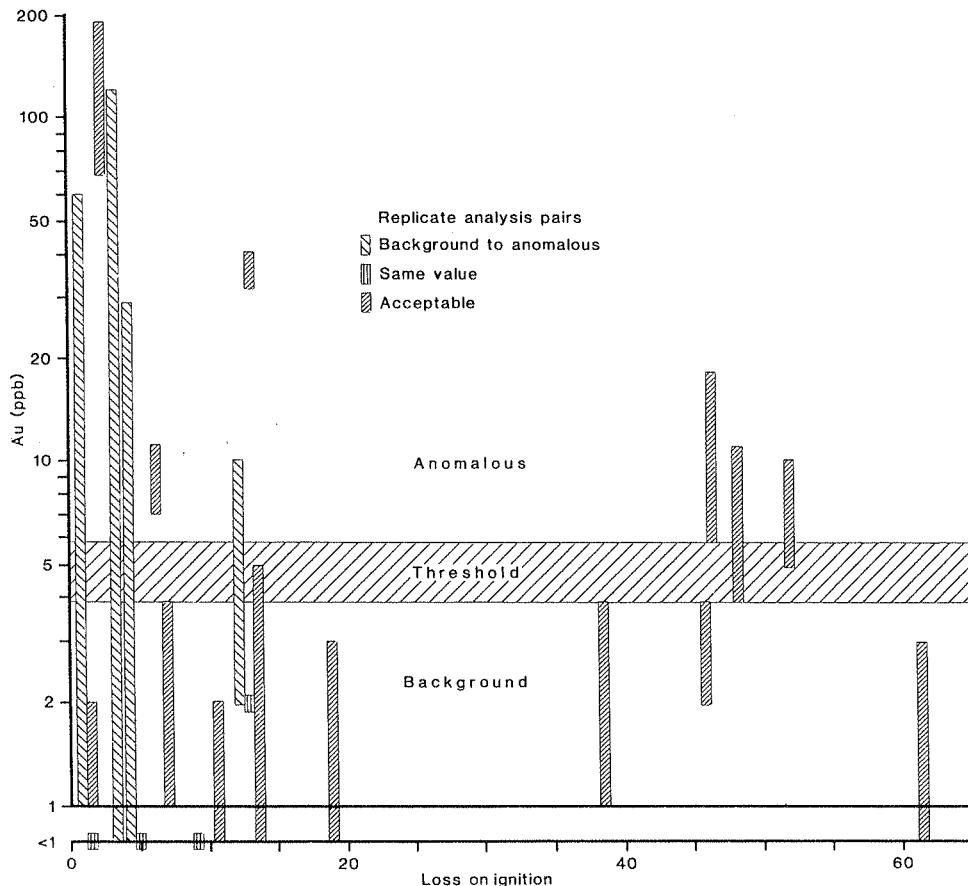


Fig. 8 Replicate gold data for 50 lake-sediment samples from northwestern Ontario—see text for explanation

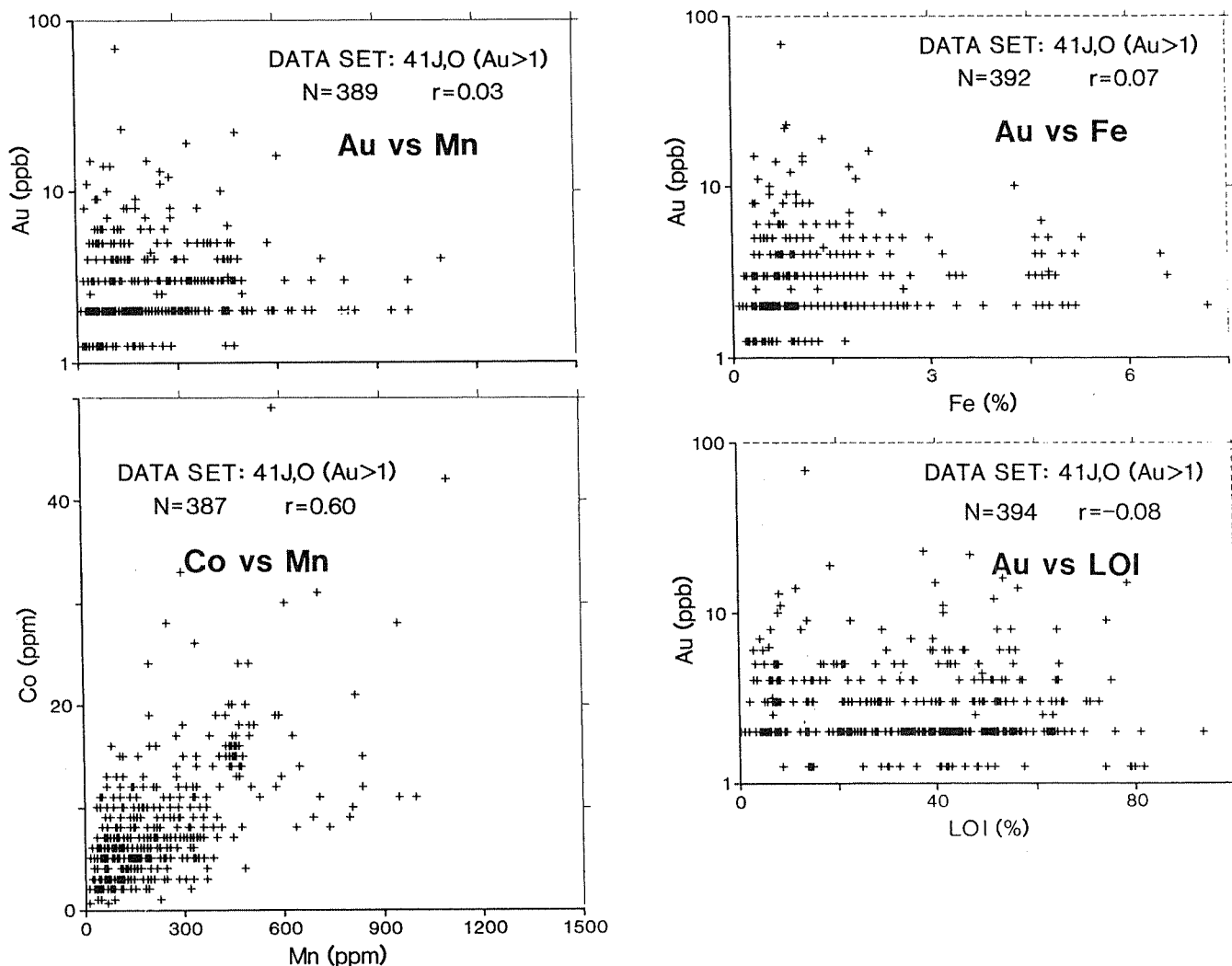


Fig. 9 Plots of lake-sediment data: Au versus Mn, Fe and LOI and Co versus Mn

axis shows the corresponding organic content as measured by loss on ignition (LOI). The figure indicates that Au analyses are more variable in low-LOI samples. Of the 22 samples with less than 11% LOI, the replicate Au analyses for five changed from background to anomalous or vice versa. In the range of 11–20% LOI two changed. By contrast, no such changes were recorded for samples with LOI levels greater than 20%. This indicates that the Au results measured on samples with high LOI are more reproducible, providing more reliable data, than those for low-LOI samples.

A third observation concerning Au in lake sediments is the lack of correlation between Au and Fe, Mn or LOI. This is important because it indicates that anomalous gold values most often reflect enhanced bedrock concentrations and/or gold-bearing mineralization and do not represent false anomalies related to scavenging. For example, x - y plots of data for Au versus Mn, Fe and LOI (Fig. 9) taken from a regional survey in Ontario clearly show a lack of sympathetic relationship between gold and these three variables. However, Co—which is known to be scavenged by Fe and Mn—exhibits a significant correlation with Mn, as shown in Fig. 9. This has a correlation coefficient of 0.6, compared to <0.1 for all three gold plots.

On the basis of these and other observations it is concluded that lake sediments are an effective geochemical medium for delineating areas of gold mineralization. As a result of this study a number of changes were made to the NGR regional lake surveys, including the addition of Au and Sb to the suite of core elements analysed; the routine reanalysis of samples

with Au values greater than the 90th percentile; the routine reanalysis of samples with less than 10% loss on ignition; and, where possible, an increase in the sample density over geologically favourable areas.

Summary

The objective of Canada's NGR programme is to establish and maintain a nationally consistent geochemical drainage survey database. Towards this end systematic surveys have been conducted since 1973. To date more than 200 surveys have been completed to NGR standards, representing 180 000 sites and covering about 2 100 000 km² throughout Canada. All of these data are in the public domain and largely available in digital form. To facilitate the retrieval of all or any part of the data a database (using the Oracle RDBMS software application) is at present being created that will include all NGR data.

Through the reanalysis component of the NGR programme the number of elements for which data are available is being increased. By 1991 more than 35 000 archived samples, representing an area of 455 000 km², will have been reanalysed by non-destructive methods. Data for upwards of 45 elements will be available for these samples. The reanalysis of samples will continue on a selective basis, guided by interest in a given suite of samples and advances in analytical techniques.

The third component of the NGR programme is the related studies. It is through these that the programme

evolves and improves. In one high-priority project that has recently started a geographical information system (GIS) is being used to integrate the geochemical data with other types of geoscientific data. The goal is to produce second-generation geochemical data that will integrate regional geochemical survey data with other geoscientific or sociological data to support spatial integration studies related to mineral exploration, public health or environmental interests.

Acknowledgement

The NGR programme is the product of years of multidisciplinary team effort from its establishment in 1973, through various technological developments, to the present computer-supported data-management and digital open-file publication system.

The authors wish to acknowledge the positive input of many individuals and organizations that have contributed to the programme over its 17-year life. These include: at the GSC, all members of the Exploration Geochemistry Sub-division, with particular reference to the efforts of Bob Garrett, Greig Lund and John Lynch and members of Drafting Unit A under Frank Williams in Cartography; science procurement managers in the Department of Supply and Services; staff of provincial geological surveys—especially Peter Davenport of the Newfoundland Geological Survey branch, who participated in the earliest development work; and numerous individuals from various contracting firms whose suggestions for improvement were often accepted. Final appreciation is to Eion Cameron and Arthur Darnley, whose management support laid the institutional foundations for these jointly organized and/or funded federal/provincial and territorial surveys, particularly during the Uranium Reconnaissance Program, 1975–79.

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