

Comparison of Geochemical Prospecting Methods Using Radium With Those Using Radon and Uranium

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ABSTRACT

The application of radium-226 geochemistry to prospecting for uranium has been tested at Bancroft, Ontario, and compared with methods using radon-222 and uranium. Sediment, soil and weathered rock samples were analyzed for radium-226 and uranium, and water samples were analyzed for radon-222 and uranium. Radium and uranium in sediments are more useful in prospecting than are radon and uranium in water. Clastic and organic sediments are both useful, but clastic sediments are superior. In sediment surveys, radium and uranium are equally useful; in intermediate-scale prospecting using soils, radium and uranium in the A and B horizons are all useful; and in detailed prospecting, all except uranium in the A horizon are useful. Weathering leaches uranium from rocks more thoroughly than radium; therefore, radium analyses are highly preferable to uranium if weathered rocks are collected.

INTRODUCTION

ELEMENTS WITH POTENTIAL APPLICATION to prospecting for uranium comprise members of the two uranium decay series as well as products of the natural fission of uranium. Uranium and radon* have received much attention and helium has been used (Hawkes and Webb, 1962). The use of radium* is new and to the writer's knowledge has not yet been applied commercially.

Radium and radon occur about midway in the uranium-238 decay series. Radium has a half-life of 1,600 years and is followed by radon, with a half-life of 3.8 days. The earlier members of the series are long-lived; therefore, any correlation between radium and uranium in recent material (water, organic material, the A horizon of soil, etc.) is due to similar geochemical behaviour, not radioactive production. The later members are short-lived. One of them is bismuth-214, the nuclide measured by the gamma-ray spectrometer. As bismuth-214 is preceded by radon, a noble gas, and by several long-lived nuclides, it may be considerably removed from its parent uranium. A gamma-ray spectrometer map is, to a certain extent, a radon map. In this respect, geophysics overlaps with geochemistry.

Because radon is a noble gas, it has been considered to be extremely mobile (Hawkes and Webb, 1962); however, its mobility in ground water and surface water may not be as great as generally assumed. The half-life of radon is 3.8 days, and its mobility is limited to the distance it can travel in a few half-lives. Below the water table, mobile gas phases are uncommon, especially in Precambrian terranes, and all the radon is dissolved in water or adsorbed. It

moves, therefore, at the rate that ground water moves — a few feet a day. It is difficult to imagine how radon below the water table could move more than a few tens of feet from its source before it has decayed to an undetectable level.

Dispersion of radon in ground water and surface water from its ultimate source in the lithosphere is aided by dispersion of its parent radium. Radium concentrations in water are low, but over the years large quantities have been carried in solution and precipitated in drainage sediments and in aquifers. In addition, radium-bearing minerals are physically transported by fluvial and glacial processes.

It has been shown elsewhere (Morse, 1970) that the level of radon in stream water is controlled by addition of radon through the decay of radium in the sediments and the influx of radon-charged ground water, and by loss of radon due to aeration and radioactive decay. Loss of radon by aeration and radioactive decay is controlled by flow volume: the ratio of water volume to bottom area (the source of radon) is higher in deep, large-flow streams than in shallow, small-flow streams, and hence the radon level is negatively correlated with flow volume.

Early results indicated that measuring radium in sediments provides a reconnaissance tool for uranium prospecting (Morse, 1969). Sampling was increased in density and extended to waters, soils and weathered rocks. The results of surveys using radium are now compared, at different scales, with those using radon and uranium.

ACKNOWLEDGMENTS

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*In this paper, radon refers to radon-222 and radium refers to radium-226, both members of the uranium-238 decay series.

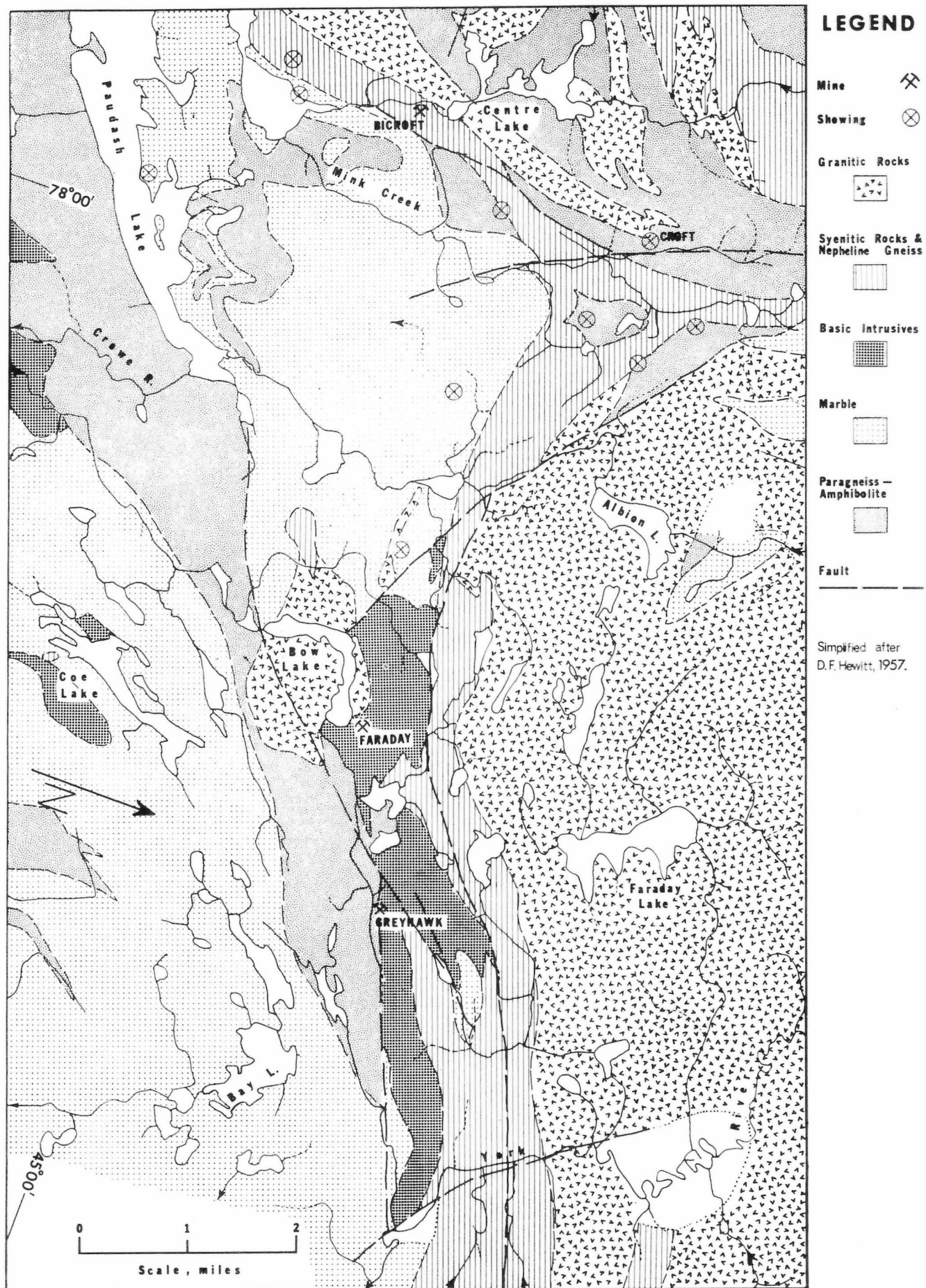


FIGURE 1 — Geology and Uranium Occurrences, Bancroft Area.

SAMPLING AND ANALYTICAL METHODS

Water and clastic and organic sediment samples were collected at 235 points over an area of 90 square miles at Bancroft, Ontario (*Figure 1*). A third of the locations yielded both types of sediment, a third only clastic and a third only organic. In addition, 46 soil samples (A and B horizons) were collected from two lines over the Faraday mine.

Sediment and soil samples were analyzed for radium and uranium, and water samples were analyzed for radon and uranium. Some water samples were analyzed for radium, but it is so low relative to the detection limit that its use as a geochemical prospecting tool is ruled out. Uranium analyses were done by fluorimetry (Smith and Lynch, 1969). The method for detecting radium in sediment and soil was developed by the writer (Morse, 1970) and is a simple modification of the method developed by Dyck (1969) for detecting radon in water. The sample is submerged in water for several days and the nascent radon in the water is measured by gas scintillometry.

RESULTS OF DRAINAGE SURVEY

The response of the different elements in water and sediment to uranium deposits and rock type is compared by plotting regional geology and analytical results on a series of base maps (*Figures 2 to 7*). Because radium and uranium are enriched in organic sediments relative to clastic sediments, data for the two types of sediment should not be plotted without qualification on the same map, otherwise a high value due to the proximity of a uranium deposit could not be distinguished from one due to the relatively high radium and uranium content of organic sediments. For this reason, it is necessary to make two maps each for uranium and radium in sediments; one for clastic and one for organic sediments. A method of combining the two types of data results in two more maps (*Figures 8 and 9*).

The common base map shows drainage, simplified geology and uranium deposits. Different types of drainage sample points — streams, lakes, swamps, ponds and springs — are distinguished on the maps by four types of symbols as well as the obvious difference in drainage pattern between lakes and streams. Points not on the drainage pattern and with no ticks represent intermittent streams. Ponds are defined as lakes which are too small to show on the National Topographic Series 1:50,000 maps. Where not obvious from the drainage pattern, the flow direction of streams is given by arrowheads. In two places the course of streams is unknown, and they are terminated on the maps by arrowheads.

Geology (after Hewitt, 1957) is represented by a single heavy broken line separating metasediments (mainly marble, paragneiss and amphibolite to the south) from plutonic rocks (mainly granite, syenite and gabbro to the north). A zone of syenitic rocks and nepheline gneiss follows this line in the west half of the map and parallels it about a mile north in the east half (see *Figure 1*). Uranium deposits are concentrated along this line (Ontario Department of Mines, 1957). Major orebodies are found in three places (Satterly, 1957): (1) in a long zone extending from the Bicroft mine to the Croft workings (see *Figure 1*); (2) in a limited area extending 2,500 feet southwest from the Faraday shaft; and (3) in a limited area extending 500 feet east and north-east from the Greyhawk shaft.

Information for the sample points downstream from the tailings ponds at the Bicroft and Faraday mines has been

left off the maps because of the possibility that ore processing has added members of the uranium decay series to the drainage. The drainage in question is Bow lake and Paudash lake and the streams draining them. Tailings from the Bicroft mill were piped across Deer creek to a tailings pond near the headwaters of a small tributary. Any leakage from this tailings pond would have entered Deer creek downstream from the sample point shown on the map. Contamination downstream from the Greyhawk mine is unlikely, because the ore was milled elsewhere.

The maps (*Figures 2 to 9*) show that all the methods studied are useful in prospecting for uranium. All the maps show a positive response to the Bicroft and Greyhawk mines. In the stream which rises $\frac{1}{2}$ mile northeast of the Bicroft mine (point a), water and both types of sediment have a high content of all the elements measured, in response to the northward extension of the Bicroft radioactive zone. The same is true of the downstream portion of the stream which runs past the Greyhawk mine. All the maps show a positive correlation of high values with the contact between plutonic rocks and metasedimentary rocks, along which known uranium deposits are concentrated.

As a geochemical prospecting medium, sediments are clearly more useful than water.

Levels of radon and uranium in lake water cannot be correlated with either proximity of uranium deposits or rock type. The uranium content in water is higher at the north end of Centre lake, a mile north of the Bicroft mine, than it is at the much closer south end. The opposite is true for sediments, in which both the radium and uranium contents are much higher near the mine than a mile north. Pond water, on the other hand, can be used in geochemical prospecting at this scale. Water in the pond near the Bicroft mine is very high in both radon and uranium. Ponds are more useful because, being smaller, their water has a more local source.

The negative contribution of lake water as a geochemical prospecting medium at this scale does not contradict the conclusions of Smith and Dyck (1969). They found that levels of both radon and uranium in lake water were positively correlated with broad areas of uranium occurrences. The anomaly they showed as being associated with the Bancroft uranium camp is almost as large as the whole area studied in this investigation. Because lake-water samples can be collected cheaply and rapidly using aircraft, they are useful in reconnaissance prospecting, but there is no point in collecting samples at the present density.

At the scale used in this investigation, stream water is more useful in prospecting for uranium than is lake water. Water in the stream which rises $\frac{1}{2}$ mile northeast of the Bicroft mine (point a) and water downstream from the Greyhawk mine has a high content of both radon and uranium.

Stream sediments, however, are again more useful than stream water.

Water in Deer creek downstream from the Bicroft mine has background levels of radon and uranium; however, sediment at the same location is high in radium and uranium. The flow rate in Deer creek is the highest in the area except for the York and Crowe rivers. Uranium-poor water from Centre lake, $\frac{1}{2}$ mile upstream, dilutes any local influx of uranium-rich water. The low level of radon has two possible explanations: (1) radon-poor water travels the half mile from Centre lake so fast that it doesn't have time to pick up a large amount of radon from the sediments of Deer creek, which is swift and turbulent; or (2) the large flow volume indicates a high ratio of average depth to area of stream bed, which results in a low ratio of radon in water to radium in sediments.

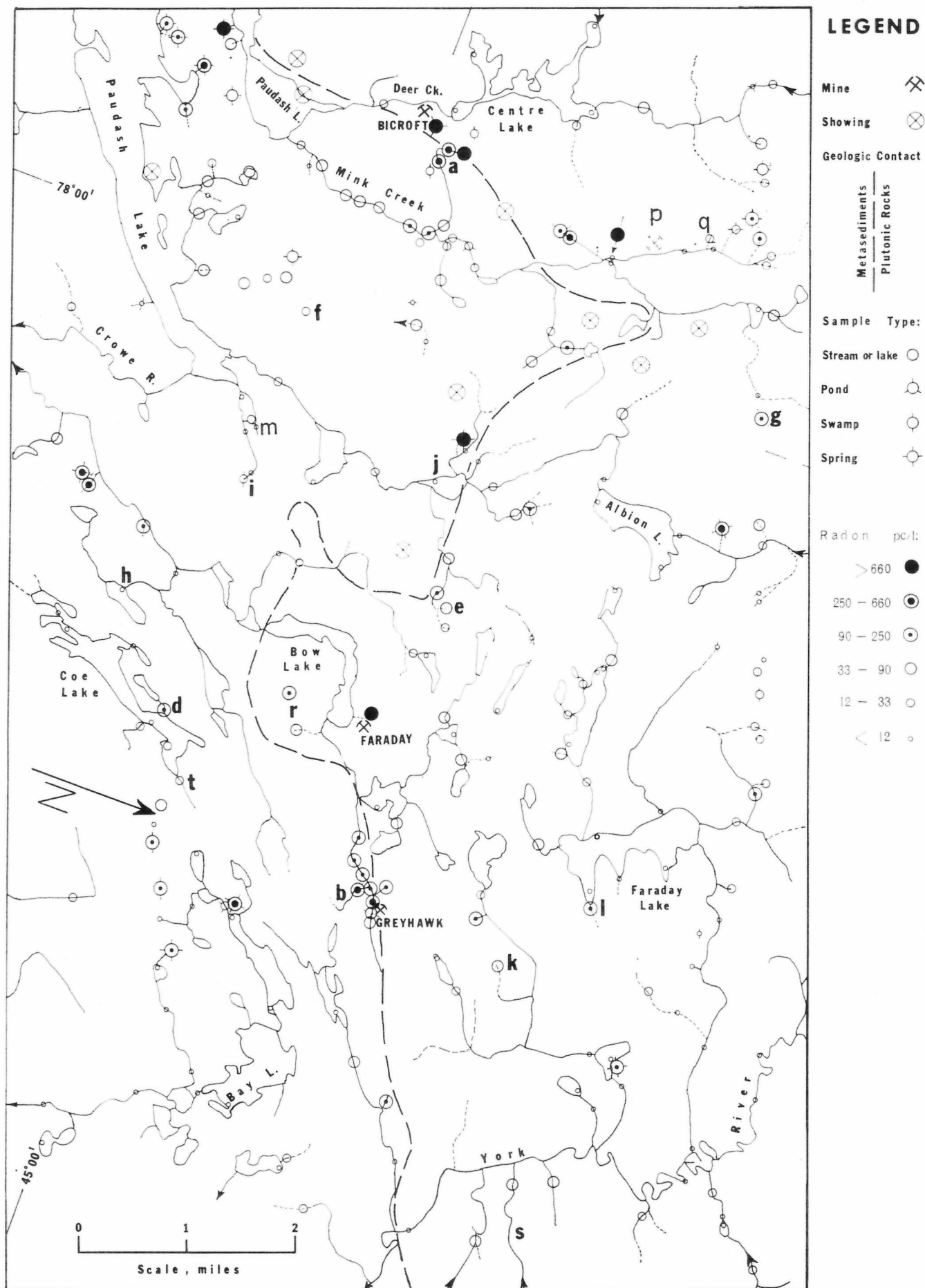


FIGURE 2 — Radon in Surface Water.

LEGEND

Mine 

Showing 

Geologic Contact

Metasediments
Plutonic Rocks

Sample Type:


Stream or lake 


Pond 


Swamp 


Spring 


Uranium ppb:

> 2.7 

1.6 — 2.7 

1.0 — 1.6 

0.6 — 1.0 

< 0.6 

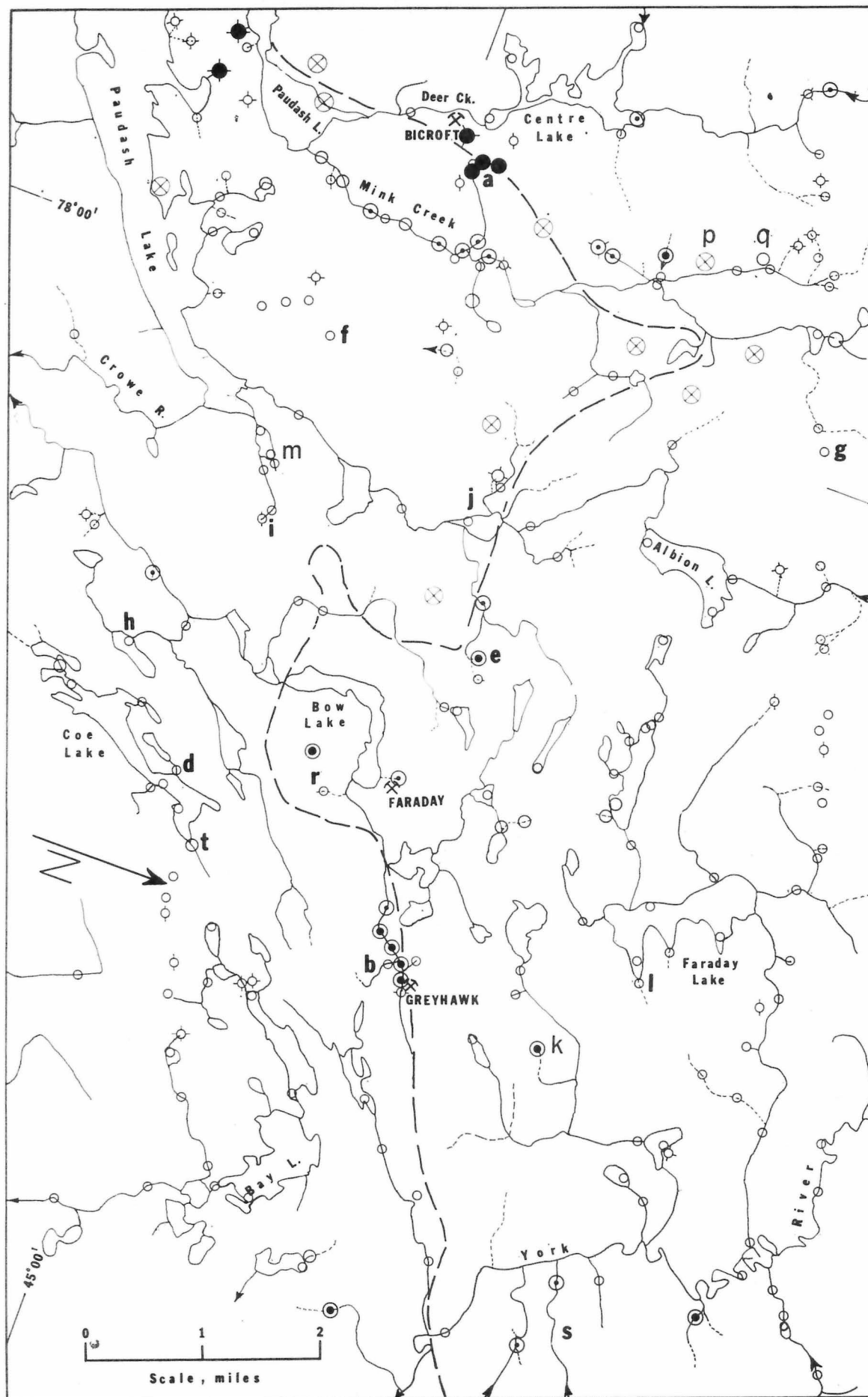


FIGURE 3 — Uranium in Surface Water.

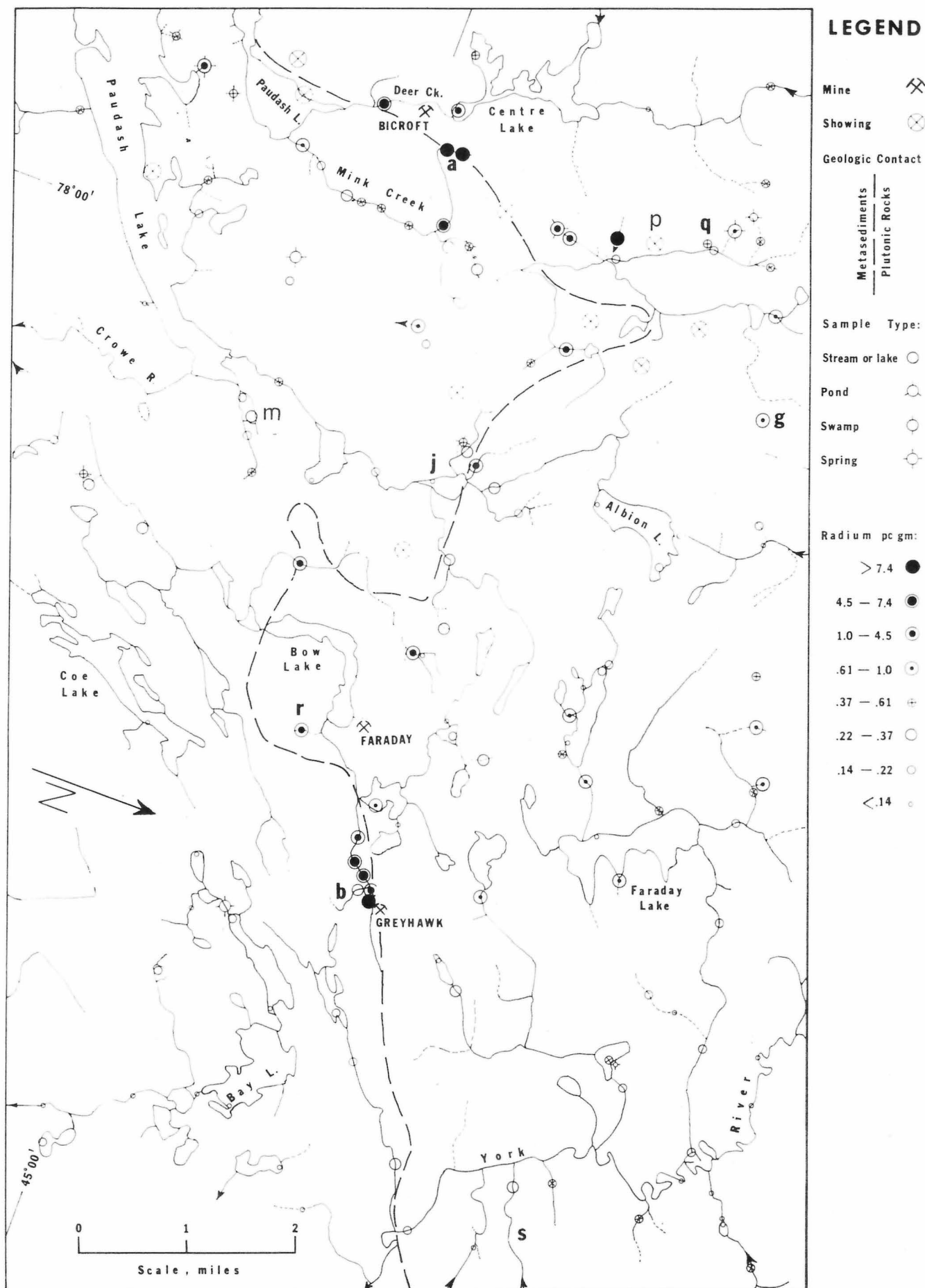


FIGURE 4 — Radium in Clastic Sediments.

The small stream shown near the Faraday mine rises in a spring directly above the workings. Its water is high in radon content and its sediment is high in both radium and uranium. The uranium content of the water, however, is lower than that in several streams not associated with known uranium deposits. The reason for this is not known.

The stream which flows past the Greyhawk mine has a tributary (point b) entering it from the south about ¼ mile downstream from the mine. Water in this tributary is high in radon content, but the sediment is low in radium. No uranium deposits are known in this area. The flow volume at this sample point is one of the lowest in the area; the stream is less than an inch deep, less than a foot wide and barely moving. The high level of radon in the water, in spite of the low level of radium in the sediment, illustrates the principle that the source of radon is in the sediments: the low flow volume and hence average depth result in a low ratio of water to emanations, and thus a high ratio of radon in water to radium in sediment.

At three key places — Deer creek, the Faraday mine and the tributary downstream from the Greyhawk mine — the analysis of stream water gives misleading results. Stream sediments at these places give "correct" results. Similarly, sediment in Centre lake gives a more accurate indication of the proximity of the Bicroft uranium deposit than does water. Thus, Walker's (1968) generalization on hydrogeochemistry is true for uranium and radon in water: "... this technique is generally a cumbersome method of stream-sediment sampling".

Sediments should generally be used in preference to water except for two cases: (1) in reconnaissance prospecting, where lake water can be sampled cheaply and rapidly by aircraft; and (2) where rapid analytical feedback is possible and necessary. Measuring radon in water is the fastest technique available — a portable radon-detecting apparatus is available* which permits on-the-spot analysis. (Measuring radon in sediments might be just as rapid as and more effective than measuring radon in water, but it has not been tried. It would be less effective than measuring radium in sediments by the writer's method.) The choice between measuring radon and uranium in reconnaissance lake-water surveys should be based on logistics. If a small laboratory can be set up in the field, and if rapid analysis is important, then radon should be used. If samples must be sent to a central laboratory, then uranium must be used.

Comparison of methods using clastic sediments with those using organic sediments, by an examination of *Figures 4 to 7*, shows that both radium and uranium respond to rock type and distribution of uranium deposits more accurately in clastic than in organic sediments.

For example, one would expect radium and uranium levels in Mink creek to drop off gradually as the creek leaves the area of uranium deposits and flows toward Paudash lake; that is, along the portion of the map near the label "Mink creek". For both elements, the drop-off is more regular in clastic than in organic sediments. The trend reverses for radium at the farthest downstream sample point, where clastic sediment has a high content. This point is connected to the Bicroft mine area by a low swampy area through which radium may have moved into Mink creek.

At several points not related to known mineralization, organic sediments are high in radium or uranium content, but not in both. These points are indicated on the maps by the letters d to g for radium, and h to l for uranium. The

anomalies are believed to be spurious, that is, not related to uranium in the rocks but due to local chemical conditions in the drainage. Support for this interpretation is given by the fact that these samples are high in only one of the two elements and low in the other. Similarly, clastic sediment is fairly low in radium at location g and fairly low in uranium at location j. With the possible exception of points e, j and k, discussed later, further investigation of these spurious anomalies for economic reasons is not recommended.

The affinity of radium and uranium for organic material in sediments (Morse, 1970) is apparently strong enough, in some cases, to mask the relationship between radium and uranium in organic sediments and in the rocks. This does not mean that organic sediments should be overlooked. A survey using only clastic sediments would leave unacceptable gaps in the coverage, because they are not everywhere present.

Several anomalies in clastic sediment need to be explained. The high level of uranium in clastic sediment in the small lake (m) off the northeast end of Paudash lake is probably due to contamination from road fill. Scattered high values along the line joining the Bicroft mine with the Croft workings (p) are due to the northward extension, along this line, of the Bicroft pegmatites (see Satterly, 1957). The high uranium value in clastic sediment nearby at point q may be explained in part by the fact that this sediment contains about 30 per cent organic material.

Five anomalies, still unexplained, are worthy of further consideration, but none is as intense as those associated with the mines. The most interesting is south and east of Bow lake at point r, where two sample points have sediment high in radium and uranium values, and one has water high in radon and uranium. The second is the triangle formed by Albion lake and points e and j; it contains several high values. The third extends off the northeast edge of the maps at point s, where three streams draining from the northeast into the York river contain high values. The fourth is at a point k, north of the Greyhawk mine, where water and organic sediment are high in uranium. The least interesting anomaly is at point t at the northeast end of Coe lake, where organic sediment is moderately high in uranium and radium.

The lack of intense anomalies is no surprise. The area has been well prospected by both amateurs and professionals and has been mapped geologically at a scale of 2 inches to the mile. This was one of the reasons for selecting the area. Probably all the uranium deposits with good surface exposure have been discovered. Discovery of anomalies was not a primary purpose.

Results for clastic and organic sediment can be plotted on the same map by finding a statistical relationship between the two types of data and then, wherever clastic sediments are not available, converting the organic results to 'clastic equivalents'. Because the data are lognormally distributed, using logs gives better correlation than using natural values.

A plot of log radium in clastic sediment against log radium in organic sediment yielded a correlation coefficient of 0.83 and a visually estimated best-fitting straight line defined by

$$Y = 0.54 + X,$$

where X and Y are logarithms (base 10) of the radium content, in picocuries per gram, of clastic and organic sediments respectively. The radium content in organic sediments is, 'on the average', 3.5 (the antilog of 0.54) times as high as in clastic sediments at the same location. Thus, before plotting the results for organic sediments

*Bondar-Clegg & Company Limited, 786A Belfast Road (M.R. 1), Ottawa 8; McPhar Geophysics Limited, 139 Bond Avenue, Don Mills, Ontario.

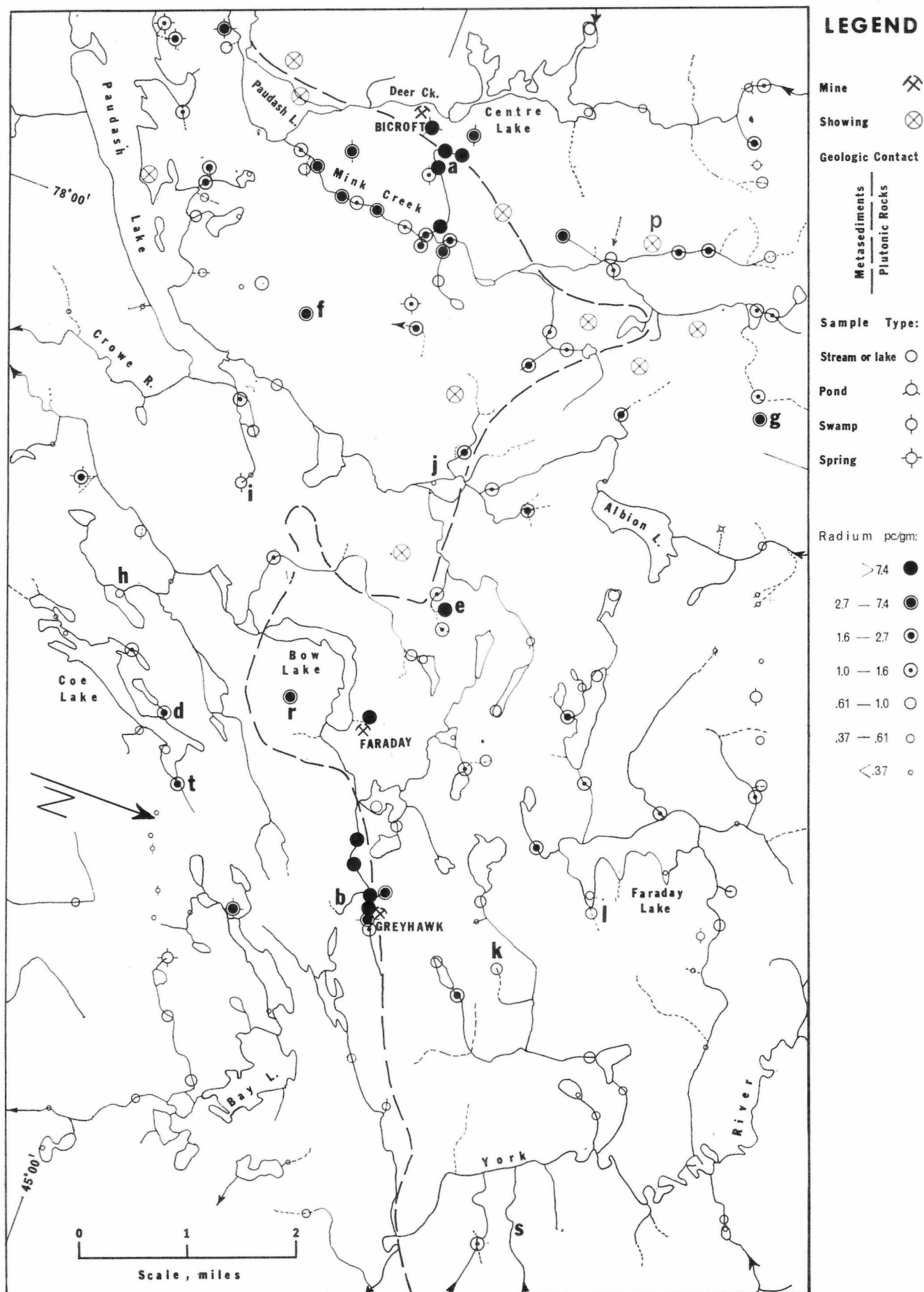


FIGURE 5 — Radium in Organic Sediments.

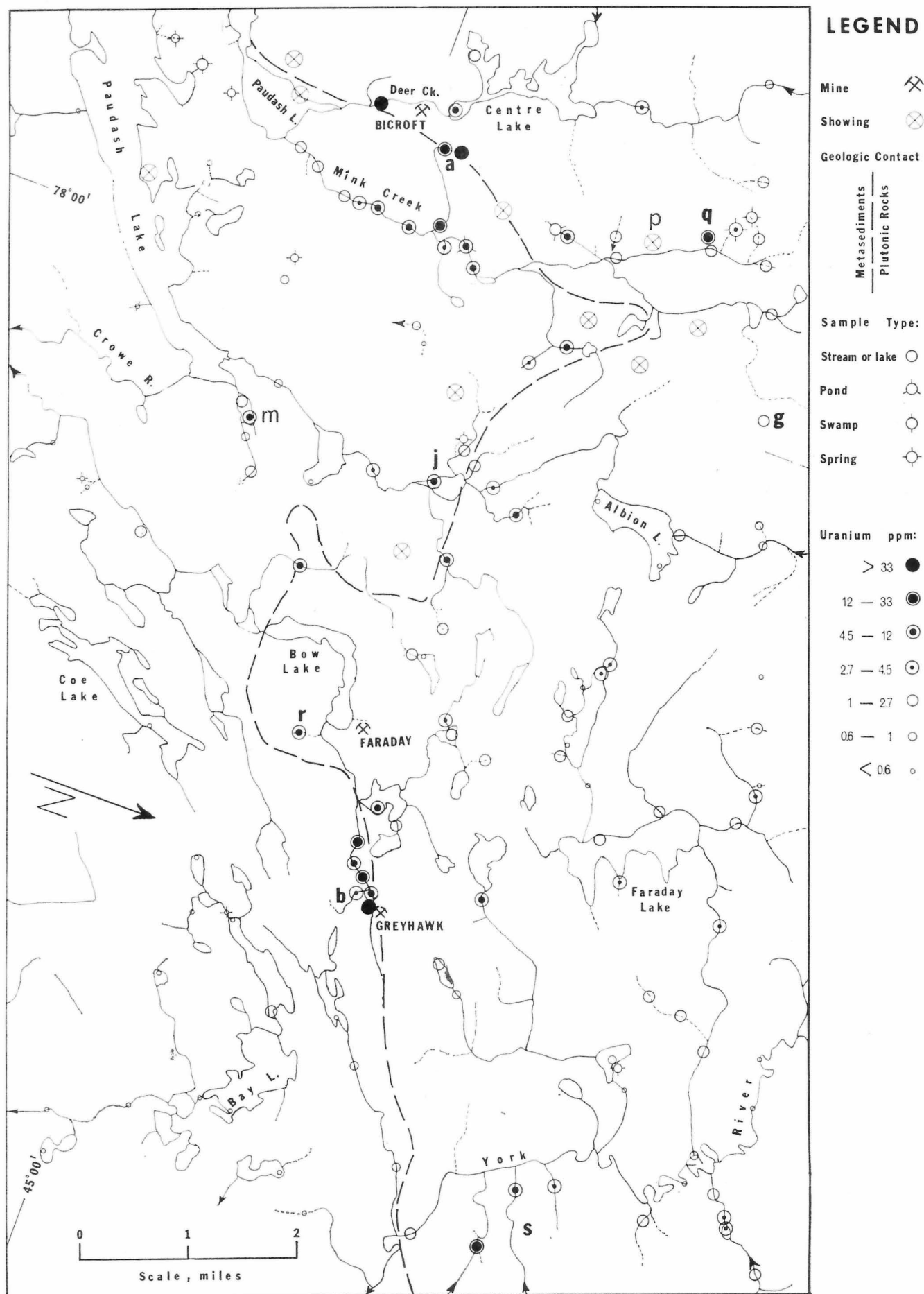


FIGURE 6 — Uranium in Clastic Sediments.

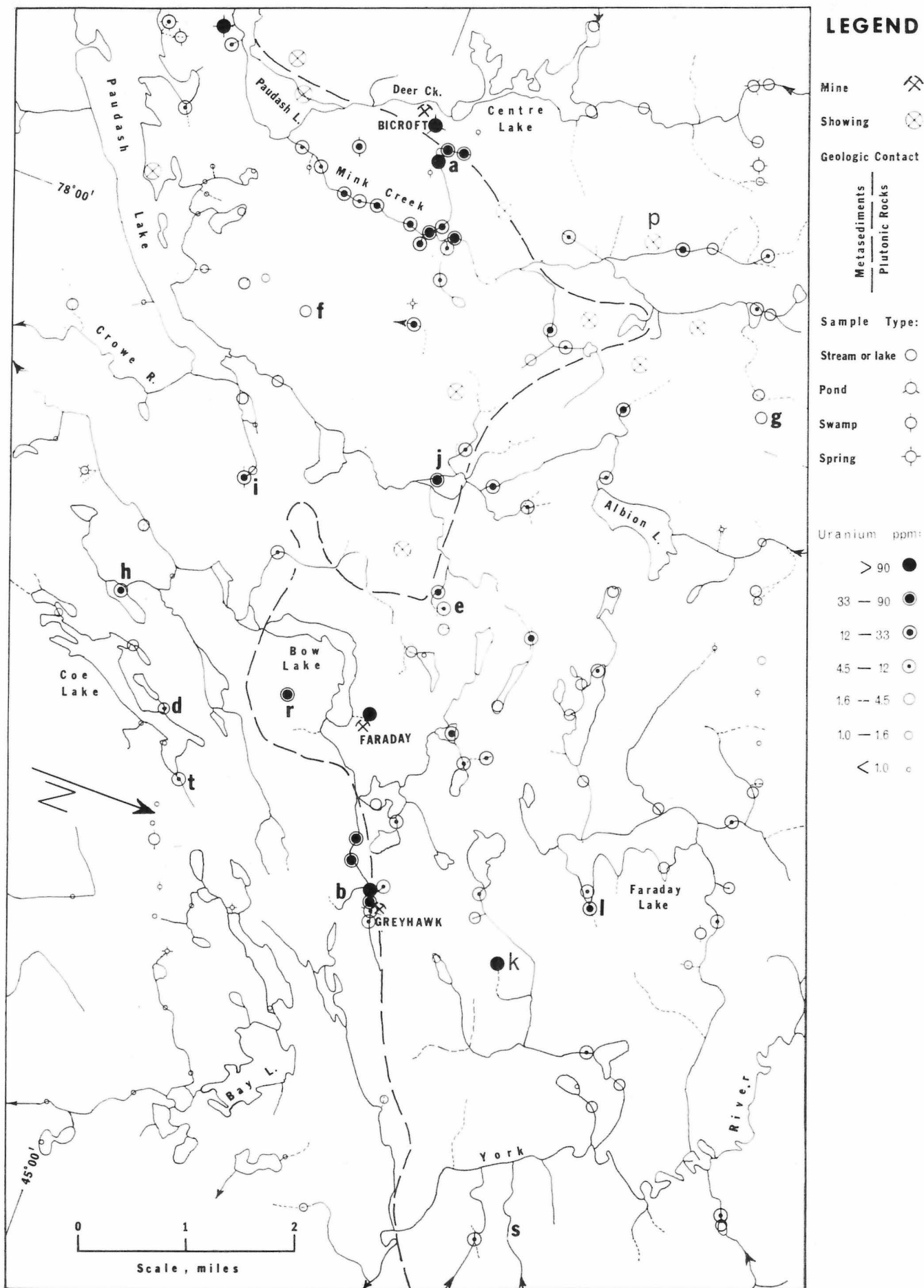


FIGURE 7 — Uranium in Organic Sediments.

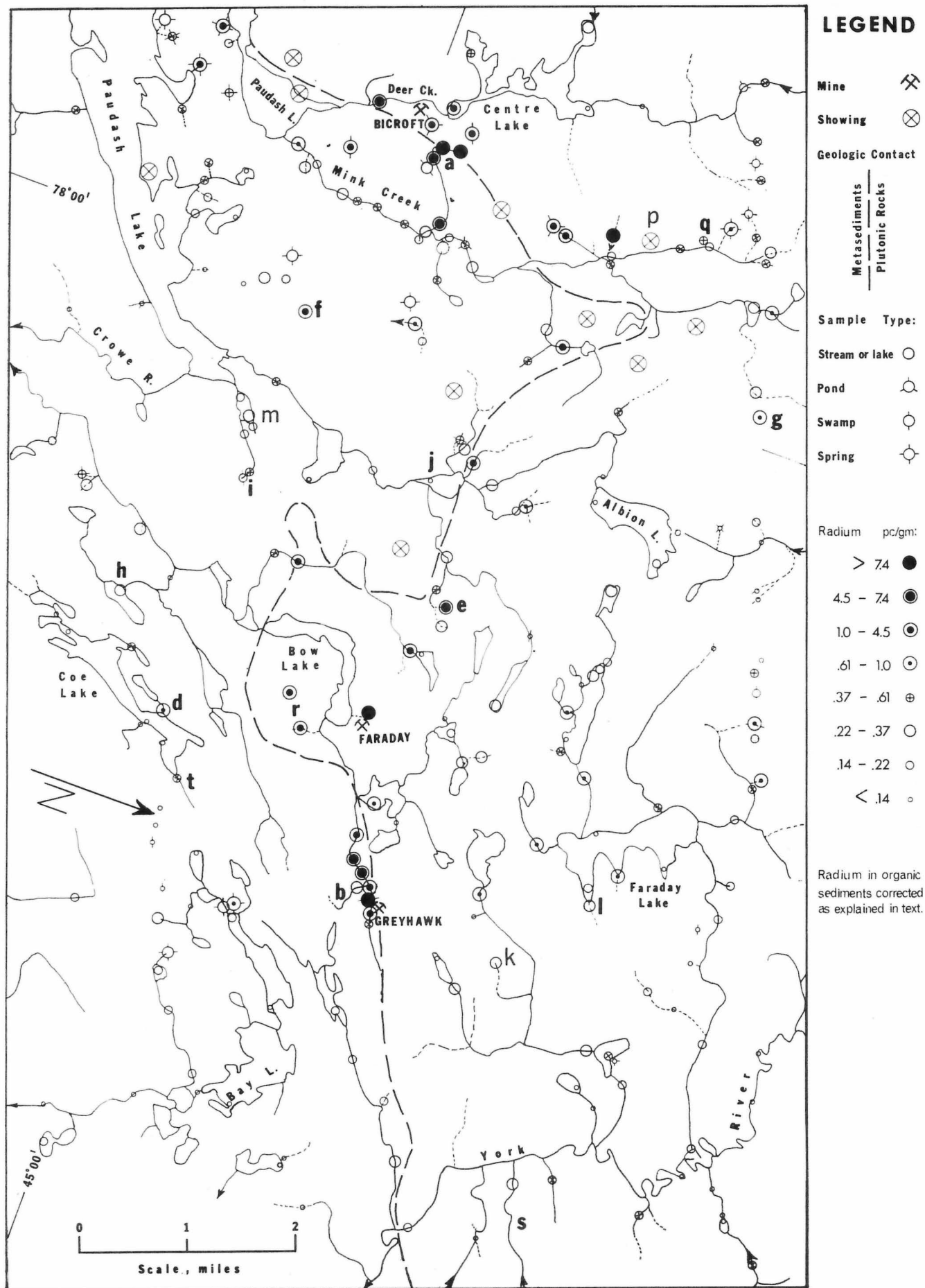


FIGURE 8 — Radium in Sediments.

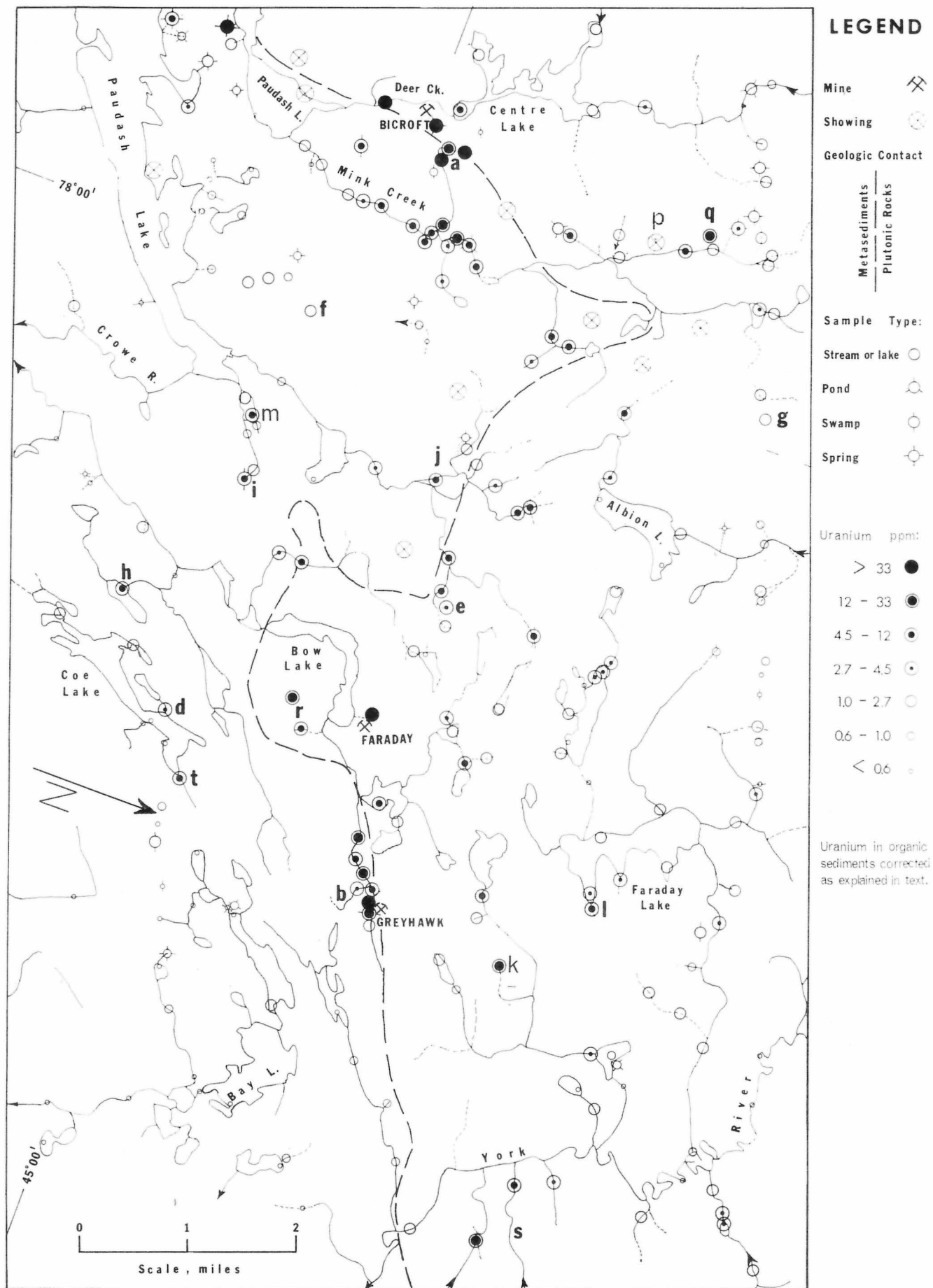


FIGURE 9 — Uranium in Sediments.

on the same map as those for clastic sediments, it is necessary to reduce them to the same 'scale' by dividing the level of radium in organic sediments by 3.5. *Figure 8* shows the results for radium in the two types of sediment plotted on the same map. For sample points with clastic sediment, the results for clastic only were used. Where organic sediments only were present, the radium value was divided by 3.5 and the result was plotted.

A similar comparison for uranium yielded a correlation coefficient of 0.74 and a visually estimated best-fitting straight line defined by

$$Y = .18 + 1.27 X,$$

where X and Y are logarithms (base 10) of the uranium content, in parts per million, of clastic and organic sediments respectively. Results for uranium in organic sediments were reduced to the same scale as those for clastic sediments according to

$$X' = \frac{Y - .18}{1.27},$$

where X' is the logarithm of the 'corrected' value of uranium in organic sediments. These 'corrected' values were plotted on the same map as uranium in clastic sediments (*Figure 9*). Again, wherever clastic sediment was available, only the results for clastic were used.

The choice between analyzing for radium and uranium in sediments is not obvious. The two elements appear to respond equally well to geology and the distribution of uranium deposits. Results of larger surveys or under different conditions may indicate a preference. Radium determinations can be made with a portable radon apparatus; thus, a laboratory for determining radium in sediment could easily be set up in the field, even without electricity. The apparatus for determining uranium in sediment is much less portable and requires electricity. On the other

hand, several days of equilibrating time are required for precise radium analyses. At present, radium analyses are not available commercially; therefore, the industry is generally limited to uranium.

RESULTS OF SOIL SURVEY

The distribution of radium and uranium in soils is compared to bedrock geology at the Faraday east line in *Figure 10* and at the Faraday west line in *Figure 11*. The figures show, on a logarithmic scale, levels of radium and uranium in the A and B horizons at each sample point. Gaps indicate places where no soil was available. Lines intersecting the bottom of the figure indicate analyses below detection limits. The distribution of rock types and ore zones is based on conversations with and mine plans provided by R. Moss of Can-Fed Resources Corporation. Contacts were projected upward from the adit level (elevation 1180 feet), using a strike of N 70°E and a dip of 55 degrees south. The surface elevation and other features are also shown.

The surface at the Faraday east line (*Figure 10*) slopes continuously to the south. The underlying bedrock comprises gabbro and one pegmatite dike.

A strong geochemical response to the uphill edge of the pegmatite is apparent in the soil. The anomaly is shifted about 100 feet downhill. The downhill shift is due to one or both of two reasons: (1) material has moved downhill due to gravity, either physically or in solution; or (2) material was transported southward by glacial activity.

Response to the uphill edge of the pegmatite is shown by radium in the A horizon, which increases six-fold, by radium in the B horizon, which increases about forty-fold, and by uranium in the B horizon, which increases about

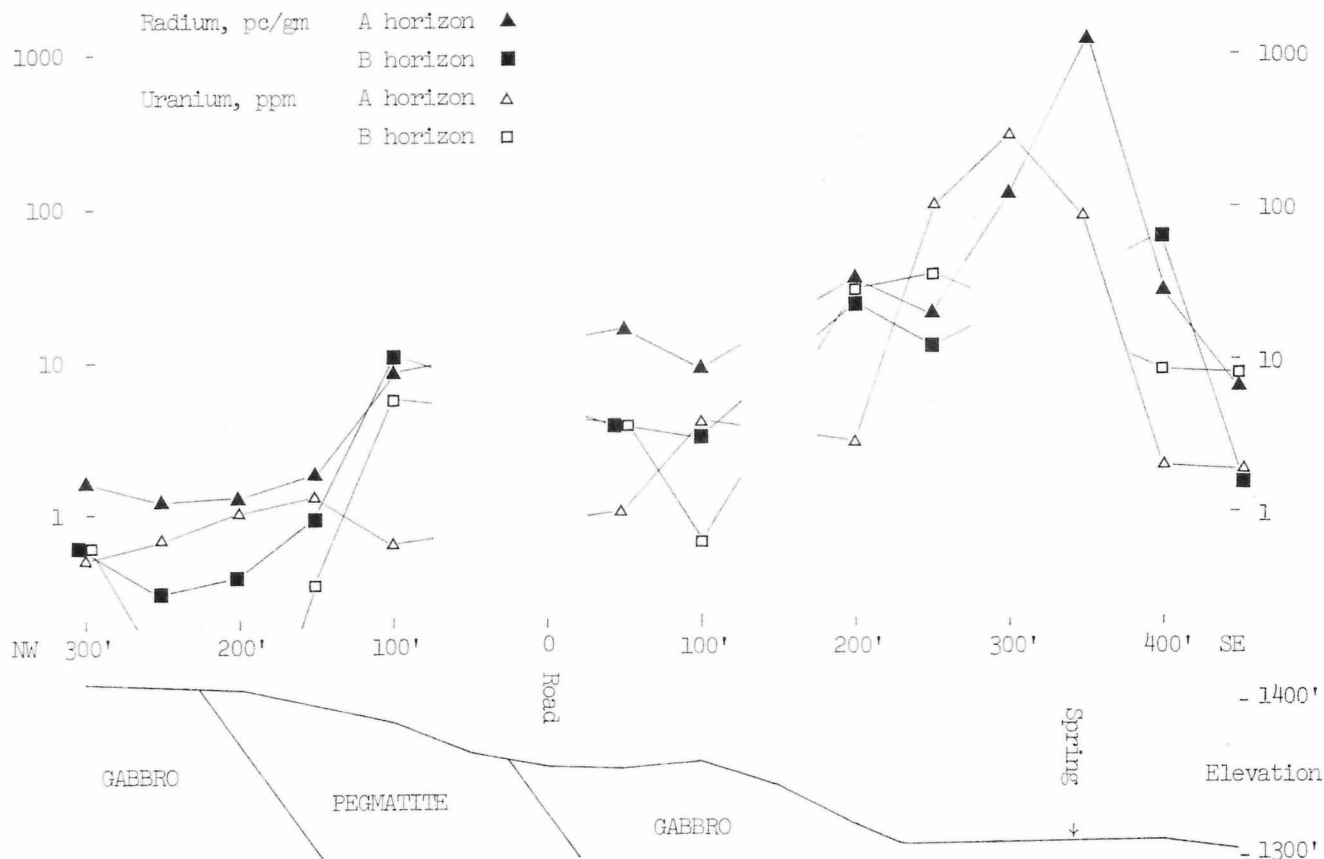


FIGURE 10 — Faraday East Soil Line.

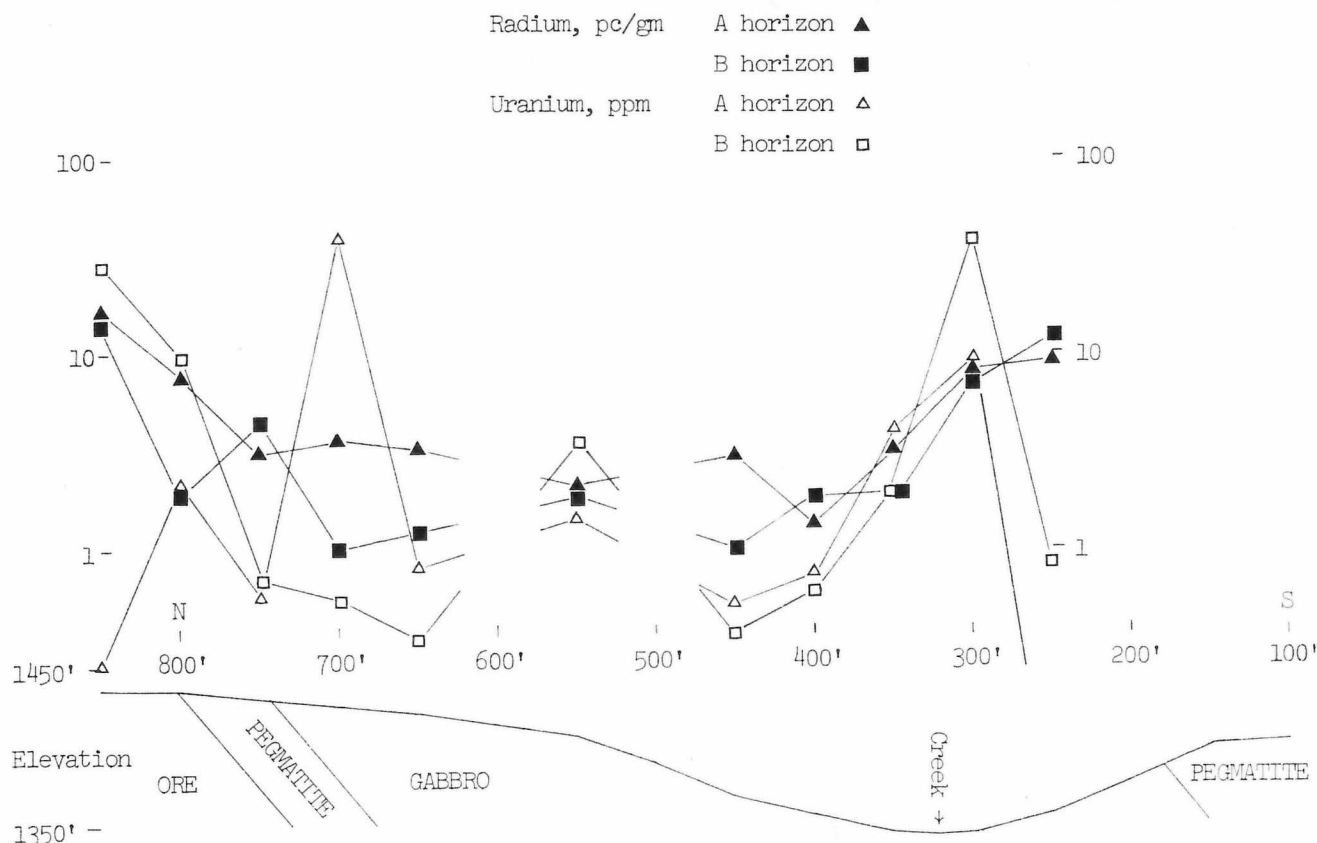


FIGURE 11 — Faraday West Soil Line.

fifteen-fold. Uranium in the A horizon does not indicate the presence of the pegmatite. The two-fold increase in uranium in the A horizon directly over the uphill edge of the pegmatite could easily be due to sampling error (Morse, 1970).

Response to the downhill contact of the pegmatite is marginal. Values drop slightly at 50 and 100 feet south. Apparently, material has moved from the pegmatite all the way to the south end of the line.

Points 300 and 350 feet south are covered by a swamp, and a spring rises between them. The B horizon is not present. Both uranium and radium values in the black organic soil at this point are extremely high. This may simply be an example of the affinity of both elements for organic matter. On the other hand, the high values may be a direct reflection of the spring. A diamond drill hole near the spring provides a path by which ground water might be communicating with orebodies.

The surface at the Faraday west line drops from north to south until near the south end, where it starts up a small hill. Orebodies and pegmatites are less regular in this part of the mine than elsewhere, and contacts shown in *Figure 11* may be misplaced by 50 feet. The orebody shown is actually 50 feet east of the line.

High values at the north end of the line, except for uranium in the A horizon, are apparently related to the orebody. The uranium peak in the A horizon at 700 feet is unexplained. High radium values south of the intermittent creek are related to the pegmatite uphill. The fact that uranium values are lower at 250 feet than at 300 feet suggests that the uranium peak at 300 feet is related to the intermittent creek rather than to the pegmatite.

Some general conclusions are evident from *Figures 10* and *11*. Radium and uranium in the B horizon and radium in the A horizon are useful in detailed prospecting for uranium. Uranium in the A horizon bears no relation to bed-

rock and little to uranium in the B horizon or to radium. It has no application to detailed prospecting. In the B horizon, radium and uranium are equally useful. Should the A horizon be collected in a detailed survey, it should be analyzed for radium rather than uranium. A similar conclusion regarding weathered rock is reached below.

The usefulness of the radium and uranium levels of soils in intermediate-scale prospecting for uranium is established by a comparison of these levels in soils over mines with those in 'background' soils. Results of such a comparison at Bancroft (Morse, 1970) suggest that both elements are useful in both A and B horizons in intermediate-scale prospecting; that is, at a density of less than 200 samples per square mile.

RADIUM AND URANIUM IN WEATHERED ROCKS

Weathered surfaces of four outcrops were sampled, and the samples analyzed for radium and uranium (Table I), the purpose being to determine which element is more readily leached. The rocks were from areas mapped by Hewitt (1957) as syenite, metagabbro, granite and hornblende paragneiss respectively. Each sample was separated into two portions, a and b, ground and then dissolved with hydrofluoric, nitric and perchloric acids.

In all cases, ratios of ppm uranium to pc/gm radium are lower than the 2.93 which would be found in unweathered rocks at equilibrium. Clearly, uranium has been leached from these rocks more thoroughly than has radium. A minimum of two-thirds of the original uranium has been leached away; if some radium has been lost, then more than two-thirds of the uranium has been leached.

The high loss of uranium relative to radium from weathered rocks has an important application to uranium prospecting: outcrop samples should be analyzed for ra-

Table I — Radium and Uranium in Weathered Rocks

| Map Unit (Hewitt, 1957) | Sample Number | Portion | Uranium (ppm) | Radium (pc/gm) | Uranium Radium |
|----------------------------|---------------|---------|------------------|-------------------|-------------------|
| Syenite* | 31E1 3203 | a | 126 | 132 | .95 |
| | | b | 186 | 115 | 1.6 |
| Metagabbro | 31F4 3813 | a | <0.5 | 1.06 | <.5 |
| | | b | 0.6 | 1.26 | .5 |
| Granite | 31F4 3818 | a | 0.8 | 0.84 | 1 |
| | | b | 1.0 | 1.04 | 1 |
| Hornblende paragneiss | 31D16 3217 | a | <0.5 | .90 | <.6 |
| | | b | 0.9 | 1.14 | .8 |

*Sample collected from an outcrop of radioactive pegmatite near the Bicroft mine.

dium rather than uranium. Early prospectors in the Blind River area were confused by high radioactivity and low uranium assays (Lang *et al.*, 1962, pp. 128-29). "Joubin theorized that because exposures . . . were strongly radioactive but samples showed little uranium or thorium, these elements might have been leached from the outcrops, leaving strongly radioactive daughter elements." Had the outcrop sample been analyzed for radium rather than uranium, the confusion would not have arisen. Radium analyses are just as easy and give a much more accurate indication of the original uranium content than do uranium analyses. This does not apply where the uranium deposits being sought are appreciably less than a million years old and the uranium decay series has not yet reached equilibrium.

RECOMMENDATIONS FOR GEOCHEMICAL PROSPECTING

Recommendations for geochemical prospecting for uranium are summarized in Table II. Material to collect and elements to determine are indicated for three sampling densities.

At the early reconnaissance stage (less than one sample per 2 square miles), drainage surveys should be used. Sediments give better results, but lake waters are often cheaper to collect. Clastic sediments should be collected wherever possible and organic sediments otherwise. A correction must be applied before showing results for organic and clastic sediments on the same map. Either radium or uranium can be used, with equal success. If waters are used, the choice between radon and uranium should be based on logistics. If a small lab can be set up in the field, then radon can be used; otherwise, uranium must be used.

At the later intermediate stage (0.5 to 200 samples per square mile), sediments are preferred. If rapid analytical feedback is imperative, then stream or pond waters can be collected and analyzed for radon. If drainage is lacking, then the A or B horizon of soils can be used. In sediment and soil surveys at this scale, radium and uranium are both useful. Clastic sediments are more useful than are organic sediments.

At the detailed prospecting stage (more than 200 samples per square mile), sampling is denser than the drainage system allows. The B horizon of soils may be analyzed for radium or uranium. If the A horizon is sampled,

TABLE II — Recommendations for Geochemical Prospecting

| Scale of Survey and Sampling Density | Material Sampled | | Element Determined |
|--|---|-----------------------|---|
| Reconnaissance < 1 sample per 2 sq.mi. | Sediments preferably if they can be collected cheaply | Clastic preferably | Radium or uranium |
| | | Organic if no clastic | Radium or uranium |
| | Lake water if sampling by aircraft | | Radon if a small field lab possible; uranium if not |
| Intermediate 0.5 — 200 samples per sq.mi. | Sediments preferably | Clastic preferably | Radium or uranium |
| | | Organic if no clastic | Radium or uranium |
| | Water if rapid analytical feedback is imperative | | Radon |
| | A or B horizon of soil if no drainage; density greater than for drainage samples | | Radium or uranium |
| Detailed > 200 samples per sq.mi. | Soil | B horizon | Radium or uranium |
| | | A horizon | Radium |
| | | Soil gas | Radon |
| | Plants | | Uranium has been used; suggest try radium |
| | Weathered rock | | Radium if older than 1 million years; uranium if younger |

then only radium can be used. Soil gas can be analyzed for radon at the sample location (Dyck, 1968), but the results of this technique have not been compared with the methods considered here. Uranium in plant parts has been used (Hawkes and Webb, 1962, p. 376). The use of radium in plant parts is suggested but has not been tried. If weathered rock is collected, and if the uranium minerals are older than about a million years, then radium analyses are highly preferable to uranium analyses.

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