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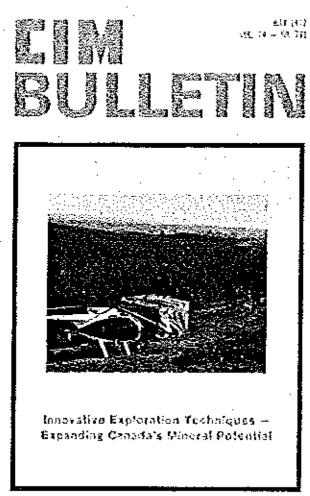

Helicopter support is essential to many of Canada's exploration projects. Photo supplied courtesy of Denison Mines Limited.

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Geochemical Exploration for Uranium In the Grenville Province of Ontario

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Abstract

A helicopter-mounted lake-sediment and lake-water survey was carried out over Grenville rocks in the Renfrew area (parts of Renfrew and Lanark counties) during four days of October, 1975. In the course of this survey. 1150 square kilometers were covered, with 246 lake-sediment and 276 lake-water samples collected from every body of water on which the helicopter could land. Sample sites, which averaged one per 4.6 square kilometers, included lakes, ponds, beaver ponds, swamps and marshes. Lake-sediment samples were taken using a G.S.C. sampler. Waters were collected directly into polyethylene bottles. At each sample site, surface and bottom-water pH, dissolved oxygen content, conductivity and temperature were measured using a Martek Water Quality Analyzer.

The lake sediments were air dried and then ball milled to pass a minus 80-mesh sieve. Lake sediments were analyzed for U by delayed neutron activation and for Mo, Cu, Zn, Pb, Fe, Mn, Ni and Co by atomic absorption techniques. The organic content of the sediments was determined by loss on ignition at 450°C. Lake waters were acidified with nitric acid on the day of collection. The U content of the waters was determined by fluorometry; the Cu, Zn, Pb, Fe, Mn, Ni and Co contents of the waters were determined by solvent extraction - atomic absorption techniques.

A close relationship was found between bodies of granitic, syenitic and pegmatitic bedrock and elevated U levels in the lake sediments. The Hurd Lake and White Lake granitic intrusives were encompassed by an annulus of higher U activity. Field inspection revealed that the U concentrations occur within a zone which may represent a contact metamorphic aureole. Within these complexes, anomalous concentrations of U appear to be associated with Mo. Information derived from the lake-water data reinforces the geochemical distributions outlined by the lake-sediment survey.

This survey was carried out in order to develop optimum sampling and analytical procedures for geochemical reconnaissance of the Grenville Province that may be carried out under the auspices of the Uranium Reconnaissance Program.

William B. Coker was born in Brandon, Manitoba, and graduated from Carleton University in 1971 with an Honours B.Sc. degree in geology. Specializing in geochemistry, he received his Ph.D. degree from Queen's University in 1974. Dr. Coker has many years' experience in both base metal and uranium exploration in eastern Canada with Phelps Dodge Corporation of Canada Ltd., SOQUEM and Rio Tinto Canadian Exploration Co. Ltd., where he was employed as a geologist-geochemist on graduation from Queen's University in 1974. In 1975, he joined the Geochemistry Section of the Geological Survey of Canada as an applied geochemist working on uranium and base metal geochemistry in the southern portion of the Canadian Shield. Current research interests lie in the study of chemical limnology and base metal and uranium geochemistry of lakes and surrounding catchment basins as applied to the interpretation of geochemical data for mineral exploration.

Ian R. Jonasson is currently working as a research scientist in the Geochemistry Section of the Geological Survey of Canada, Ottawa. He was born in Melbourne, Australia, in 1939 and attended the University of Melbourne, from where he graduated with an Honours Science degree in 1962. He completed his Ph.D. thesis at the University of Adelaide in 1967 at the Department of Physical and Inorganic Chemistry. Thesis material and subsequent post-Doctoral studies, under the auspices of a Nuffield Foundation Fellowship, included work on the kinetics of heterogeneous catalysis (by oxide surfaces) of oxidation-reduction reactions, and investigations of rapid hydrolysis reactions of transition metal coordination compounds. In 1969, he was awarded an N.R.C. Post-Doctoral Fellowship at the Geological Survey of Canada to study the surficial geochemistry of mercury. This work led in turn to extended studies on the use of vapours and gases in soil-air and water in mineral exploration. Lately, Dr. Jonasson has been engaged in research on the nature and mechanisms of elemental dispersion, particularly on stream systems in both mountainous and flat terrain. The results of this work are being applied to the development of improved methods of geochemical reconnaissance search for concealed orebodies and to more valid interpretation of such field data.

Keywords: Mineral exploration, Exploration techniques, Geochemical exploration, Uranium, Grenville Province, Lake sediments, Lake waters, Renfrew area, Molybdenum, Copper.

Introduction

AN ORIENTATION SURVEY of the trace-element geochemistry of drainage-basin sediments and surface stream and lake waters was carried out in an area covering parts of Renfrew and Lanark counties. The survey, which covered all of the 1:50,000 map sheet of Renfrew (31F/7), was completed in four days of flying with a Hughes 500-C helicopter.

This work forms a continuing part of the National Geochemical Reconnaissance (N.G.R.) program, which comprises not only regional reconnaissance surveys, but also detailed sampling within selected orientation scale projects and follow-up studies.

A major objective of the program is to direct attention to areas which may prove of interest in uranium geoexploration. In some cases, as in Eastern Ontario, an area may already be well known for its uranium occurrences, but geochemical methodologies which might be employed to locate further zones of interest have not been thoroughly tested.

In particular, the Renfrew area, which lies to the east and within 80 km of the Bancroft Mining District, has not received the attention it might otherwise have deserved because of the proximity to known uraniferous zones.

Thus, the orientation survey of the Renfrew area, described herein, was designed to permit testing of geochemical methods with regard to their responses to typical Grenville geological and environmental influences. The information gathered could be viewed, on the one hand, as research information and, on the other, as the basis for anticipated future regional surveys of these and similar nearby terrains.

Geology and Previous Work

The geology of the area has been described by Quinn *et al.* (1956) and published as Geological Survey of Canada Map 1046A, Renfrew (Fig. 1). A compilation of the geology of Renfrew County showing, among other things, the relationships between the Bancroft and Renfrew areas, has been published by the Ontario Department of Mines as Map No. 53b, Renfrew area (Satterly, 1944). Of principal interest from the viewpoint of uranium possibilities are three granitic bodies which are located, respectively, near Renfrew town, surrounding Hurd Lake and west of White Lake. Smaller similar bodies lie to the west of Calabogie Lake, in Brougham Township and in the northwest of the area covered (Grattan Twp.). All of these intrusives comprise granites and/or granodiorites with some syenite facies. Some true syenites have also been mapped near White Lake and in Brougham Township. The Hurd Lake granitoid differs from the others in that it contains extensive formations of granite pegmatites which are known to host minor occurrences of molybdenite and, occasionally, uraninite. Prominent zones of hornblende and other types of gneiss commonly surround the granites, although the nature and grade of alteration of the metamorphic rocks observed clearly depends on the nature of the sediments which have been intruded. To the west and south of the Hurd Lake granite lies a zone of Grenville marbles which contain showings of sphalerite and galena (Renprior Claims). Close to these zinc-lead showings, but still within the Hurd Lake pegmatites, are some old workings from which molybdenite was once mined (Vokes, 1963; Satterly, 1944). The most prominent of these are the Zenith and Buckhorn mines, which now reveal their presence by a few overgrown pits, shafts and trenches. The more significant ones lie in Brougham Township and are now known as the Hunt and the Ross-O'Brien mines, where the host rocks for mineralization are mainly amphibolite and gneiss. No uranium showings have been reported from these areas.

A considerable amount of prospecting and geophysical work has been carried out close to and across the survey area.

A study of the radioactive pegmatites of the Renfrew area has been made by Charbonneau and Jonasson (1975). Their work followed on previous investigations of uranium showings within the Ordovician March - Oxford formations, which lie between the eastern limits of the study area and Ottawa (Charbonneau *et al.*, 1975a; Jonasson and Dyck, 1974). Other reports of radioactive pegmatites in the Gatineau Hills, Quebec (Hogarth, 1970), and studies of the uraniferous Bancroft (Satterly, 1957) and Mont Laurier (Allen, 1971), pegmatites, also form part of the background to this present work.

The airborne radiochemical work of Charbonneau *et al.* (1975b) and the G.S.C. (1976) in the Ottawa Valley west of Ottawa and certain cross-country

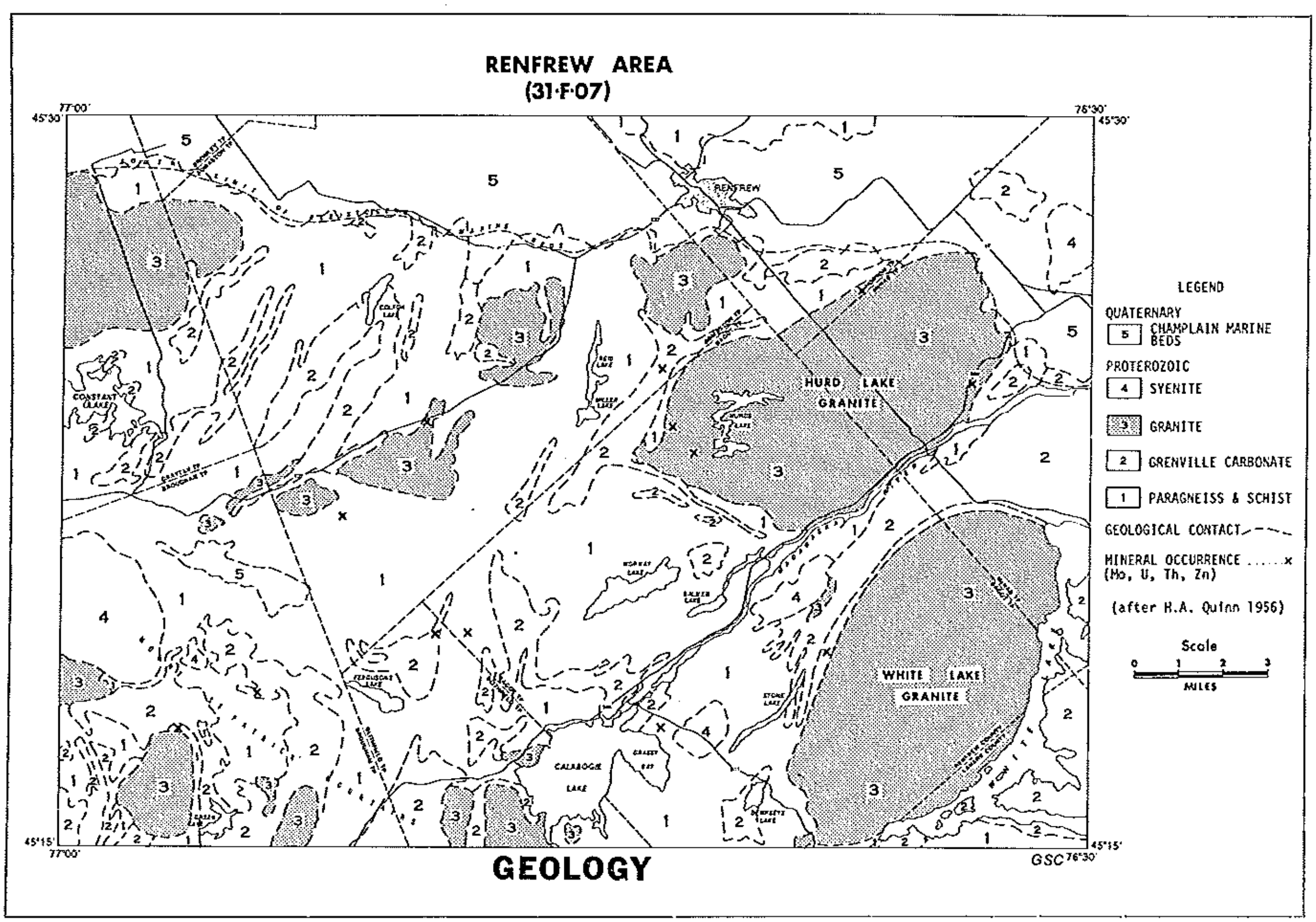

FIGURE 1 — General geology, Renfrew area, Ontario.

airborne gamma-ray spectrometry profiles which transect the Renfrew area have also indicated significant radioactive anomalies in the study area (Darnley *et al.*, 1971).

The working hypothesis which drew Charbonneau and Jonasson into the Hurd Lake area is twofold. Firstly, earlier works noted above indicated that a "source" area in Precambrian rocks of Grenville age for uranium found in Paleozoic sediments should lie immediately to the west and north of these formations. Secondly, the chemical and mineralogical similarities between pegmatites found at Bancroft and Mont Laurier, where there is a positive correlation of radioactivity with contained magnetite or biotite, leads one to look for similar relationships in the Renfrew-area granites. In fact this is so (Charbonneau and Jonasson, 1975). Satterly's map (1957) also shows a general correlation between the structure of granitoid masses with peripheral gneiss and related radioactive occurrences at Bancroft and Renfrew.

Charbonneau and Jonasson (1975) concluded their investigation by suggesting that possibly there exists a continuous belt of radioactive granitoids between Bancroft and Mont-Laurier. The regional unconformable contact of Grenville rocks and the underlying granitic basement is considered to have generated, through remobilization, uranium-enriched pegmatites worthy of further attention with regard to mineral exploration.

In this present work, it was resolved to check surficial geochemical responses against known and considered underlying geology with regard to uranium occurrence.

The Survey

In the course of this orientation survey, which was conducted in October 1975, 1150 km^2 (450 mi.^{2}) were covered, with 246 lake-sediment and 276 lake-water samples. These were collected from every body of water on which the helicopter could safely land. Sample sites, which averaged one every 4.6 km^2 (1.8 mi.^{2}), included lakes of all sizes, ponds (permanent and intermittent), beaver dams, true swamps and flooded marshes. Heavy rains in the area had broken dry conditions some 5 or 6 days prior to commencement of the survey, and as a consequence the ease of landing at certain sites was enhanced due to increased water flows in intermittent drainage courses. The effects this circumstance had on the availability of sediment samples and on the condition of water samples can be discussed.

The physical nature of a lake sediment, usually collected from what was thought to be the deepest part of the lake, did not vary much for samples from deep, permanent lakes. It was commonly a thixotropic gel, brown, black or green in colour, sometimes smelling of hydrogen sulphide. Occasionally, pink or yellow sediments would be gathered, but these were more typical of shallower lakes such as White Lake. Often these were more chaff-like in texture and less mature than gels. No difficulty was experienced in collecting such samples. Lake waters were clear, but sometimes stained yellow in the shallower lakes, presumably by dissolved organic substances.

Some 30 more water samples than sediments were collected. Sediment recovery was reasonably good in permanent waterfilled swamps, where rotting organic matter or bog soils were readily gathered, but in grassy marshes it was very poor. It is suspected that a number of these latter sites were intermittent water bodies and in fact there was no true sediment to be collected. The sampler would not penetrate the "lake" bottom at all. This situation was also true of most beaver dams and also in the flooded northern reaches of Calabogie Lake and Black Donald Lake. The last two bodies were sampled for water only, due to the inability of the sampler to recover any sediment.

It would seem that in any relatively young water body there has not been sufficient time to lay down a drainage-basin sediment of any thickness which can be usefully sampled. The two large lakes mentioned above are products of fairly recent flooding due to dam building. These lakes were found to be too deep to sample in their centers; i.e., in the "original" lake basins wherein a normal sediment would be readily available.

The water bodies within the granite west of White Lake were found to be particularly difficult to sample, not only for the abundance of beaver dams and intermittent ponds, but also for the inaccessibility of flooded marshes due to dead-head trees. Consequently, coverage with sediments is more sparse in this region than elsewhere in the survey area.

The water samples from ponds suspected to be flood-filled were generally very clear and fresh-looking. It is considered here that they could well closely reflect the trace geochemistry of the rocks they have recently drained particularly for elements considered to be hydrogeochemically mobile, such as U.

As will be shown later, the presence of dissolved carbonate is probably ubiquitous through the study area; water pH was almost invariably alkaline. Such conditions are favourable for the dispersion and retention in solution of the elements U, Mo and, to a lesser extent, Zn, but less favourable for, say, Cu, Pb, Fe and Mn.

Sampling Techniques and Analytical Procedures

Sediment samples were obtained using a G.S.C. sampler. Surficial (top 5-10 cm) sediment, at the sediment-water interface, was avoided.

Surface waters were collected directly into polyethylene bottles and acidified (250 μl of HNO_3 per 125 ml of water) on the day of collection.

Measurements of the surface and bottom-water pH, dissolved oxygen content, temperature and conductivity were made using a Martek Mark V Water Quality Analyzer. Sample depth was also recorded.

A number of standard observations, as well as the Martek data, were recorded on lake-sediment and lake-water field data cards for the corresponding sample taken at each sample site. The field data cards have been described by Garrett (1974).

Air drying generally resulted in the organic-rich bottom sediment samples becoming extremely hard. The samples were disaggregated, using a mortar and pestle and an alumina ball mill, to obtain a fine powder which could pass through a minus 80-mesh sieve.

A 1-g sample of minus 80-mesh lake sediment was digested in a test tube with 6 ml of a 4M HNO_3 - 1M HC1 mixture overnight. After digestion, the sample solution was cooled to room temperature and diluted to 20 ml with distilled water. The contents of Cu, Zn, Fe, Mn, Pb, Co and Ni were estimated by atomic absorption spectrophotometry. Analyses for the latter three elements were carried out using simultaneous, automatic background correction.

A 500-mg sample of minus 80-mesh lake sediment was decomposed in 1.5 ml of concentrated HNO_3 overnight, 0.5 ml of concentrated HCl was added and the solution was allowed to cool to room temperature. An 8-ml aliquot of a 1250-mg/ml Al solution was then added and the solution was made up to 10 ml with distilled water. Mo was estimated by direct aspiration of the sample solution into the nitrous oxide - acetylene flame of an atomic absorption spectrophotometer.

TABLE 1 — Surface Lake Waters — Renfrew

		min.	$\bar{x}-2\sigma$	$\bar{x}-\sigma$	$\bar{x}$	$\bar{x}+\sigma$	$\bar{x}+2\sigma$	max.
Normal	Temp., °C	10.0	12.1	13.1	14.2	15.2	16.3	17.0
	pH	7.8	7.9	8.0	8.1	8.2	8.3	8.5
	Cond., µmho/cm	13	8	70	132	194	256	297
	O_2, ppm	2.3	6.3	7.9	9.5	11.1	12.7	13.9
Log Normal	U	0.0	—	0.02	0.07	0.23	0.79	3.0
	Zn	*0.2	—	—	0.4	0.9	2.2	24
	Cu	*0.2	—	—	0.3	0.5	0.9	7.8
	Pb	*2.0	—	—	2.1	2.6	3.3	65
	Co	*1.0	—	—	1.5	2.7	4.8	5.0
	Ni	*0.2	—	0.6	1.8	5.6	17	105
	Fe	*5	—	10	39	157	636	2394
	Mn	*5	—	—	20	48	115	508

*Values equal half detection limit; all metal values in ppb (ng/ml); 204 samples.

A 50-ml aliquot of the acidified water sample was extracted in 6 ml of MIBK with 3 ml of 1% APDC. The contents of Zn, Cu, Pb, Ni and Co in the concentrate were estimated by atomic absorption spectrophotometry. The contents of Mn and Fe in the water samples were determined by direct atomic absorption spectrophotometry.

The delayed neutron activation method of analysis, by which the lake-sediment samples were analyzed for total U, was developed by Atomic Energy Canada Ltd., Commercial Products Division, and is described in some detail by Boulanger *et al.* (1975).

The fluorometric method of analysis of the lake-water samples for acid-extractable uranium was based on that described by Smith and Lynch (1969).

The organic carbon content of a lake-sediment sample is proportional to the per cent weight loss on ignition (Coker and Nichol, 1975). Loss on ignition

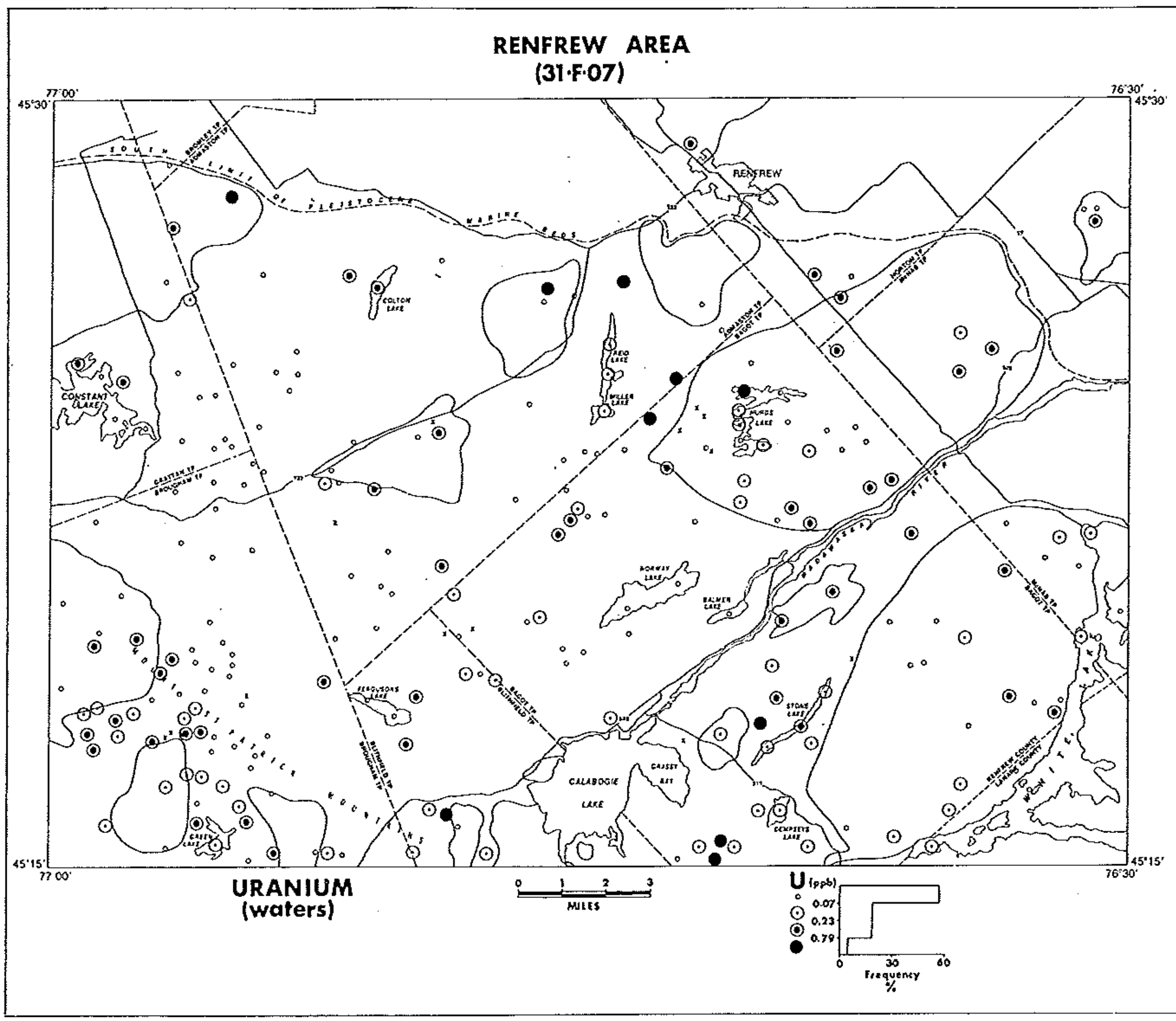

FIGURE 2 — Distribution of uranium in surface lake waters, Renfrew area, Ontario.

(L.O.I.) was determined on a 1-g portion of sample by ashing during a three-hour, time-controlled temperature rise to 450°C.

Results and Discussion

A summary of the analytical data for 204 surface water samples is presented in Table 1. Both physical and chemical measurements are given. Temperature, pH, conductivity and dissolved oxygen content were found to be distributed normally, whereas trace metal contents were found to be distributed log normally. pH was observed always to be alkaline and to exhibit little variation from site to site. The range of 7.8 to 8.5 suggests that carbonate-bicarbonate buffering is controlling water acidity. It is considered that these small pH variations will not have a significant effect on the levels of trace metals measured in the lake waters. Conductivity measurements yielded the lower set of values in granitic terrane and the higher set of values in carbonate-enriched terrane, as might be expected. All surface waters were more or less oxygenated; the effects that the observed variations might have on the nature of speciation of U and Mo in particular are not yet known. Of the trace metals, Ni, Pb and Zn sometimes reached high local levels (Table 1), compared with respective mean values for the whole region. U values reached 3.0 ppb, compared with a regional mean of 0.07 ppb. By comparison, Cu data are relatively featureless. Fe and Mn were also determined to provide information on mechanisms which may exert some control on observed levels of U.

The distribution of elevated U values in the surface lake waters appears to be confined to the periphery of certain granitoid intrusives (Fig. 1.); viz., those near Hurd Lake and west of White Lake (Fig. 2). Zn and Pb were found to be highest in lakes within Grenville marble units, as would be anticipated from a knowledge of mineral showings in the study area.

Although interesting in their own right, data from water samples are best viewed with complementary sediment data (Table 2). It is evident from the information presented that U distribution in sediments (Fig. 3) is much the same as in waters (Fig. 2). The same granites are outlined, but some additional areas of interest appear around a pegmatitic granite west of Calabogie Lake.

Exact correspondence of water and sediment anomalies is missing, however taken together the respective data reinforce each other and do direct attention to the same geological features. This is

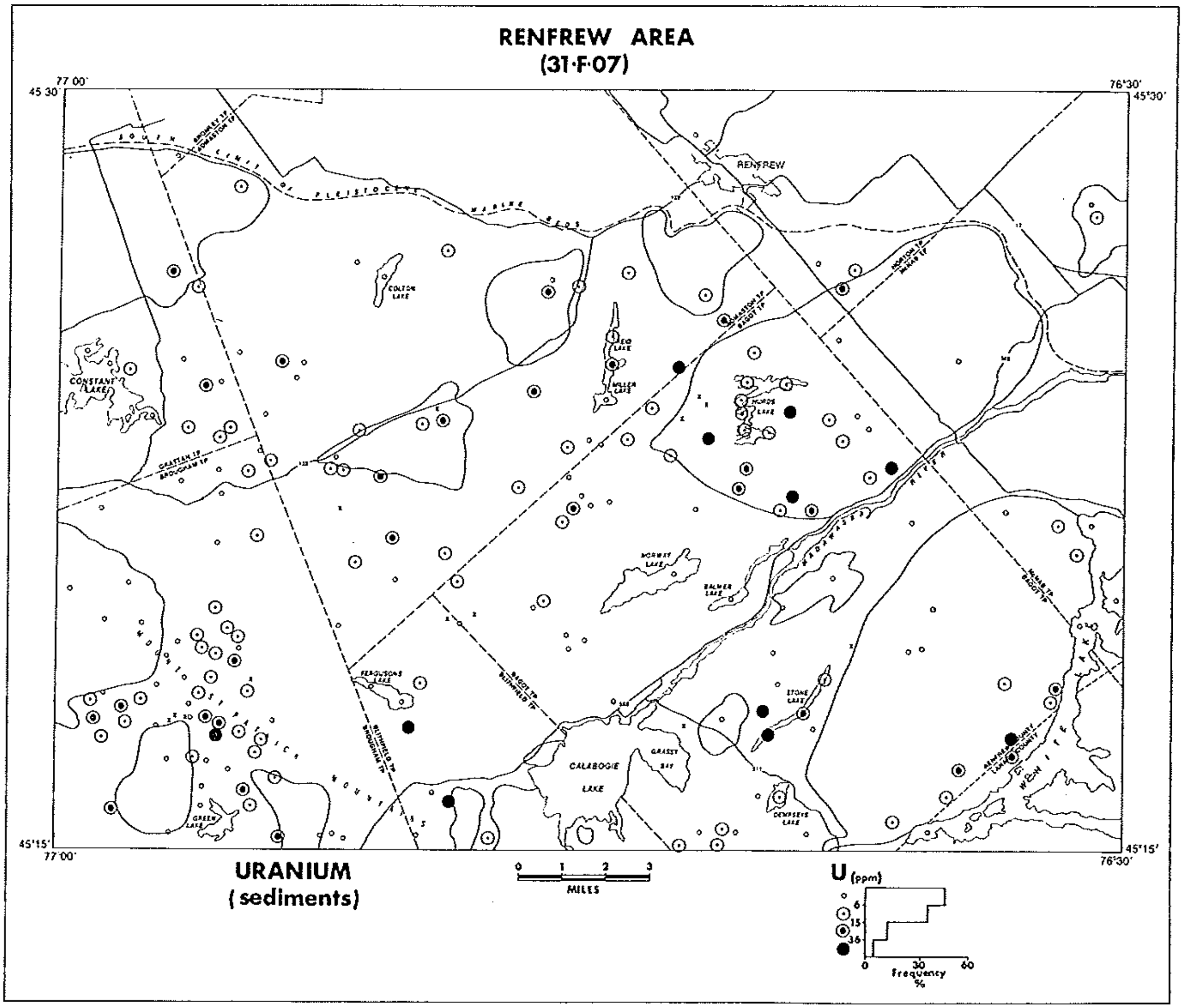

FIGURE 3 — Distribution of uranium in lake sediments, Renfrew area, Ontario.

		min.	$\bar{x}-2\sigma$	$\bar{x}-\sigma$	$\bar{x}$	$\bar{x}+\sigma$	$\bar{x}+2\sigma$	max.
Normal	Depth, m	1	—	—	6	12	17	34
	Temp.,°C	4.0	5.9	9.2	12.5	15.8	19.1	17.0
	pH	7.6	7.7	7.9	8.0	8.1	8.3	8.5
	Cond., µmho/cm	14	—	39	156	273	390	1324
	O_2, ppm	0.2	—	3.0	6.8	10.6	14.4	14.8
Log Normal	U	0.5	1.0	2.5	6.1	14.9	36.4	281
	Mo	0.5	1.1	2.0	3.8	7.1	13.3	23.6
	Zn	17	29	46	73	115	184	706
	Cu	*1	6	11	21	38	68	151
	Pb	*1	—	3	7	14	27	450
	Ni	*2	—	6	10	16	27	45
	Co	*1	—	2	4	8	14	15
	Mn	24	4	8	165	338	691	11800
	Fe %	0.1	1.6	3.2	0.6	1.3	2.5	12.7
	L.O.I. %	6	27	41	62	—	—	90

TABLE 2 — Lake Sediments — Renfrew

*Values equal half detection limit;
trace metal values in ppm;
166 samples;
physical data refer to bottom waters.

particularly true of the Hurd Lake granite, where there is an annulus of elevated U values (water, sediments or both) around the intrusion. Field inspection, using scintillometers, of some of these locations confirms the presence of radioactive mineralization in pegmatites and skarns.

The regional distributions of Mo (Fig. 4) suggest a close correspondence between U and Mo mineralization around the peripheries of the granites. Field inspection again revealed the presence of molybdenite showings in a number of old mining operations west of Hurd Lake, some of which were observed to be radioactive (A. E. Soregaroli, G.S.C., pers. commun.).

Another area of high Mo values occurs in amphibolites, schists and paragneisses in the Mount St. Patrick highlands. In this case, however, there are no U highs associated with the known Mo occurrences, which are located entirely in paragneiss (A. E. Soregaroli, G.S.C., pers. commun.) Rather, the overlapping U and Mo anomalies lie to the south of the Mo mineralization and appear to be related to a granitoid intrusive.

These observations lead to the conclusion that there are two types of Mo mineralization influencing the hydrogeochemical survey data. The first type is that

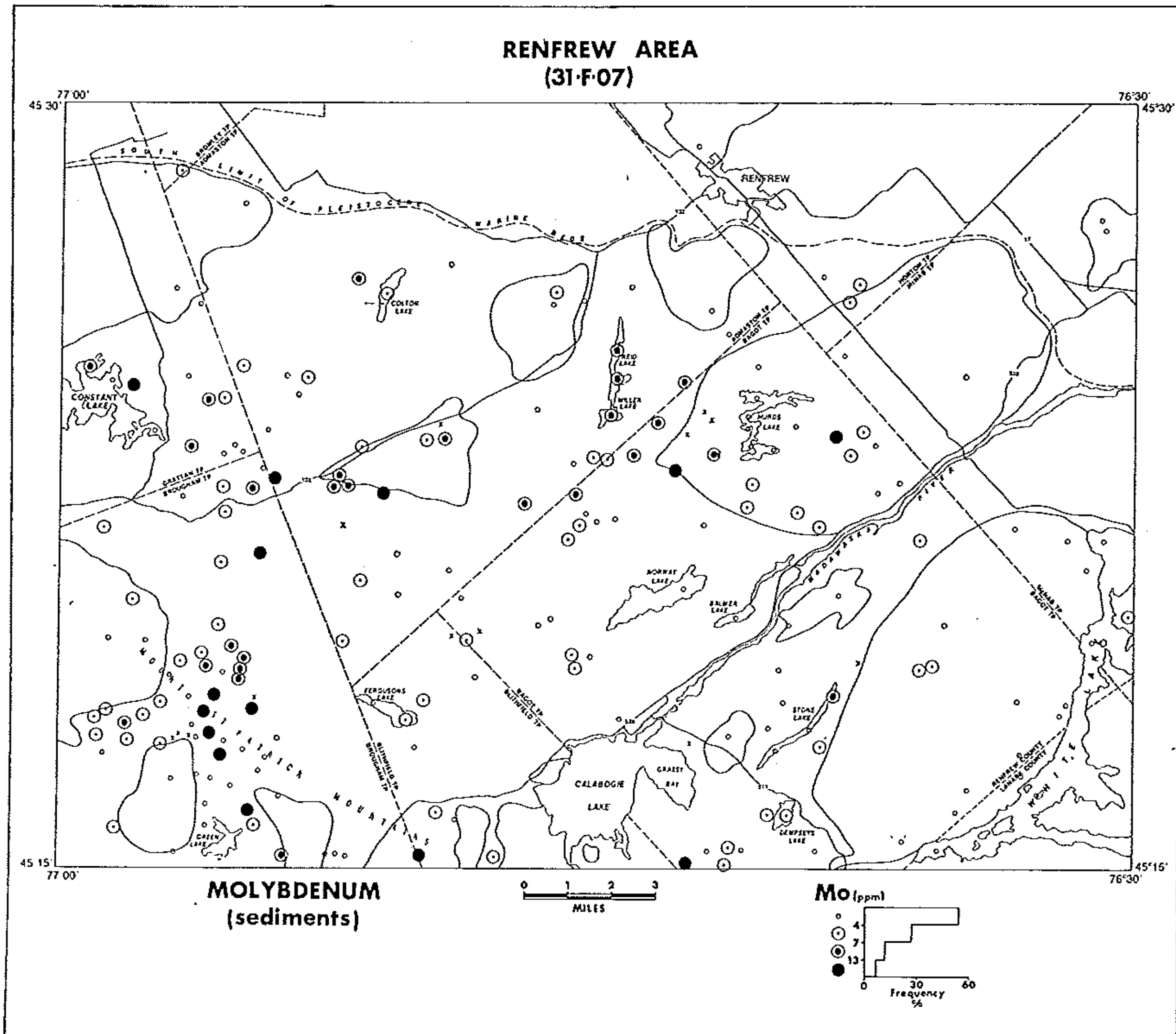

FIGURE 4 — Distribution of molybdenum in lake sediments, Renfrew area, Ontario.

which is found in the contact metamorphic aureoles surrounding certain granitoids (e.g., Hurd Lake). Molybdenite is found mainly in pegmatites, hornblende gneiss and pyroxenites. Occasionally some is found in true granite. These Mo aureoles are not necessarily wholly coincident with U (or radioactivity) anomalies, but are always in close proximity. It is possible that cogenetic Mo and U show different mobilities in this type of environment and have tended to separate during metamorphism and remobilization. All of these zones contain considerable carbonate-enriched skarns and their presence may have a bearing on the nature of remobilization processes. Moreover, the skarns themselves could well be of interest as hosts of U-Mo mineralization.

The second type of Mo mineralization is that which is associated with interfingered gneisses and carbonate-rich skarns, and which, on the basis of field examinations, does not show much radioactivity. The Mo showings at the defunct Ross-O'Brien Mine are typical examples.

At the Hunt Mine, a granite intrusive is to be found well within the mineralized zone, but there is apparently no associated radioactivity.

The distribution of Cu in sediments is shown in Figure 5, but it would seem that the Cu occurrence is related to granites rather than to metasediments.

Other element distributions, such as Zn, Ni, Pb, Co, Mn and Fe, were studied. However, there is no indication in the data derived from this survey that these could be useful as indicators of possible U mineralization. Moreover, there is no evidence from known mineral showings that such relationships could be anticipated.

Figure 6 is an elemental association map which displays the top 15% of data for each of U, Mo, Cu, Zn and Pb [i.e., all values $> (\bar{x} + 1\sigma)$]. Using an empirical form of cluster analysis, which is based on elemental assemblages as represented by known mineral occurrences, a series of anomalous zones have been outlined.

In summary, these are: U and Mo associations around granites and pegmatites near Hurd, White and Calabogie lakes; Mo mineralization in the Mount St. Patrick highlands; and Pb and Zn associations west of Hurd Lake and north of Mount St. Patrick village, both in Grenville marbles.

The latter Pb-Zn anomaly cannot yet be related to any known showings and is worthy of further investigation for possible Zn occurrences.

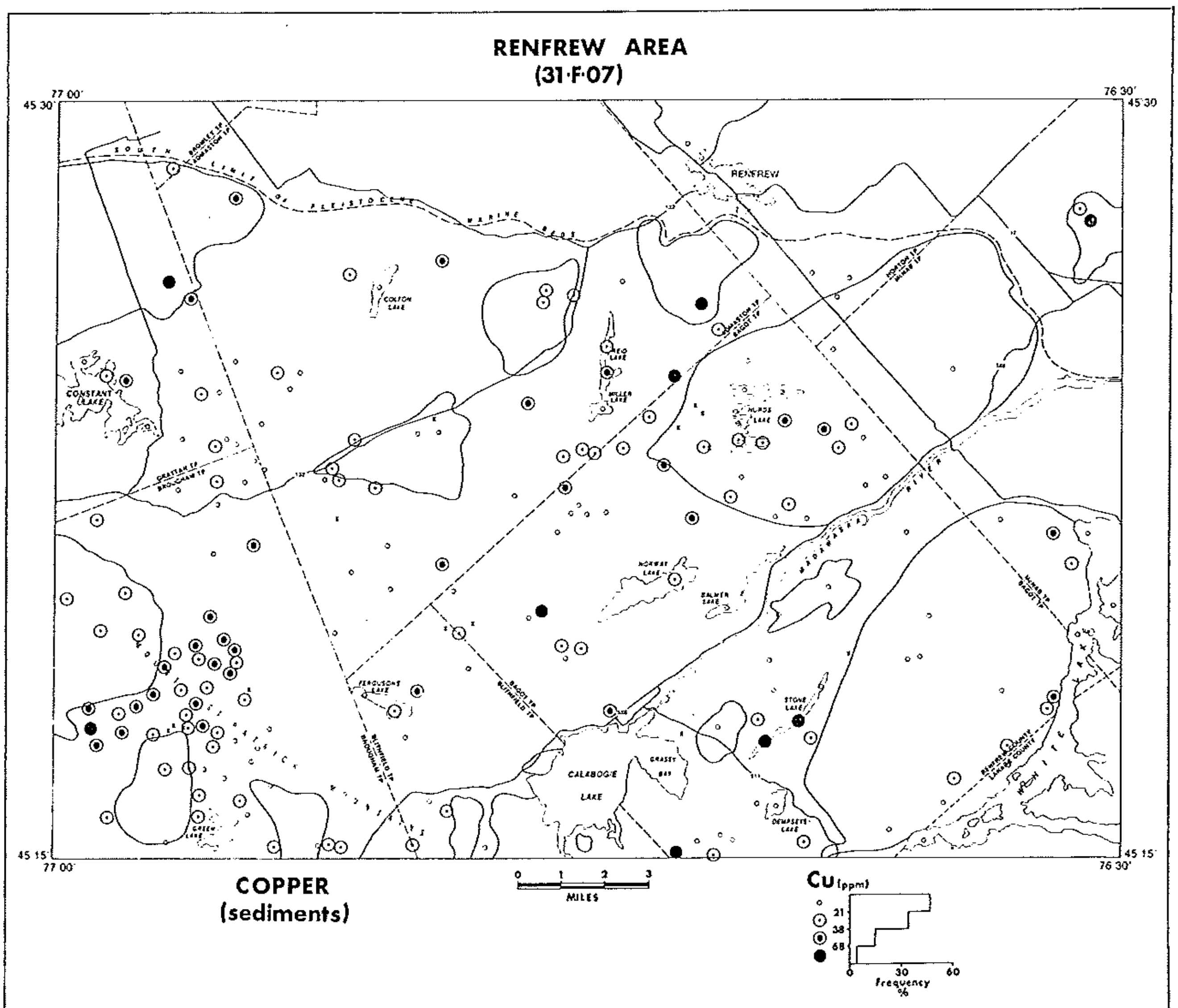

FIGURE 5 — Distribution of copper in lake sediments, Renfrew area, Ontario.

Conclusions

The usefulness of detailed hydrogeochemistry in the search for U mineralization in the Grenville geologic province of Ontario has been demonstrated clearly.

At the detailed scale employed, it has proved possible to outline areas wherein targets of limited size, such as the Hurd Lake radioactive pegmatites, may be located. Both waters and sediments can be sampled with positive results, although each has its own advantages. Waters can be collected anywhere and, except for the very large lakes, neither size nor permanence seems important. Sediments may be usefully employed in true lakes and old swamps. They can yield further useful data on elements other than U which may prove to be accessories in U mineralization assemblages. The prospecting level of sampling has proved to be efficient in outlining favourable geology and perhaps certain structures with possible mineral potential. The next stage of the hydrogeochemical procedure would be to use stream sediments and waters to fill in gaps in coverage.

On the other hand, the broad extent of the anomalies outlined indicates that reconnaissance-scale lake-sediment geochemical sampling every 13 km² (5 mi.²) using lakes, the larger ponds and true swamps, would be successful in locating these zones.

There is clearly a definite value in interpreting the hydrogeochemical dispersion patterns in terms of elemental associations which are based on a knowledge of trace and minor-element chemistry of known mineral assemblages in the study area. Perhaps data could be more usefully presented in this rather simplistic form of cluster analysis, which has a very sound basis in fact.

The same scale of drainage-basin lake sampling would also seem to be of value in seeking Pb-Zn prospects in Grenville marbles and skarns and also for locating new Mo occurrences in metamorphosed sediments.

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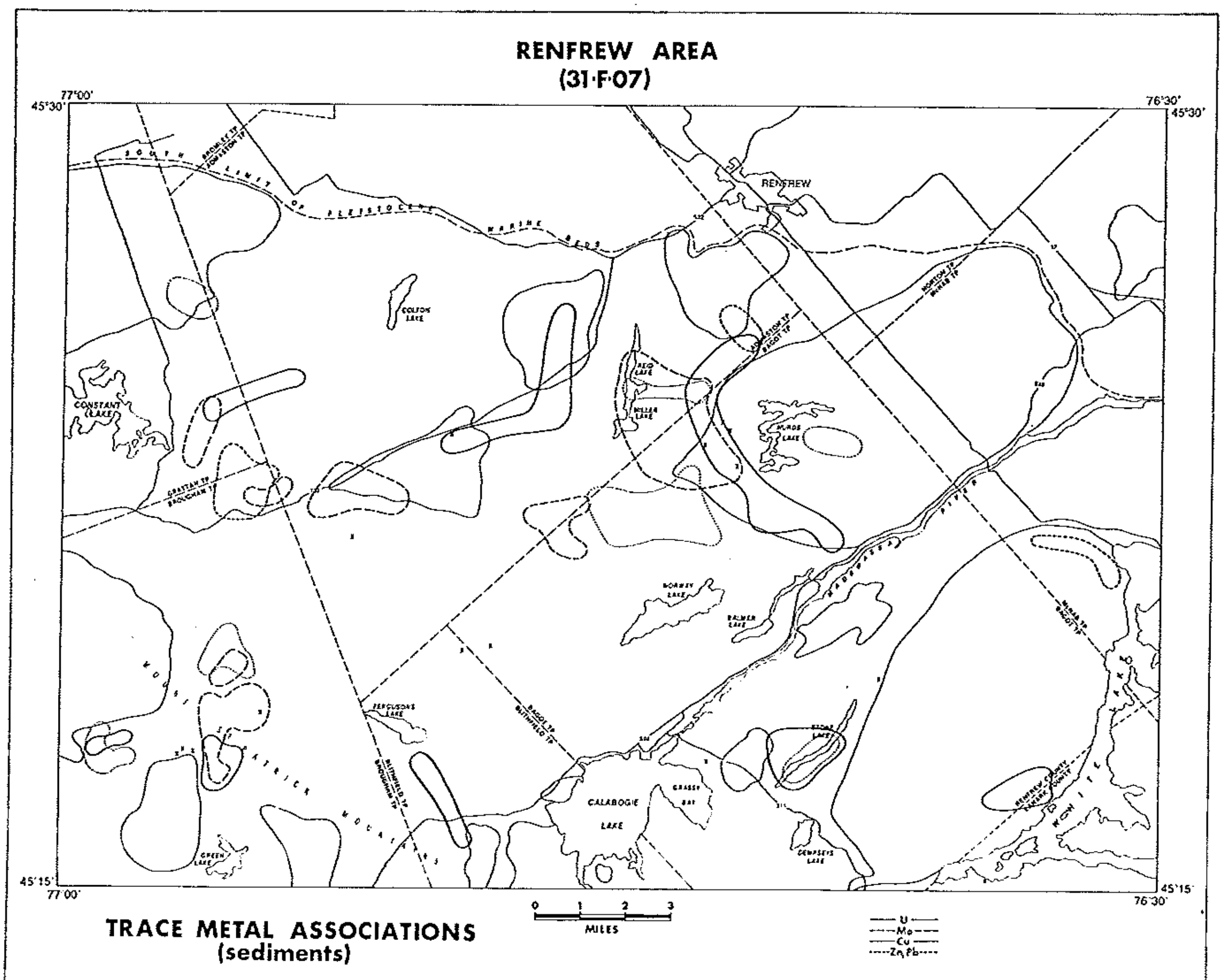

FIGURE 6 — Trace metal associations in lake sediments, Renfrew area, Ontario.

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Geosat Committee in U.S. Sets Goals

ARTHUR A. BRANT, consulting geologist and a director of the Geosat Committee, reports that the following operational framework has evolved. The corporation or company assuming membership by contribution (the only type of membership available) is asked to permit designated and appropriate personnel to periodically serve on Geosat subcommittees or panels for what in total may amount to about two weeks per year.

From this technical, and to some extent managerial, pool the ongoing subcommittees are formed, and panels, to deal with specific items, are assembled. These panels informally interface with NASA or similar agencies in the planning and specification stages on an item-by-item basis, feeding in the desirable geologic objectives. The panels report back to the ongoing Geosat subcommittees.

Such panels at present are involved in:

(1) the planning and specifications of the possible Stereosat mission of 1979 or 1980, to provide worldwide stereo coverage;
(2) the orbital flight test (OFT) shuttle experimental camera mission, 1980? — the geological and cartographic parameters essentially coincide;
(3) evaluation of the Seasat and OFT shuttle radar test data, 1978 and 1980;
(4) selection of geologic test cases to be covered and/or evaluated by existing and experimental technology, 1977;
(5) NASA — Mineral and Energy Resources — tentative 5-year research plan;
(6) presentation by Geosat for the necessity of raw data being available as an output form of all geologically relevant space data acquisition.

The following ongoing Geosat subcommittees are functional:

(1) A Satellite Technology Subcommittee to evaluate present and future technological means and capabilities.
(2) A Geological Objective Subcommittee to establish the desirable indicative geological parameters that should be sought.
(3) An Industry Advisory Subcommittee to assess the direction and results of the Geosat effort.
(4) A Governmental Liaison Subcommittee to present the governmental agency side, with representatives from NASA and the U.S.G.S. and hopefully from N.S.F. and the Association of State Geologists.
(5) A Public Relations and Education Subcommittee, to provide and disseminate to industry and the geologic profession information on Geosat efforts, and on remote sensing potential and problems.
(6) A Benefits Evaluation Subcommittee to assess the application, and, if possible, the economic benefits that could result.

Precambrian Field Excursions

AS PART of the Graduate Course in Precambrian Field Geology, the University of Toronto will again be running two 14-day field excursions. The first excursion, **September 10-24**, will cover Archean and Proterozoic geological problems, including the examination of classical areas in the Superior Geotraverse region (Pickle Lake - Atikokan - Shebandowan - northern Minnesota) - Thunder Bay region - Michipicoten area - Sault Ste. Marie region. The second excursion, **October 10-24**, will cover the Elliot Lake - Sudbury - Timmins - Kirkland Lake - Noranda - Cobalt - Grenville Province region. Emphasis is placed on using the field exposures and relationships as insight into fundamental problems of the Precambrian crust.

Interested persons should contact A. M. Goodwin or W. M. Schwerdtner, Department of Geology, University of Toronto, Toronto, Canada. Cost estimate will be made available on request.

Reconnaissance-Level Geochemical and Radiometric Exploration Data from the Vicinity of the Rabbit Lake Uranium Deposit

E. M. Cameron and **S. B. Ballantyne**,
Geological Survey of Canada,
Ottawa

Abstract

Reconnaissance radiometric and geochemical data have been obtained for an area on the western shore of Wollaston Lake that includes the Rabbit Lake uranium deposit. The study area is extensively drift covered. The geochemical data were obtained by analysis of center-lake sediments and surface waters for a variety of elements and other constituents. The airborne radiometric data comprise measurements of eU, eTh and K obtained with a 50,000-cc NaI (Tl) detector at a mean terrain clearance of 120 m and 5-km flight-line spacing.

Uranium in lake sediments and uranium in waters are the most effective geochemical indicators of uranium mineralization; the other elements measured are not notably anomalous. A sample site density of one per 13 km² is more than adequate for identification of the mineralized area. Because many water samples contain close to or below the current analytical detection limit of 0.05 ppb U, the use of sediments is generally favoured for broad-scale reconnaissance in the region. Uranium in these lake sediments appears to be little influenced by variations in the organic or iron and manganese content.

The most effective radiometric indicator of the mineralization is the eU/eTh ratio. This parameter is less influenced by environmental variation on the ground beneath the flight line than eU alone. The eTh/K ratio is anomalous under the Athabasca Formation unconformity where, in places, the uranium mineralization is localized.

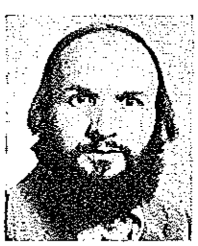
Introduction

THE GEOLOGICAL SURVEY OF CANADA commenced in 1975 a Federal-Provincial Uranium Reconnaissance Program (U.R.P.) (Darnley *et al.*, 1975). One component of this program is geochemical reconnaissance within the Canadian Shield using lake sediments and lake waters as sampling media (Cameron and Hornbrook, 1976). In the Shield, the other component of the program is airborne radiometric surveys at 5-km line spacing.

One of the first areas chosen for both geochemical and radiometric reconnaissance was a 52,000-km² area of northwestern Manitoba (reconnaissance survey areas 6-9, Fig. 1). This area is heavily drift covered, with outcrop amounting to only 1%. Because most previous lake-sediment surveys in the Shield had been carried out in areas of much less extensive drift (e.g. Allan *et al.*, 1973a, 1973b), it was necessary to test the method in terrain similar to that of northwestern Manitoba. Fortunately, to the west, across the Saskatchewan border, there is the Rabbit Lake uranium deposit of Gulf Minerals (Canada) Ltd. on the southwestern shore of Wollaston Lake. This deposit occurs in terrain that is similar to that of northwestern Manitoba, both in terms of solid and surficial geology. Through the cooperation of Gulf Minerals (Canada) Ltd., lakes within the company's property were sampled in the latter part of September, 1974, prior to the start of the U.R.P. in 1975. The results of this orientation study were sufficiently encouraging that the full-scale geochemical reconnaissance of northwestern Manitoba was carried out in 1975. These data from Manitoba have since been released (Hornbrook *et al.*, 1976). Also in 1975, an airborne radiometric survey was carried out in northwestern Manitoba and parts of Saskatchewan. Part of the area covered includes the Gulf Minerals (Canada) property. This report describes the results of the 1974 geochemical orientation survey and the 1975 airborne radiometric reconnaissance of this property.

Center-lake, organic-rich sediments and surface waters were collected using a helicopter. Sampling conditions were not ideal, with thin ice coating many of the lakes. This limited the number of sites available for sampling. A basic sampling interval of one site per 13 km² was used, but this was supplemented by additional samples, near known mineralization. The radiometric measurements for

Eion Cameron was born in Inverness, Scotland, and received a PhD degree in geology from the University of Manchester. Since 1967, he has been head of the Geochemistry Section of the Geological Survey of Canada. His principal professional interests have been the geochemistry of sedimentary rocks, statistical methods applied to geochemistry, and various aspects of geochemical exploration.



S. Bruce Ballantyne was born in Stratford, Ontario. He worked several field seasons in mineral exploration in Northwestern Ontario before obtaining his degree in earth sciences, in 1973, from the University of Guelph. After joining the Geological Survey of Canada in 1974 as an applied geochemist, he was involved with geochemical studies in the Northwest Territories and Saskatchewan and is currently concerned with a geochemical uranium reconnaissance program in British Columbia.

Keywords: Mineral exploration, Exploration techniques, Reconnaissance exploration, Geochemical exploration, Radiometric exploration, Rabbit Lake deposit, Uranium, Factor analysis, Statistical data.

eU, eTh and K were obtained at a mean terrain clearance of 120 m and a speed of 190 km/hr using a 50,000-cc NaI(Tl) detector array. The flight-line spacing was approximately 5 km. The radiometric data have been corrected for background, height variation and spectral scattering (Grasty, 1972).

The writers wish to thank F. C. Perry, exploration manager for Gulf Minerals (Canada) Ltd., and his staff for kindly facilitating the geochemical study reported here.

Description of Study Area

The survey area is located on the western shore of Wollaston Lake (Fig. 2). The elevation of the lake is 398 m and the maximum elevation is 522 m. There is an abundance of lakes, but no greater than that found over much of the Canadian Shield. The country is moderately densely forested.

GEOLOGY

The area was mapped at reconnaissance scale by Fahrig (1958) and in greater detail by Wallis (1971). A greatly simplified map, based on the results of these workers, is shown in Figure 2. In general, the rocks are poorly exposed.

The Proterozoic Athabasca Formation, comprising flat-lying, unmetamorphosed conglomerates and quartz sandstones, overlies a series of metamorphic and igneous rocks. This series contains metamorphosed arkosic, quartzitic, psammitic, pelitic and calcareous sediments and mafic rocks. These are intruded by coarse-grained granites and pegmatites. The metasedimentary rocks are tightly folded along northeast and east-northeast trends and are metamorphosed to mid-amphibolite facies. The metamorphism is of Hudsonian age.

SURFICIAL GEOLOGY

Because of the extensive glacial cover, the surficial geology is of particular importance in interpreting the geochemical and radiometric results. Part of the study area has been mapped by Wallis (1971), and his map is reproduced in only slightly modified form (Fig. 3). Glacial cover thickens from east to west, with an estimated 50 m of drift along the western margin. Striae, drumlins and other directional features indicate that glacial transport was from the northwest.

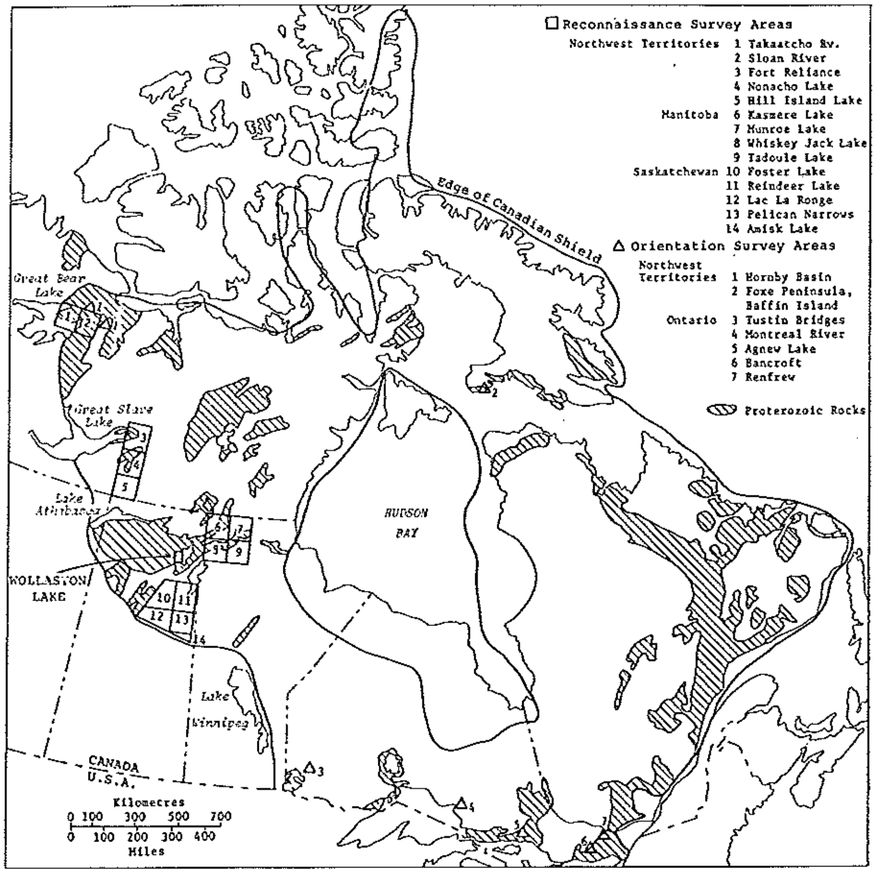


FIGURE 1 — Index map showing the Wollaston Lake study area and other orientation and reconnaissance geochemical surveys for uranium within the Canadian Shield carried out by the G.S.C. during 1974 and 1975.

ECONOMIC GEOLOGY

The Rabbit Lake deposit has been described by Knipping (1974). The orebody occurs immediately below the Athabasca Formation unconformity in brecciated dolomites that form the axial portion of a northeast-trending synform. Primary uranium minerals are colloform and massive pitchblende, sooty pitchblende and some coffinite. Only minor quantities of sulphides are present, and Knipping found a dearth of other metals in the ore (e.g. ≦ 200 ppm Cu).

The orebody bottoms at shallow depth (~ 100 m), and this was one of the features that led Knipping to suggest that it was derived by supergene enrichment beneath the unconformity. He suggests that uranium released by intense surface weathering was carried in subsurface waters migrating through the highly permeable base of the Athabasca Formation. It was trapped at the present location of the orebody by a pH-Eh "barrier". Based on data by Fahrig (1961), Knipping believes that water flow was from east to west along the existing paleoslope.

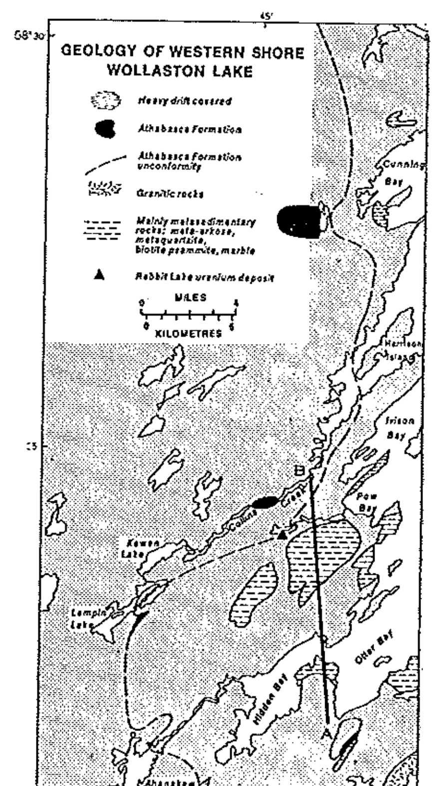


FIGURE 2 — Geological sketch map of western shore of Wollaston Lake.

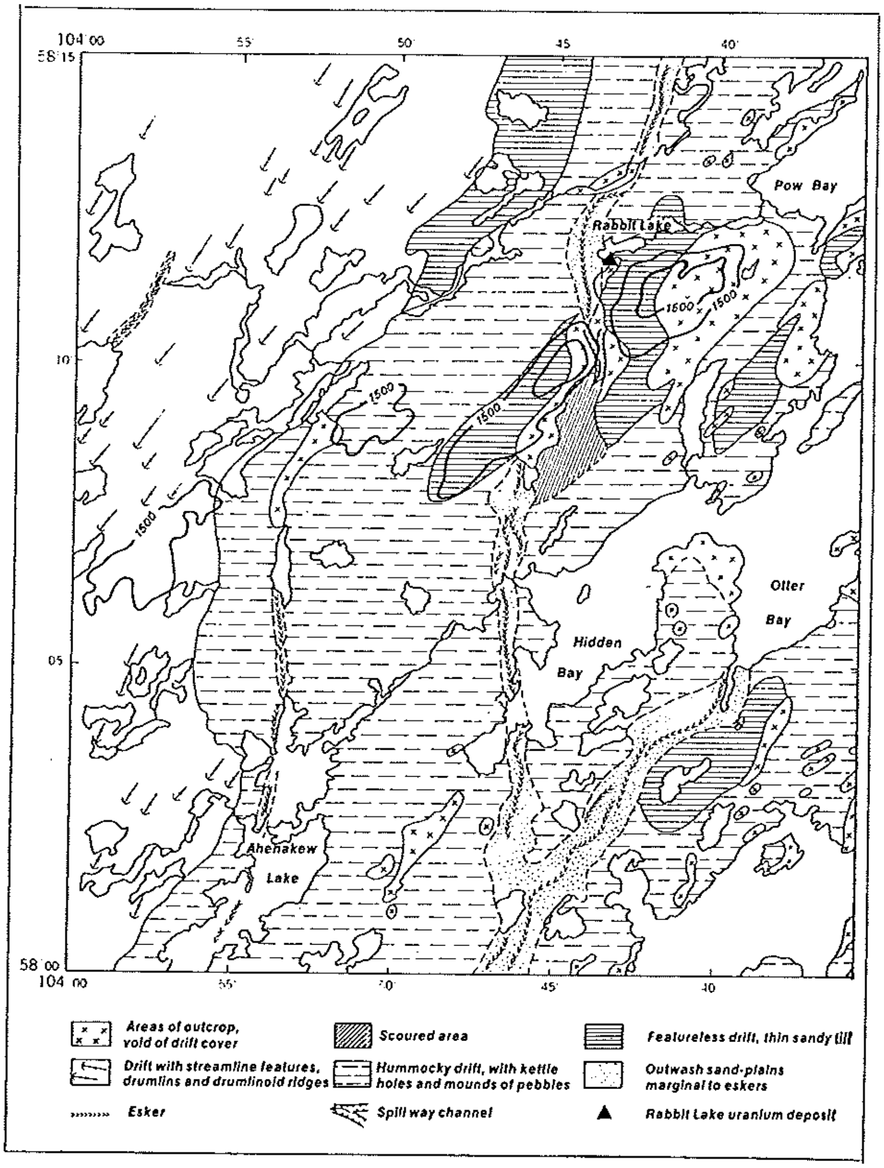


FIGURE 3 — Surficial geology and topography of southwestern shore of Wollaston Lake (from Wallis, 1971).

Prior to discovery of the deposit, an airborne radiometric survey, carried out at 45-60-m terrain clearance and 0.40-km spacing, located the target anomaly. This was 0.8 km long and showed a peak of two times background (Cawley, *in* Wallis, 1971, p. 59). Outwash from an esker obscured bedrock, but mineralized float was found in test pits. Cawley quotes a strike length of at least 430 m for the body and grades of 0.18%-0.65% U_3O_8.

CONTAMINATION

In 1974, when lake sediments and waters were sampled, some changes had been made in the natural environment. Rabbit Lake was almost completely drained. The orebody, located on the south side of the lake, had been trenched, but had not been excavated for mining. A number of roads had been driven through the mining area and the mill was almost complete. What effect did this have on the composition of the geochemical samples? For the sediments, the sampling device used collects material from greater depth than that influenced by historical events. This has been shown by W. Coker (unpublished data) for lakes near the uranium mines in the Bancroft area of Ontario. For the waters, it is probable that Rabbit Lake waters and those of the two lakes down-drainage to Pow Bay (Fig. 3) have been affected by mining activities. This question will be discussed later in the report.

TABLE 1 — Statistical Data and Factor Analysis Matrix — 95 center-lake sediments and surface waters

STATISTICAL DATA						VARIMAX FACTOR MATRIX								
					Factor	1	2	3	4	5	6	7	8	9
Unit	Geometric Mean	Arithmetric Mean	Log Standard Deviation	Range	Sum of Squares	2.63	2.41	2.36	2.37	1.85	1.26	1.07	1.03	0.65
%	22.4	30.3	.39	2.0 — 89.5	L.O.I.	.90								
%	1.40	2.44	.45	0.18 — 18.0	Fe				.87					
ppm	209	447	.47	20 — 7450	Mn			.28	.88					
ppm	66.	92.	.33	10 — 680	Zn	.49				.26				.72
ppb	32.	40.	.32	5 — 140	Hg	.84			.35					
ppm	11.0	13.0	.27	3 — 53	Cu	.71	.32			.49				
ppm	1.9	2.9	.34	< 2 — 27	Pb								.98	
ppm	5.6	7.2	.31	< 2. — 30	Ni					.87				
ppm	3.1	4.1	.32	< 2 — 18	Co				.58	.70				
ppm	0.15	0.18	.23	< 0.2 — 0.6	Ag						.94			
ppm	3.8	4.7	.32	< 1 — 50	As	.44			.43	.37	—.51			
ppm	2.2	2.9	.30	< 2 — 20	Mo							.92		
ppm	4.3	19.	.53	0.7 — 568	U_{SED}		.84	.27		.28				
ppb	0.05	0.66	.61	< 0.05 — 24	U_{WATER}		.90							
ppm	6.4	8.1	.32	< 1.0 — 45.6	Alkalinity		.28	.92						
—	—	6.71	—	4.60 — 7.80	pH			.92						
μMhos	28.8	33.3	.21	13.5 — 141	Conductivity		.71	.63						

Geochemical Results

ANALYSIS

Air-dried sediment samples were pulverized, then sieved to obtain the minus-80-mesh fraction. Zn, Cu, Pb, Ni, Co, Ag, Mn and Fe were determined by atomic-absorption methods after extraction with cold 4M HNO_3/M HCl. Background correction was used for Pb, Ni, Co and Ag. Mo was also determined by atomic absorption, but after hot concentrated HNO_3 and HCl digestions. A cold-vapour atomic-absorption method was used for Hg after digestion in cold HNO_3/HCl. Arsenic was measured colorimetrically using silver diethyldithiocarbamate after extraction in 6M HCl. The uranium analysis was achieved by delayed neutron counting. Loss on ignition (L.O.I.) was determined by heating to 500°C for 3 hours. L.O.I. is measured as an index of organic content. Coker and Nichol (1975) found a very close correlation between L.O.I. and carbon content for lake sediments over a wide range of concentration: L.O.I.% = 2.4 x C%.

Water samples were collected in 500-ml polyethelene bottles. They were not acidified and all measurements were made within one month of sampling. U was measured fluorimetrically on 5-ml aliquots. Because of the low content of U, careful duplicate determinations were averaged. Alkalinity was measured as ppm $CaCO_3$ equivalent and conductivity as μMhos at 25°C.

For certain elements, arbitrary values were assigned for concentrations less than the detection limit. For these, the detection limit and the arbitrary value (in brackets)are: Pb 2(1), Ni 2(1), Co 2(1), Ag 0.2(0.1), As 1(0.5) and Mo 2(1), all as ppm; and Hg 10(5) and U in water 0.05(0.02) as ppb.

STATISTICAL DATA

Statistical data for the 95 pairs of sediment and water samples are given in Table 1. Cu, Hg Pb, Ni, Co and Ag are present in the sediment samples only at background concentrations. Anomalous amounts of Zn, As, Mo and U are present in certain samples. The latter element shows very strong variation, and highly anomalous concentrations to in excess of 100 times background, as represented by the geometric mean (Table 1, Fig. 4).

Fe, Mn and the L.O.I. index of organic content was measured because of the control these components may exert over trace metal concentrations. Their relatively high variability (Table 1) indicates that this set of sediment samples is not particularly homogeneous. In part, this may be related to the difficult sampling conditions. The presence of lake ice did not always allow the optimum sampling site to be chosen.

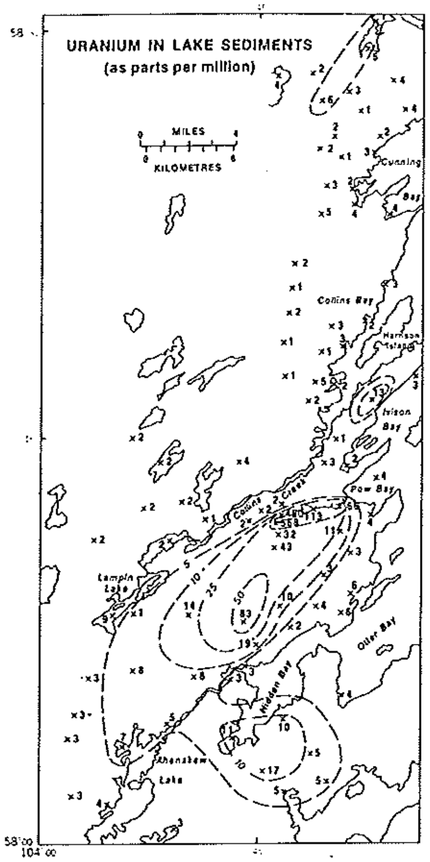


FIGURE 4 — Uranium content of lake sediments.

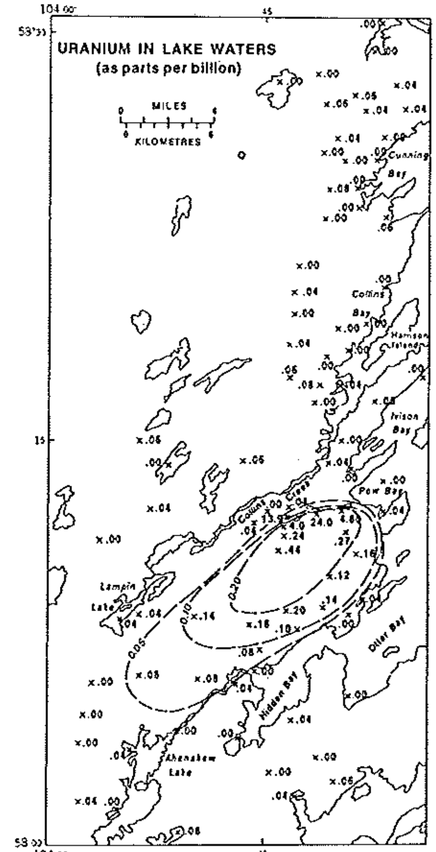


FIGURE 5 — Uranium content of lake waters.

For the waters, the low background content of U should be noted. In a relative sense, however, this component shows even more anomalous values than U in sediments, with contents to approximately 500 times the geometric mean down-drainage from the orebody. (Fig. 5). The pH is near-neutral in most samples, although one water had a pH of 4.6. The conductivity measurements show that most waters have a low content of dissolved solids. Alkalinity is also mostly low, with some moderate values.

FACTOR ANALYSIS

The inter-element relationships may most conveniently be summarized in a factor analysis matrix. The Varimax matrix given in Table 1 was computed using Program Geofact (Cameron, 1967). Logarithmically transformed data were used for all variables except pH, because the element distributions more closely approximate a log-normal than a normal distribution. The matrix comprises 9 factors that account for 92% of the total data variance. Only factor loadings greater or equal to 0.25 are shown. Factor scores (Cameron, 1967) were also computed and plotted on maps. The following conclusions were drawn by examining the factor matrix and score maps:

(a) — U in sediments and U in water are strongly associated with each other (factor 2) and with known mineralization. Factor 2 also contains a fairly strong loading for water conductivity, and weaker associations are indicated for Cu and alkalinity in the water. It should be noted that there are no strong associations between other trace metals and this "uranium mineralization factor". This is not surprising in view of the "pure" nature of the uranium mineralization noted by Knipping (1974). An important feature shown by this factor is that neither organic material (as L.O.I.) nor Fe or Mn appear to have any notable influence on the

U content of lake sediments. This supports similar conclusions reached by Cameron and Hornbrook (1976) and by Cameron and Allan (1973).

(b) — There is a strong association among alkalinity, pH and conductivity (factor 3). This undoubtedly reflects the influence of the carbonate rocks on the water chemistry. U in sediments and Mn have weak loadings on this factor.

(c) — Organic matter (as L.O.I.) does appear to have a positive influence on the precipitation of Hg and Cu and, to a lesser extent, Zn and As (factor 1). However, here the effect is on samples with background concentrations of these metals. In the case of Zn, the influence of organic matter in center-lake sediments has been investigated by Garrett and Hornbrook (1976).

(d) — Fe and Mn are shown to be strongly associated by factor 4, probably as Fe-Mn oxides in the sediments. There are weaker loadings for Co, As and Hg on this factor, which may indicate some control on their precipitation by these oxides.

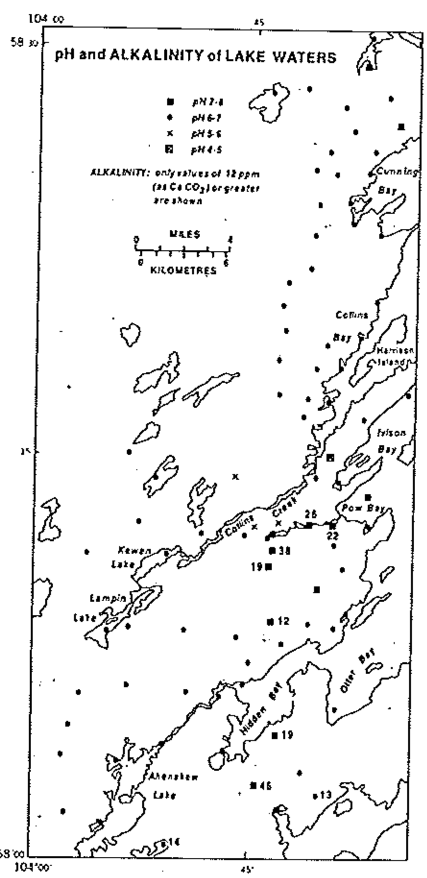


FIGURE 6 — Alkalinity and pH of lake waters.

(e) — Factor 5 shows a strong correlation between Ni and Co, and there are weaker loadings for Cu, Zn, As and U. The factor represents low-level variation in these elements, because samples with high positive scores contain only 6-30 ppm Ni and 2-18 ppm Co. Although the origin of the factor is not known, many of the samples with high factor scores occur within a few miles of Rabbit Lake.

(f) — Much of the variation of Mo and Pb and a large part of that for Zn is independent of the other variables measured (factors 7, 8, 9). Of the three, only Zn is of possible economic interest. Samples with 680 and 250 ppm Zn occur west of Ahenakew Lake and samples with 470 and 450 ppm occur in the Cunning Bay area. These values are definitely anomalous. For 3670 center-lake samples from northwestern Manitoba, the 95 percentile is 180 ppm Zn (Hornbrook *et al.*, 1976).

(g) — The nature of factor 6 (Ag vs As) is unknown. It should be interpreted with caution, as all but 14 of the samples have Ag contents at or below the detection limit. However, it is of interest that all 14 samples, containing 0.4-0.6 ppm Ag, occur in the general vicinity of the Rabbit Lake deposit.

URANIUM DISTRIBUTION

By far the most effective indicator of known U mineralization in this area is U itself. With the possible exception of water conductivity, the other variables measured are of little value for reconnaissance-level exploration.

Uranium in sediments (Fig. 4) shows an extensive and well-defined anomaly that lies mainly to the south and the southwest of the deposit. The highest values are found in Rabbit Lake itself, down-drainage from Rabbit Lake (toward Pow Bay) and in a lake 8 km south of Rabbit Lake (83 ppm U). There is a very sharp cut-off to background values north of Rabbit Lake.

Uranium in waters (Fig. 5) provides an anomaly that is almost identical in distribution to that of U in sediments. However, the area enclosed by the 0.05-ppb U contour, at 130 km², is smaller than the very extensive sediment anomaly of 216 km² enclosed by the 5-ppm U contour. This difference may very largely be caused by the 0.05-ppb detection limit cut-off for U in waters.

The high values for U in sediments in Rabbit Lake and down-drainage from Rabbit Lake testify to the active oxidation and dispersion of this element from the deposit. An examination by the senior author of the south shore of the drained Rabbit Lake, near the deposit, showed a thick crust of iron oxides on boulders up to the original water line. This would suggest acid leaching of the deposit, with precipitation of iron in the neutral lake waters. Knipping (1974, p539) notes that: "The process of leaching and deposition is going on at the present time. Waters issuing from fractures in the orebody or from diamond drill holes are strongly uraniferous".

The highest U values in sediments and waters come from lakes on and marginal to an area of bedrock exposure and thin drift which lies along a prominent topographic ridge that trends southwest from Pow Bay (Fig. 3). The Rabbit Lake deposit lies on the northern flanks of the ridge. The anomalous trend continues southwest from the ridge over a largely drift-covered area. Because this direction parallels the direction of glacial transport (and the strike of the metamorphic rocks), it suggests that, perhaps, mineralized bedrock fragments were carried southwestward by ice. The resulting drift has been leached by groundwaters, releasing U to the lake systems. Considering the distribution of the main U anomaly in relation to ice direction and the ridge, it is doubtful if the anomaly has been solely derived from mineralization transported from the Rabbit Lake deposit. Since the discovery of this orebody, intense prospecting has been carried out in the area. Two additional deposits have been found (*Northern Miner*, 4 March, 1976), but their location is not known. These deposits may be substantially influencing the geochemical patterns shown in Figures 4 and 5. Note should also be taken of the satellite lake-sediment anomaly directly south of Hidden Bay. The peak of this anomaly, 17 ppm U, lies in a drift-covered area southwest of the peninsula between Hidden Bay and Otter Bay. On this peninsula, over bedrock exposure, including carbonate horizons, the most anomalous eU/eTh radiometric measurement was obtained (see discussion below). Here also there may have been southwestward transport of mineralized bedrock.

INFLUENCE OF CARBONATE ON URANIUM MOBILITY

The mobility of U is enhanced in carbonate-bearing waters. In Figure 6, the principal features of the distributions of lake-water pH and alkalinity are shown. There are two principal areas of increased alkalinity and pH. The first is south and east of Rabbit Lake, the other south of Hidden Bay. Both areas contain carbonate rocks (Knipping, 1974; Wallis, 1971) and both have anomalous contents of U in lake sediments (Fig. 4).

Cameron and Hornbrook (1976) have compared the spatial correlation between U in lake sediments and lake waters within four areas in the Canadian Shield. A poor correlation was found in two areas where carbonate rocks are abundant (Renfrew, Ontario, and Foxe Peninsula, Baffin Island). Presumably, the higher carbonate content of these waters retards the precipitation of U from U-rich waters, producing a poor correlation between the two media. For two areas where carbonate rocks are less abundant (Kasmere Lake, Manitoba, and the area reported here), the correlation is good. Maurice (1977, this issue) has discussed the influence of alkalinity on U dispersion for the Foxe Peninsula. Over a 4,000-km^2 region he showed that, although uraniferous zones are defined by the U content of both media, some zones are outlined more distinctly by the sediments than the waters and vice versa. At low alkalinities, the sediments are most useful; at higher alkalinities, the waters are most useful. On the Foxe Peninsula, the critical alkalinity separating the two fields is approximately 16 ppm as $CaCO_3$, or, in terms of pH, approximately 7.4. Of the 95 water samples reported here, only 6 have alkalinities in excess of 16 ppm and only 2 have pH values greater than 7.4. Thus, the useful nature of the U-in-sediment anomaly for the Rabbit Lake area, and the good correlation between U in the two media, tends to confirm the earlier findings.

It is of interest to note on Figure 6 that Rabbit Lake is situated midway between a group of lakes with low pH (4-5) and a group with high pH (7-8).

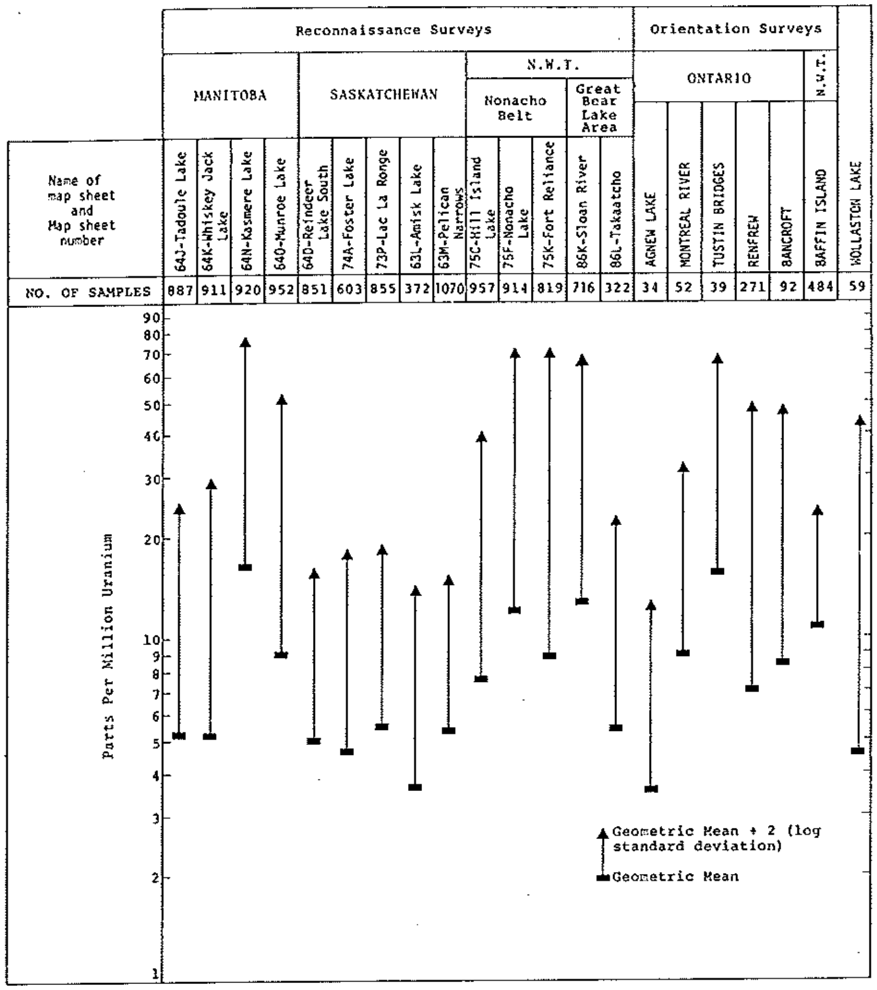


FIGURE 7 — Abundance and threshold levels for uranium in center-lake sediments collected during 1974 and 1975 seasons.

IMPLICATIONS FOR GEOCHEMICAL RECONNAISSANCE

In Figure 7, the abundance of U in lake sediments from this area along the western shore of Wollaston Lake is compared with data from lake-sediment surveys, carried out by the G.S.C. in 1974 and 1975. The reconnaissance surveys were all carried out at a sample density of one per 13-km^2 miles. In order to make the present data comparable, a 13-km^2 grid was laid over Figure 4 and one site selected from each occupied square. This produced 59 rather than 95 samples. All U measurements given in Figure 7 were obtained by delayed neutron counting. This comparison shows that the Rabbit Lake deposit occurs in an area of low mean background content for U. The arbitrary threshold value is, however, high. It is of interest that the Kasmere Lake area, northeast of Wollaston Lake, and therefore a potential "source area" for U, has a very high background content for this element.

In terms of practical reconnaissance, the 13-km^2 sampling density is more than adequate to detect the 217-km^2 Rabbit Lake anomaly. Rabbit Lake itself, as the largest lake in its 13-km^2 sampling grid, and on a well-developed drainage system, would certainly have been sampled during routine reconnaissance. As noted above, the geochemical contrast over background for this lake is in excess of 100. What if the deposit had not been situated on the edge of a lake on a well-developed drainage chain? Apart from the Rabbit Lake to Pow Lake drainage, there are three lakes south of Rabbit Lake with geochemical contrasts in the range 7 to 19 times mean background and a larger number with weaker contrasts.

Uranium in lake waters is somewhat less useful for reconnaissance. For the area defined by the 0.05-ppb contour in Figure 5, the median U in sediment to U in water ratio is 97,000. This is exclusive of the Rabbit Lake to Pow

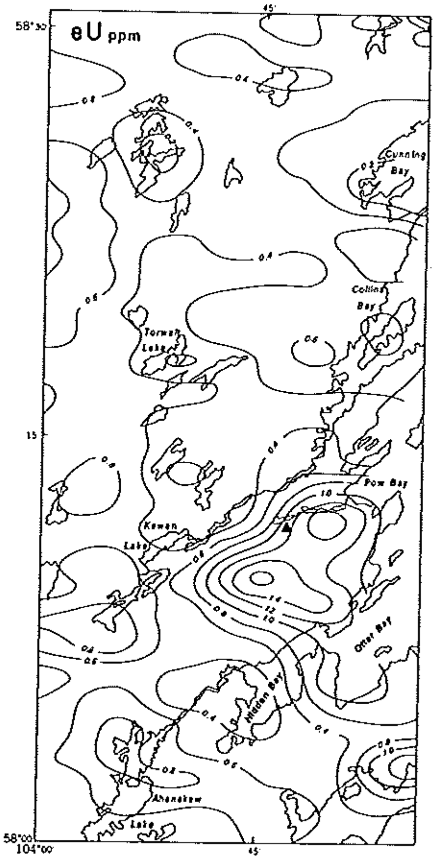


FIGURE 8 — Radiometric uranium distribution, as contours.

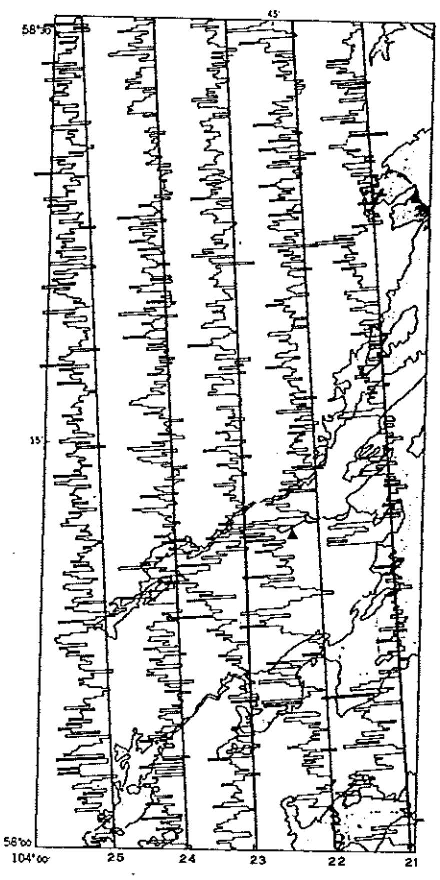


FIGURE 9 — Radiometric uranium distribution, as profiles. For scale, the spacing between profiles is equivalent to approximately 75 counts/2.5s.

Bay drainage, which gives a median ratio of 23,000, perhaps indicative of contamination of these waters. Excluding the latter drainage waters, all samples are in the sub-ppb U range, presenting difficulties in measurement with present analytical technology (Cameron and Hornbrook, 1975).

Radiometric Results

AVAILABLE DATA

Reconnaissance radiometric data for the study area are compiled on 1:250,000 map sheet 64L, Wollaston Lake (Anon., 1976). This information has been published as:

(a) Stacked profiles of seven radiometric parameters for each flight line. They are: integral counts per 0.5 second; U, Th and K counts per 2.5 seconds; and the concentration ratios eU/eTh, eU/K and eTh/K. Factors for converting airborne measurements to element concentrations were obtained by reference to test strips of known concentration (Grasty and Charbonneau, 1974).

(b) Contour maps of: integral count; the eU, eTh and K concentrations; and the eU/eTh, eU/K and eTh/K ratios. The contour maps were prepared by averaging seventeen 2.5-second counting intervals (equivalent to approximately 2 km) along flight lines, after removing intervals over lakes. This produces a 2-km (along lines) by 5-km (between lines) grid for contouring. As the surface area so averaged includes water in swamps and ponds, the indicated surface concentration will be lower than the true concentration of outcrops or overburden.

URANIUM

The contour map for eU as ppm is shown in Figure 8 and the profiles in Figure 9. The former shows a well-developed anomaly with a ueak of 1.6 ppm eU striking southwest from Pow Bay. Along profiles 22 and 23, this anomaly shows as a broad ridge of high values, with maxima of approximately 90 counts/2.5s. This contrasts with a background of 10-30 counts/2.5s to the north and south, with maxima to 50 counts/2.5s.

The peak of 1.6 ppm eU is not particularly intense compared to values found in areas near to a number of other known deposits, particularly those that have a genetic relation to igneous rocks within the immediate area. For instance, Darnley *et al.* (1975) have shown that for Bancroft and Blind River, Ontario, and Mont Laurier, Quebec, 7 to 21% of the areas flown exceed 2 ppm eU.

The distribution of this U anomaly, both in contour and profile form, may be compared with the topography and surficial geology (Fig. 3). Also, in Figure 10 the profiles for a number of parameters along the Pow Bay-Hidden Bay sector of flight-line 22 have been plotted in relation to the known geology. This comparison shows that the main anomaly coincides with bedrock and a thin till-surfaced ridge trending southwest from Pow Bay. This is the most extensive area of bedrock and thin till and, with relief in excess of 300 feet, it is the most prominent topographic feature within the study area. In addition, along line 22 there are maxima of 90 counts/2.5s at the ridge and over bedrock exposures and thin drift on the north shore of Hidden Bay and on the peninsula east of Hidden Bay. To the west, on line 24, which is mostly over drift, there are no notably anomalous features on the U profile (Fig. 9).

It would thus appear that, in part at least, the radiometric U anomalies in the Rabbit Lake area are caused by bedrock exposure contrasting with drift and also, perhaps, by topography. These features may influence the radiometric measurements in two ways. Firstly, the transported drift may have a lower U content than bedrock. Secondly, areas of bedrock exposure, or sloping ground, have a lower proportion of water-filled swampy cover than do flat-lying areas of drift. These waterlogged areas retard gamma radiation.

Darnley (1973) has advocated the use of ratios, particularly eU/eTh, in exploration for U. Their use reduces the variation caused by amount of outcrop, variation in the solid angle of measurement caused by topographic relief, and wetness of the ground. In addition, he notes that, although the ratios between the three radioelements remain relatively constant over a wide range of rock types, they change near U or Th mineralization.

Contours for eU/eTh (Fig. 11) show an irregular anomaly, to 0.20, that increased eastward to the shore of Wollaston Lake. The

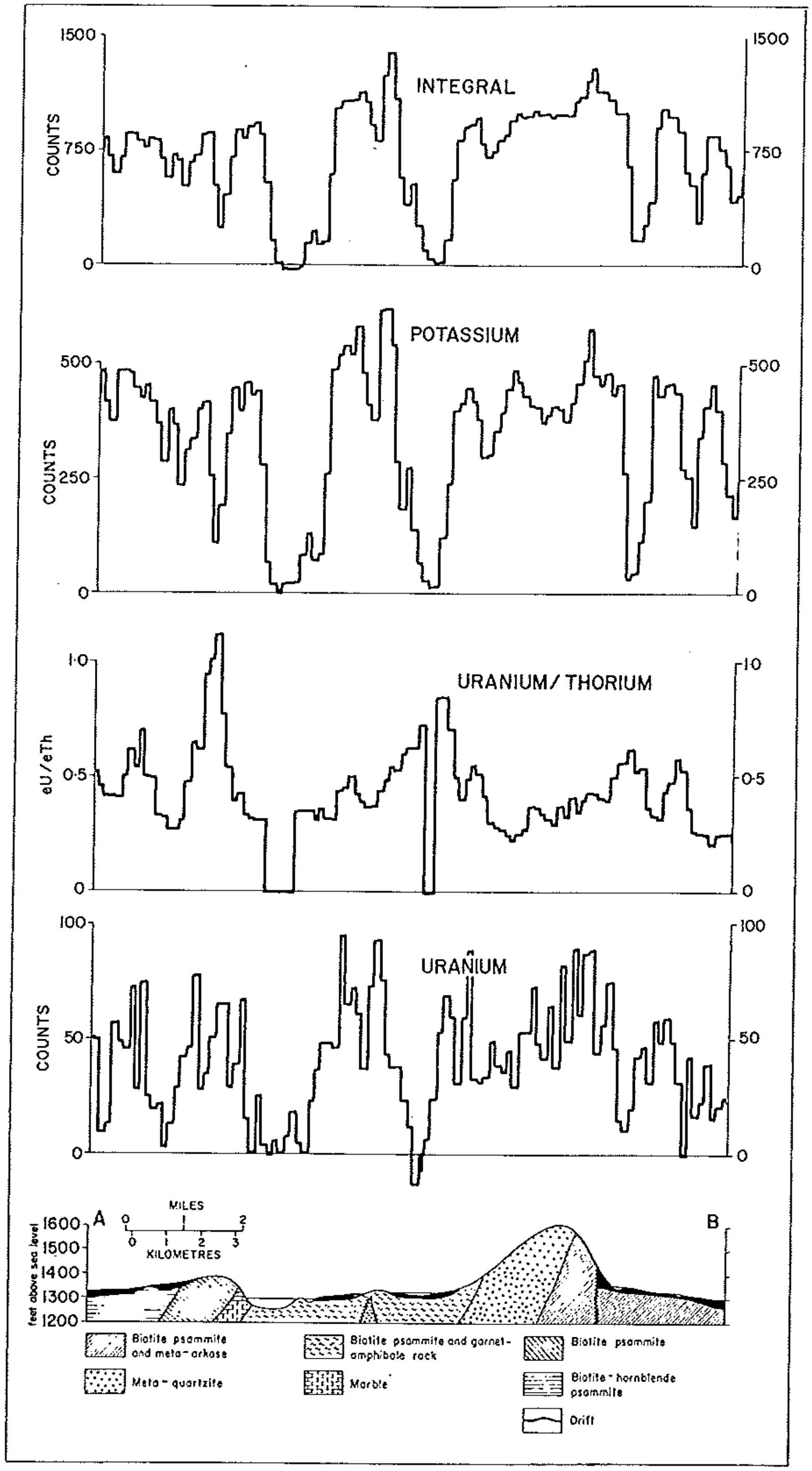


FIGURE 10 — Radiometric profiles, Pow Bay to Hidden Bay. For location of flight line see Figure 2, A-B. Geology after Wallis (1971).

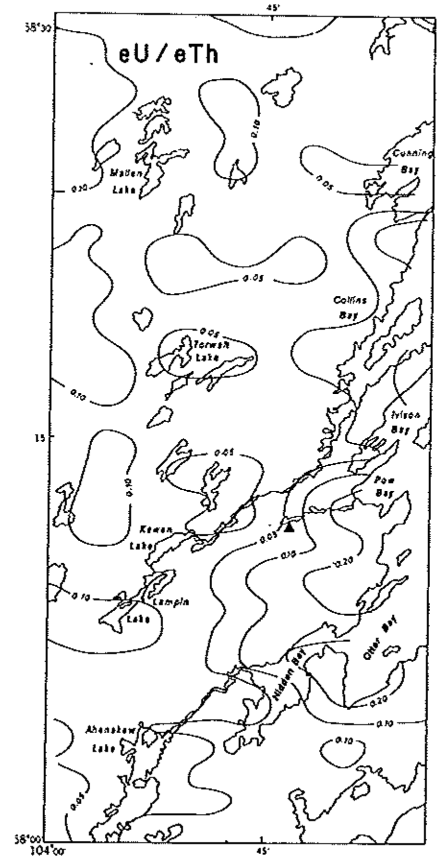


FIGURE 11 — Distribution or eU/eTh ratio, as contours.

profiles (Fig. 12) provide more useful information. On line 23 there is a broad plateau with values at the 0.30 level over the ridge southeast of Pow Bay. At either end there are peaks to 0.65. On line 22 there is another broad plateau in the range of 0.30-0.40, with peaks at either end of 0.60 (north) and 0.80 (south). Farther south on the peninsula, east of Hidden Bay, is the highest peak of 1.10. Elsewhere on profiles 22 and 23, eU/eTh shows moderate relief in the range of 0.10-0.40, so that the peaks south and southwest of Pow Bay have a contrast of 3-4 time average background.

How effective a reconnaissance indicator are these eU/eTh peaks south and southwest of Pow Bay? To judge this, all profiles within the Wollaston Lake 1:250,000 sheet were examined. This comprises an area of 13,000 km² inclusive of large lake areas. There is a total of 45 peaks in the range of 0.6-0.7 eU/eTh, 23 of 0.7-0.8, 22 of 0.8-0.9, 10 of 0.9-9.10, 4 of 1.0-1.1, 1 of 1.1-1.2,2 of 1.2-1.3 and 1 of 1.4-1.5. Thus, the peaks of 0.6 and 0.65 are of limited diagnostic value, but that of 1.10, found over the peninsula east of Hidden Bay, would certainly have drawn attention to the area. Because the two peaks greater than 0.65 were detected on the same flight line, one might conclude that a reconnaissance flight-line spacing of 5 km is adequate, but any increase in this spacing is not justified.

The eU/eTh peaks on either side of the topographic ridge along line 22 can be seen to be over areas of drift downslope from the ridge. Without ground follow-up, it is not possible to explain these features. They could be related to *in-situ* uranium mineralization or to the dispersion of the Ra^{226} decay product of U downslope and subsequent trapping in the swampy, drift-covered area. However, even if this latter explanation is true, it implies the presence of leachable uranium mineralization.

OTHER PARAMETERS

The contour maps for the integral count and for K show anomalies southwest of Pow Bay that are very similar in form to that for U. They too are presumably related to the outcrop-surfaced ridge discussed above. For the integral, the peak of this anomaly is 900 counts/0.5s, compared to a background of 300-500 counts/0.5s to the north and south, and for K, 2.0%, compared to background values in the range of 0.6-1.0%. Because both U and K increase over the ridge, the contoured eU/K shows only a weak anomaly.

The radiometric data for Th in the study area are of interest. Anomalies for this element occur along the Athabasca Formation unconformity throughout the area shown in Figure 2. The pattern is best shown by eTh/K, with anomalies to 0.0015. This is approximately three times the background throughout the Wollaston Lake 1:250,000 sheet. These anomalies are almost certainly caused by Th-rich heavy mineral concentrations in the basal Athabasca Formation.

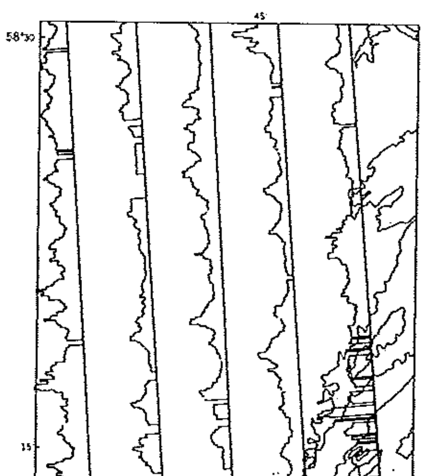


FIGURE 12 — Distribution of eU/eTh ratio, as profiles. For scale, the spacing between profiles is equivalent to a eU/eTh ratio of approximately 0.75.

Conclusions

The data provided by geochemical and radiometric reconnaissance can clearly focus attention on a restricted area around the Rabbit Lake deposit. The contrast of the anomalies is such that in any large-scale survey of the surrounding region, the Rabbit Lake area would have been a high-priority target for more detailed exploration.

In the case of the radiometric surveys, the eU/eTh ratio is the most effective indicator of mineralization and the 5-km line spacing is adequate. For the geochemical surveys, U in both lake sediments and waters are effective indicators and one site per 13-km² is a more than adequate sample density. If all U-mineralized areas were to give as strong a response as the Rabbit Lake area, a lesser density could be employed. Although U in waters gives a satisfactory response, its low abundance in these Shield waters relative to its analytical detection limit suggests that U in sediments will be a more effective indicator where the geochemical contrast of U mineralization is weaker.

The strongest radiometric and geochemical anomalies in the area come from, or are near to, areas of bedrock exposure which occur along ridges or prominences. The remainder of the study area, mostly drift covered, has a generally low abundance of U, both by geochemical and radiometric measurements. The question arises as to whether these areas are low because they are covered by far-transported drift of low U content or, alternatively, whether this drift is locally derived and is reflecting a similarly low U content in the underlying bedrock. Although this question can not be authoritatively answered without follow-up surveys, the available evidence suggests that the latter alternative is true. There is a distinct geochemical anomaly over thick drift down-ice from the main radiometric and geochemical anomalies along the ridge. There is reason to believe that the presence of relief on the Athabasca Formation unconformity played some part in localizing U mineralization. This is because the deposit occurs at approximately the location where the unconformity intersects the base of the ridge trending southwest from Pow Bay (Wallis, 1971). Thus, above-average concentrations of U in rocks may be quite restricted in extent within this area.

In this region, the costs of lake-sediment sampling for uranium alone at one site per 13-km² is roughly comparable to radiometric surveys at 5-km line spacing. For each, the cost is approximately \$4 per km². Because of the rapidity with which lake waters may be sampled by helicopter, hydrogeochemical surveys for U at the above sample density may be carried out for approximately \$2.50 per km².

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(Un) Certain Exploration Facts From Figures

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Abstract

This paper is an attempt to place Canadian Precambrian volcanogenic deposits in perspective, by examining and compiling data regarding certain neglected fundamentals of size, grade, value, frequency distribution and spatial density. The discovery roles played by various exploration methods are compared and contrasted, and, using empirical methods, the probabilities of discovery are discussed, combined with the use of an effective 'cost-per-target' program. From these basic observations, realistic exploration judgments may be made. Using similar methodology, this format may be applied to other types of deposits.

Precambrian volcanogenic deposits occur in a natural geometric progression in size. They number 110, of which 70% are pre-producers, producers or past-producers. These deposits are bonanzas and generally have a 'net pre-smelter' value of between $43 and $62 per ton. The statistically typical deposit is that which occupies the modal position, has 400,000 tons of ore, a value of $20 million and occurs with a frequency of 40%. A median deposit has 1.4 million tons of ore, a value of $70 million and occurs with a frequency of 15%. An upper-decile deposit has 13.3 million tons of ore, a value of $750 million and occurs with a frequency of 6.5%. The major, mid-upper-decile deposits have a minimum of 50 million tons of ore, a value of $3 billion and occur with a frequency of 4%. Five major volcanogenic deposits occur in the Precambrian and account for 54% of production. This contrasts with 55 deposits (all below the median) which account for 3.9% of production.

The deposits tend to occur in clusters, and well-developed, prolific districts, such as Noranda, have a density of 1 deposit per 23 square miles. This contrasts with the newer Sturgeon Lake district, which has a density of 1 deposit per 125 square miles. Relatively 'low-risk' opportunities occur in areas of high density and offer a better chance for discovery of modal or median-type deposits. On the other hand, 'high-risk' opportunities occur in areas with a low density, and these areas are more likely to yield a deposit in the upper-decile range.

During the past 20 years, AEM surveys have discovered 17% of the deposits, which contain 41% of the total tonnage. In contrast, 75 years of prospecting have discovered 44% of the deposits, which contain 48% of the total tonnage. Modal, median and upper-decile AEM discoveries tend to be between 3 and 4 times larger than similar discoveries made by other methods.

Empirically, realistic odds for discovery occur in the range between 100:1 and 500:1. This is substantiated by the results of several successful exploration companies. Due to the role played by random chance, there is no control over the ultimate size and value of the discovery. However, an effective 'cost-per-target' program will insure that funds are available to test a sufficient number of meaningful targets over an (un)certain period of time. This has been shown to be the case with an outlay of between $500,000 and $15 million, extending up to 10 years in some instances.

Julian Boldy obtained his M.A. and M.Sc. degrees in geology from Trinity College, Dublin. He immigrated to Canada in 1956 and for the following twelve years was engaged in mineral exploration for the Falconbridge Group, located in Thunder Bay, Yellowknife and Noranda. While in Noranda, he was involved in the discovery of the Delbridge deposit in 1965, which was aided by the development and use of mercury geochemistry as a pathfinder to buried sulphide deposits.

Between 1968 and 1969, he was on the staff of Kennco Explorations Ltd. In 1969, he joined Freeport Canadian, and for the following six years directed and managed their Canadian operations, including the 1973 discovery of the Reed Lake deposit in northern Manitoba. Between 1975 and 1976, he was engaged in a consulting capacity with the Minerals Division of Shell Canada Ltd.

In July 1976, Mr. Boldy joined Gulf Minerals Canada Limited as chief geologist, and is based in Toronto.

Keywords: Mineral exploration, Exploration techniques, Precambrian deposits, Volcanogenic deposits, Discovery rates, Frequency distribution, Electromagnetic exploration, Copper, Zinc, Data analysis.

Introduction

"THERE is no more common error than to assume that, because prolonged and accurate calculations have been made, the application of the result to some fact o fnature is absolutely certaih": A. Whitehead, mathematician.

The use of the word '(un)certain' in the title of this paper, together with a pertinent quotation, signifies a major paradox encountered by those engaged in exploration — the uncertainty in making deductions for the interpretation of basic exploration data. Deductions within the bounds of subjective reasoning have continuously to be made, and these are less likely to pose problems at a later stage if all the relevant data are available for examination. This will often show the subtle interrelationship that exists between '(un)certain' facts of nature on the one hand and exploration data defined in precise mathematical terms on the other. For example, during the past twenty years, much effort and many millions of dollars have been expended by about three dozen exploration companies in the quest for volcanogenic metal deposits in the Precambrian. Most of these companies were unsuccessful. During this period, considerable literature on various geologic aspects of these deposits appeared. However, only a few papers (Agterberg 1971; Derry 1968, 1970; Roscoe 1971; Sullivan 1970) were written about certain exploration fundamentals. Data on deposit size, grade, value, frequency distribution and spatial density patterns, in addition to the discovery role played by various exploration methods, need to be stated. Probabilities of discovery relative to the objectives and standards of the exploration company also need to be examined and discussed, together with an analysis of exploration costs based on a simple 'cost per target'.

No attempt has been made in this paper to mention the obviously important role played by geology in exploration (Sangster 1972). An understanding and appreciation of the volcanogenic ore environment is of prime importance, however geology is but one of the disciplines in exploration, as are geophysics and geochemistry, business practice and common sense.

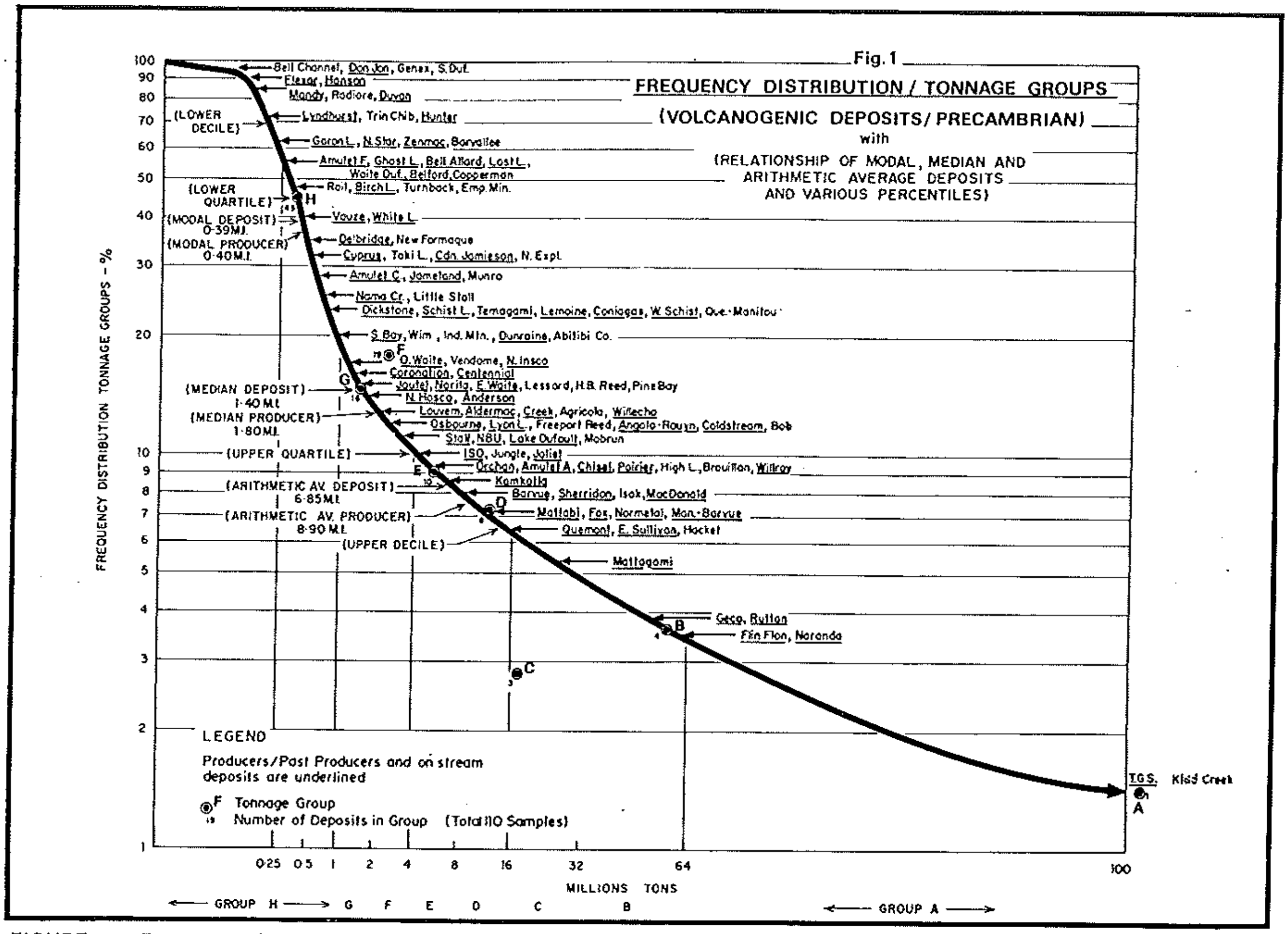


FIGURE 1 — Frequency distribution of tonnage groups, showing all deposits, with position of average, median and modal deposits.

Rather, an attempt has been made to place data in perspective, and to try and define the 'norm' and various levels of central tendency, while relating the facts of frequency distribution and value of the various deposits, their spatial density, the role of various search methods, and the over-all bearing of these functions to the probabilities of exploration discovery.

At best, this paper will have succeeded in its intent if the reader has become more aware of the wide spectrum of volcanogenic deposits that exist in the Precambrian and certain key factors exhibited by them — coupled with the role of uncertainty in problems related to the probability of exploration discovery.

Note on Compilation of Data*

The essential background data come from the Financial Post's *Survey of Mines* publication and the Northern Miner's *Canadian Mines Handbook*, 1975-1976. In addition, reference has been made to various federal and provincial publications. Tonnage and grade figures shown in this paper are a combination of past production and current ore reserves. The total figure should not be construed as a final figure for any deposit. In certain instances, because of incomplete data and lack of access to ore reserve figures, certain calculations and projections have had to be made in order to tentatively classify some deposits within specific tonnage groups.

The paper is not intended to be a mathematically precise statistical presentation, but its use is rather in describing certain facts as they are known to exist, and in making '(un)certain' deductions in the application of the results to the field of exploration.

*Compiled March 1976.

BASIC DEFINITIONS

One of the most essential needs is utilizing a method whereby a 'measure of central tendency' can be calculated which is relatively unaffected by a few extreme values, and which would result in a more meaningful description of the product in question.

The most commonly used measure of central tendency is the *Average* or *Arithmetic Mean.* However, this value is affected by extremes. A good 'measure of central tendency' is that called the *Median Value.* This occurs midway in a progression of numbers, with 50% of the items occurring above and 50% below the critical median value. From this point, various percentile points in a numbers progression can be obtained and used as reference points. Another 'measure of central tendency' is that called the *Modal Value.* This figure represents the most commonly occurring value in a numbers progression and is even less affected by extreme values.

For the purpose of this paper, arithmetic average, median and modal values have been calculated; in addition, various percentile points of reference have been obtained. The significant figures are those that are based on measures of central tendency.

TONNAGE GROUPS

For economic reasons, the most significant variable is that of size, as metal grades more often than

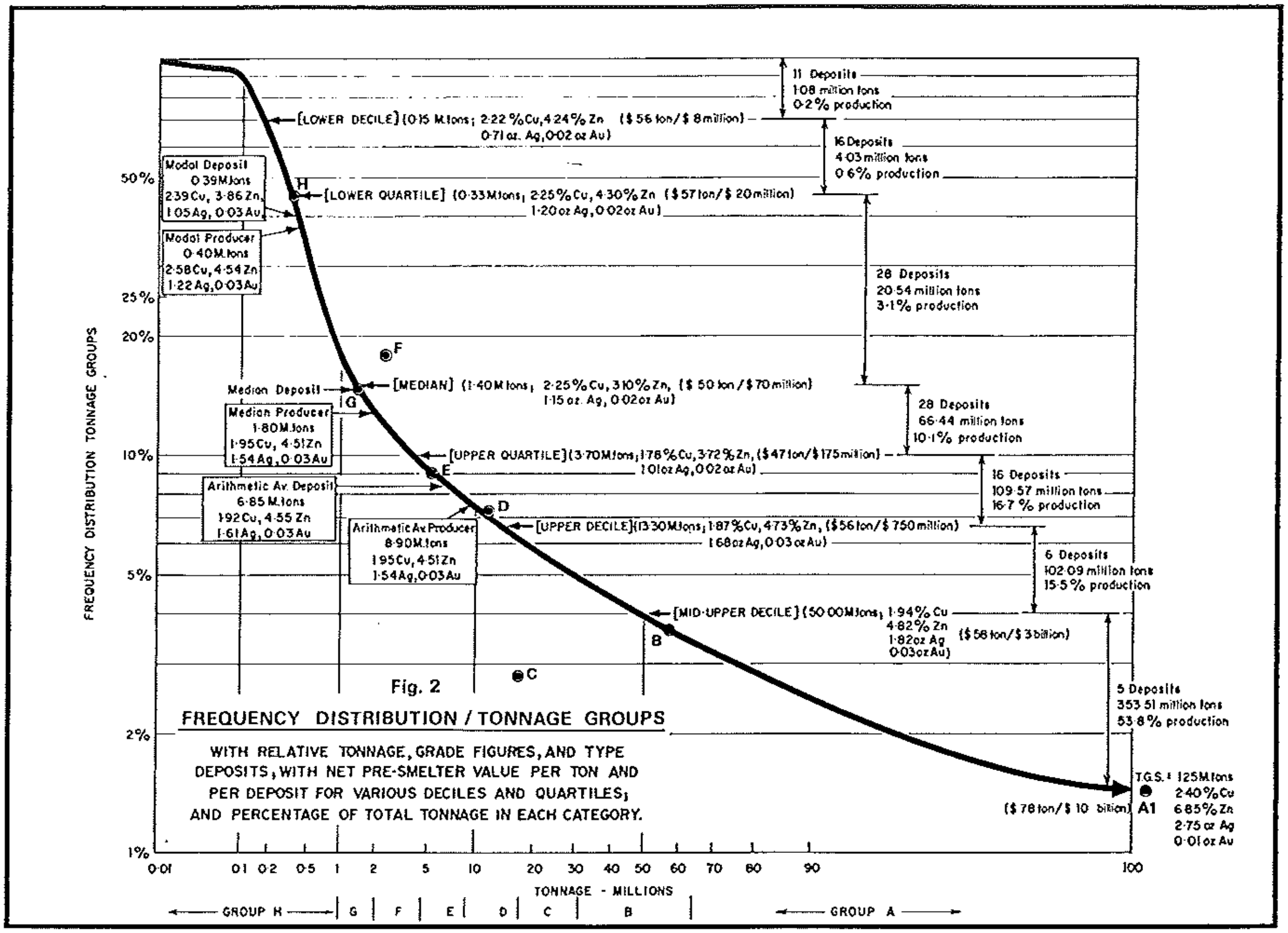


FIGURE 2 — Frequency distribution of tonnage groups, showing tonnage type, grade, and net pre-smelter value per ton and per deposit, in various percentile positions.

not occur within reasonably well defined ranges. A histogram of a simple arithmetic progression represents a method whereby an infinite number of deposits can be easily grouped. However, for the purposes of this exercise, the geometric progression of number groups has been taken as more meaningful and more easily used to show the almost natural order of distribution (Fig. 1). These tonnage groups, i.e. A, B, C, D, etc., form the base for the calculations and observations which follow.

FREQUENCY DISTRIBUTION

Utilizing the geometric progression of tonnage groups, a true as possible representation of the population can be obtained and a certain frequency distribution pattern outlined (Fig. 2). The number of deposits that occurs in any one group is known, and their percentage distribution can be calculated and the results plotted as a frequency distribution curve which is fairly representative of the total population.

Figures 1 and 2 show that 54% of the total tonnage comes from only five deposits, four of which occur in group B and one in group A. In addition, over 75% of all deposits occur in the three smallest groups, F, G and H, the largest deposit of which contains less than 4 million tons, and cumulatively the three groups in question account for only 14% of the total tonnage.

A modal deposit occurs in group H, has 390,000 tons and occurs with a frequency of approximately 40%. It also occupies a position just above the lower quartile. A modal producer has similar characteristics.

A median deposit, on the other hand, occurs in group G, has 1.4 million tons and occurs with a frequency of approximately 15%. A median producer, however, has 1.8 tons and occurs with a frequency of 13%. The arithmetic average deposit occurs in group E, has 6.85 million tons and occurs with a frequency of approximately 8.5%. A producer in this category has 8.9 million tons and occurs with a frequency of 7.5% Both occur in the upper-quartile range.

Particular attention should be paid to the location of the upper-decile position with a frequency of 6.5%. This marks the base of really significant volcanogenic deposits with tonnages in excess of 13 million tons (Mattabi, Fox, etc.) and a minimum deposit value of $750 million. Only twelve deposits of this tonnage size are known to date to occur in the Canadian Precambrian. Table 1 shows the distribution of certain volcanogenic deposits in the Precambrian and compares them to others in various tectonic environments in Canada.

GRADE AND VALUE/TON/DEPOSIT

Grade calculations for the various points of reference have been made by utilizing normal procedures, such as 'averaging' the values for the various metals within specific tonnage or type groupings, and, in the case of the percentiles, averaging the values evenly distributed above and below the various percentile points to obtain the value at the percentile point.

In order to set a certain value against any particu-

TABLE 1 — Comparative Table — Selected Volcanogenic Deposits in Canada

Class	Precambrian Shield	Appalachian	Cordilleran
Top Deposit	Kidd Creek	Brunswick 12	Brittania
Mid-Upper Decile	Flin Flon, Horne, Geco, Ruttan	Heath Steele, Caribou	—
Upper Decile	Mattagami, E. Sullivan, Quemont, Hacket R, Mattabi, Fox, Manitou-Barvue	Buchans, Brunswick 6, Murray Brook	Sam Goosly?
Upper Quartile	Normetal, Barvue, MacDonald, Sherridon, Isok L, Kamkotia, Orchan, Willroy, Amulet A, Chisel, Poirier, High L, Iso, Jungle, Stall	Tilt Cove, Whalesback, Gull-bridge, Little Bay, Canoe L, Half Mile L, Clearwater, Armstrong A	Granduc?
2nd Quartile	NBU, Mobrun, Lake Dufault (3), Coldstream, Osbourne, Lyon L, Reed L (2), Anglo-Rouyn, Bob, Louvem, Aldermac, Will-echo, Agricola L, N. Hosco, Anderson, Joutel, Norita, E. Waite, Lessard, Coronation, Centennial, Pine Bay	Eustis, Solbec, Ming, E. Rambler, Cupra, Weedon, D'Estrie, Nigadoo, Key Anacon	Anyox
3rd Quartile	O. Waite, Vendome, New Insco, South Bay, Wim, Indian Mtn., Dunraine, Dickstone, Schist L (2), Coniagas, Tema-gami, Lemoine, Little Stall, Amulet C, Jameland, Cuprus, Can. Jamieson, Delbridge, Vauze	Wedge, Huntingdon, Austin Brook, Pilleys Isl., Harvey, Suffield, Stratmat W.	Western Mines, Sunro
Lower Quartile	White L, Rail, Birch L, Amulet F, Ghost L, Bell Allard, Garon L, North Star, Zenmac, Lyndhurst, Mandy, Flexar	Main Rambler, Lockport, York Harbour, Moulton, Betts Cove, Captain	Tulsequah, Hart R

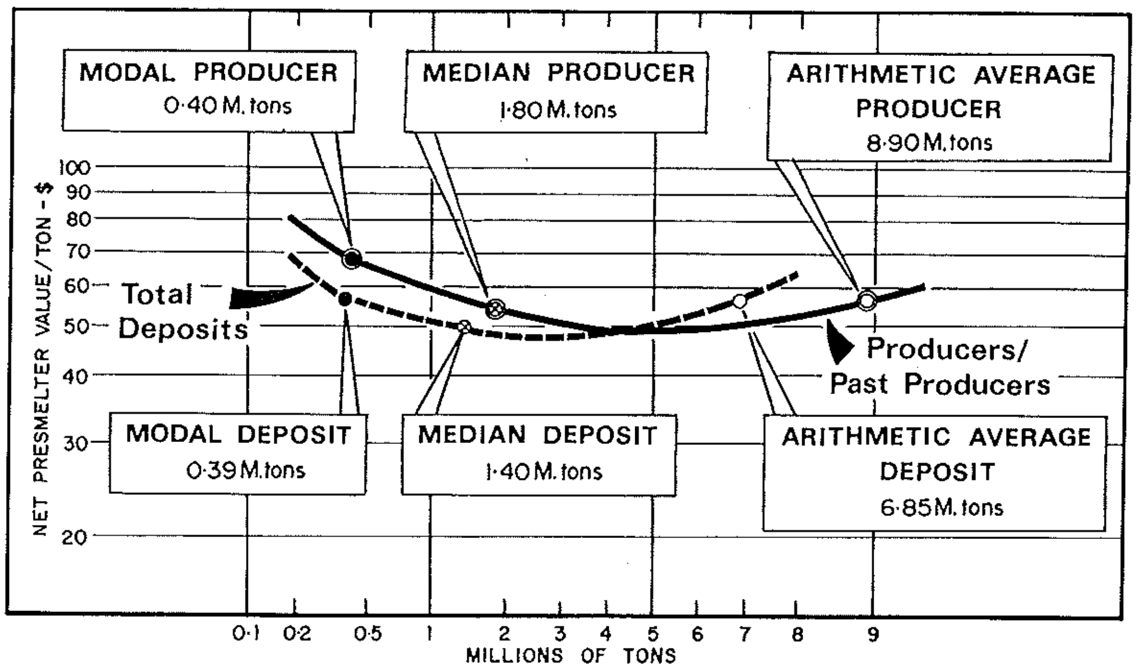


FIGURE 3 — Net pre-smelter value per ton for average, median and modal deposits, and producers in similar categories.

lar unit, and in order to compare and contrast the value of the various units, it was decided to base the value of a ton of ore on its 'net pre-smelter value' rather than its 'gross value', using a fixed price base for the various metals. The 'net pre-smelter value' excludes all costs, but takes into consideration the fact that only certain percentages of the metals are recovered. A fairly typical recovery pattern for normal concentrates of the various metals is: copper 90%, zinc 85%, silver 65% and gold 50%. The base price used for these metals is: copper 70¢/lb, zinc 35¢/lb, silver $3.00/oz, and gold $100.00/oz.

There is a relatively narrow range of dollar values between the percentile-type deposits and also between the average, median and modal deposits and the respective producers or past producers in their categories (Figs. 3, 4, 5). Also, the value of a deposit in any tonnage group is fairly constant, with the particular exception of the TGS Kidd Creek deposit and those in group E (4-8 million ton range) and, to some extent, group H. Furthermore, the modal deposits of northern Manitoba, the median deposits of Western Ontario and the Northwest Territories, and the arithmetic-average deposits of the Northwest Territories are the more valuable deposits in their class.

SPATIAL DENSITY

The spatial density of volcanogenic deposits, or the cluster distribution pattern, can be classified from small district-sized blocks to larger regional-sized blocks (Table 2). Because of the difficulty in outlining the periphery of a district, the numbers of deposits that occur within a standard 500-square-mile block are counted and the density per square mile calculated. A similar method was used to calculate the regional density. A possible position for a district 'median ratio' would be approximately 1:50, which could suggest that those districts with a lower density could be potentially of exploration interest, assuming, of course, that all other factors causing the high density distribution are also present.

Relatively low risk exploration occurs in areas of high density (i.e. Noranda, Flin Flon, Abitibi) and

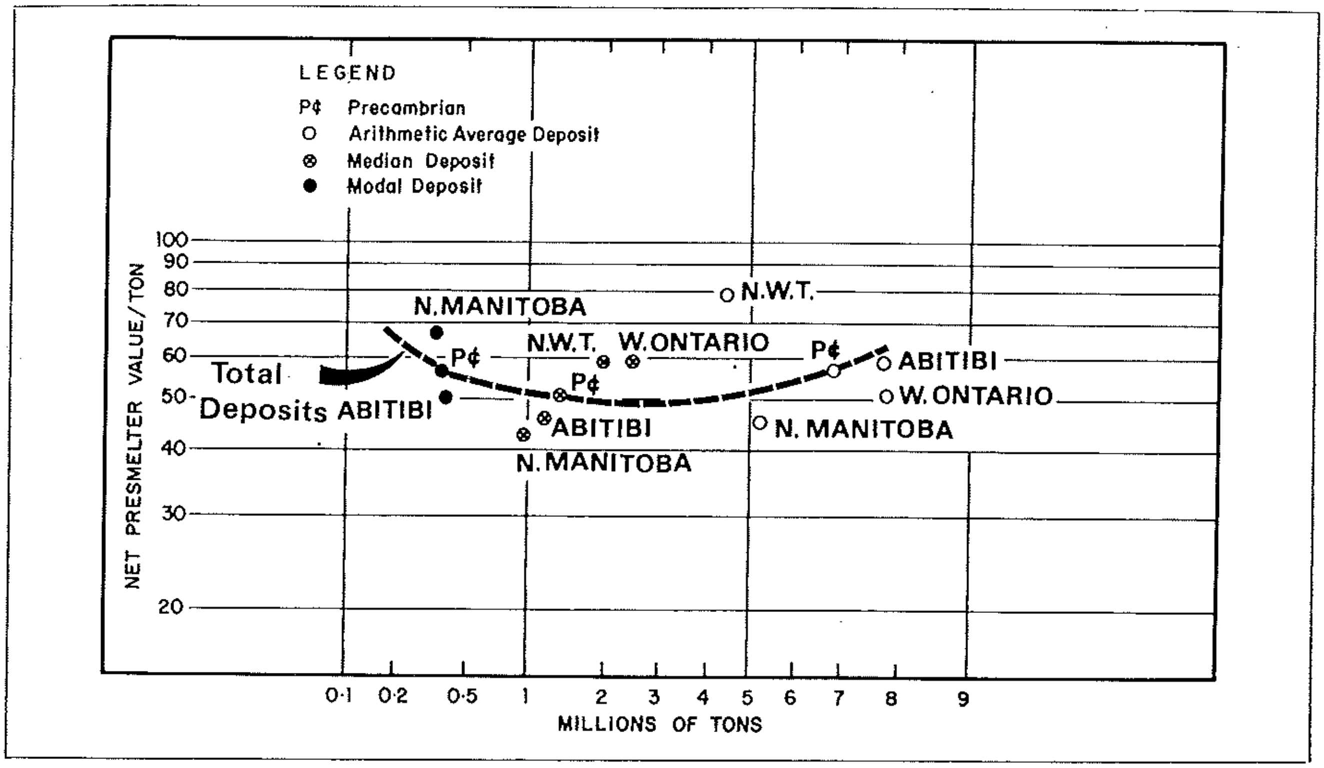
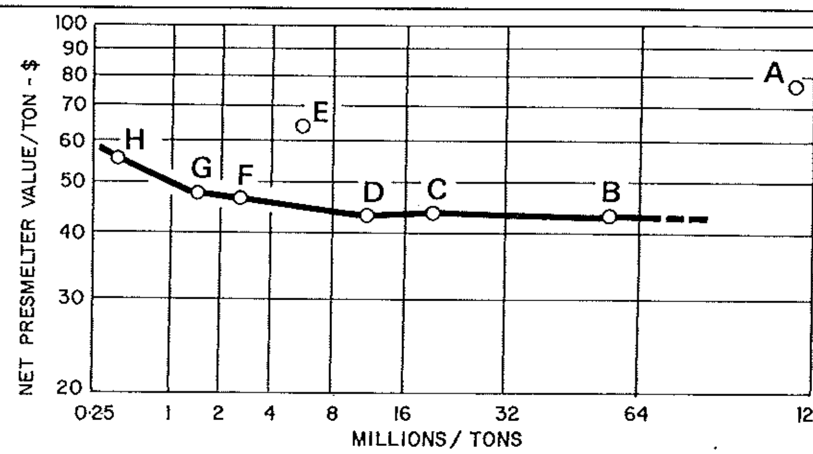


FIGURE 4 — Net pre-smelter value per ton for average, median and modal deposits for various regions.



GROUP	M/Ton/Range	No. Deposits	Av.Size	%Cu	%Zn	oz./Ag	oz./Au	Net/Ton
A	64 - 128	1	125·00	2·40	6·85	2·75	0·01	$76·83
B	32 - 64	4	57·13	1·95	2·41	0·75	0·06	$43·38
C	16 - 32	3	20·14	0·77	5·24	0·65	0·04	$44·20
D	8 - 16	8	11·61	0·96	4·39	2·03	0·01	$ 42·74
E	4 - 8	10	5·46	2·12	5·55	0·88	0·02	$62·44
F	2 - 4	19	2·65	2·14	2·88	1·22	0·02	$47·47
G	1 - 2	16	1·40	2·26	2·86	0·85	0·02	$48·15
H	0 - 1	49	0·39	2·39	3·86	1·05	0·03	$56·62

	Recovery	Price
Cu	90%	@ 0·70¢lb
Zn	85%	@ 0·35¢lb
Ag	65%	@$3·00oz.
Au	50%	@$100·00oz

FIGURE 5 — Net pre-smelter value per ton for various deposit size groups.

there is a better chance for the discovery of deposits at least of the modal type for the district, and hopefully of the median type, until such time as the point of diminishing return occurs. By contrast, relatively high risk exploration occurs in areas of low density (i.e. Timmins, Sturgeon Lake, Slave), or even those areas with no known deposits. These areas offer a better chance for the discovery of deposits in the higher percentile ranges (greater than the median) until the point of diminishing return is reached.

As a matter of further interest, the Abitibi belt contains 61% of the total volcanogenic base metal tonnage in the Shield, northern Manitoba contains 23%, western Ontario contains 12% and the Northwest Territories contains 4%, to date. Figures 6 and 7 illustrate the distribution of copper and zinc grade and tonnage for the various districts in the Precambrian.

ROLE OF EXPLORATION DISCOVERY METHODS

Figure 8 shows the relative position and role played by various discovery methods, the size groupings and frequency distribution of deposits to which they relate, and the modal, median and percentile positions of contrasting discovery methods, with selected examples.

It is interesting to note that aerial geophysics during the past twenty years has discovered 17% of the deposits, which however contain 41% of the total tonnage. This contrasts with surface prospecting discovering 44% of the deposits, containing 48% of the total tonnage, over a period of 75 years. Ground geophysics, in turn, is responsible for 29% of discoveries which represent 9% of the total tonnage; and geological methods (occasionally supported by geochemistry) have discovered 9% of the deposits, representing 2% of the total tonnage.

These data show the important part played by aerial geophysical surveys over the past twenty years. A median AEM discovery contains 3.30 million tons, which is nearly three times the size of a median discovery made by other methods. Furthermore, a modal AEM discovery contains 2.80 million tons and is at least four times larger than modal discoveries made by other methods. A really significant AEM discovery would be that which occurs in the upper quartile of its class, which actually corresponds to

TABLE 2 — District and Regional Density Pattern

District	Dimensions	No. Deposits	Density per Sq. Mile
Noranda	500 sq. mls.	22	1:23
† (Chibougamau)	"	(16)	(1:31)
Flin Flon	"	13	1:38
Snow Lake	"	11	1:45
Mattagami	"	8	1:62
Val d'Or - Barraute	"	6	1:83
Timmins	"	5	1:100
Sturgeon Lake	"	4	1:125
Region	**Dimensions**	**No. Deposits**	**Density per Sq. Mile**
Noranda - Barraute	5000 sq. mls.	36	1:139
Flin Flon, Snow L. Sherridon	"	30	1:167
* Total Abitibi	60,000 sq. mls.	59	1:1000
* Total N. Manitoba	"	33	1:1800
* Total 'Slave', N.W.T.	"	7	1:8600

*All Lithologies
†Vein-Shear Type (included for comparison with volcanogenic types)

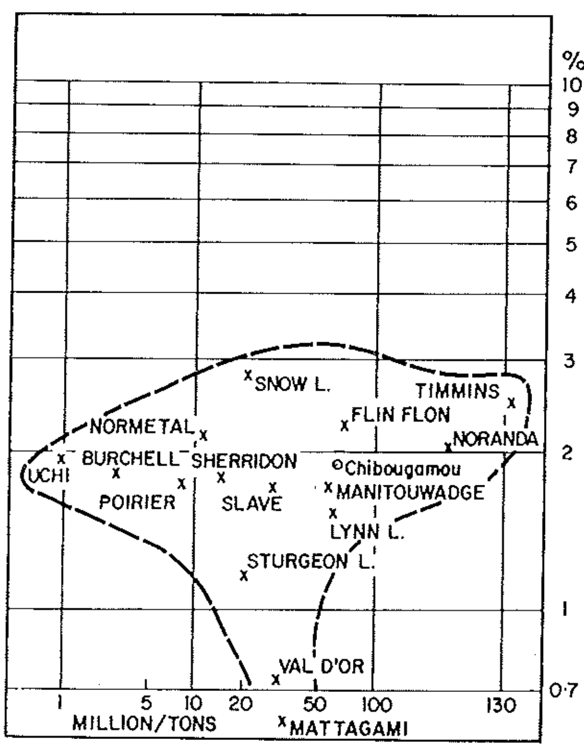


FIGURE 6 — Distribution district — copper grade and tonnage.

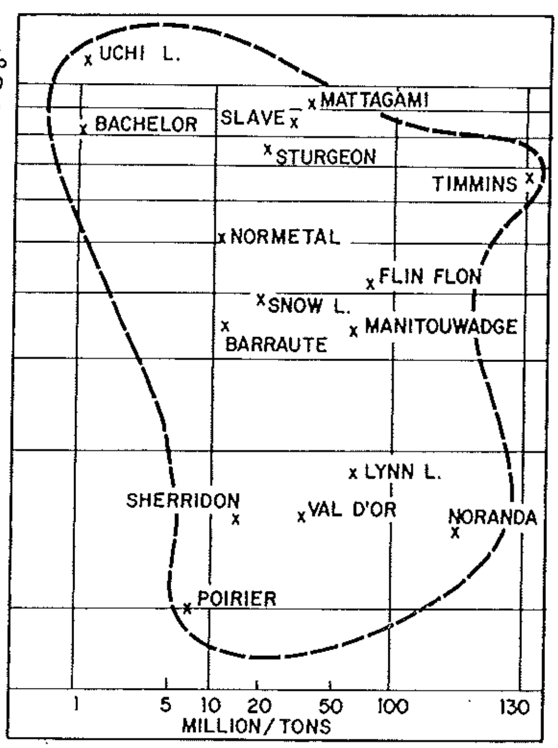


FIGURE 7 — Distribution district — zinc grade and tonnage.

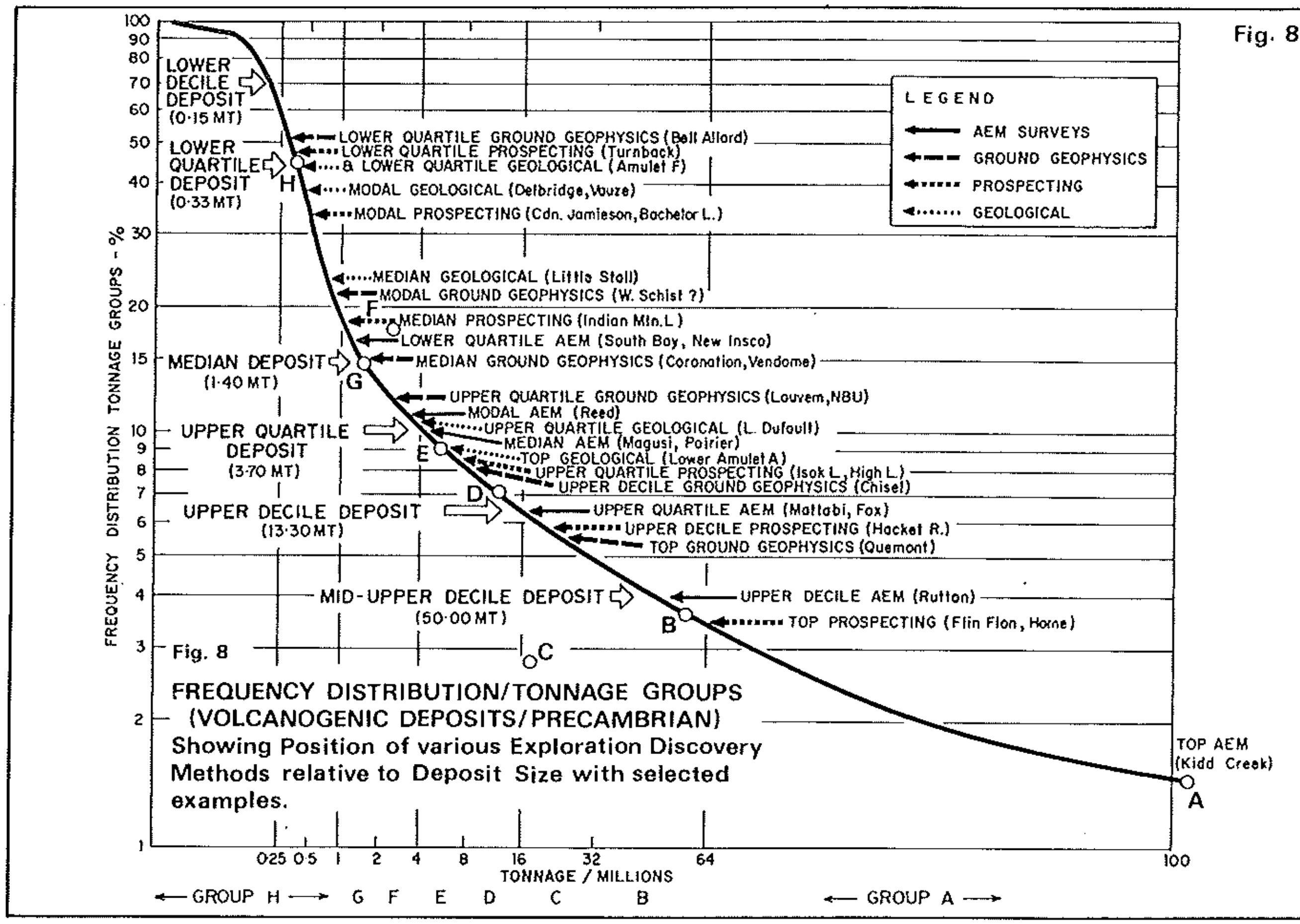


FIGURE 8 — Frequency distribution tonnage groups, showing position of various exploration discovery methods relative to deposit size.

an upper-decile deposit containing 13.30 million tons, and is larger than upper-quartile discoveries made by other methods. A similar situation exists in comparing upper-decile discoveries made by AEM systems and other exploration methods.

PROBABILITY OF DISCOVERY

The quotation at the beginning of this paper puts in perspective the role of mathematical calculations in determining the probability of discovery in absolute terms. Nevertheless, with an understanding of the limitations of mathematics, as applied to exploration, a certain appreciation of the probabilities of discovery is needed in order to place in perspective the target or prize so eagerly sought.

A probability is a likely happening. There are varying degrees of certainty between absolute certainty and absolute impossibility. In mathematical terms, absolute certainty is $P = 1$ and absolute impossibility is $P = 0$. Hence:

$$P = \frac{\text{Number of occurrences of an event}}{\text{Total number of trials/chances}}$$

In exploration, this can be expressed as empirical probability as follows:

$$P = \frac{\text{First discovery}}{\text{Total number of trials (drill tests)}}$$

In Figure 9, *Column A* is the whole scale of probability and the possible position of various exploration companies on that scale.

Column B is an enlargement of the lower 10% of the scale in Column A, i.e. where $P = .10$ or less. The position of certain companies, i.e. No.'s 1, 2, 3 etc., on this scale was derived by utilizing the formula shown above. The listed companies drilled a previous number of barren holes before a significant discovery. They are as follows: Company No. 1, 12 holes; No. 2, 40 holes, No. 3, 65 holes; No. 4, 88 holes; No. 5, 123 holes; No. 6, 130 holes; No. 7, 135 holes; and in the case of Company No. 8, approximately 900 holes prior to discovery of a significant deposit. With additional statistics (often unavailable), this list can be enlarged, however the majority of companies would still occur in positions approaching the point where $P = 0$.

Column C is an enlargement of the lower 10% of Column B where $P = .01$ or less. It is in this area where lottery prize winners occur. The smallest prize has a probability of $P = .0008$, equivalent to odds of 1200:1, similar to ratios for one or two successful end members in exploration. Beyond this point, the other prizes have astronomical P values, with odds greater than 120,000:1 for top prizes.

This comparison with a lottery brings a sense of realism into exploration discovery. It shows the difficulty of obtaining any winning ticket, although in exploration there is always the possibility that should a discovery be made, it may occur at the upper end of the probability scale, and hopefully have a high prize value.

The indeterminate role played by random chance is impossible to quantify. Statistically, a prize winner is much more likely to obtain a lower-valued prize because there are more available chances (and deposits) in this category. Similarly, an ore finder

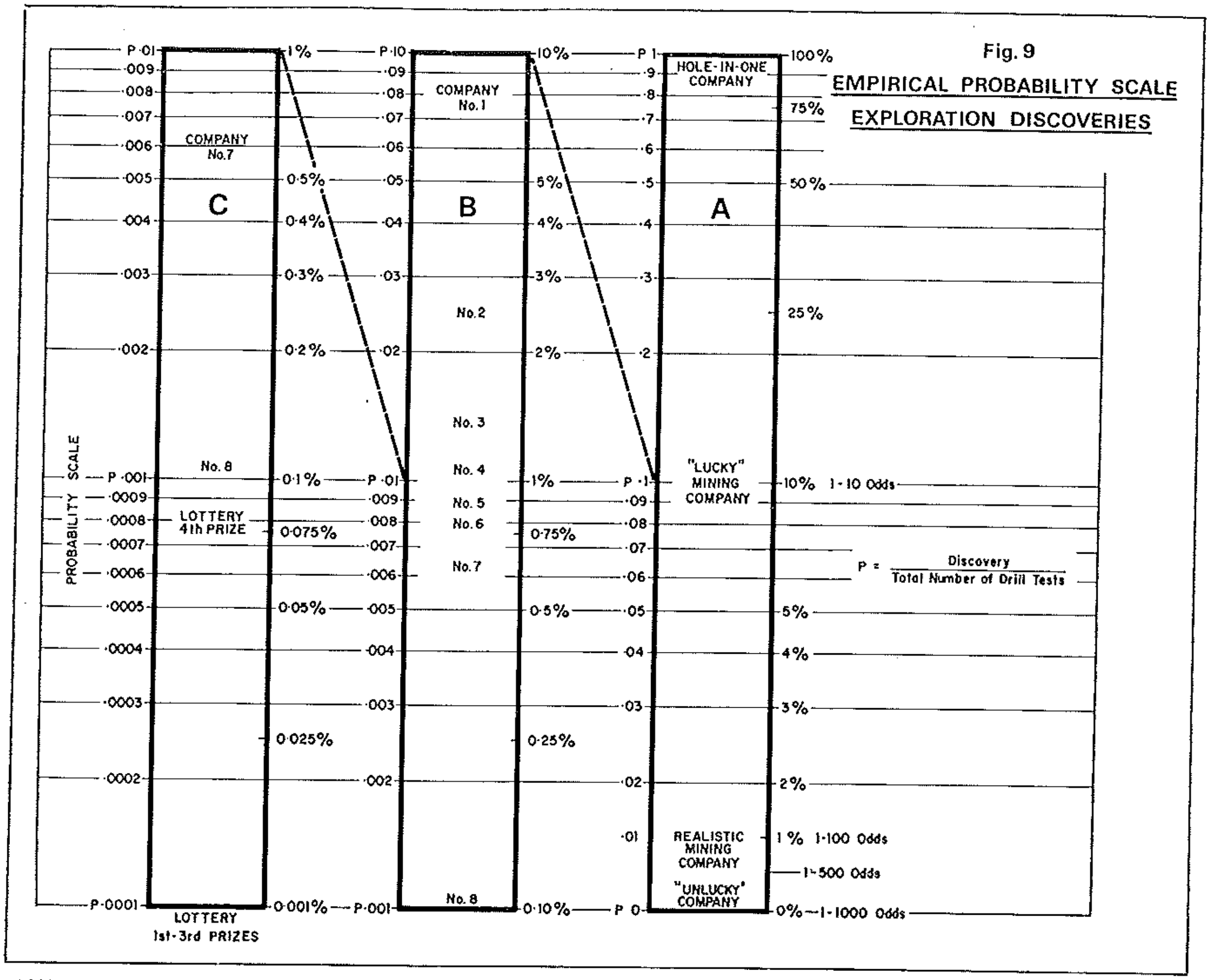


FIGURE 9 — Empirical probability scale — volcanogenic discoveries.

TABLE 3 — Relationship of Empirical Discovery Odds and Frequency Odds to Specific (value/size) Volcanogenic Deposits in the Precambrian

Deposit Type	Value ($000,000)	Tons (000,000)	Frequency Distribution	Frequency Odds (a)	Empirical Discovery Odds (b)	Actual Odds (c)
Mid-Upper Decile	3000	50	4.0%	25:1	100:1	2500:1
Up. Decile	750	13.3	6.5%	15:1	100:1	1500:1
Up. Quartile	175	3.7	10.0%	10:1	100:1	1000:1
Median	70	1.4	15.0%	7:1	100:1	700:1
Modal	20	0.4	40.0%	2.5:1	100:1	250:1
Lr. Quartile	18	0.33	45.0%	2:1	100:1	200:1
Lr. Decile	8	0.15	70.0%	1.5:1	100:1	150:1

Note (a) Frequency odds obtained from frequency distribution.
(b) Empirical discovery odds obtained from probability scale; using 100:1 odds as an example.
(c) Actual odds obtained as product of (a) × (b); value is dependent on empirical odds used. This can be expressed as follows: $F_o \times E_o = A_o$; where F_o are the frequency odds, which are a fixed entity; E_o are the empirical odds, which are variable; and A_o are the actual odds, which can be obtained for any specific class of deposit, as shown in the equation.

should be more likely to discover a modal deposit, as more of these types exist in nature. However, this does not necessarily happen, as can be shown by the attractive value of the prizes won by Company No. 1, No. 3 and No. 8, each of whose 'events' occurred at various points on the empirical probability scale, and were conducted under variable philosophies, but resulted in at least upper-decile-type deposits. Realistically, empirical odds for exploration discovery probably occur in the range of between 100:1 (P = 0.1) and 500:1 (P = .005), within which range several exploration discoveries have been made.

It should be remembered, however, that for every successful company there are many others who 'played' the game and lost, because, in some instances, o ftheir lack of appreciation of the odds, particularly when applied to the larger, less frequently distributed deposits (Table 3).

COST-PER-TARGET ANALYSIS

Various companies have a multi-faceted approach to mineral exploration in their quest for a variety of commodities within the context of their operations and within the limits placed on them by exploration budgets.

Regardless of the size of the exploration group and its budget, a yardstick of its efficiency can be realized to some extent by analyzing its 'cost-per-target' figure. This is obtained by dividing the total budget of the group by the number of *meaningful* targets that have been drill-tested. Based on a unit cost of $250,000 per area investigated by modern AEM systems, there is no reason why approximately 20 targets cannot be tested for a cost of $12,500 per target, except in remote areas. For those groups engaged primarily in 'grass-roots' situations, it is important that approximately 50% of their budget be allocated to the drill-testing of meaningful targets, in order to be able to participate for a sufficient period of time, to lower the odds against discovery in their own favour.

Factors relating to spatial density are also of importance in exploration. Relatively 'low risk' exploration occurs in areas of a high density distribution of deposits. These areas (i.e. Noranda, Flin Flon, Abitibi) offer a better chance for discovery of a modal or median-type situation. On the other hand, 'higher risk' opportunities occur in areas containing a low density distribution pattern (i.e. Timmins, Sturgeon Lake, Slave), and these are more likely to contribute a deposit in the upper-quartile ranges and hence make a significant contribution.

Conclusions

The massive sulphide volcanogenic deposits of the Precambrian occur in a natural geometric progression in size. They number 110, of which 70% are in the pre-production stage, or are producers or past-producers. The deposits contribute 70% of Canada's zinc production and approximately 35% of its copper. Fifty-four per cent of this production is obtained from only 5 deposits, which occur in the mid-upper-decile size range, are 50 million tons in size, have a minimum net pre-smelter value of $3 billion each and occur with a frequency distribution of 4%. At the other end of the spectrum, 3.9% of production is obtained from 55 deposits, all of which fall below the median. These deposits are 'bonanzas' in the sense that, although sparingly distributed, they contain relatively high values and are generally worth between $43 and $62 per ton.

The statistically typical volcanogenic deposit is that which occupies the modal position and can be described as approximately 400,000 tons of ore with a net pre-smelter value of $20 million. This occurs with a frequency of 40% and is positioned above the lower-quartile line. The statistical median deposit can be described as 1.4 million tons of ore with a net pre-smelter value of $70 million and with a frequency distribution of 15%.

Deposits which can be considered of real economic significance and more than likely to make a meaningful contribution to a company occur in the upper-decile range, with in excess of 13 million tons and a net pre-smelter value of $750 million, but with a frequency distribution of 6.5%. To date, approximately a dozen deposits occur in this class, and in the past they were being discovered at the rate of one deposit every four to five years, using modern exploration techniques.

These significant upper-decile-sized deposits correspond to those which occur in the upper quartile of AEM discoveries. Even the smaller, upper-quartile-sized deposits (3.7 million tons, value of $175 million, frequency distribution of 10%) correspond to a median AEM discovery, have values of between three and four times that of deposits discovered by other means and remain worthwhile targets.

Empirically, realistic odds for discovery occur in the range of between 100:1 and 500:1 in most cases (slightly better odds than exist in winning a minor prize in a lottery). However, with an appreciation of the odds and an awareness of the roles of uncertainty and random chance, those odds should not look too formidable, particularly if exploration is approached in a realistic fashion and a sufficiently high proportion of funds are conserved (50% of project budget) for testing a reasonable number of *meaningful* targets over an (un)certain period of time. The past history of several companies has shown that a significant discovery can be obtained with an outlay of between one half million dollars and fifteen million dollars over a period of time, extending up to 10 years in some instances.

In closing, it may be apt to mention a quotation attributed to Arthur Holmes, the well-known geologist, which complements Whitehead's: "To reason without data is nothing but delusion".

Acknowledgments

The writer would like to thank the management of Shell Canada Ltd., particularly Dr. A. B. Baldwin, manager, Minerals Division, for permission to publish this paper, which was part of a study of Canadian mineral deposits, with the writer involved in a consulting capacity. In addition, I would like to acknowledge the cooperation of R. van Ingen, senior geologist, Minerals Division, who was party to many discussions relating to the role of statistics and exploration; and also D. O'Shannessy for drafting the figures. Finally, I am indebted to the handbook on "Facts from Figures" by M. J. Moroney, which outlines statistics for the layman.

The writer assumes responsibility for any errors which may appear in the text and for any conclusions reached in this publication.

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Survey of Undeveloped Mineral Deposits

THE MINERAL DEVELOPMENT SECTOR of the Department of Energy, Mines and Resources in Ottawa has recently released "A Survey of Known Mineral Deposits in Canada That Are Not Being Mined", by R. C. Annis, D. A. Cranstone and M. Vallée. It is a compilation of information that is hard to find elsewhere in one place, gleaned chiefly from EMR's National Mineral Inventory Files.

The deposits listed in the report are divided into two groups:

(i) deposits that are neither in production nor announced for production, but are considered by the authors to be economically mineable today or within reach of being so before the year 2000; and

(ii) deposits considered as unlikely to be economically mineable before the year 2000.

The compilation lists the following items:

1. Deposit or property name and ownership.
2. Deposit location by National Topographic System area and by latitude and longitude.
3. The exploration/development stage of each deposit expressed as a number code.
4. A summary of the geology of the deposit.
5. Published (or estimated) tonnages and grades, with the year in which the figures were published or estimated.
6. A summary of the history of exploration and development work that has been done on each property.
7. Remarks on the present status of many of the deposits. These remarks are the (mostly unsubstantiated) impressions of the authors.

The document does not pretend to be a complete inventory of all known undeveloped deposits in Canada. Nevertheless, because it can be a handy source of reference, copies are provided on request from:

Publications Distribution Office,
Mineral Development Sector,
Department of Energy, Mines and Resources, 580 Booth Street,
Ottawa, Ontario K1A 0E4.

Geochemical Methods Applied to Uranium Exploration in Southwest Baffin Island

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Abstract

Under the auspices of the Federal-Provincial Uranium Reconnaissance Program, a geochemical orientation survey was undertaken in an area of uraniferous Lower Proterozoic (Aphebian) rocks near Cape Dorset in southwest Baffin Island. The main objective of this study was to establish a methodology for a future reconnaissance geochemical program using lake samples over a 300-mile Lower Proterozoic rock belt that occurs along the southern coast of Baffin Island.

Mineralogical and chemical studies of known radioactive occurrences, combined with detailed sampling of secondary environment media in the vicinity of the showings, indicate that uranium is the most significant pathfinder, despite considerable enrichment of other metals in the uraniferous rocks. Significant geochemical patterns produced by uranium in lake waters and uranium in lake sediments have been obtained, but their relative usefulness depends on the distribution of carbonate bedrock, which in turn affect the bicarbonate content of lake waters. In southern Baffin Island, because of erratic variation in lake-water alkalinity, it is recommended that both waters and sediments be sampled on a routine basis. The need for lake-water acidification to prevent depletion of soluble metal ions in samples resulting from adsorption on the walls of the containers and/or suspended solid matter is discussed briefly.

The base metal potential of the area was examined in some detail and found to be significant, particularly for a Lower Proterozoic gossanous formation that occurs throughout southern Baffin Island.

Introduction

IN EARLY 1975, at a time of growing public awareness of the limitations of conventional sources to satisfy a rapidly increasing world demand for energy, the federal government, through the Geological Survey of Canada, undertook a major uranium exploration program in an effort to increase substantially Canadian reserves of nuclear fuels. Thus, the Federal-Provincial Uranium Reconnaissance Program (Darnley *et al.*, 1975) was created, with the following main objectives:

(1) to provide industry with high-quality reconnaissance exploration data to indicate those areas of the country where there is the greatest probability of finding new uranium deposits; and

(2) to provide government with nation-wide systematic data to serve as a base for uranium resource appraisal.

The technical aspect of the program involves both geophysics (γ-ray spectrometry) and geochemistry, the choice between methods for a given area being based on such factors as topography, amount of rock exposure, and the geology or metallogeny of the area. The geochemical activities are performed in three stages: orientation, reconnaissance and follow-up.

The orientation surveys are designed to provide control data that will be used in the planning and execution of the reconnaissance surveys. These, in turn, involve systematic geochemical sampling of large areas of the country, generally encompassing some or all of the total area of a favourable geological unit. During the follow-up stage, the anomalies outlined in the reconnaissance surveys are verified and interpreted.

This paper describes the orientation phase of an integrated geochemical program for uranium and base metal exploration in southern Baffin Island. Interest in radioactive minerals in southern Baffin Island dates back to the mid 1960's, when a mineralized boulder containing 5.6% uranium oxide was discovered on Apex Hill near the town of Frobisher Bay. Several airborne radiometric surveys have since been

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Keywords: Mineral exploration, Exploration techniques, Geochemical exploration, Uranium exploration, Lead, Baffin Island, Lake waters, Lake sediments.

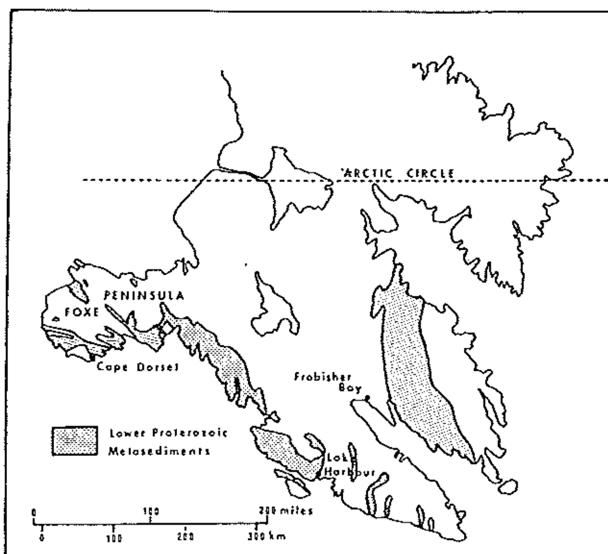

FIGURE 1 — Location of Lower Proterozoic rocks in southern Baffin Island.

carried out by exploration firms, with indications of high radioactivity, generally in association with a 300-mile-long belt of Lower Proterozoic (Aphebian) rocks situated along the south coast of Baffin Lsland between Lake Harbour and the western extremity of Foxe Peninsula (Fig. 1). As several interesting showings had been discovered within this unit near Cape Dorset, this area was selected for the present orientation survey.

The immediate objectives of our work were to examine the extent and mechanisms of metalliferous dispersion around the showings and to assess their detectability using different geochemical means. The survey also enabled us to set a series of guidelines that will form the basis for a future reconnaissance geochemical operation over the entire Lower Proterozoic belt of southern Baffin Island.

Geology and Mineralization

In the late 1950's and early 1960's, the Geological Survey of Canada conducted a mapping program in southern Baffin Island; the information is contained in several publications by Blackadar (1959, 1962 and 1967). This author summarizes the Proterozoic geology of southern Baffin Island as a complexly folded succession of granite, migmatite and quartz-feldspar gneissic rocks, commonly containing bands of crystalline limestone, graphitic schists, quartzites, and mafic schists and gneisses.

The radioactivity in the Cape Dorset area is predominantly associated with coarse to pegmatitic granite sills and dykes contained within the metasediments. However, several granites and gneissic granites of appreciable surface extent, commonly located in proximity to the pegmatite showings, have been found to be anomalously radioactive.

One of the most interesting uranium occurrences in the area is situated 28 miles northeast of Cape Dorset. The radioactive outcrop is approximately 2,000 feet long and varies in width from 50 to 250 feet. Its surface is, in many places, heavily stained by secondary uranium minerals. The bulk of the radioactivity in fresh pegmatite samples was found to be caused by uraninite; however, a mineral belonging to the thorite-uranothorite series was also identified in heavy-mineral concentrates of some of the specimens. The radioactive minerals are disseminated in the host rock and individual grains are of the order of ½ to ¾ mm in size. Other minerals found in the heavy-mineral concentrates were molybdenite, pyrite, zircon, ilmenite and apatite; molybdenite was observed macroscopically in several hand specimens.

In weathered pegmatite, the uraninite is altered in two different ways. Most frequently, the uranium from the breakdown is mobilized and eventually converted to the secondary mineral soddyite ($5UO_3.2SiO_2.6H_2O$), which tends to accumulate in the fractures. This is the most common form of alteration and is responsible for the bright yellow staining observed on the outcrop. Another type of alteration observed microscopically consists of the formation of a rim of kasolite ($PbU.UO_3.SiO_2.H_2O$) around the uraninite grains. It is suspected that the lead in the kasolite originates from the radiogenic decay of the uranium.

The following grades are quoted from Laporte (1974) and are based on the analysis of twenty-five selected samples from this showing:

	Maximum	Average
U_3O_8	.340%	.058%
ThO_2	.060%	.027%

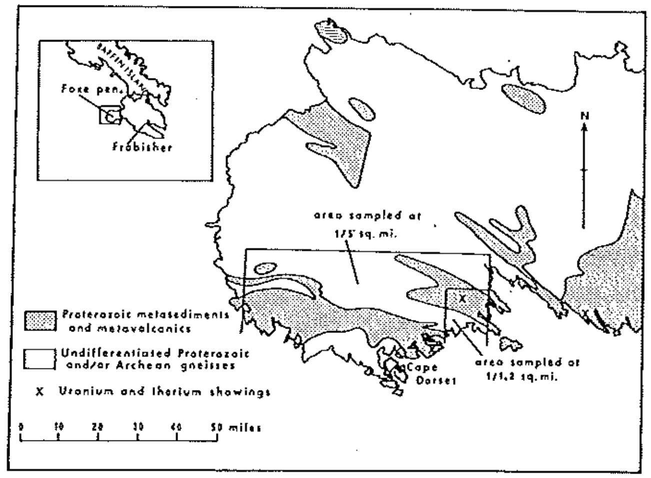

FIGURE 2 — Location of the study area and known uranium and thorium mineralization in Foxe Peninsula.

Analysis of a limited number of rock samples collected by the writer confirms these values.

Field and Analytical Procedures

During the initial field operations, detailed investigations of mineralized showings and their immediate surroundings were carried out. The work involved grab sampling of mineralized outcrops for chemical and mineralogical determinations, and the detailed sampling of secondary-environment media (lake, pond and stream waters and sediments) within a one-mile radius of the showings. This aspect of the field work was aimed at obtaining data that would help select the most meaningful pathfinders for geochemical exploration.

The field activities that followed consisted of semi-detailed lake water and sediment sampling of all lakes that were on the 1/250,000 map in a 125-sq.-mile area centered on the uranium showing 28 miles northeast of Cape Dorset (Fig. 2). The sampling was carried out by helicopter and resulted in a site density of 1 sample per 1.2 sq. mile. This allowed us to establish pertinent operational guidelines, such as optimum sample density, relative usefulness of water versus sediment sampling, etc., for helicopter-supported geochemical surveying in southern Baffin Island.

The lake survey was later extended to cover a 1500-sq.-mile area of southern Foxe Peninsula at a density of 1 sample per 5 sq. miles, thus covering most of the western end of the South-Baffin Lower Proterozoic belt (Fig. 2). This reconnaissance-scale surveying was carried out primarily to obtain data for an initial appraisal of the mineral potential of this zone.

Center-lake sediment sampling was carried out using the Hornbrook-designed tube sampler (Hornbrook *et al.*, 1975), suspended on a 30-meter, quarter-inch sash cord. This technique was found to be satisfactory in most situations, but for very shallow lakes (less than 3 meters) a Ponar jaw sampler was preferred. The sediment samples were dried, ball milled to -200 mesh (0.8 mm) and analyzed for uranium by delayed neutron activation. In addition, the samples that were collected in the 125-sq.-mile area around the main showing were analyzed for Fe, Mn, Cu, Pb, Zn, Ni and Mo by atomic absorption spectrophotometry after a HNO_3-HCl acid digestion. They were also analyzed spectrographically for ten other elements: Ag, V, Cr, Be, La, Y, Sr, Ba, Co and Ti.

Lake-water samples were collected in 500-ml polyethylene bottles using a rapid sampling system (Cameron and Durham, 1975). The apparatus also provides for direct measurements of pH, temperature and specific conductivity. Duplicate samples were collected at 20% of the sites and, for half of these, one sample in each duplicate pair was acidified in the field to monitor the need for water acidification in future hydrogeochemical surveys in that region. At the end of the field season, the water samples were analyzed fluorimetrically for uranium by the technique described by Smith and Lynch (1969) and for Cu, Pb and Zn by atomic absorption after an APDC-MIBK solvent extraction.

The rock samples were analyzed chemically for U and Th and by emission spectrometry for 41 minor and major elements.

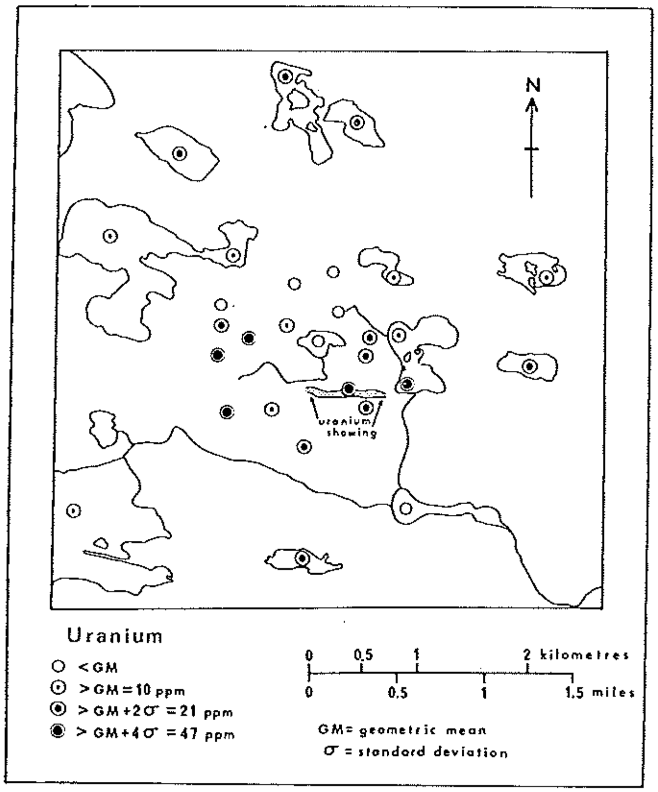

FIGURE 3 — Uranium distribution in lake and pond sediments in the vicinity of the uranium showing.

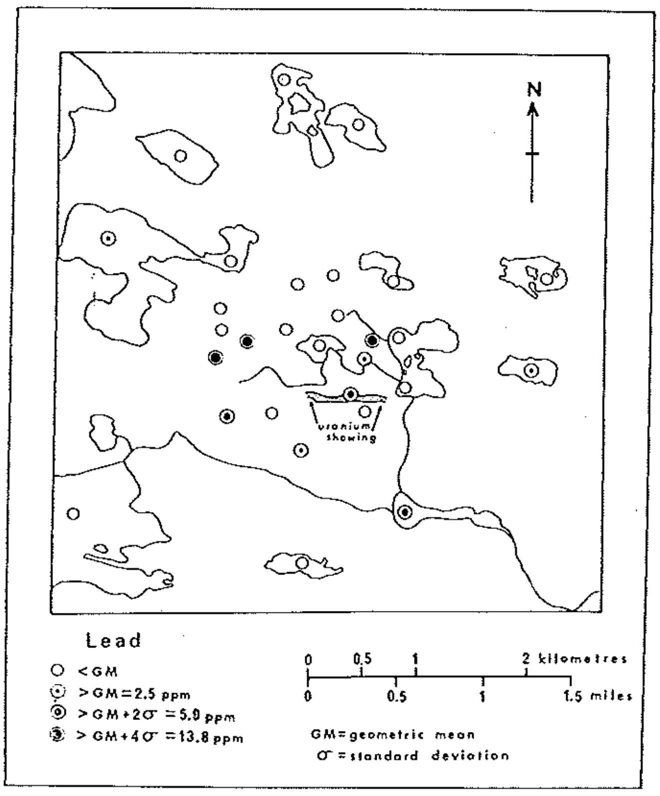

FIGURE 4 — Lead distribution in lake and pond sediments in the vicinity of the uranium showing.

Results and Discussion

The results of multielement spectrographic analysis of selected rock samples from the radioactive showings show that, apart from U and Th, only Pb and Mo are sufficiently enriched to serve as potential pathfinders for this type of mineralization. The concentration ranges for lead and molybdenum measured in four fresh samples are 150 to 662 ppm and 126 to 142 ppm respectively. In addition, some of these samples were found to be abnormally high in yttrium (max. 73 ppm), vanadium (max. 70 ppm) and barium (max. 2620 ppm) compared to normal concentrations for these elements in acidic intrusive rocks.

Figures 3 and 4 show the distributions of uranium and lead in lake and pond sediments in the vicinity of the showing 28 miles northeast of Cape Dorset. Both patterns reflect the presence of nearby radioactive rocks, but the low mobility of lead translates into a significantly smaller anomaly compared to that for uranium. Most surprisingly, however, the high Mo concentrations in the uraniferous rocks did not generate molybdenum anomalies in the surrounding lake and pond sediments. In fact, all Mo levels measured in the vicinity of the showing were below the regional mean plus one standard deviation. Yttrium, vanadium and barium, although slightly enriched in a few lake sediments, did not produce any significant pattern and their value as pathfinders here is probably negligible.

SEDIMENT VERSUS WATER SAMPLING

The preceding discussion suggests that uranium is the most appropriate metal to seek in lake samples in geochemical prospecting for the Baffin Island type of radioactive deposits. This is confirmed by both the semi-detailed and reconnaissance surveys. At a sample density of 1 in 1.2 sq. miles, lake sediments show a 45-sq.-mile uranium anomaly around one showing (Fig. 5). As the enriched lakes are located in several drainage basins, the size of this anomaly probably reflects the importance of this uraniferous area, which should be the object of further intensive prospecting.

At a sample density of 1 in 5 sq. miles, interesting uranium anomalies were outlined throughout the 1500-sq.-mile area surveyed. However, it was found that, although most of the anomalous areas were revealed on both uranium-in-lake-water and uranium-in-lake-sediment distribution maps, some of the anomalous patterns were considerably more revealing in the waters than in the sediments and vice versa. There were also a few cases where anomalies were outlined in one medium and not at all in the other.

An attempt is made here to establish a criterion that may assist the explorationist in deciding whether

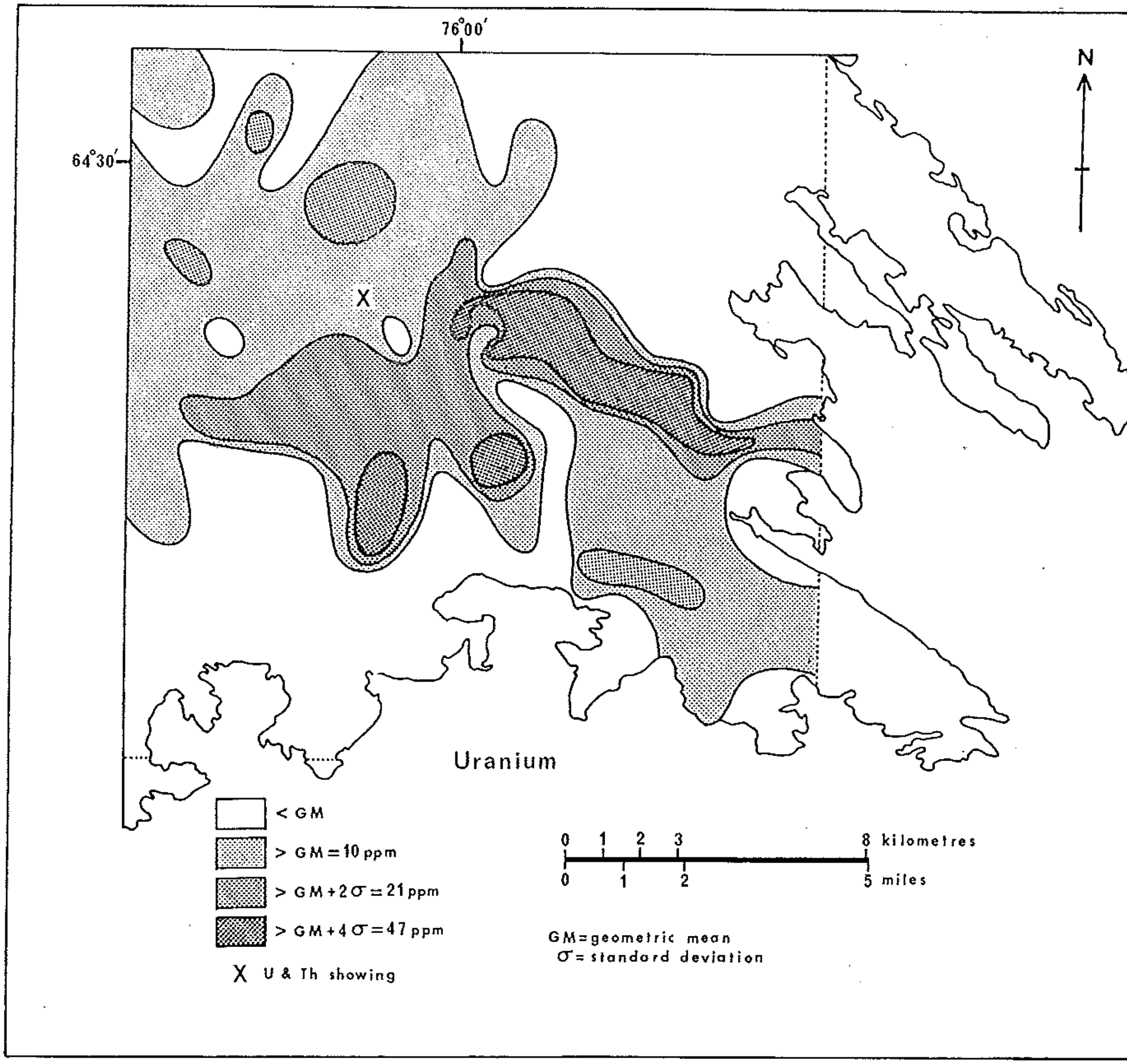

FIGURE 5 — Uranium distribution in lake sediments in the 125-sq.-mile area around the U and Th showing. Sample density is 1 in 1.2 sq. miles.

to sample lake waters or lake sediments for uranium analysis in a given area. This question is one of economic importance, not only because it may affect the success of a survey in terms of outlining geochemical anomalies and, ultimately, mineral discoveries, but also because it can substantially affect the over-all cost of an operation. There are some clear-cut advantages and disadvantages to both techniques and many of these have been discussed by Cameron and Ballantyne (1975). For example, by using the automated lake water sampling apparatus, lake waters can be sampled 200% faster than lake sediments, reducing costs accordingly. On the other hand, sediment samples permit the determination of a wider range of elements and therefore constitute a better multipurpose exploration tool than waters. However, on the basis of their respective ability to indicate uraniferous areas, the choice between sediments and waters is less obvious.

Figure 6 shows the relation between uranium concentrations in waters and sediments in anomalous lakes randomly selected throughout the survey area. The different fields are limited by the thresholds (0.52 ppb U for waters and 22 ppm U for sediments), defined, in each case, as the geometric means plus two standard deviations. The figure indicates that, although many lakes have anomalous waters as well as anomalous sediments (field B), an important proportion of the lakes are either anomalous in their waters (field A) or their sediments (field C). In this context, we examined the role of the bicarbonate ion content of lake water, a factor long recognized as influencing uranium solubility (Bowie *et al.*, 1971). The "relative anomaly contrast" for each lake is plotted in Figure 7 against its water alkalinity (dissolved bicarbonate ions). The "relative anomaly contrasts" were obtained by performing the following calculations:

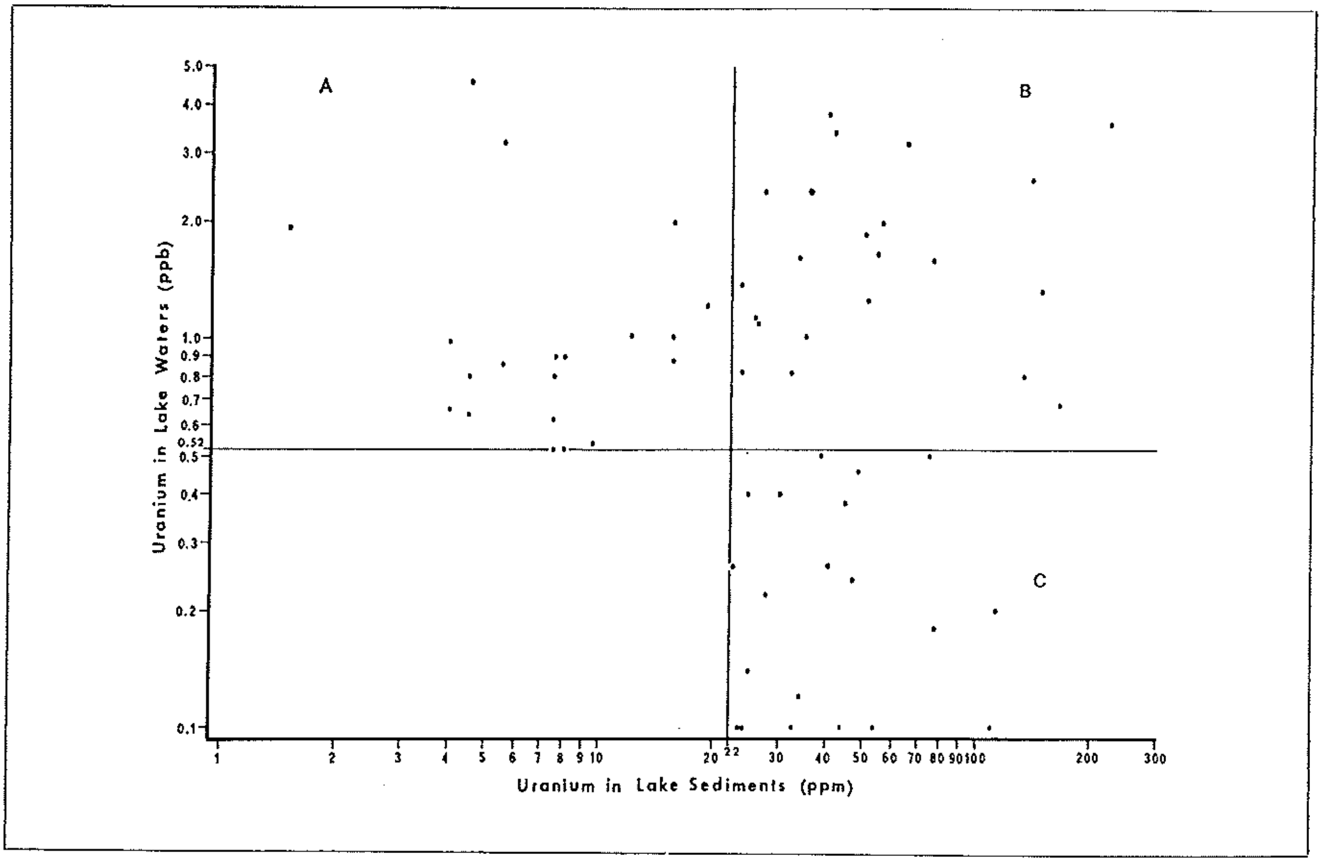

FIGURE 6 — Uranium in lake sediments vs uranium in lake water in anomalous lakes of southern Foxe Peninsula.

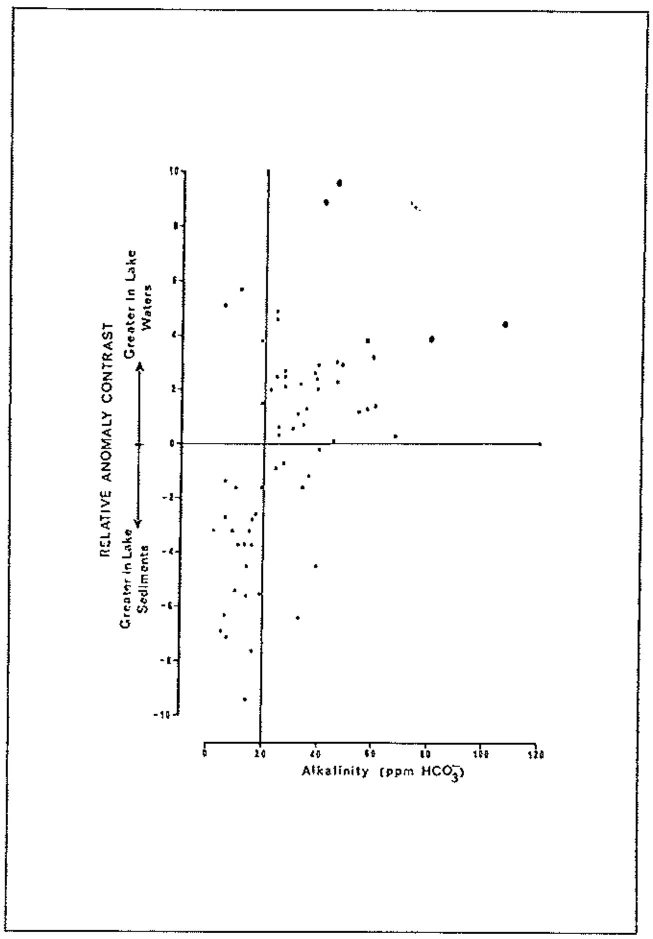

FIGURE 7 — Relative anomaly contrast vs alkalinity in anomalous lakes of southern Foxe Peninsula.

from $\text{Log GM}_w + X\sigma_w = \text{LogU}_w$
and $\text{Log GM}_s + Y\sigma_s = \text{LogU}_s$

$$X = \frac{\text{LogU}_w - \text{Log GM}_w}{\sigma_w}$$

$$Y = \frac{\text{LogU}_s - \text{Log GM}_s}{\sigma_s}$$

$$X - Y = C$$

where GM = geometric mean for waters (w) and sediments (s);
σ = standard deviation in log units for waters and sediments;
U = uranium concentration in water in ppb, and in sediment in ppm;
C = relative anomaly contrast.

A positive relative anomaly contrast indicates, therefore, a water anomaly that is more intense than the corresponding sediment anomaly; a negative relative anomaly contrast indicates the reverse. The distribution of the dots in Figure 7 shows clearly that, at low alkalinities, the lake sediments are in most cases more useful than the lake waters in indicating uranium dispersion in the area — and vice versa.

Although the 20-ppm HCO_3^- line (Fig. 7) seems to separate the two fields in the present study, we cannot assume this value to be valid for other parts of the country. This is because the importance of HCO_3^- as a mobilizing agent for uranium is likely to be affected by other factors (organic matter, temperature, etc.), some of which will vary from one area to another. It is therefore recommended that, prior to the undertaking of any major geochemical operation for uranium exploration, the influence of bicarbonate in controlling the distribution of uranium between sediments and water be examined in pilot studies.

As the alkalinity of a lake has an influence on its pH, and because the pH, unlike alkalinity, may be easily measured on the spot, it is possible to keep a constant check on the validity of water or sediment sampling during the operation. Figure 8 is a plot showing the relative anomaly contrasts versus pH; it indicates that at low pH values (< 7.42 in the present case), sediments should be sampled in preferance to waters and vice versa.

In southwest Baffin Island, the lake-water alkalinities show substantial variation in a relatively small area, resulting in a poor correlation (r = .23) between uranium in lake waters and uranium in lake sediments. This high degree of variation reflects the erratic distribution of carbonate rocks in the area. Similar correlation studies made elsewhere in the country have been reported by Cameron and Hornbrook (1976); they report values or r = .71 in Manitoba and r = .80 in the Rabbit Lake region, probably reflecting more homogeneous carbonate geology in these areas. In another study in the Renfrew region of Ontario, however, a low value of r = .23 was found.

The practical implications of this are that if the correlation between uranium in waters and uranium in sediments is high in a certain area, the alkalinities are probably sufficiently consistent that one type of survey only (waters or sediments depending on whether the alkalinities are high or low) may be sufficient for that region. If, on the other hand, "r" is low (< .3 for example), it may be preferable to sample both waters and sediments on a routine basis.

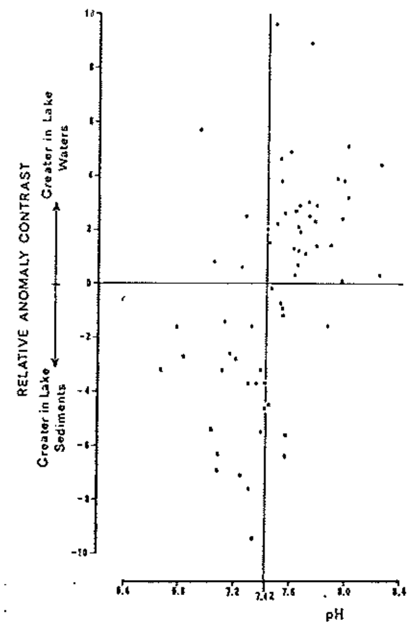

FIGURE 8 — Relative anomaly contrast vs pH in anomalous lakes of southern Foxe Peninsula.

THE BASE METAL POTENTIAL OF SOUTHERN BAFFIN ISLAND

Despite the fact that, to the writer's knowledge, no base metal occurrences of any significance have ever been reported in southern Baffin Island, future geochemical operations in that area should not fail to examine its base metal potential. These recommendations derive from favourable indications obtained in the present survey.

Base metal geochemical anomalies, some of which are very intense, were found in association with a gossanous Lower Proterozoic formation that occurs throughout southern Baffin Island and which Blackadar (1967) called "rusty paragneiss". This author describes this unit as a medium-grained, shistose, rusty rock, generally associated with garnetiferous biotite-quartz-feldspar gneiss and crystalline limestone, and adds that the rusty alteration is due to oxidation of pyrite and, less commonly, other iron-rich minerals.

One of the most interesting of these anomalies occurs near the southeastern extremity of the study area. Here, the lake sediments are significantly enriched in Cu, Zn, Ni and Mo in a strike-oriented elongated pattern for a distance of over 10 miles. The enriched zone coincides almost exactly with a band of rusty paragneiss mapped by Blackadar *(op. cit.)*. Figure 9 illustrates the copper-in-lake-sediments distribution for the anomaly. Zn, Ni and Mo follow almost identical patterns, and Table 1 shows anomaly contrasts for these elements in the lake sediments and for Cu and Zn in the lake waters by comparing peak values with regional background and threshold levels. It is interesting to note that Cu and Zn anomalies in the waters show greater anomaly contrast than Cu and Zn anomalies in the sediments.

TABLE 1 — Geochemical Characteristics of Base Metal Anomaly Illustrated in Figure 9

	Element	GM	GM + 2σ	Peak Value	Anom. Contrast*
(a) Sediments .		(ppm)	(ppm)	(ppm)	
	Cu	16.6	30.9	329	9.58
	Zn	48.0	78.0	495	9.54
	Ni	17.7	36.2	440	8.96
	Mo	3.5	6.8	83	5.80
(b) Waters......		(ppb)	(ppb)	(ppb)	
	Cu	0.54	1.00	34.0	13.62
	Zn	0.70	1.50	83.3	12.90

GM = geometric mean
σ = standard deviation.

$$\text{*Anom. Contrast} = \frac{\text{peak value} - \text{GM}}{\sigma}$$

WATER ACIDIFICATION

Water acidification consists of adding sufficient acid (in the order of 1 ml concentrated acid to 1 liter of water) to lower the pH of water samples in order to prevent adsorption of dissolved metal ions on the walls of the container and/or on suspended solid matter. This procedure is generally carried out soon after sampling, but whether or not it should be performed at all is a question that is still open to debate among geochemists.

In the present study, acidified water samples that have above-threshold metal concentrations were found to contain, on the average, 29.7% more uranium, 35.1% more copper and 107.6% more zinc than the corresponding non-acidified duplicates — and this after a three-month storage period. The differences here most likely reflect adsorbed metals on the walls of the plastic containers, because southern Baffin Island lakes are practically free of suspended matter and tests have shown that the plastic containers used in the present study are free of contaminating metals. Despite these figures and the limited data available, the writer concludes, after comparing acidified and non-acidified water samples over a wide range of metal concentrations, that acidification has negligible effect on geochemical patterns, although it definitely causes a sharp increase in the mean and threshold levels for the metals investigated. This point of view may not apply to other parts of the country, however, particularly those areas where lakes contain abundant suspended organic matter. Research is currently in progress at the Geological Survey of Canada to further evaluate the effects of water acidification on hydrogeochemistry (Cameron and Durham, 1975).

Conclusion

The orientation work reported in this paper provides valuable information that will assist in the planning and execution of future reconnaissance geochemical programs in southern Baffin Island and facilitate data interpretation. It has shown that helicopter-supported geochemical lake surveying in that area is feasible and relatively simple due to the abundance of small and generally shallow lakes that contain ample sediment and very clear waters (Maurice, 1975).

The conclusions with respect to other pertinent aspects investigated in the present study may be summarized as follows.

1. Although several elements, including U, Th, Mo and Pb, and to a lesser extent Y, V and Ba, were found to be enriched in uraniferous rocks, only uranium and lead produced significant patterns in lake and pond sediments in the vicinity of the showings

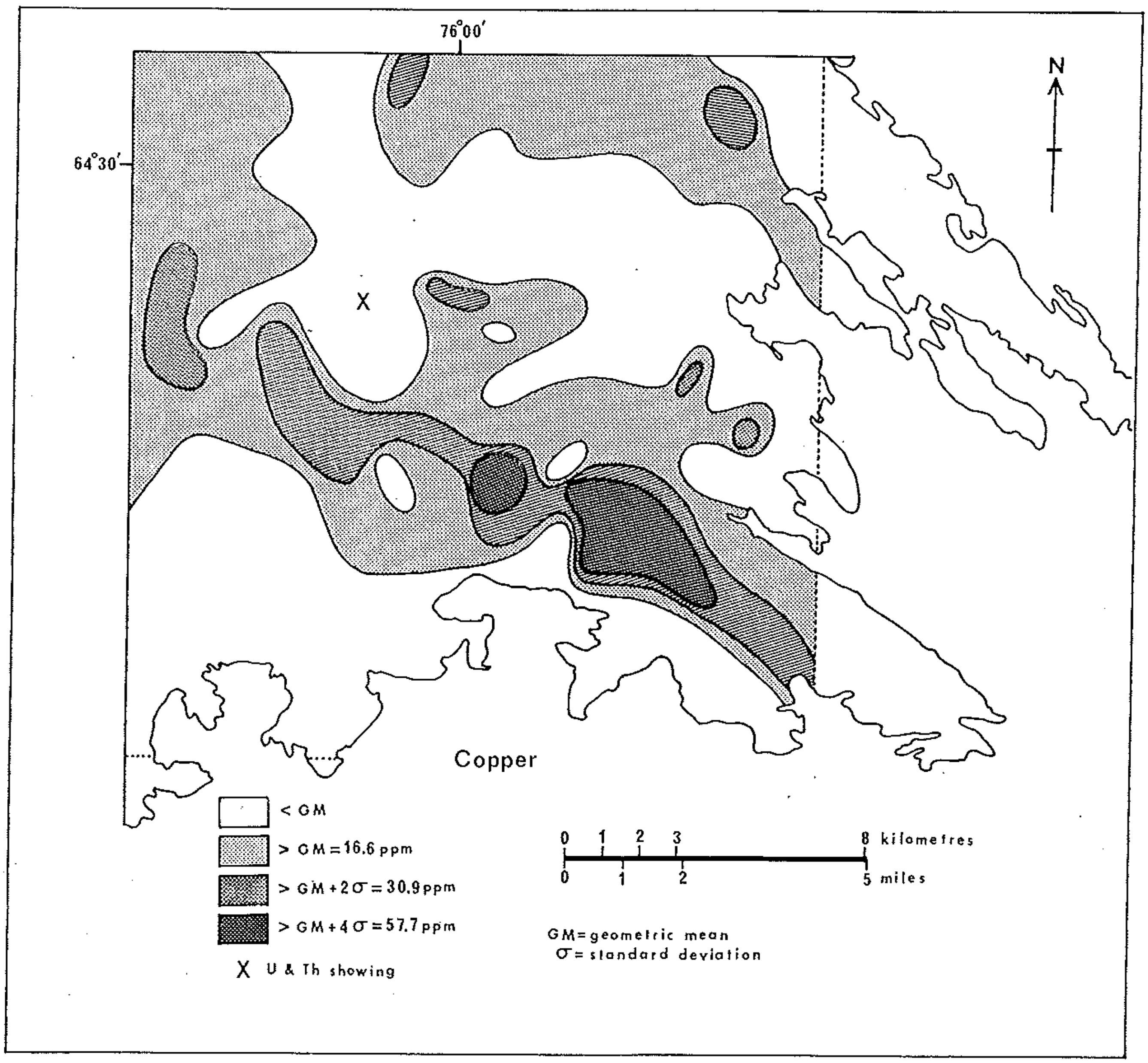

FIGURE 9 — Copper distribution in lake sediment in 125-sq.-mile area of southeast Foxe Peninsula. Sample density is 1 in 1.2 sq. miles.

and, therefore, only these elements may be considered useful pathfinders. The limited dispersion of Pb from the source, however, tends to restrict the use of this metal at other than a very detailed scale of surveying. Uranium, on the other hand, proved to be the most appropriate element to seek at both detailed and reconnaissance scales.

2. Lake-sediment surveying at a semi-detailed scale (1 sample in 1.2 sq. miles) produced a 45-sq.-mile uranium anomaly around the showing situated 28 miles northeast of Cape Dorset, suggesting a high uranium potential in this area. Further prospecting is recommended to confirm this assumption.

3. The bicarbonate content (alkalinity) of lake waters was found to have considerable influence on the distribution of uranium between waters and sediments in lakes. This parameter may be helpful in guiding the explorationist in deciding whether to sample waters or sediments in a given area. In southern Baffin Island, because lake alkalinities vary considerably from one area to another in response to the erratic distribution of carbonate bedrock, it is recommended that waters and sediments be collected on a routine basis in future reconnaissance geochemical programs.

4. Interesting base metal anomalies in lake waters and sediments, which appear to be related to a gossanous formation that occurs throughout southern Baffin Island, were outlined during the present survey. On the basis of these observations, it is recommended that the base metal potential of southern Baffin Island be carefully examined in future geochemical surveys, despite the fact that no base metal occurrences of any significance have ever been reported in that area.

5. Acidification of lake-water samples in southern Baffin Island appears to have limited effect on uranium and base metal (Cu and Zn) geochemical patterns, but causes a significant increase in the mean and threshold levels.

Acknowledgment

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