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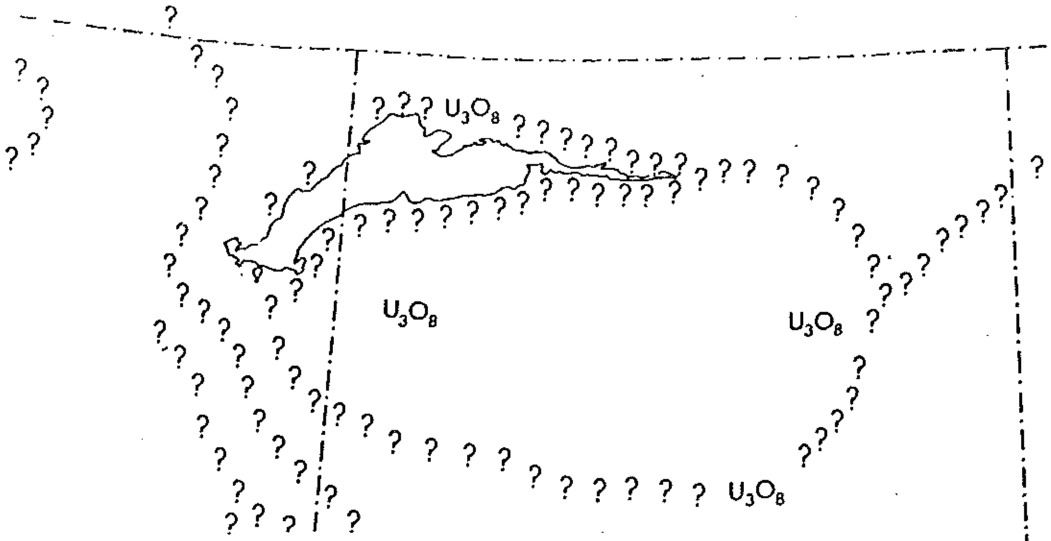

GEOCHEMICAL RECONNAISSANCE FOR URANIUM UTILIZING LAKES OF THE CANADIAN SHIELD

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GEOCHEMICAL RECONNAISSANCE FOR URANIUM UTILIZING LAKES OF THE CANADIAN SHIELD

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ABSTRACT

Lake sediments and/or lake water geochemical reconnaissance surveys have been carried out in the Canadian Shield by the Geological Survey of Canada, Provincial governments, the mineral exploration industry and various universities and research institutions over the last several years.

At the Geological Survey of Canada, in support of the Federal-Provincial Uranium Reconnaissance Program, utilization of Shield lakes has evolved to the point where centre-lake bottom sediment and/or surface lake water are routinely collected over thousands of square miles of Canadian Shield.

Sufficient orientation, reconnaissance and follow-up surveys have been, or are about to be, completed to permit an examination of the effectiveness of lakes as a source of sample media for uranium reconnaissance.

In this paper, the objectives, methodology and effectiveness of lake sediment and water surveys are briefly described and relevant studies are discussed.

These data show that uranium contents of centre-lake bottom sediment and surface lake water provide meaningful information on the concentration and distribution of uranium in the Canadian Shield for exploration or resource appraisal.

INTRODUCTION

Lake sediment and/or lake water geochemical reconnaissance surveys have been carried out in the Canadian Shield by the Geological Survey of Canada, Provincial governments, the mineral exploration industry and various universities and research institutes over the last several years.

Wide-interval reconnaissance surveys for uranium, a mobile element in Canadian Shield terrain, provide information on the distribution of uranium in the crust. The targets, regions of the crust containing higher than average contents of uranium, are of sufficient size to be adequately delineated at a sample density of 1 sample per 13 km^2 (5 mi^2). Such regions may constitute sources from which uranium has been derived and subsequently concentrated in younger adjacent rocks, or which contain within their boundaries areas with sufficient concentrations of uranium to be economically interesting. Lake sediment and/or water surveys have identified many such regions in the Canadian Shield.

Some of these surveys and other relevant studies are described to demonstrate that utilization of Canadian Shield lakes as sample sources provides meaningful regional information on the distribution and concentration of uranium.

URANIUM RECONNAISSANCE PROGRAM

Many of the Canadian Shield lake surveys in recent years have been carried out under the auspices of the Federal-Provincial Uranium Reconnaissance Program (U.R.P.). The urgent necessity for information on, and exploration for, uranium has been discussed by Williams (1975). Basically, to fulfil forecast requirements for new uranium deposits, the Federal government, together with Provincial governments, is conducting a multi-million dollar 10 year program directed at further delineation of Canada's uranium resources. The objectives of the program are to provide the mineral industry with high quality reconnaissance data; to indicate those areas of Canada where there is the greatest possibility of finding new uranium deposits; and to provide governments with nationally consistent systematic data to serve, with other relevant geoscience data, as a base for uranium resource appraisal.

METHODOLOGY

National Geochemical Reconnaissance (N.G.R.), which was commenced recently by the Geological Survey of Canada, provides a consistent set of sampling, analysis, data processing and publication methodologies for a variety of Federal and Federal-Provincial programs. These are described by Hornbrook and Garrett (1976). N.G.R. methodology was applied to the Canadian Shield in 1974, 1975 and 1976 covering a total of 274,000 km^2 (105,800 mi^2). Earlier lake sediment reconnaissance surveys by the Geological Survey of Canada were based on near-shore lake sediment sample media (Allan et al., 1973) and centre-lake bottom sediment sample media (Davenport et al., 1974). The latter has been shown to be both logistically and technically more advantageous. The relevant work of others in lake sediment geochemistry is cited in Hornbrook and Garrett (1976) and covered more fully by Nichol et al. (1975). Currently, a great variety and amount of research is in progress contributing to the rapid growth of knowledge concerning the complex problems of lake geochemistry.

At the Geological Survey of Canada, U.R.P. work involves orientation studies, reconnaissance surveys (N.G.R. methodology) and follow-up studies. A complete description of the methodology used at the Geological Survey of Canada and by many exploration companies may be found in Hornbrook and Garrett (1976). Basically, centre-lake bottom organic-rich sediments, from the deepest part of suitable lakes, and surface lake waters are collected at an average density of 1 sample per 13 km^2 (5 mi^2). A two-man team, utilizing a turbine-type helicopter, maintain a collection rate of 15 sample sites per hour calculated on the basis of flying hours while traversing. Figure 1 illustrates the centre-

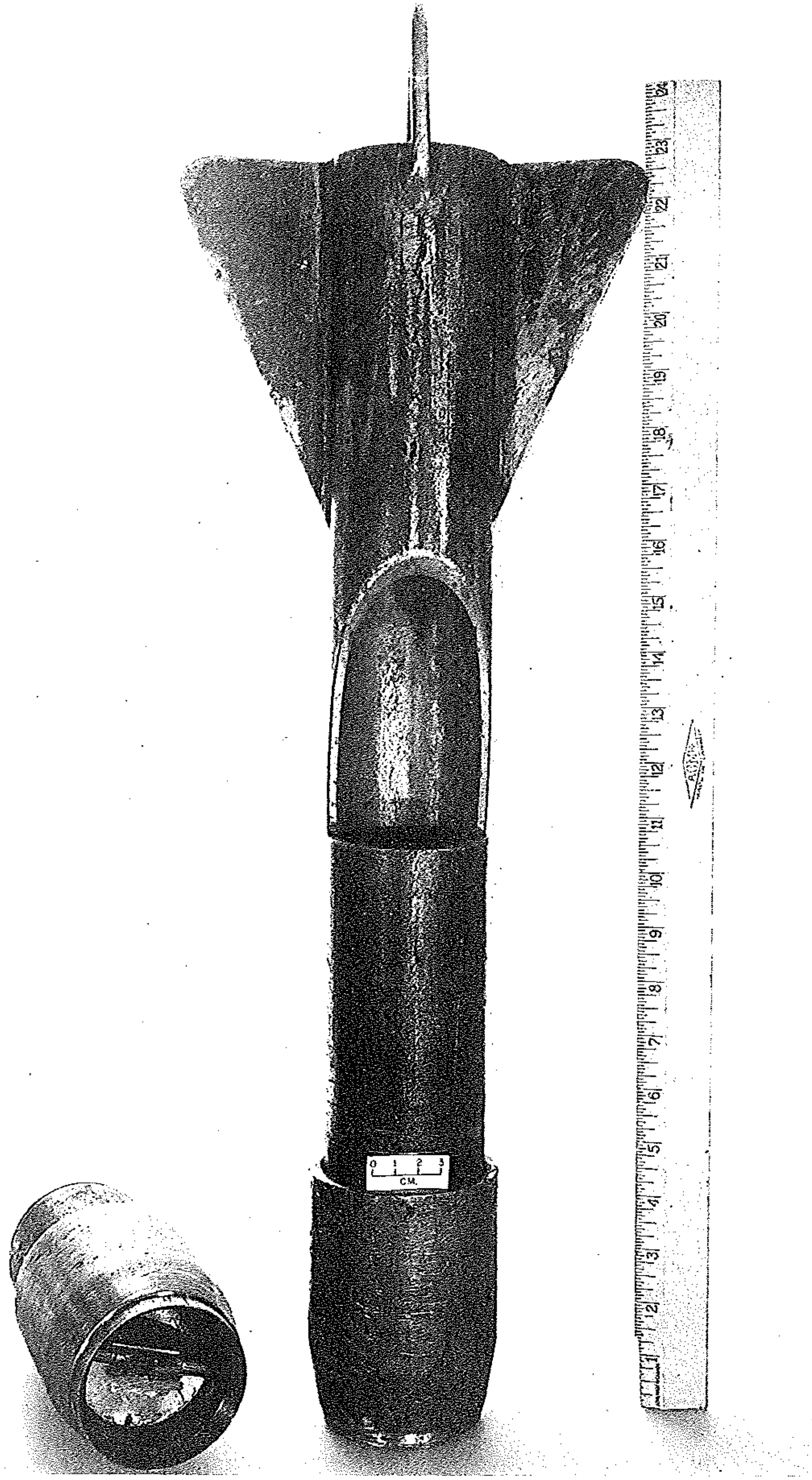

Figure 1. Centre-lake bottom sediment sampling apparatus, 1976 model.

lake bottom sediment sampling device developed at the GSC. Paper-bagged samples are field dried and shipped to a sample processing laboratory where the drying is completed prior to disaggregation, ball-milling and seiving to minus 80-mesh (177 μ) size. After insertion of quality control and replicate samples, the Zn, Cu, Pb, Ni, Co, Ag, Mn and Fe contents of the lake sediments are determined by atomic absorption spectroscopy with background correction made for Pb, Ni, Co, and Ag. Mo in sediments is determined by atomic absorption spectroscopy but with a different flame and sample digestion. Mercury in lake sediments is determined by the cold vapour absorption spectroscopy method. Arsenic is determined colorimetrically. The U content of the lake sediments is determined by the delayed neutron activation method of analysis. Organic content is estimated by determining the percent weight loss on ignition. U in waters is determined by fluorometry and/or the fission track method.

Field recorded data and analytical data are merged and the analytical data for each element is plotted at 1:250,000 scale using symbols to represent selected concentration ranges.

ORIENTATION STUDIES

Orientation studies may be carried out in an area prior to a reconnaissance survey or in a given area suitable for investigating problems related to interpretation of lake sediment and/or water data. As an example, throughout the early seventies Jonasson (1976) undertook detailed hydro-geochemical studies of two lakes in the Grenville Geological Province west of Ottawa, Ontario. As well as recognizing the complexities of the hydro-geochemistry of lakes, and avenues for further research work, the relevant conclusions developed were: 1) It is advisable to avoid collecting samples from shallower zones of the lake bottom which represent a chemically less-stable environment; 2) The homogeneity of deep water organic sediments is the best feature of this type of sample in terms of matrix constituents and trace metal levels; 3) It would appear that once a certain level of organic content is exceeded (i.e. 10 per cent carbon) further increase has relatively little impact on trace metal variations; 4) The fine sediments in deep water are more likely to be independent of local shoreline influences both organic and mineral, but at the same time continue to reflect major chemical, geological and mineralogical features where these occur. Thus, the usefulness of centre-lake bottom sediments as sample media for geochemical surveys was confirmed.

In 1975, Coker and Jonasson (1976) carried out an orientation survey over an 1150 km^2 (450 mi^2) area in the Grenville Geological Province west of Ottawa, Ontario. This survey provided the basis for the 22,300 km^2 (8600 mi^2) wide-interval, centre-lake bottom sediment and surface water survey completed in 1976. For this detailed orientation survey, the average sample density was one sample per 4.6 km^2 (1.8 mi^2). The survey outlined targets of limited size and favourable geology and perhaps certain structures with possible mineral potential.

They concluded that the broad extent of the anomalies outlined indicated that reconnaissance-scale geochemical sampling at one sample per 13 km^2 (5 mi^2) using lakes, ponds and true swamps would be successful in locating these targets.

REGIONAL SURVEYS

Figure 2 illustrates uranium data from a centre-lake bottom sediment survey carried out in Saskatchewan in 1974. This is a simplified version

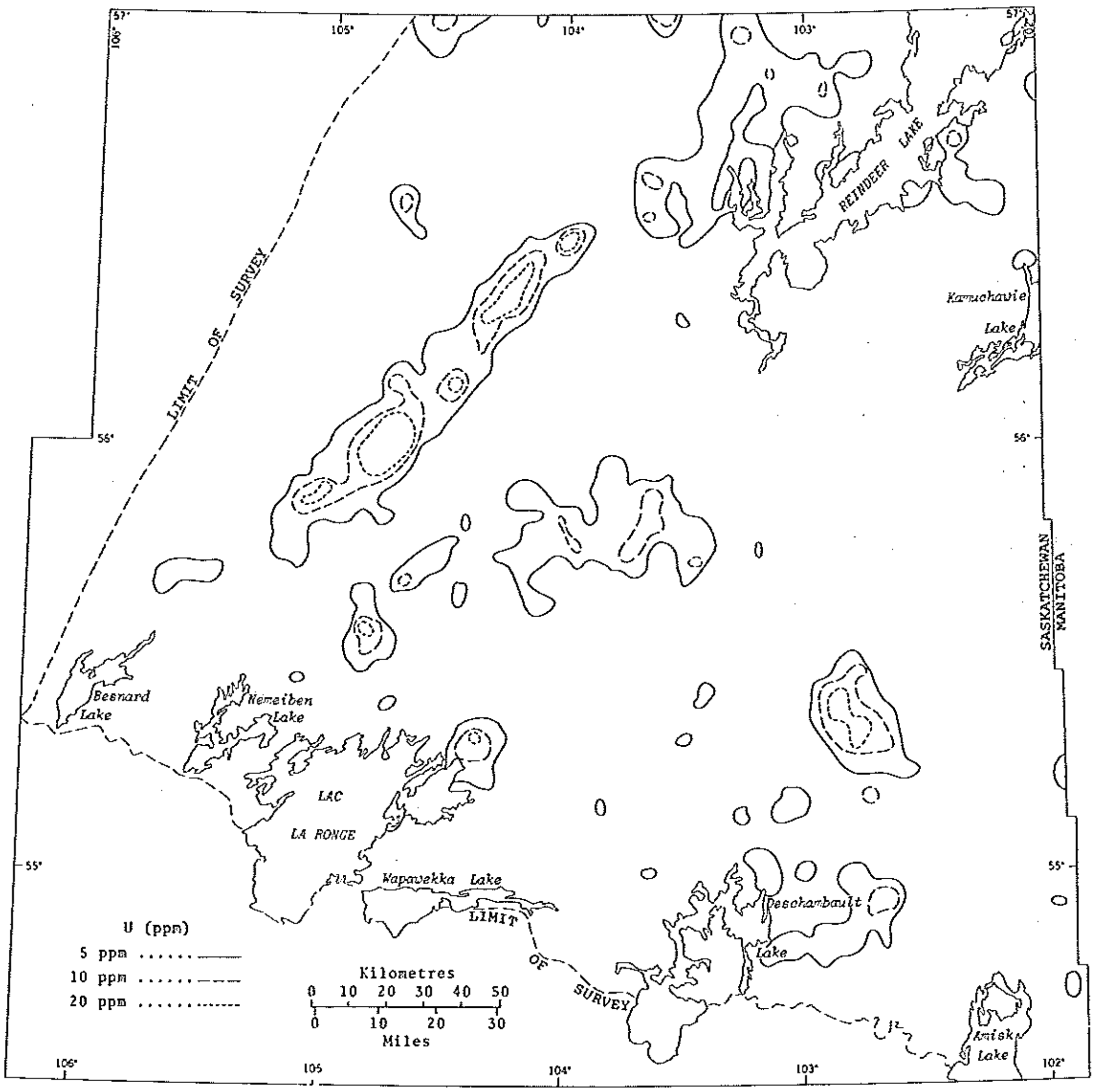

Figure 2. Regional distribution of uranium in centre-lake sediments, east-central Saskatchewan (after Cameron and Hornbrook, 1976).

for clarity and the complete data set may be obtained on white copy maps (Hornbrook et al., 1975) or on microfiche (Hornbrook and Garrett, 1976). Regional uranium anomalies, defined by the 10 ppm contour (uranium determined by fluorometry), as large as 1300 km^2 (500 mi^2) in size, delineate regions of the Shield as potential uranium sources and/or target areas for further follow-up uranium exploration.

Similar target regions of the Shield in Figure 3 were defined by the 20 ppm uranium contour in northwestern Manitoba. This is also a simplified version of the uranium distribution: the complete data set may be obtained on white copy maps (Hornbrook et al., 1976a). The major northeasterly uranium trend in the northwest corner of the survey area overlies Hurwitz Group sediments and the northeastern extension of the Wollaston Fold Belt into Manitoba from Saskatchewan. Since release of these data the region has undergone active exploration and follow-up studies.

Again (Figure 4), large regions of the Nonacho belt, N.W.T., were defined by the 20 ppm uranium contour as east-west trends. Some of the most interesting anomalies are related to known and previously unknown uranium occurrences but the majority of the regional anomalies are apparently related to acid igneous rocks that have slightly above normal uranium content (Maurice, pers. comm.)[1]. These data are available on white copy maps (Hornbrook et al., 1976b).

Therefore, the utilization of centre-lake bottom sediments as sample media for wide interval geochemical reconnaissance is a viable and effective means of identifying large regions of the Canadian Shield for

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[1] Y.T. Maurice, Geochemistry Section, Geological Survey of Canada

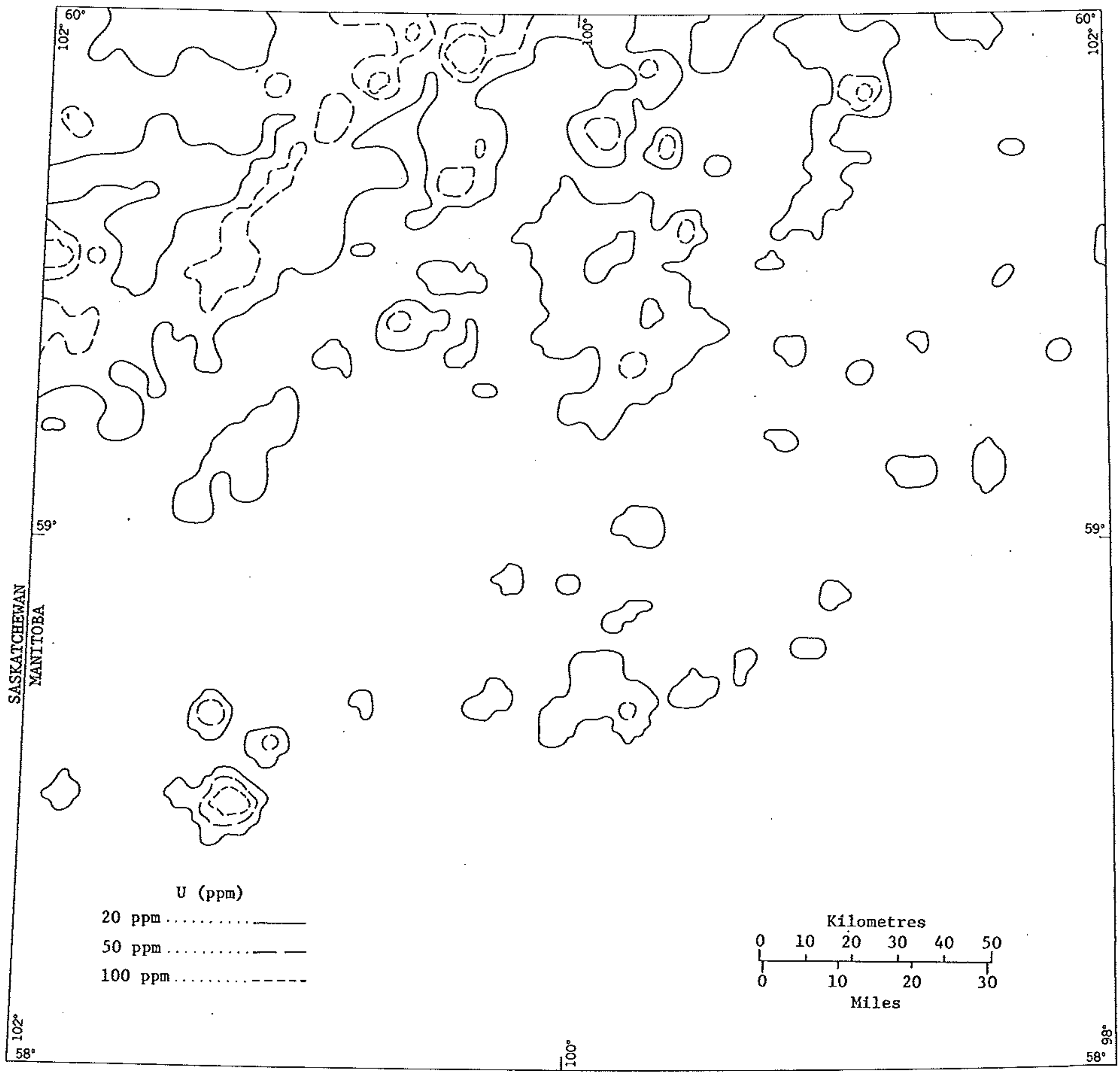

Figure 3. Regional distribution of uranium in centre-lake sediments, northwestern Manitoba.

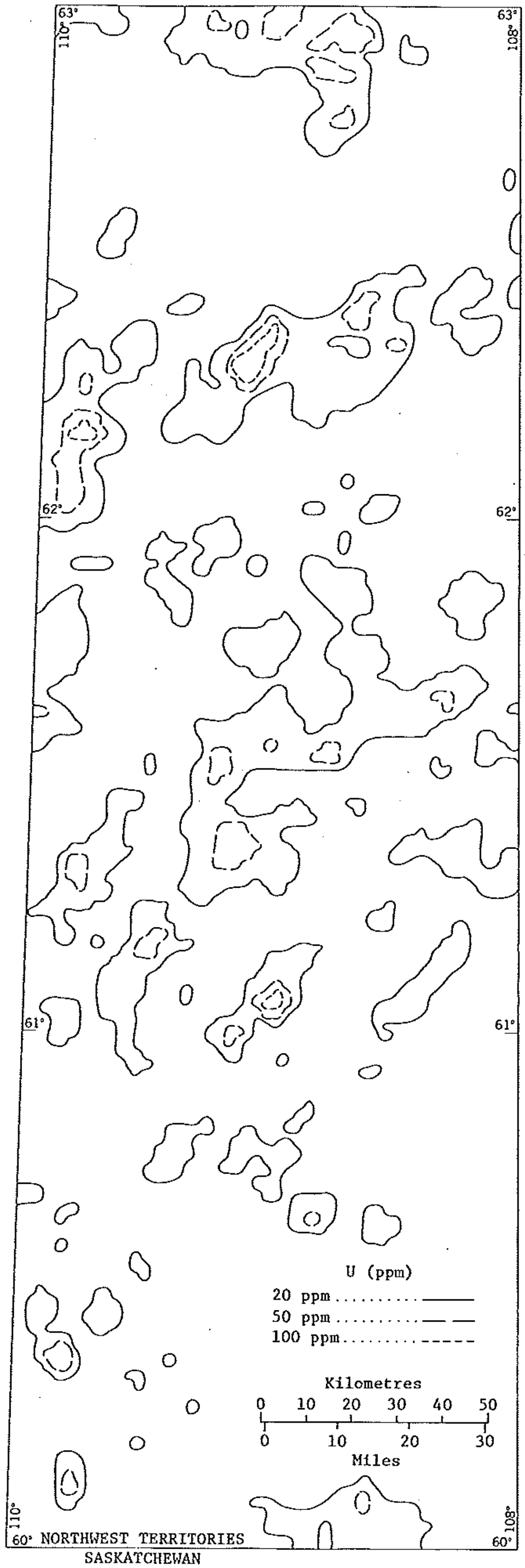

Figure 4. Regional distribution of uranium in centre-lake sediments, Nonacho Belt, Northwest Territories.

follow-up uranium exploration.

FOLLOW-UP STUDIES

Follow-up studies of uranium and other element distribution patterns developed by wide-interval reconnaissance surveys have taken place. They include the work of Haughton and Lehto (1975) on the 1974 Saskatchewan survey, where successful anomaly confirmation studies were reported. Further work of this nature is discussed by Lehto et al. elsewhere in this publication. Feedback on the follow-up work by the mineral exploration industry shows an encouraging success rate but seems to be related to the degree of basic comprehension of the published data and geochemistry. For example: the exploration industry has, to some extent, taken up claim blocks in surveyed areas covering bulls-eye anomalies in the belief that strong uranium anomalies must always be related to uranium mineralization. Coker (pers. comm.)[1] has confirmed during the 1976 follow-up studies in Manitoba that uranium anomalies of several hundred ppm magnitude may be associated with, and derived from, granitoid bodies (i.e. Hudsonian quartz monzonite) rather than a point source of uranium mineralization. Further to this, Coker felt that the element associations are more significant than concentration alone and should be used for the preliminary assessment of the economic possibilities of uranium anomalies. Thus, the search should be for those anomalies that have the appropriate association of mineralogically related elements - Cu, Mo, Ag, Co, Ni, etc. Such anomalies may not be the strongest uranium anomalies developed during the survey and, in fact,

[1] W.B. Coker, Geochemistry Section, Geological Survey of Canada.

they may not be significantly anomalous at all.

The complete results of the 1976 follow-up studies of the 1975 N.G.R. surveys in Manitoba and in the Nonacho Belt, N.W.T. have not yet been published. However, Coker (1976) in Manitoba, and Maurice (1976) in the Nonacho Belt have described their general approach to follow-up studies carried out to explain and identify the source of uranium or other element anomalies and to test certain procedures and techinques.

RELEVANT STUDIES

Abundance and Threshold Levels

Figure 5 shows the abundance of uranium in centre-lake bottom sediments in the 1974 and 1975 reconnaisaance survey areas and the 1975 orientation survey area. Uranium determinations were by neutron activation analysis and each data set is composed of several hundred determinations. The plot of the geometric mean and arbitrary threshold level of the geometric mean plus two $\log_{10}$ standard deviations shows a wide variation among map sheets and within regions. Obviously there is no simple anomaly classification or threshold concentration value that will universally apply throughout the Canadian Shield. In each survey, depending upon rock type, relief, glacial history, bedrock exposure, vegetation etc., a number of appropriate threshold values for anomaly assessment have to be determined. For example: the uranium geometric mean and two standard deviation level over the flat-lying, overburden covered, Proterozoic sandstones of the Takaatcho River sheet (96L) are respectively 5.8 and 21 ppm U, whereas over the immediately adjacent rocks of the Cameron Bay and the Echo Bay Groups in sheet 86K, the equivalent uranium levels are more than two times greater. Thus, it is

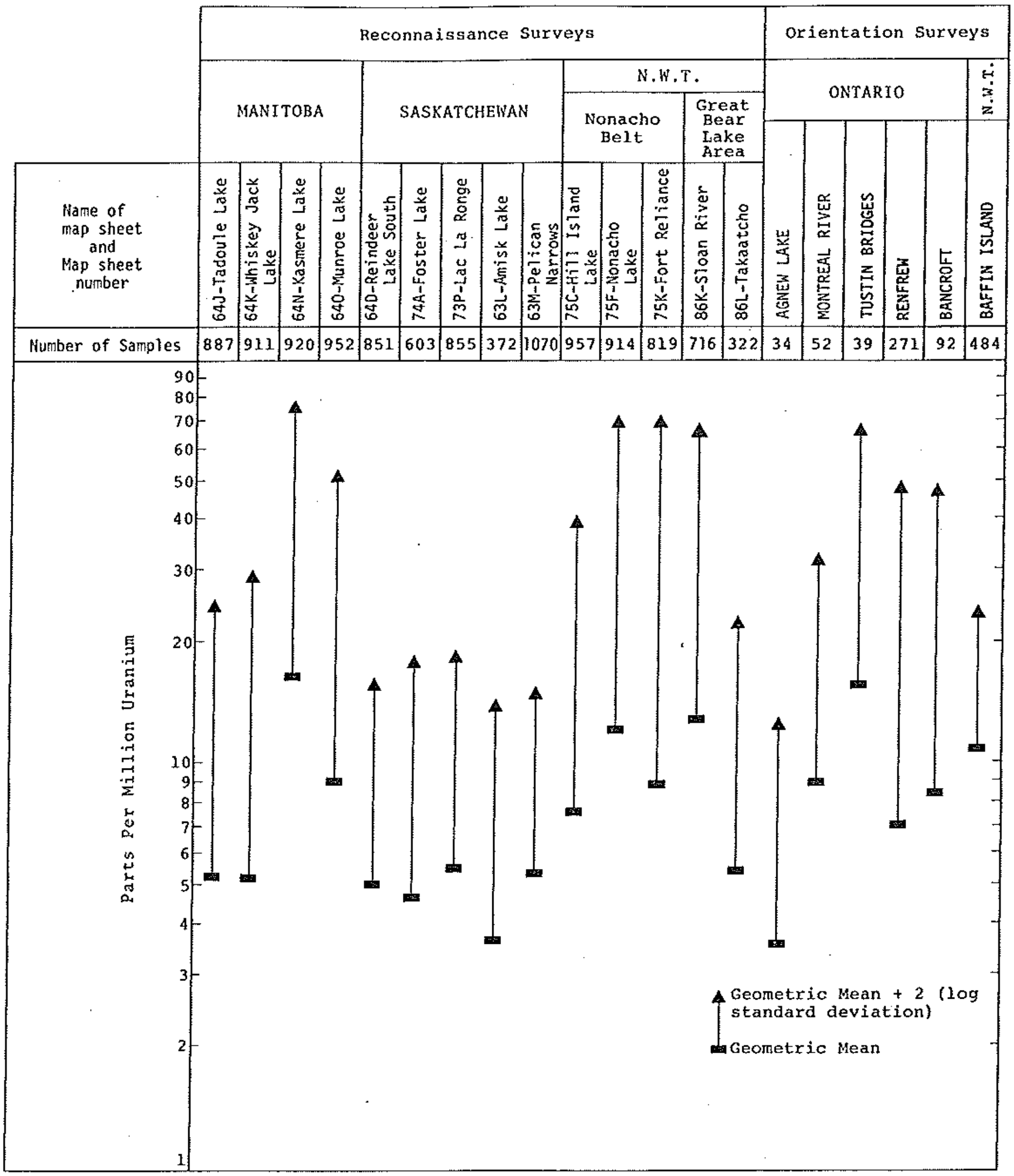

Figure 5. Abundance and threshold levels for uranium in centre-lake sediments collected during 1974 and 1975 seasons. (After Cameron and Hornbrook, 1976).

essential to assess uranium concentrations in terms of bedrock type, exposure etc. Otherwise, threshold levels of 20 ppm uranium may be overlooked relative to much higher values over uranium-rich igneous rocks. A more subtle aspect in selection of uranium concentration worthy of investigation, derived from follow-up studies, involves choosing those values that are accompanied by appropriate concentrations of mineralogically related elements such as Mo, Cu, Ag, As, or Ni, (Coker, pers. comm)[1]. Such uranium concentrations are not necessarily the highest values of uranium present.

Great Bear Lake Resampling

A 3520 km^2 (1360 mi^2) portion of the Sloan River Sheet (86K) containing 272 reconnaissance survey grid cells each 13 km^2 (5 mi^2) in area was resampled immediately after the routine centre-lake bottom sediment survey was completed. The complete survey of 86K, 86L and 96I, Great Bear Lake area, has been published (Hornbrook et al., 1976c).

Two hundred and fifty-three grid cells were sampled twice, 9 cells were sampled only during the resampling and no sample could be collected from 10 cells. At almost 90 percent of the 253 cells the resample site was located in a different lake in the cell square; in 27 cells it was in the same lake; and it was at the same site in only 1 cell.

The uranium data for these two surveys are shown as moving weighted average contour maps in Figures 6 (routine survey) and 7 (resample survey). A combination of survey data from 515 sites giving an apparent sample density of one sample per 6.5 km^2 (2.5 mi^2) is shown by a similar contour map in Figure 8. The original routine survey and the resample

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[1] W.B. Coker, Geochemistry Section, Geological Survey of Canada.

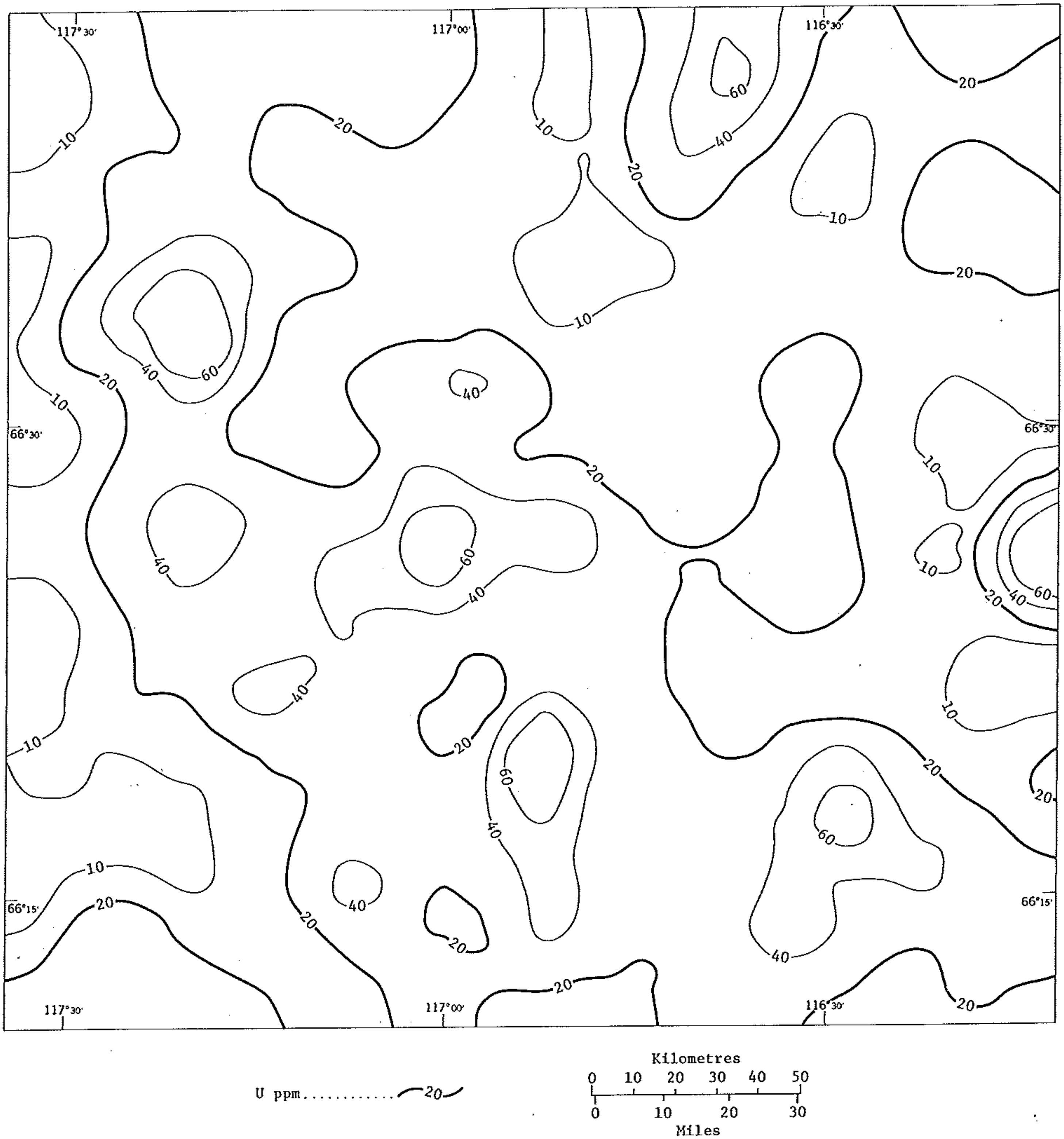

Figure 6. Great Bear Lake study area: Routine reconnaissance uranium data.

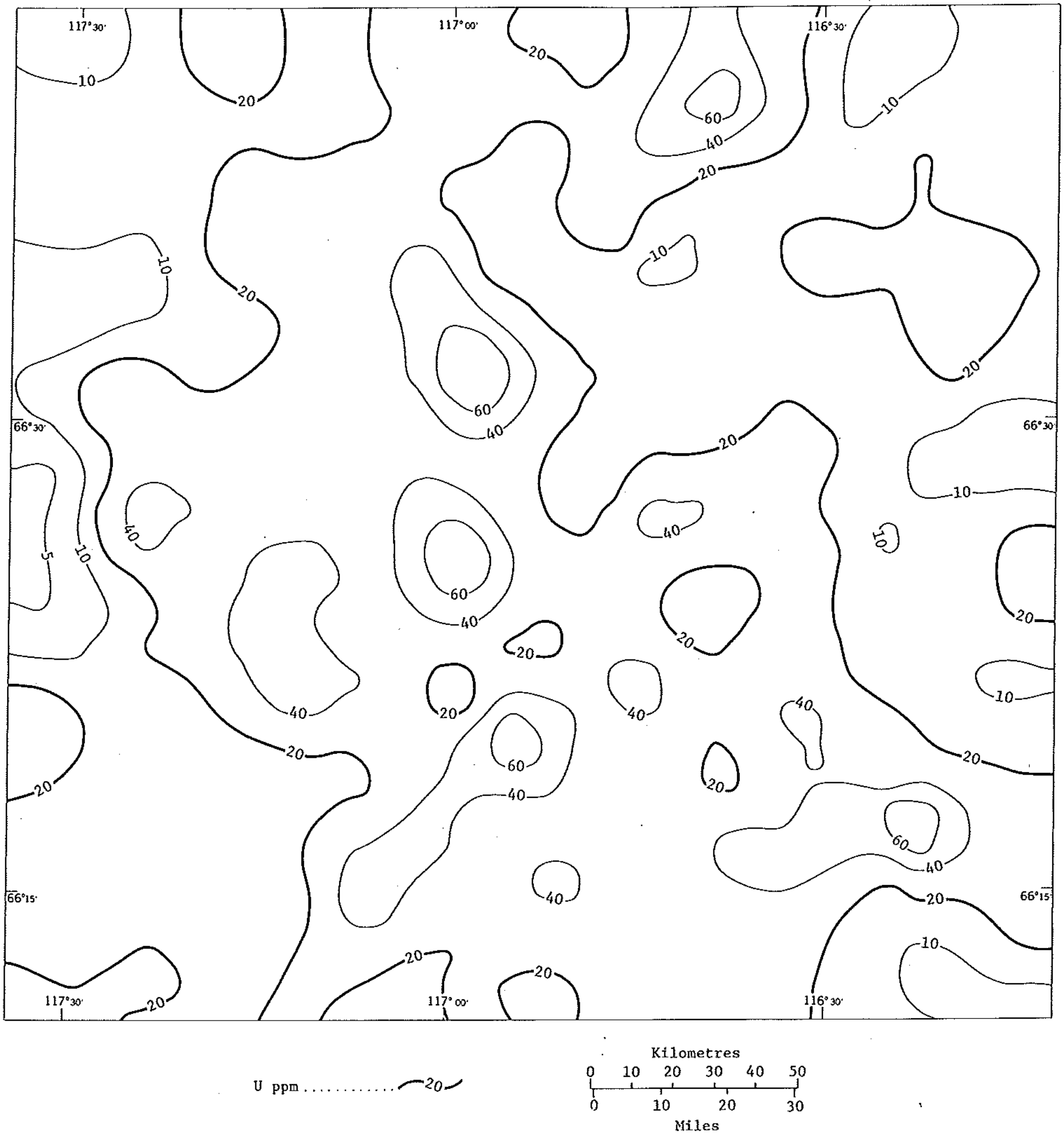

Figure 7. Great Bear Lake study area: Resampling uranium data.

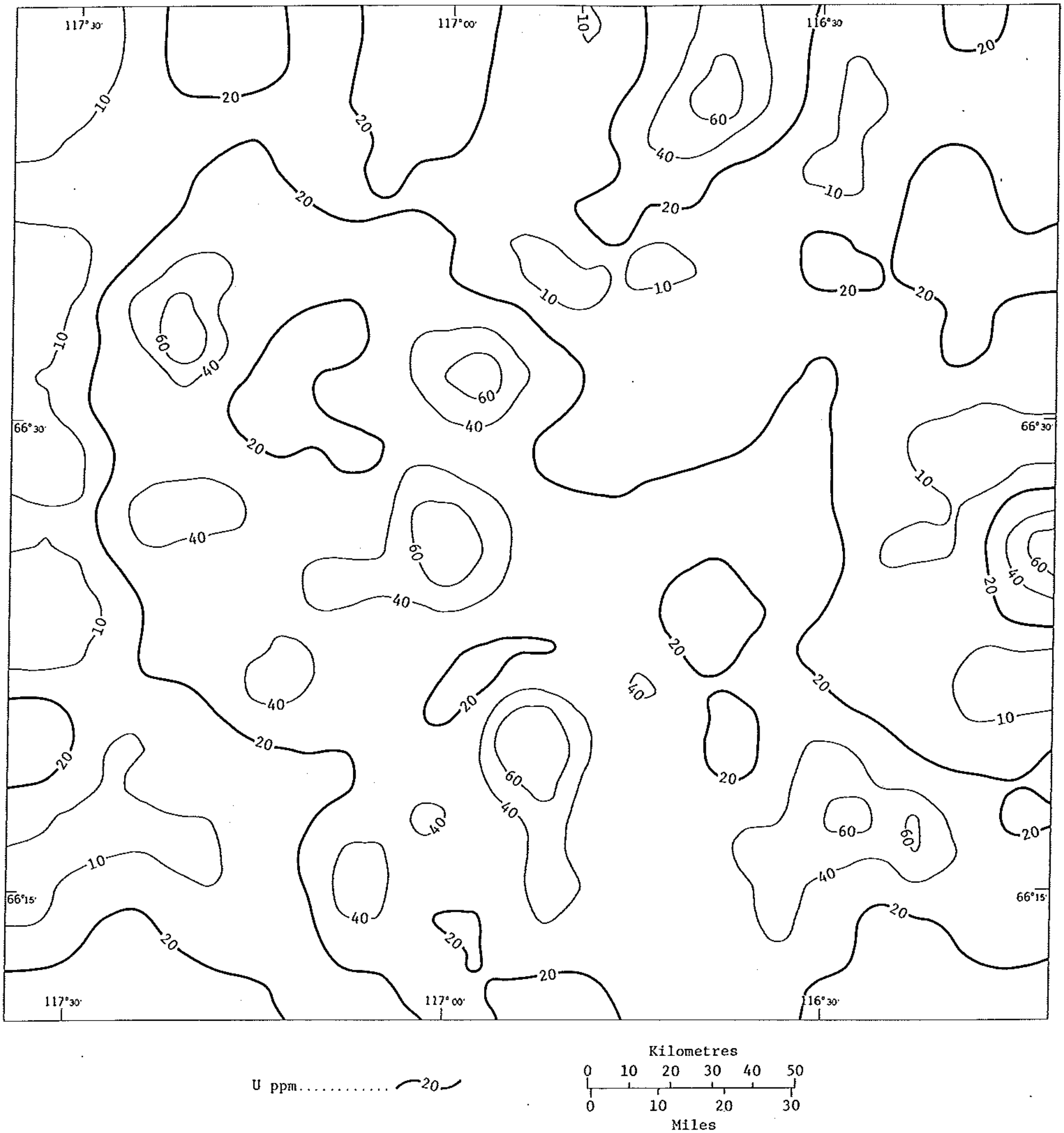

Figure 8. Great Bear Lake study area: Routine reconnaissance together with resampling uranium data.

survey produced nearly identical data sets for uranium as shown in Table 1.

	Routine Survey	Resample Survey
U ppm	percent distribution	percent distribution
2-5	5.53	5.93
5-10	17.79	15.81
10-20	34.39	33.20
20-50	32.81	36.36
50-100	7.91	7.11
100-200	1.58	1.58
No. of Samples	253	262
Geometric Mean	17.694 ppm	18.028
Log_{10} Std. Dev.	.342	.338

TABLE 1 - Routine Reconnaissance Survey and Resample Survey Statistics.

The broad regional uranium trend from southeast to northwest as defined by the 20 ppm contour has been similarly outlined by both surveys, which are essentially independent from each other (Figures 6 and 7). The appropriate location of the routine reconnaissance survey anomalies within the trend or adjacent to it are reproduced by the re-sampling survey, but they are not always perfectly coincident nor are they expected to be. Because the sampling crew endeavoured to re-sample in a different lake in each cell, where frequently more than one suitable lake (ideal under contract specifications) was not available, the resampling survey data, from such a marginally suitable lake, could be considered to be less than ideal for some cells. This situation resulted in the loss of the single anomaly at the central eastern margin and another in the northwest portion of the resampled area, but not the single anomaly in the north. An objective of wide-interval surveys is to develop broad regional trends, not bulls-eye anomalies, and in this case, an independent resample survey, less than ideal for some cells, has confirmed the regional trend or distribution of uranium. Because the original survey must be considered ideal, then the ultimate comparison is between the collective data from both surveys (Figure 8) and the original survey (Figure 6). Here a confirmation of the wide-interval sample density is provided by the fact the collective data from both surveys at apparently twice the sample density (Figure 8) does not develop different regional trends from that expressed in the routine wide-interval survey (Figure 6). Further confirmation of the validity of the routine survey is supported by the fact that it provides evidence of all anomalies, as well as the regional trends expressed in the collective survey (Figure 8) carried out at twice the sample density.

Despite the established validity of the regional trend pattern, a follow-up detailed survey over the trend may develop an entirely different orientation of local anomalous zones within the trend that relate more specifically to structure, bedrock geology, surficial deposits, etc.

Uranium in Lake Water Versus Uranium in Lake Sediments

Whether to sample waters, or sediments or both in wide-interval reconnaissance survey lakes continues to be a problem, as described by Cameron and Hornbrook (1976). Economically it is much cheaper to collect only lake waters to determine the content and distribution of uranium. However, even if water sampling was universally feasible, a great deal of the uranium data is less than 0.05 ppb U which is the detection limit for the fluorometric analytical methods generally used for hydrogeochemical exploration. Development of new methods involving irradiation, resins, etc. are in progress, which will provide much lower detection limits.

Other problems would include seasonal variation. Macdonald (1969) has found no significant seasonal variation, except during spring break-up, of surface lake waters from the Beaverlodge area Saskatchewan. Meyer (1969), however, found a 2-4 times increase between September 1966 and mid-summer 1967 of the uranium content of lake waters in Labrador. At the Geological Survey of Canada, studies of uranium in waters have revealed problems in storage, preservation and frequently long-term precision in the sub-parts per billion range.

Figures 9 and 10 show the relationship between uranium content of waters and sediments respectively in northwestern Manitoba and eastern Ontario near Renfrew.

The horizontal line of dots near the bottom of Figures 9 and 10 occurs because fluorometric uranium data less than the detection limit is shown at half of the detection limit. In Manitoba, the detection limit was 0.07 ppb U and in Ontario, 0.04 ppb U. In the Manitoba study, the correlation between log transformed water and sediment data is quite good, indicating the potential use of only waters to determine the uranium distribution. However, in eastern Ontario, the correlation is poor, demonstrating that the use of water as a sample medium will not supplant the routine use of lake sediments.

The relationship of uranium in waters to uranium in sediments is essentially a function of the nature of the waters and the water-sediment system. In the Renfrew area of eastern Ontario, carbonate rocks are moderately abundant. Carbonate bearing solutions can dissolve uranium (Hostetler and Garrels, 1962; Ostle and Ball, 1973). Uranium can be maintained in solution by complexing with carbonate ions (Dyck, 1975), thus providing reasonably wide dispersion before dilution of the carbonate-rich waters. The dilution reduces the effect of the carbonate ions permitting precipitation of uranium in the generally reducing and/or

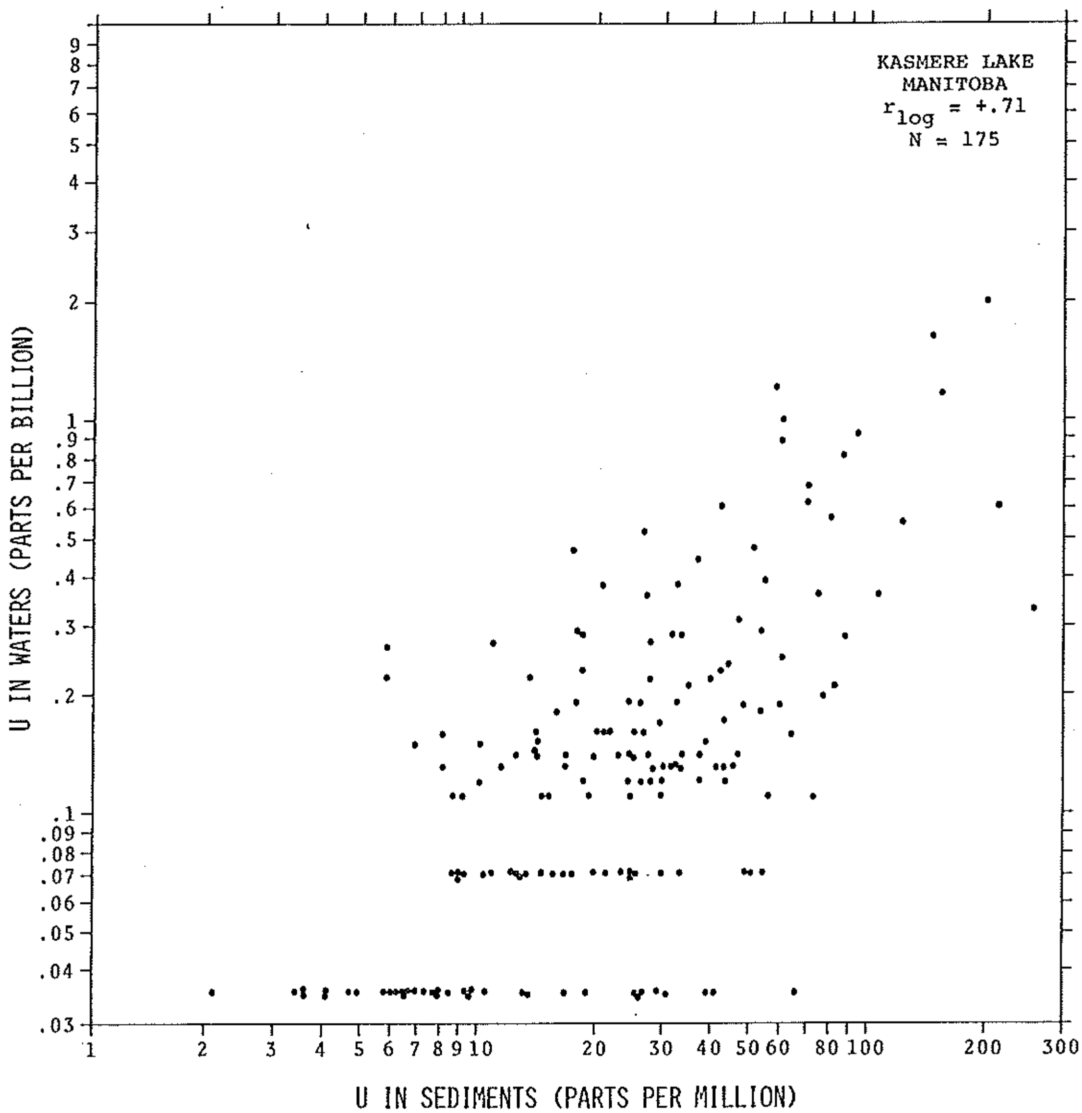

Figure 9. Plot of uranium in lake waters versus uranium in lake sediments for sample sites in the Kasmere Lake area, Manitoba (N.T.S. 64N/14, 15 and 16), (after Cameron and Hornbrook, 1976).

sulphide bearing lake sediments of the northern Shield (Andrews-Jones, 1968). In areas of carbonate rocks, the content and dispersion or uranium in waters is enhanced while that of uranium in sediments is suppressed. Thus, the positive correlation is not developed.

Therefore, water surveys cannot universally replace sediment surveys

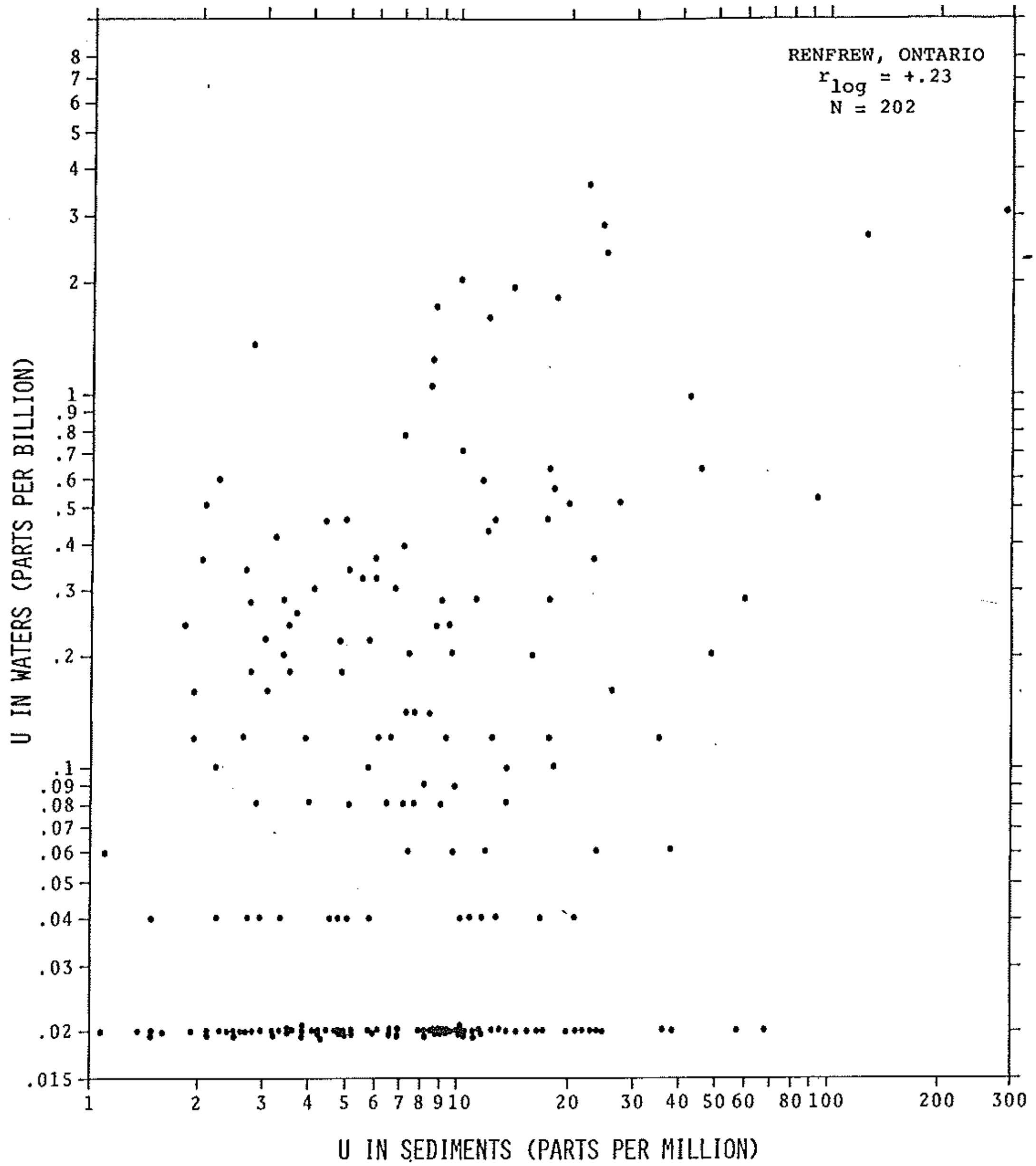

Figure 10. Plot of uranium in lake waters versus uranium in lake sediments for sample sites in N.T.S. 31F/7, 1:50,000, Renfrew, Ontario (after Cameron and Hornbrook, 1976).

but are a very useful complement to confirm anomalous patterns and/or to provide patterns in areas where carbonate-rich waters are widespread. The fluorometric determination of U in field laboratories was carried out to guide follow-up studies in Manitoba and the Nonacho Belt, Northwest Territories. The clinching point for the mandatory use of sediments is that several elements essential for geochemical interpretation detectable in sediments are not detectable, for all practical purposes, in lake waters.

Uranium Versus Manganese, Iron and Organics

Organic material, iron and manganese are widely thought to act as scavengers in lake sediments producing spurious anomalies through enhancement of metal values. This relationship is only partly true, as demonstrated in the 1974 Saskatchewan survey, for uranium (Cameron and Hornbrook, 1976), and zinc (Garrett and Hornbrook, 1976). The relationship is essentially a function of the environment of the lake and the locations in the lake of the sample site: i.e. Barren Lands, southern Shield, shoreline site, inlet/outlet site, or centre-lake bottom site.

Table 2 shows correlation coefficients, based on $\log_{10}$ transformed data, of uranium to manganese, iron and organics for thousands of centre-lake bottom samples collected in Manitoba, Saskatchewan, the Northwest Territories and eastern Ontario. These coefficients, although statistically significant, are much less than the coefficients frequently found for uranium with other elements. In the Northwest Territories for example, uranium correlation coefficients with Cu are .70, and .47, and in Manitoba .58. The correlation of U with the scavengers Mn, Fe and organics is not high. The relationship of uranium with Fe, Mn and organics is less than that observed with mineralogically related elements

Correlation Coefficients Uranium vs.		Cu	Mn	Fe	LOI
Manitoba 51,800 km^2 (20,000 mi^2)	3633	.58	.25	.18	- .12
Saskatchewan 51,800 km^2 (20,000 mi^2)	3816		.29	.33	-.07
Nonacho Belt, NWT 36,200 km^2 (14,000 mi^2)	2685	.47	.19	.10	.27
Great Bear Lake NWT 15,500 km^2 (6,000 mi^2)	1054	.70	.35	.30	.23
Ontario 23,300 km^2 (8,600 mi^2)	1180		.10	.21	.04
Location/area	n				

TABLE 2 – Correlation coefficients, U vs. Cu, Mn, Fe, and LOI based on $\log_{10}$ transformed data.

as illustrated in Table 3. In Table 3, multiple regression analysis was carried out by the method of forward selection (Efroymson, 1960) and the significance of each step of the regression was determined by an analysis of variance. The regression was continued until an addition to the equation was not significant at the 95 percent confidence level. The relationship revealed is in terms of the percentage of the variability of uranium distribution accounted for by individual and collective variables. It is possible to assess the relationship in this manner despite the non-linear relation between uranium and the variables because, usually, only a minor proportion of the samples constitute the non-linear phase as shown by Garrett and Hornbrook (1976). Iron, manganese and organics are obviously not major controls of the variability of the uranium distribution in centre-lake bottom sediment samples collected in reconnaissance survey lakes from eastern Ontario, southern Shield, to the Great Bear Lake area, northern Shield. The vegetation types covered by these reconnaissance surveys range from mixed deciduous-conifer forests of southern Canada through the Boreal forest of central Canada, north to the forest and barren Lands of the northern Shield (Rowe, 1959).

It is evident that mineralogically and/or geologically related elements such as Cu, Mo, Co and Ni co-vary with uranium and they have a strong relationship. To regress uranium against Mn, Fe and LOI would provide predicted uranium values free from their influence and an anomaly plot of uranium values and distribution that would probably have much the same regional features as a plot of raw untreated data.

The question of scavenging may, however, become acute when assessing the uranium content at certain individual sites where the content of Mn, Fe, or organic material is such that they play a geochemically significant

MULTILINEAR REGRESSION STUDIES

MANITOBA (n = 3633)

variable	sign	proportion of variation %	cumulative %
Cu	+	33.55	33.55
Mo	+	8.51	42.06
LOI	−	7.79	49.85
Fe	−	.79	50.64
Mn	+	.32	50.96
Hg	−	.17	51.13
Co	−	.17	51.30

SASKATCHEWAN (n = 3816)

variable	sign	proportion of variation %	cumulative %
Co	+	11.12	11.12
Cu	+	3.12	14.24
Fe	+	3.29	17.53
Pb	+	1.17	18.70
Mo	+	1.47	20.17
LOI	−	1.01	21.18
As	−	.42	21.60
Mn	+	.30	21.90

NONACHO BELT, NWT (n = 2685)

variable	sign	proportion of variation %	cumulative %
Cu	+	22.56	22.56
Ni	−	10.45	33.01
Pb	+	4.33	37.34
Mo	+	5.15	42.49
Mn	+	.61	43.10
Hg	−	.27	43.37
Fe	−	.22	43.60
		.23	

GREAT BEAR LAKE, NWT (n = 1054)

variable	sign	proportion of variation %	cumulative %
Cu	+	48.72	48.72
Mo	+	8.19	56.91
Zn	+	1.00	57.90
Ag	+	.33	58.24
Co	+	.24	58.48
Ni	−	.38	58.86
Hg	+	.26	59.12

RENFREW AREA, ONTARIO (n = 1180)

variable	sign	proportion of variation %	cumulative %
Cu	+	9.98	9.98
Zn	+	3.75	13.73
Mo	+	2.89	16.62
Hg	+	1.43	18.05
Co	+	.83	18.88
Pb	+	.72	19.60
As	−	.70	20.30
LOI	−	.35	20.65
Mn	−	.33	20.98
Fe	+	.31	21.29

TABLE 3 - Multilinear regression of uranium vs. several measured variables, elements and LOI.

role in the variability. As mentioned earlier, detailed investigations of the relationship of U and Zn to Mn, Fe and loss on ignition (LOI) have revealed that they can play a significant role in controlling uranium or zinc content of a lake sediment, but only at certain restricted concentration ranges. Fortunately, the bulk of the Saskatchewan lake sediment analytical data for U and Zn lies in concentration ranges greater than the range where the influence of Mn, Fe or organics have a critical role. Figure 11 was prepared by dividing the LOI range from 0 to 40 percent into 20 equal groups of 2 percent each, and above 40 percent the groups are 5 percent and lastly 10 percent wide. The vertical bar and horizontal cross were placed, in a horizontal sense, at the appropriate mean LOI for each group: the cross indicates the mean uranium value and the extent of the vertical bar covers the 95 percent confidence bounds about the mean uranium. The geometric mean for uranium is 4.9 ppm and for LOI is 28.5 percent. In Figure 11, above 10 percent LOI, the sympathetic increase of U and LOI ceases where U values stabilize about the geometric mean independent of increasing organic content. Therefore, above 10% LOI the organic content of a lake sediment is not a limiting factor to producing uranium concentrations above the geometric mean, whereas below 10% LOI the organic content is a limiting factor. Approximately 12 percent of the Saskatchewan survey samples have an organic content of less than 10 percent and those samples may have their uranium content limited by the availability of organic constituents for organo-metallic bonding etc.

In a restricted study area, such as one or two lakes, with a high proportion of anomalous uranium values, and near-shore sample site

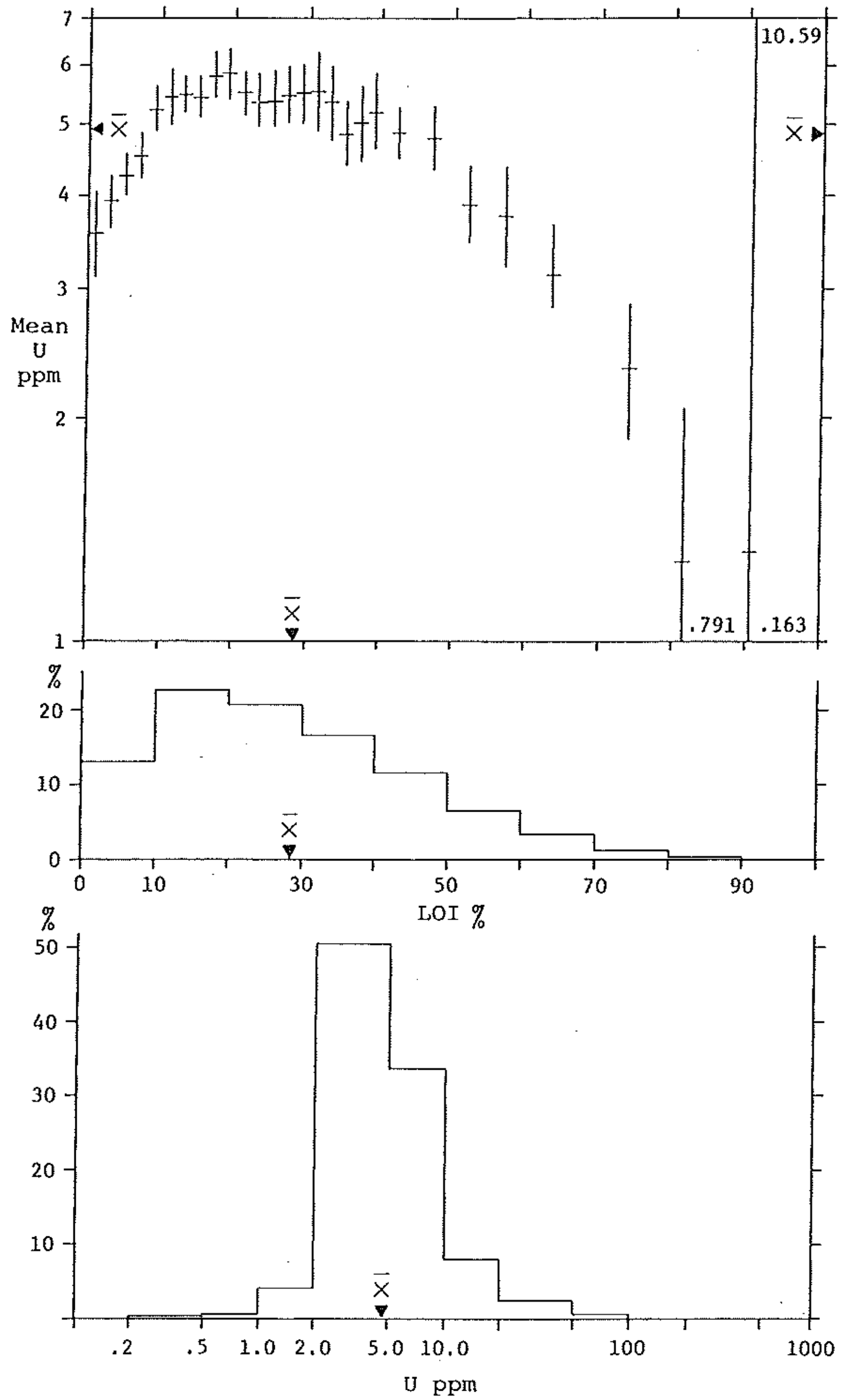

Figure 11. Graphic display of the relationship between uranium and LOI, and histograms for uranium and LOI.

locations, a plot such as Figure 11, would depict a sympathetic relationship between LOI and increasing uranium. The data would lack sufficient background uranium values characteristic of a regional survey and the dominant numbers of organic-rich centre-lake samples to reveal the break-over at 10 percent LOI. Nearshore samples of lake sediments are predominantly less than 10 percent LOI - a category, which on a regional basis, would produce a uranium data set strongly influenced by the organic content.

CONCLUSIONS

The experience of the Geological Survey of Canada, provincial governments, the mineral exploration industry, various universities and research institutes gained over several years of geochemical exploration has shown that successful uranium exploration in the Canadian Shield is possible utilizing lake sediments and/or waters.

The Federal-Provincial Uranium Reconnaissance Program (geochemical phase) in the Shield, and other similar terrain, has specifically developed, tested and applied methodology to utilize lake sediments and waters to delineate the content and distribution of uranium and some related elements for exploration and resource appraisal purposes.

Evaluation of regional trends of anomalous uranium concentrations, which do vary throughout the Shield, should incorporate information on the bedrock geology and overburden.

Uranium anomalies having a spatial correlation with appropriate mineralogically and/or geologically related element assemblages constitute a priority target, particularly for follow-up exploration. Significant, but uneconomic, uranium anomalies may be related only to acid igneous rocks with above background uranium content.

The validity of the sample density and uranium distribution trends of a wide-interval reconnaissance survey has been established for uranium by an independent resampling survey of the same area.

The determination of U in lake water provides a useful adjunct to lake sediment surveys, particularly in carbonate terrain, but it cannot be considered to provide a Shield-wide alternate to a multi-element regional lake sediment survey.

The variability of an N.G.R. centre-lake bottom sediment uranium survey data set is not influenced by the common scavengers (Fe, Mn and organic content) except possibly under restricted circumstances of sample site location and certain concentration ranges. Such a data set is influenced by Cu, Mo, Co, Ni etc. that have a mineralogical and/or geological association. This latter feature is a desirable characteristic because it is a positive aid for interpretation and discrimination among regional uranium anomalies.

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