

Willy Dyck

Abstract

The elements of the ^{238}U decay series of interest in geochemical exploration are uranium, radium, radon, and helium. Each element has specific radiochemical and/or geochemical properties which make it a useful tracer for uranium ore deposits.

Uranium is easily oxidized to the hexavalent state in the presence of oxygen in natural waters. Its mobility in surface waters is enhanced by the complexing action of carbonates in neutral and basic waters, of sulphates in acid waters, and of silicates in neutral waters. Organic matter adsorbs uranium strongly and is responsible for decreasing migration of the UO_2^{2+} ion in natural waters. The effect of complexing and adsorption of uranium in natural environments explains some of the results of field surveys carried out by the Geological Survey of Canada in Bancroft, Ontario and Beaverlodge, Saskatchewan areas.

The hydrogeochemical techniques employing radium and/or radon are best suited to detailed or semidetalled investigations of radioactive occurrences. Their ease of detection and short range make them excellent tracers for pinpointing uranium occurrences or outlining radioactivity too weak for the gamma-ray spectrometer or the fluorimeter.

Helium and radon in well waters in the National Capital region correlate well with the geology. Radon highs correlate with the Precambrian igneous and metamorphic rocks and except for one instance also with the March member of the March-Oxford Formations of Lower Paleozoic age in which surface radioactivity near South March and Marchhurst has been found. Helium highs coincide with the outcropping sandstones of the Rockcliffe Formation.

Introduction

Uranium is once more the "in" metal and can be expected to remain "in" for longer than it has at any time in the past. The energy crisis will see to that, unless, of course, vast new oil pools are discovered quickly.

There is probably more written about uranium than any other element. No doubt its potential for war and peace is responsible for this concerted effort. As an energy source, independently of oil, it can maintain and even improve our standard of living in spite of the prophets of doom who see only the dark side in man's efforts to use the earth. Although nuclear and thermal pollution are problems — they are soluble.

It is the business of the prospector to find this precious metal — uranium. Geochemistry is one way. This paper reviews the main radiochemical and geochemical principles which make possible the detection of uranium in the natural environment and illustrates with field tests where possible.

Radiochemical and Geochemical Principles of Uranium and its Decay Products

Pure uranium consists of two isotopes; ^{238}U (99.3 per cent) and ^{235}U (0.7 per cent). It is actually that little bit of ^{235}U that turns our Canadian heavy water nuclear reactors on. Both uranium isotopes have nearly identical physico-chemical properties and hence are never found separate in the natural state. Furthermore, their per cent abundance is quite constant. Recently, however, for the first time an ore deposit in Africa reportedly has only 0.4 per cent ^{235}U and there is evidence that this orebody was a natural reactor at one time. Each isotope decays to lead through a number of discrete transformations and characteristic half-lives by the emission of several radioactive alpha and beta particles and gamma rays. For the exploration geochemist ^{235}U is of no importance. Unless specifically mentioned the subsequent discussion will refer to ^{238}U only.

The principal decay products of ^{238}U are shown in Figure 4.1. The elements of interest to the exploration geochemist are accentuated by heavier boxes. The Ra-Rn couple is easily detected and quite specific for uranium. The third naturally occurring radioactive series, ^{232}Th , also is of interest. The other elements in the series are difficult to detect, have too short a half-life, or are not specific for uranium to be of use in geochemical exploration. The various characteristic gamma rays emitted by the various decay products and the branching decay modes of several of the products are not shown in Figure 4.1. These characteristic radiochemical properties of the decay products of ^{238}U make it relatively easy to detect the element with high precision at low concentrations provided the whole chain remains intact. Thus, the principal gamma ray of 1.76 Mev emitted by ^{214}Bi is used in gamma-ray spectrometry to identify uranium.

Weathering usually causes some disproportionation particularly in the surface environment. The main reactions of ^{238}U and ^{226}Ra in the surficial environment are listed in Figure 4.2. The first reaction occurs everywhere in the solid phase and is partly responsible for the occurrence of pitchblende, the mineral with a varying composition of UO_2 and UO_3 depending on the age and preservation of the mineral. In addition to making it easy to detect uranium the radioactivity also disrupts the crystal structure in which the uranium is bound and hence permits water and oxygen to enter and oxidize UO_2 to UO_2^{2+} . This species, in neutral or basic waters, complexes easily with carbonate ions and forms soluble silicates, and in acid media, complexes with sulphate ions. In areas of intensive vegetation, humic acids either in solution or in the sediments of lakes and streams strongly complex with uranium. Most of the uranium is found in the sediments because

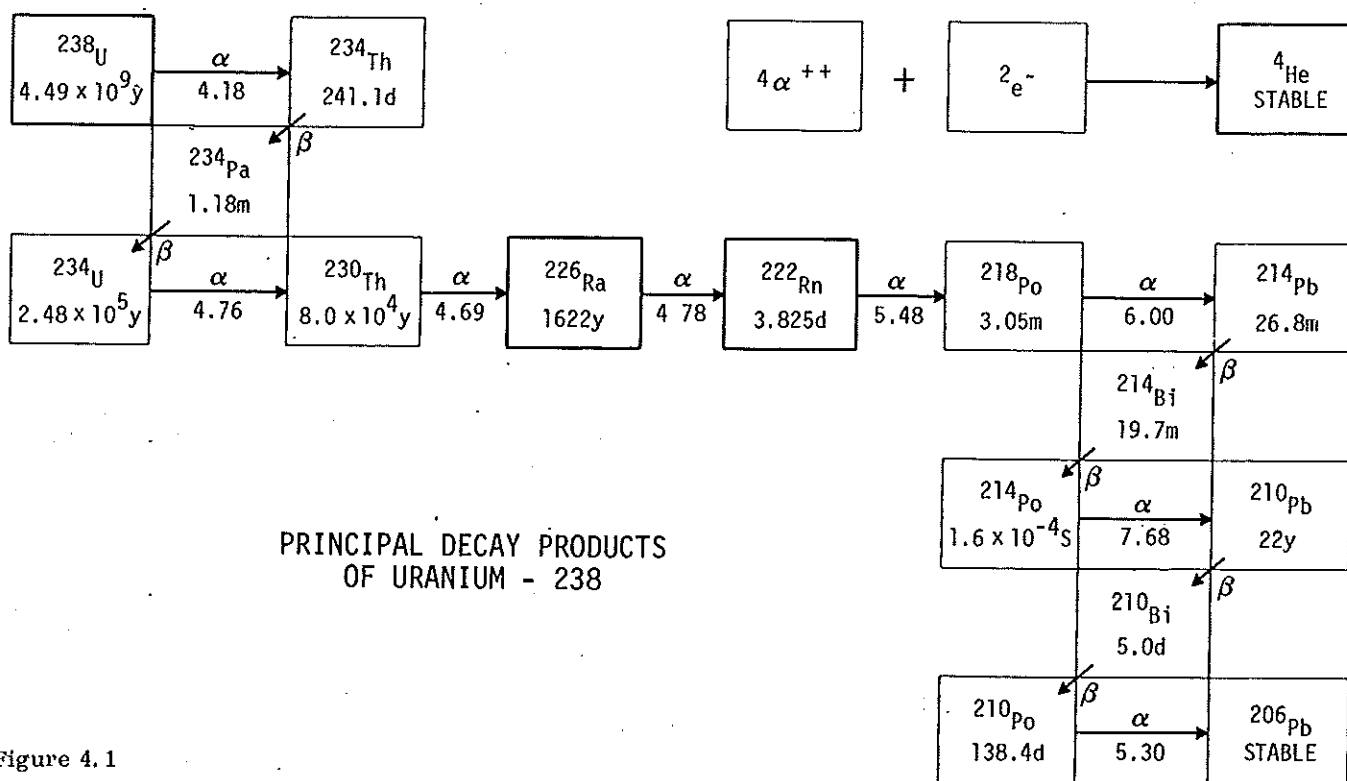


Figure 4.1

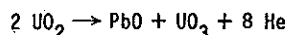
of the larger amounts of organic matter in the sediments relative to that dissolved in water. As a result of the ease of oxidation and complexing of uranium its mobility or range in the surficial environment is relatively large compared to almost any other trace element. Radium, on the other hand, forms insoluble compounds with the ever present carbonates and sulphates and it is only in the presence of chlorides that it becomes more mobile. Radium, however, will move long distances by successive adsorption and desorption on the walls of water channels even at very low concentrations and with time an appreciable radium concentration will build up. This build-up becomes particularly noticeable at the mouth of springs where iron and manganese precipitate upon oxidation coprecipitating radium.

Radium and helium are chemically inert. They belong to the noble gas family. Radon because of its relatively short half-life of 3.8 days is closely tied to radium, its immediate parent. Its range, as a rule, is not much greater than that of radium. Tests indicate that radon can move up to 6 m in soils and less than that in still waters, but in moving waters, such as streams or lake surfaces, its range can be 100 to 200 m beyond that of radium. Helium is very light and therefore diffuses rapidly, and, as a result, near surface soil gases have atmospheric helium concentrations even over weakly radioactive zones which are easily picked up by the radon method.

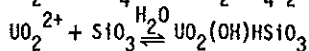
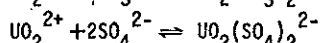
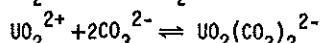
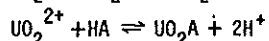
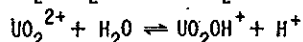
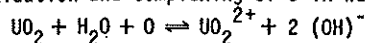
Idealized profiles of these four elements of the uranium series over a deposit are shown in Figure 4.3.

The relative intensity scale is rather subjective and may apply only under certain conditions. The offset from the vertical is meant to illustrate the downslope movement of soil and water over the deposit. One can present a number of arguments for deviations from this norm. Thick overburden, particularly clays, can effectively seal off the deposit and leave no surface expression over the deposit. In such instances drilling to bedrock is necessary. But even minute movement of groundwater between overburden and bedrock can result in an anomaly some distance downslope if the water comes to the surface or enters wells. As indicated in Figure 4.2, uranium is quite mobile in an oxidizing environment and hence will produce extensive weak haloes when the water regime is active. Radium being much less mobile will focus sharply and more intensely over the deposit. Radon will extend the radium range but seldom by more than 100 m. Radon is rather closely tied to radium because of its short half-life. The relative sharpness of the anomaly for radium and radon is due to the low mobility of radium and the high sensitivity of the method of detection, namely individual alpha particle counting. Ideally, helium should have the largest range but because of its great mobility it dilutes rather quickly near the surface to a concentration level which is indistinguishable from atmospheric air. In groundwater systems sealed from the atmosphere, however, a rather long path for helium could be expected. The fact that considerable quantities of helium are found in natural gas pockets confirms this postulate.

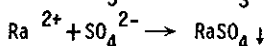
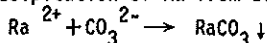
1. Self oxidation of uraninite



2. Oxidation and complexing of U in water



3. Precipitation of Ra from solution



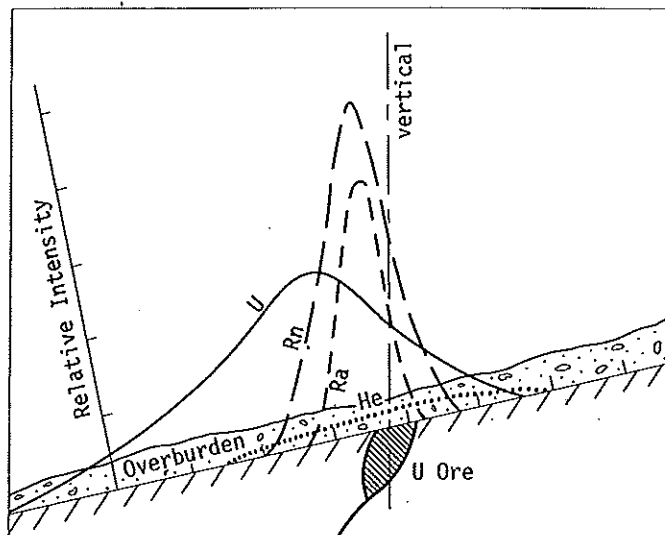
4. Rn and He are inert chemically

Figure 4. 2.

Hydrogeochemical Methods of
Prospecting for Uranium

Regional and semidetalled surveys

To illustrate the geochemical principles summarized in the previous section, the results of a number of field tests carried out by scientists of the Geological Survey of Canada are presented below. Most of the work is published hence only brief reference to the highlights will be made here. Hydrological techniques, particularly those employing surface lake and stream waters, are well suited to large parts of the Canadian Shield; this becomes evident at once by glancing at the map. The distribution and range of uranium and radon in surface lake waters in the Beaverlodge area are shown in Figures 4. 4 and 4. 5, respectively (Dyck *et al.*, 1970). The uranium still zeros in on the Beaverlodge Camp even at the low sample density of 1 sample per 12 square miles, whereas radon already loses coherency at a sample density of between 1 sample per square mile and 1 sample per 5 square miles. The effect of organic matter and limestone on the uranium content in stream sediments and waters is shown in Figure 4. 6. While the anomaly pattern is affected little by applying a correction to the uranium content depending on the amount of organic matter present in the sample, the size of the anomalies are reduced. Humic acids in organic matter strongly complex uranium and when these sink to the bottom they carry with them the uranium which would otherwise be in solution. In areas of intense vegetation the range of uranium in the surface water systems is reduced noticeably. Sampling densities, therefore, have to be adjusted to allow for this factor. A good example of the effect of carbonate



Idealized profiles over a uranium deposit

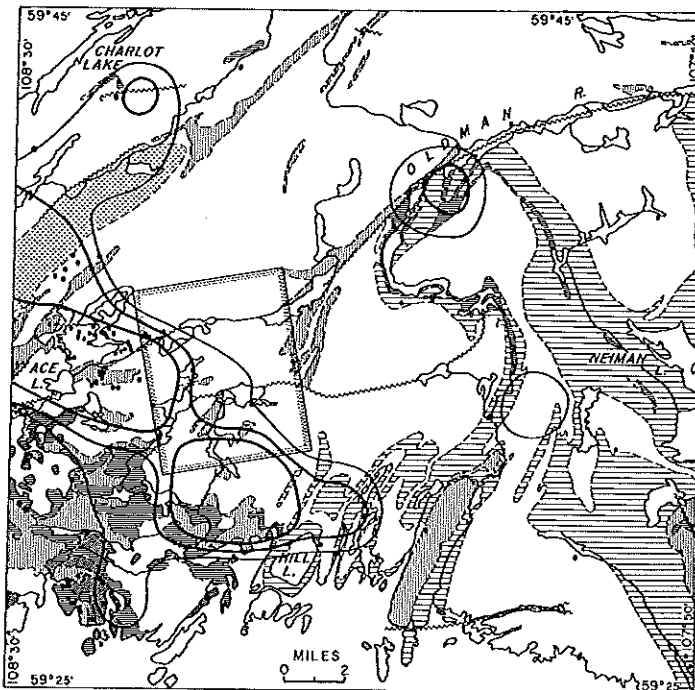
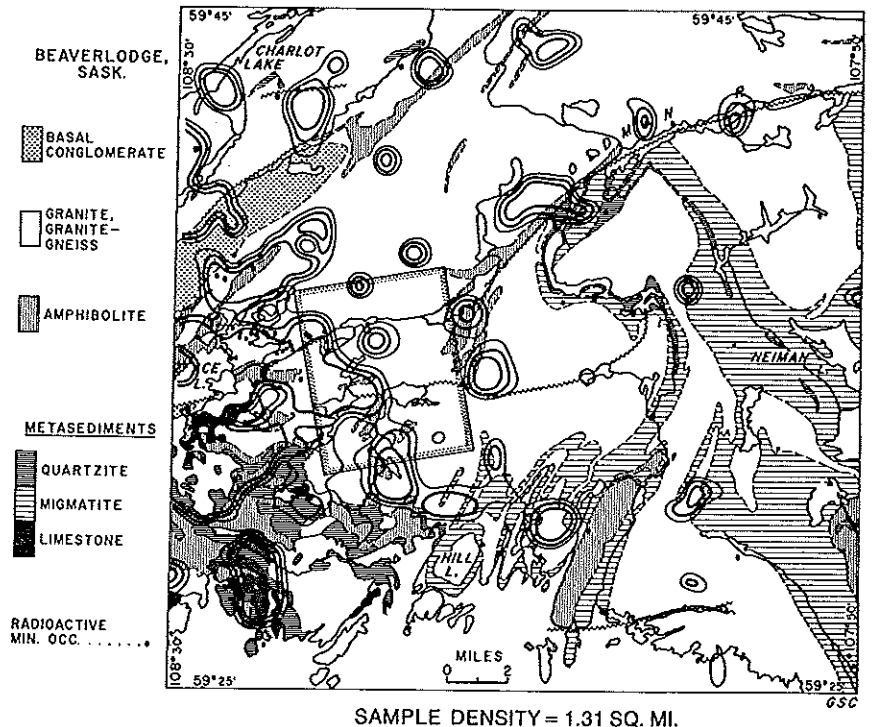
Figure 4. 3

ions complexing uranium is evident in the southwest corner of the map-area shown in Figure 4. 6. This is the only area containing carbonate rocks with the result of a much enhanced uranium content in the stream waters and a correspondingly suppressed uranium content in the sediments.

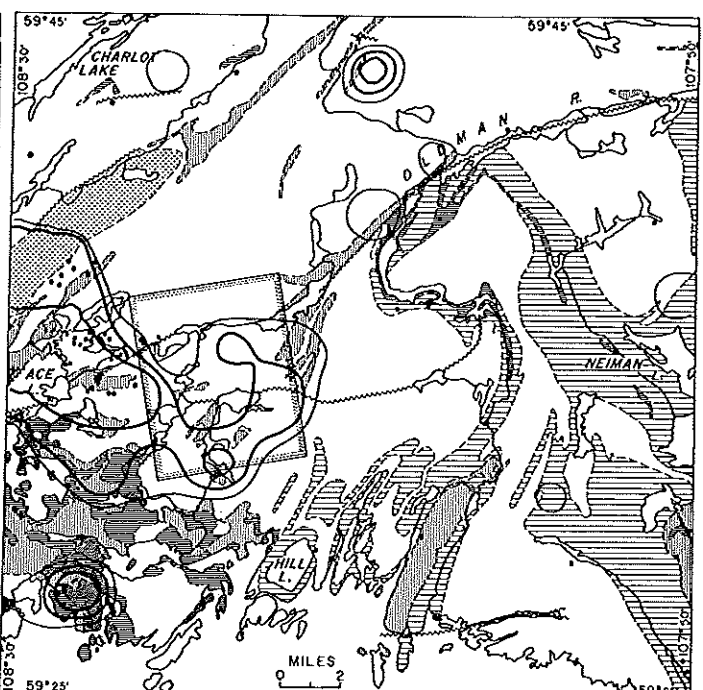
The uranium and radon maps of stream waters of the Bancroft area produced by A. Y. Smith in 1968 (Boyle *et al.*, 1971) show the relative ranges of the two elements fairly well. A large uranium anomaly downstream from the actual occurrences indicates its greater mobility in water. No doubt the carbonates in the area enhance this mobility. Radon on the other hand is confined to the radioactive zones, and hence points out its potential for more detailed work. Since radon is so closely linked to radium it is not surprising that Morse (1969) got equally good results by analyzing stream sediments for radium.

During the summer of 1974, Dyck and Cameron (1975) carried out a semidetalled radon-uranium survey of the uranium anomaly mapped out by Allan and Cameron (1973) during the geochemical reconnaissance of parts of the Bear-Slave province. This anomaly had shown up clearly at a lake sediment sampling density of 1 sample per 10 square miles. The lake water uranium and radon survey was carried out at a density of 1 sample per square mile. The results are shown in Figure 4. 7. Both elements outline new highs within the original anomaly. No mineralization was discovered in a one day ground follow-up in this area but the results illustrate the usefulness of the hydrogeochemical technique in reducing areas of search in successive steps involving smaller areas with increased sampling densities.

Figure 4. 4. Uranium in surface lake waters, Beaverlodge, Saskatchewan, 1969.



SAMPLE DENSITY = 1/12 SQ. MI



SAMPLE DENSITY = 1/5 SQ. MI.

Figure 4.5. Radon in surface lake waters, Beaverlodge, Saskatchewan, 1969.

BEAVERLODGE,
SASK.

BASAL
CONGLOMERATE

GRANITE
GRANITE-
GNEISS

AMPHIBOLITE

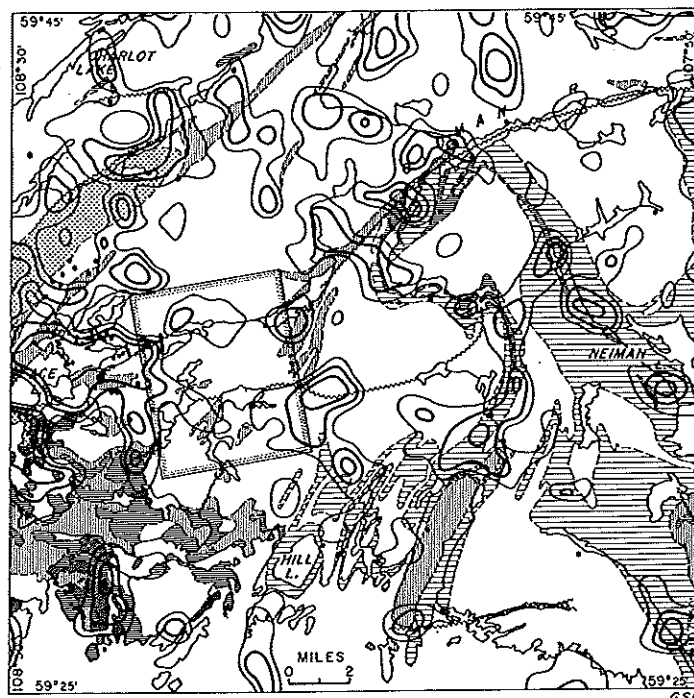
METASEDIMENTS

QUARTZITE

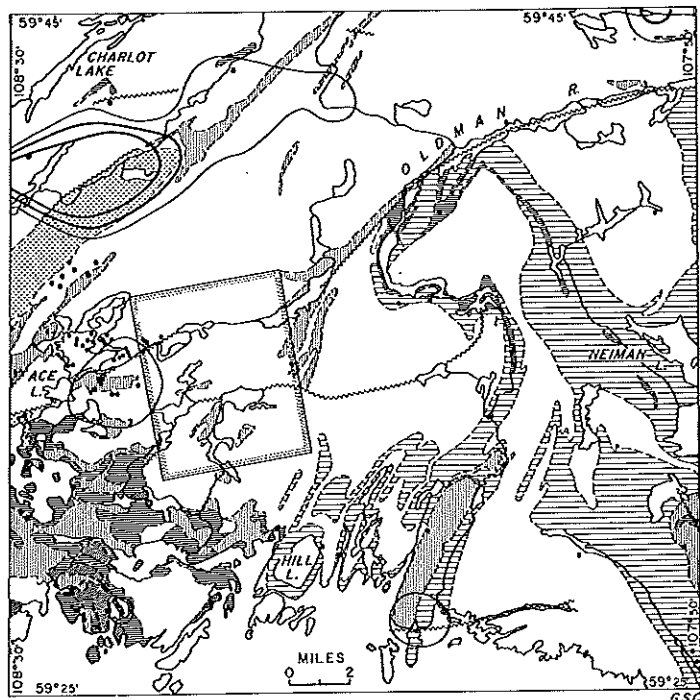
MIGMATITE

LIMESTONE

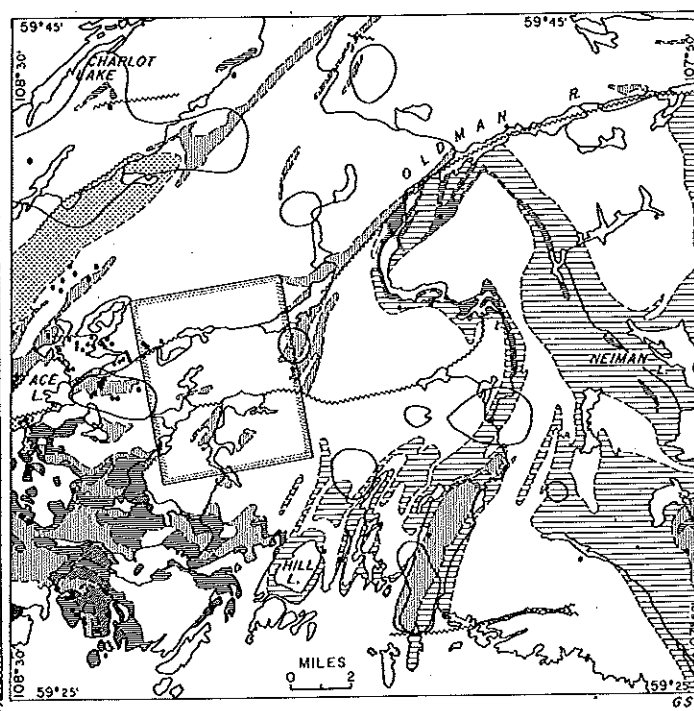
RADIOACTIVE
MIN. OCC.



SAMPLE DENSITY = 1.31 SQ. MI.



SAMPLE DENSITY = 1/12 SQ. MI.



SAMPLE DENSITY = 1/5 SQ. MI.

Figure 4.6. Effect of organic matter and limestone on the uranium content of streams in the Beaverlodge area, Saskatchewan, 1969.

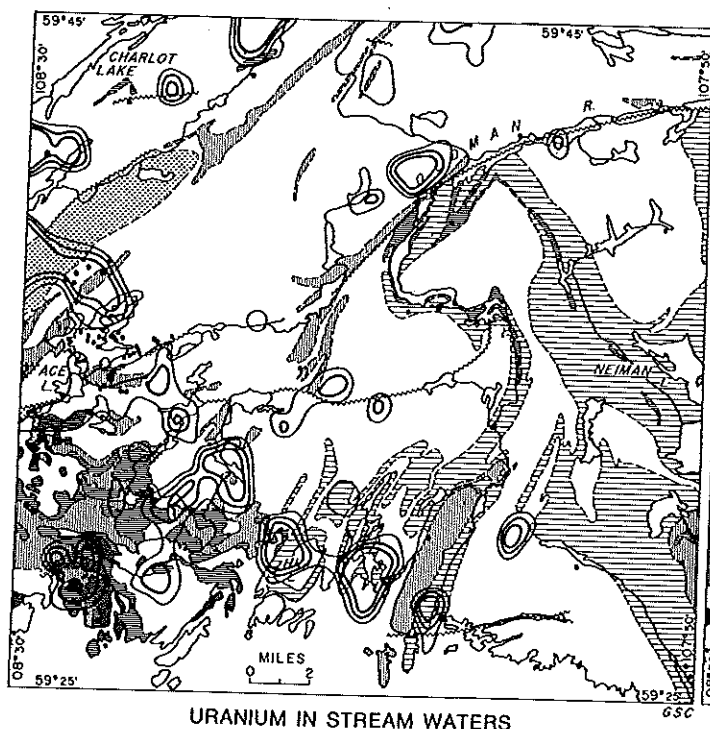
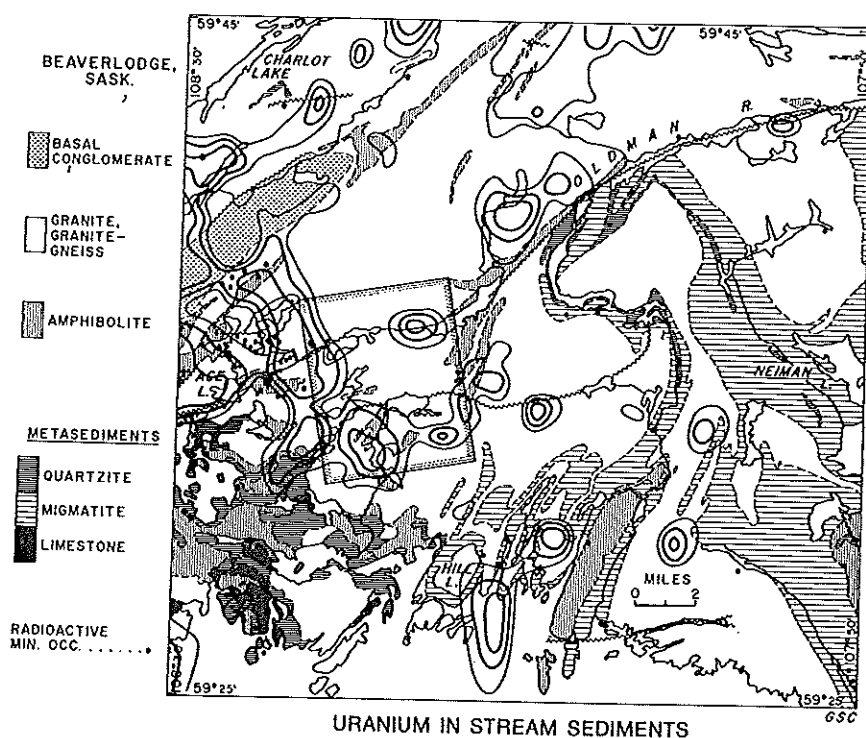
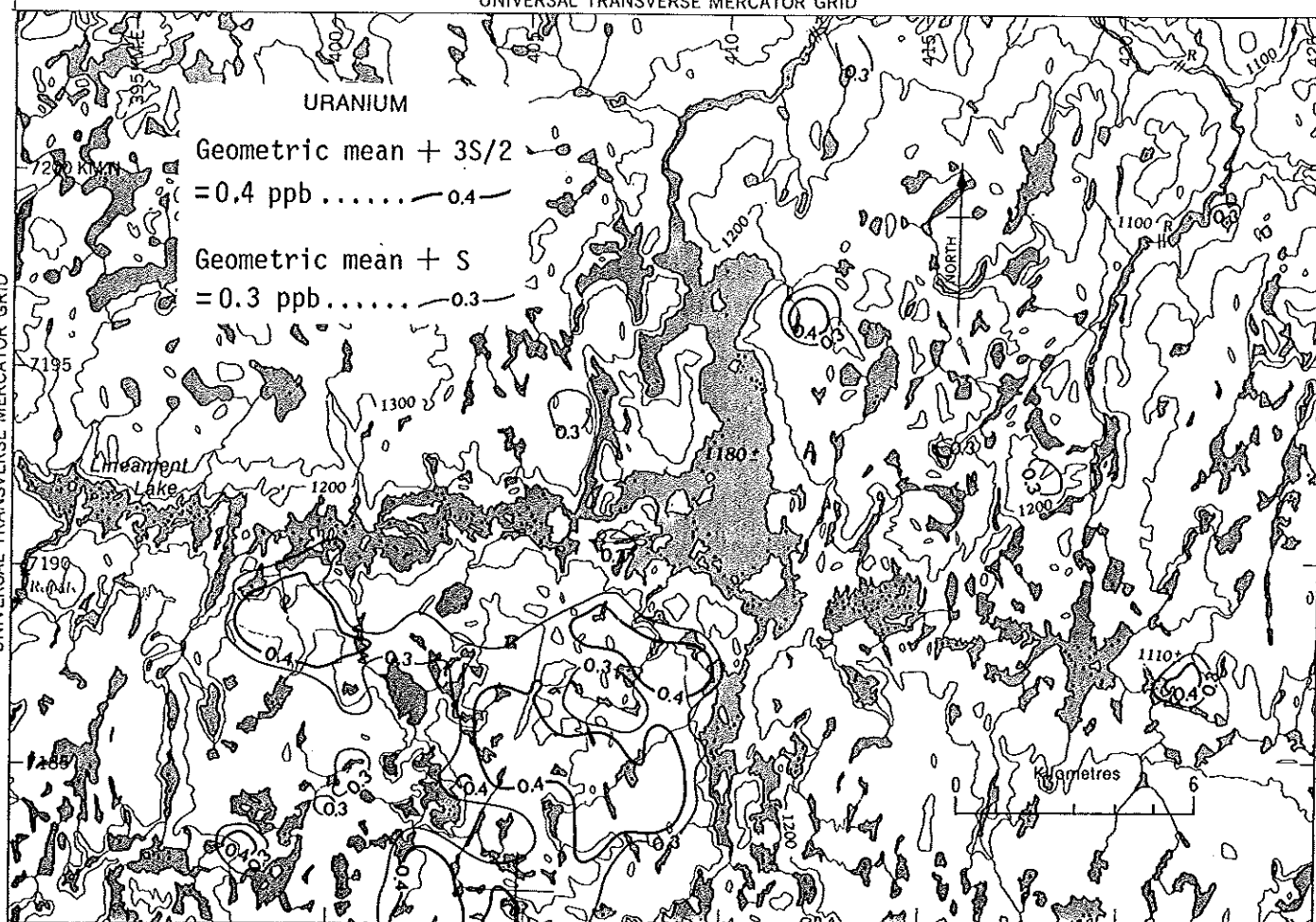
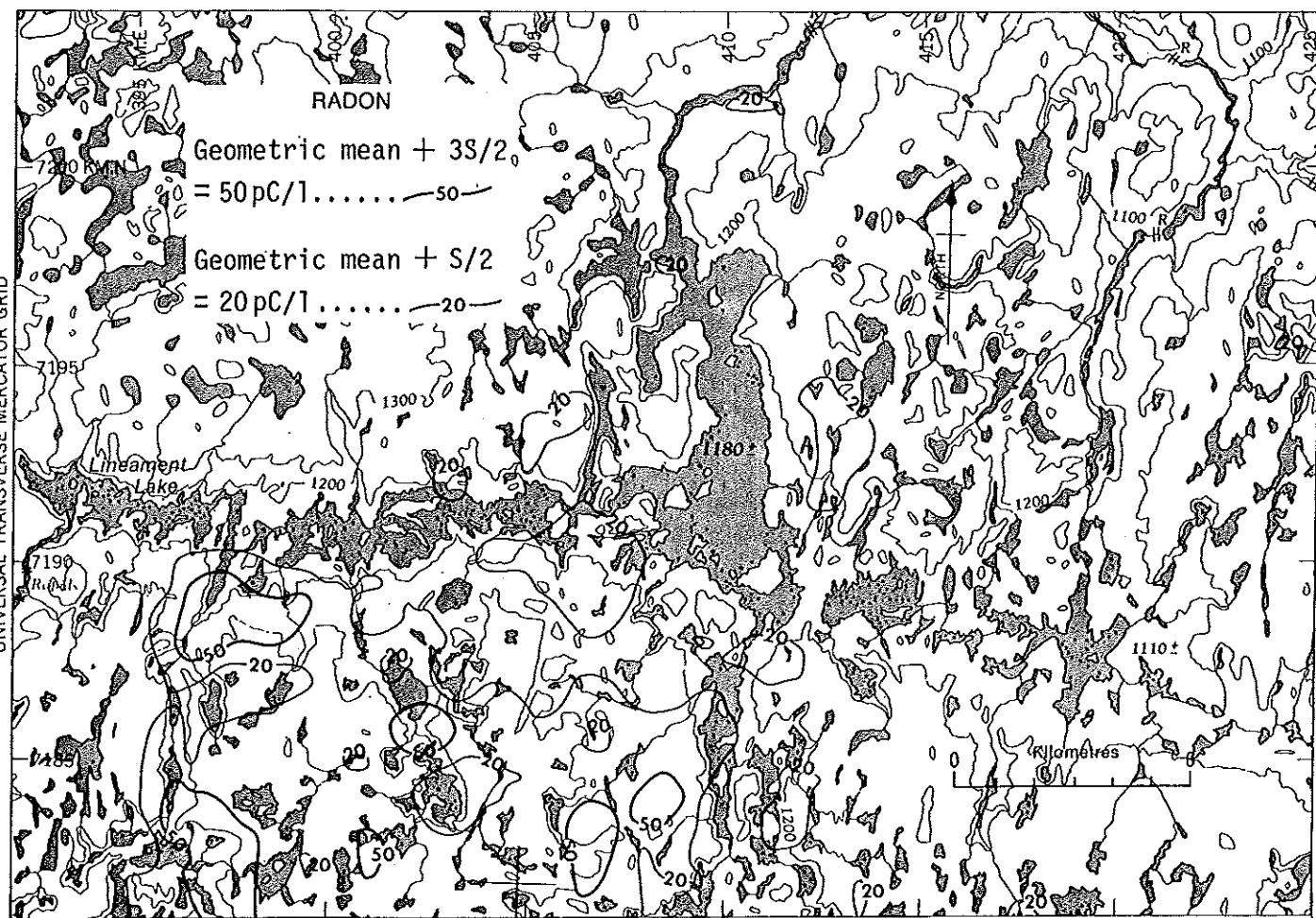


Figure 4.7. (opposite) Radon and uranium in surface lake waters, Lineament Lake geochemical survey, 1974.

UNIVERSAL TRANSVERSE MERCATOR GRID



UNIVERSAL TRANSVERSE MERCATOR GRID



It should be pointed out that while radon and uranium in water surveys are perfectly adequate for outlining uraniferous areas and pinpointing mineralized zones they have a drawback relative to sediments; namely, radon decays and uranium may disappear into the wall of bottles upon long storage. A sediment, on the other hand, can be analyzed for a number of elements besides uranium at some future date. Since sample collection is a major part of the total cost of a geochemical survey it makes good sense to collect sediments. Collecting water samples, however, is a great deal

faster than collecting sediment samples; a good crew can take 25 to 30 water samples per hour compared with 12 to 15 sediment samples per hour using a turbine helicopter.

The method of using radon and helium concentrations in well water surveys is still in the experimental stage. Figure 4.8 shows the results of a survey in the National Capital region, with samples collected as recently as January 1975. No attempt has been made to correct for variations in well depth or type of pumping system. A clue as to the effect these variables

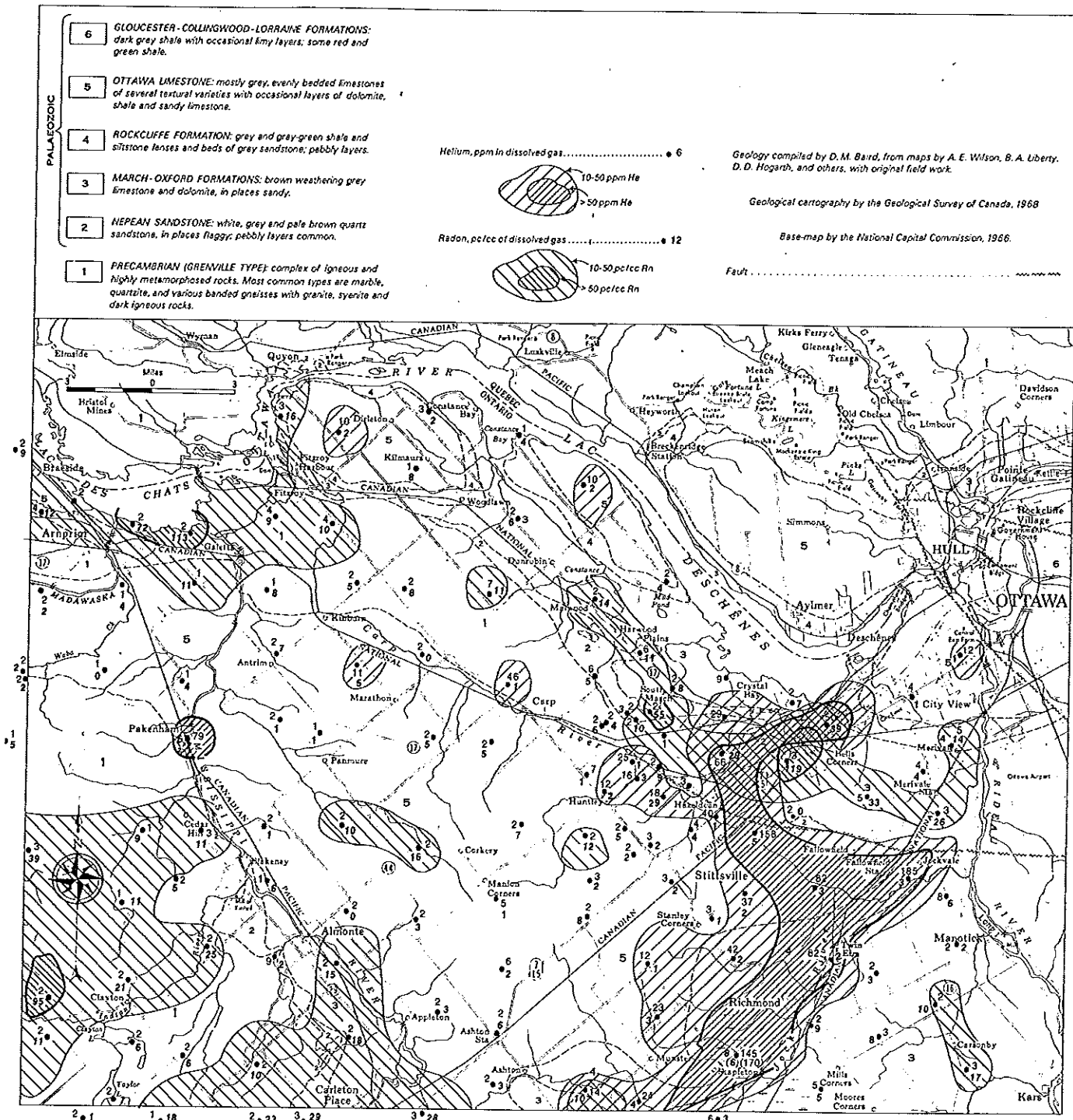


Figure 4.8. Helium and radon in wells of the National Capital region.

have on the concentration of helium and radon is found in the oxygen content of the water. It is a measure of the combined effects of automatic volume control which bleeds atmospheric air into the pressure systems, nearness to surface waters, and intensity of oxygen consumption in the groundwater. All that can be said at this point is that of the 130 samples tested so far none with a high oxygen content have had above background helium levels. Samples with no oxygen or low oxygen contained background or anomalous helium levels. Broadly speaking the radon highs coincide with the igneous rocks and/or the limestones of the March Formation clustering around the southeasterly-trending tongue of Ottawa limestone. An unmistakable helium high appears roughly coincident with the grey-green shales and sandstones of the Rockcliffe Formation and tapers out in the limestones and dolomites of the March-Oxford Formations. The northerly trending helium anomaly suggests an aquifer which drains into the Ottawa River at Graham Bay. The author does not wish to imply that these helium values are indicative of uranium ore but believes that roll-type uranium ore deposits, for example, should produce helium haloes which could move considerable distances in groundwater channels under the right conditions and hence be detectable by sampling well waters on a regional scale. There are several weakly radioactive surface showings at the contact of the March and Nepean Formations in the South March area which have been described in several reports: Grasty *et al.*, 1973, Steacy *et al.*, 1973, and Jonasson and Dyck, 1974. Both radon and helium in the wells increase in content between Bells Corners and South March. At this time one can only postulate mechanisms for the increased helium content. It is known that anomalous radon is closely related to uranium mineralization but the source of helium is not so easily established. It can and does move large distances through porous formations and can come from great depths along fractures. Natural gas and oil pools attest to this. While atmospheric air contains 5 ppm and gases in surface waters in equilibrium with air 2 ppm, some natural gas wells contain as much as 8 per cent helium (Lipper and Wilcox, 1960). Gases in spring waters from the Canadian Rockies contain 1.4 per cent helium and in Tanzania a spring gas contained as much as 17.9 per cent helium (James, 1967). By comparison the helium content of gases from waters in or near uranium deposits in Elliot Lake can reach 5.7 per cent (Dyck, unpublished). Russian scientists report up to 2.7 per cent helium in such gases (Shukolyukov and Tolstikhin, 1965).

Detailed investigations

The hydrogeochemical method of prospecting for uranium deposits mainly employs the elements uranium, radium, and radon in natural waters and is well suited for detailed investigations. Helium, because it is expensive, too difficult to measure, and even more difficult to interpret, has not been used often in uranium exploration. In Canada, surface waters have been used almost exclusively, but in Russia groundwater

have been used quite extensively and profitably. Under favourable conditions this method can detect uranium deposits at considerable depth. In mountainous terrain this method can detect deposits buried 300 to 400 m and in foothill regions 50 to 70 m (Novikov and Kapkov, 1965). The interpretation of results of hydrogeochemistry are rather difficult because the results depend on so many environmental factors including climate, chemistry of the elements, geology, mineralogy, hydrodynamics, etc. of the region. Of utmost importance is the background concentration of the elements in an area. In northern climates and mountainous regions a uranium concentration of 10^{-6} g per litre may be anomalous, whereas in arid regions evaporation of water will give backgrounds of the order of 10^{-4} g per litre. In zones of intensive oxidation (high eH) uranium is leached from rocks; in zones of reduction (low eH) uranium is precipitated from solution. Waters from acidic rocks enriched in uranium are more radioactive than waters circulating in rocks of basic composition. Waters with intensive circulation and intensive outflow are weakly radioactive. Flow waters with a limited circulation tend to become mineralized and may become strongly radioactive. In mountainous areas with rugged relief, waters near the peaks are weakly radioactive but at the foot of mountains one can encounter highly radioactive springs even in the absence of uranium deposits. Hotsprings may be particularly misleading. Coming from a deep and reducing environment where uranium is immobile and radium mobile, the waters become loaded with radon from the radium which has deposited on the water channel walls and mouths of the springs at or near the surface. It is conceivable that the source of this radium may be ordinary rock situated miles from the hotspring.

The uranium content in water is also influenced by the total solids content or the main ion content of water such as HCO_3^- and SO_4^{--} . Carbonated waters will be enriched in uranium, especially in rocks with disseminated uranium. Sulphate ions will carry uranium in solution only in acidic waters. Evaporation in arid regions will lead to the concentration of salts and hence uranium and radium in water. Therefore a rise in the uranium content is of greater interest if it is based on total solids in water. A quick and useful approximation of total solids can be obtained by measuring the specific conductance of the water.

The extent of radioactive equilibrium between the three main elements of interest in uranium exploration is a useful guide in recognizing ore potential. In general the radon/radium ratio in waters is either one or greater than one. Because radon is a gas it is more mobile than radium. Radon, therefore, will enter the water phase while its parent remains trapped in the solid phase either as part of the mineral or as adsorbed ions on the walls of the water channels. In surface waters the radon/radium ratio is much greater than one; most of the radon in surface waters comes from the radium adsorbed on the sediments at the bottom of streams and lakes. The radium/uranium ratio in groundwaters is less than one under oxidizing conditions and greater than one under reducing conditions.

These ratios simply reflect the redox conditions in existence in any one environment. In surface waters where oxidizing conditions prevail the radium/uranium ratio is invariably much less than one.

In summary several criteria are given below which will help in deciding on the significance of radioactive anomalies in groundwater:

- (1) A threefold or greater increase in the content compared to the background of a region.
- (2) Occurrence of anomalous amounts of all four elements (Rn, Ra, U, and He).
- (3) Increased content of tracers such as molybdenum, lead, copper, zinc, arsenic, phosphorous, and vanadium.
- (4) A sharp rise in concentration of mobile radioactive elements after a rain or thaw period of up to ten times in the presence of uranium deposits; not more than four times in the absence of a uranium deposit.

Once a radioactive zone has been outlined by the techniques described above, detailed tests are required to detect the source of the radioactivity. Naturally the gamma-ray scintillometer plays a large part in these investigations. However, uranium and radon in waters and soils can be applied profitably, particularly in regions of persistent overburden. The zinc sulphide (silver activated) radon counter is more sensitive than the scintillometer; under favourable conditions mineralization at depths of 20 feet have been observed. The soil radon traverse obtained in Elliot Lake (Dyck, 1969) illustrates the use of the radon counter in soil tests. Other soil tests over radioactive pegmatites in the Gatineau Hills and in Bancroft have shown that the radon counter can be used advantageously to outline buried uranium mineralization. Tests over ore in the Bancroft area carried out by Liard and Phelan (pers. comm.) again show a clear soil radon signal over buried uranium mineralization which is stronger than the gamma-ray scintillometer signal. These tests are of special interest because they were carried out in the winter with snow and with frost in the ground. Soil radon tests, however, are not applicable nor are they successful everywhere.

For example, in Beaverlodge a soil radon traverse over the St. Louis Fault not far from the uranium mine at the edge of the town of Eldorado was essentially negative because the area as a whole has very little overburden and hence radon soil tests become difficult.

Recently a new radon detection method called the Track-Etch Technique has detected uranium ore at depths of several hundred feet (Gingerich, 1974). As radon cannot diffuse such distances migration of radon to the surface or underground pressure pulses forcing radon up at irregular intervals must be postulated to explain this depth penetration. Track-Etch has the advantage of integrating the radon signal over a longer period of time. It works on the principle of alpha particle track formation in photographic emulsions which are buried in the ground for a specified length

of time. Its disadvantages compared to the zinc sulphide (silver activated) radon counter are: its results are not available immediately, and the emulsions cannot differentiate between ^{222}Rn and ^{220}Rn , the Rn isotope of the ^{232}Th series.

In parts of Labrador and elsewhere, groundwater is very near the surface so that soil air is virtually nonexistent (Dyck, 1972; N.R. Newson, pers. comm.). In such instances detailed work is best carried out by measuring radon in the water.

Winters in Canada are rather severe and long. The question as to what happens to radon in or under ice frequently comes up. As a result of such enquiries a test was carried out in the winter of 1970 in the Gatineau Park. A hole was drilled through lake ice where a small radioactive pegmatite dyke juts into the lake. An unexpected complication arose when water was discovered between two layers of ice. The radon content of this water was appreciable, but much lower than in the main body of the lake suggesting diffusion through the ice or movement of water through cracks in the ice. About 20 water samples from the main body of the lake were taken in sixteen ounce plastic bottles, some were frozen immediately and kept frozen for a day; others were kept in the liquid state for a day; still others were analyzed immediately. The results showed clearly that samples in the liquid state lost appreciable amounts of radon in a day whereas the frozen samples retained essentially all the radon. The radon retentivity of ice makes possible radon surveys of lakes and streams in sub-zero temperatures using plastic bottles.

The diffusion of radon in soils has been studied by a number of authors. It is generally accepted that radon cannot move beyond about 20 feet in soils by true diffusion. In water the diffusion path seems to be even shorter. This is evident from the results shown in Figure 4.9. Both radon and uranium drop to zero within the top 10 to 20 feet and experience a rise within the bottom 10 to 20 feet. The behaviour of radon is easily explained by diffusion and decay - that of uranium is not.

The 1968 radon pattern is similar to that of 1971 although not quite the same spot was sampled (note the difference in depth). The source of radon and uranium are pegmatite dykes on the north shore of the lake. Natural flow and wind action moves the constituents across the lake and down to a certain depth. The radon concentration gradually goes to zero due to dilution and decay. Near the bottom radon diffuses from the sediments into the water until it is again depleted by decay and dilution. But uranium has a very long half-life and therefore cannot disappear by decay. And yet the uranium profile is similar to that of radon. The rise in uranium near the bottom can be due partly to carbonate complexing and partly to finely suspended organic matter which slowly settles out. But the increase near the top is difficult to explain unless one postulates a recent injection of uranium into the lake as a result of a flushout of uranium from the pegmatite dykes.

Helium could also become a useful tracer for uranium ore deposits during or after the drilling phase

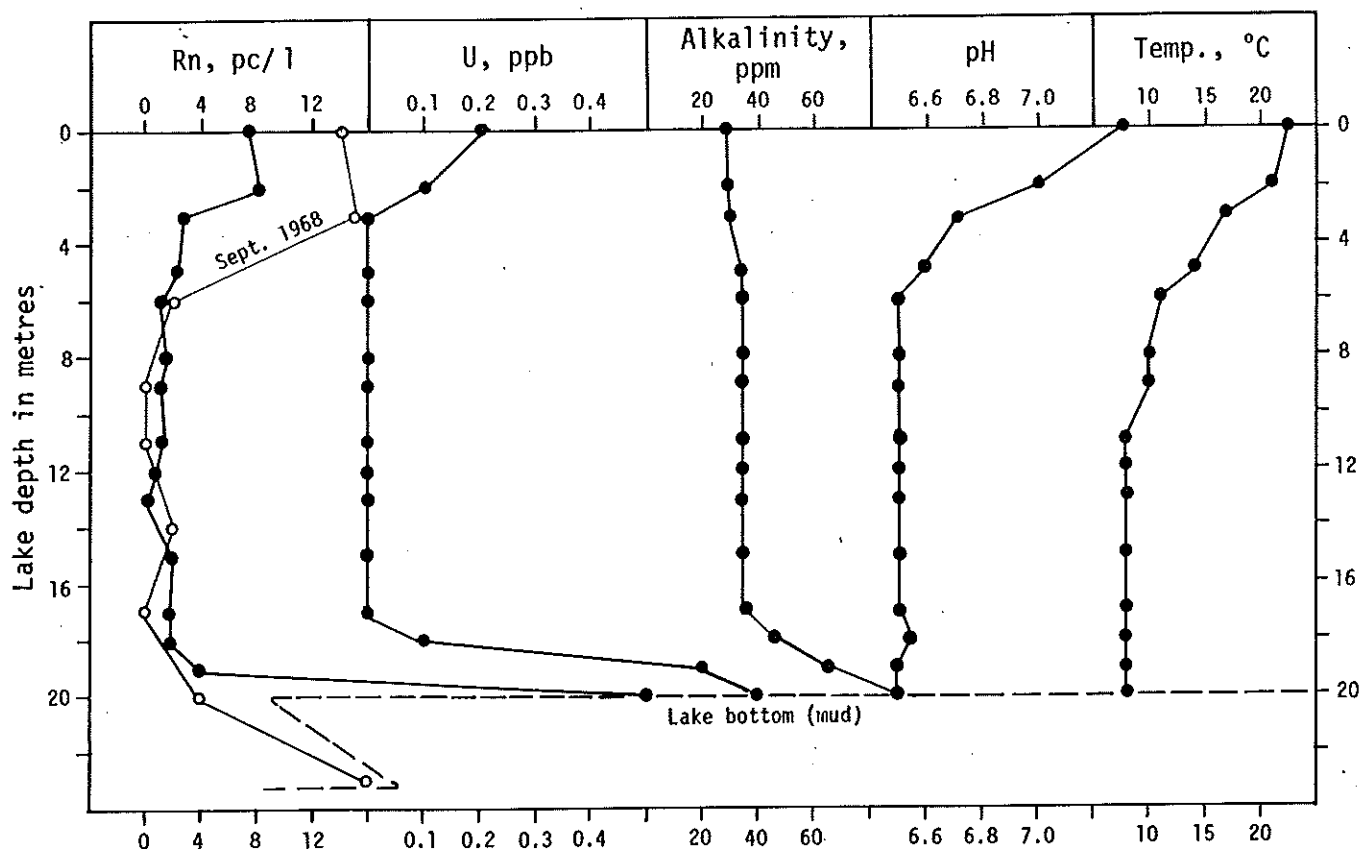


Figure 4.9. Vertical distribution of radon, uranium, alkalinity, pH and temperature in Fortune Lake, Gatineau Park, Quebec in July 1971.

of exploration. Its great mobility even in rocks suggests that drillholes in the vicinity of a uranium deposit would act as conductors of helium from the deposit and hence reveal the presence of ore even though the drill encountered only weak mineralization. Analysis of water samples from drillholes in radioactive zones show that helium does increase with an increase in uranium content but the relationship is not linear. There is no doubt that rock porosity and rate of ground-water turnover play an important role in the rate of loss of helium from the ore. Background information to evaluate the usefulness of helium in detailed uranium exploration has been collected by the author over the past two years.

At the end of May 1973, 46 water samples from 2 radon anomalies in the vicinity of Moncton, New Brunswick comprising 2 stream, 10 spring, 11 well, and 23 drillhole water samples were collected and analyzed. The anomalies occur in Pennsylvanian and Mississippian red sandstones, conglomerates, and minor shales. Radon concentrations of from 0 to 18 nanocuries per litre of water were encountered. Drillhole profiles from these anomalies suggest that one stems from a weak shallow radioactive zone as

indicated by decreasing radon with depth and showing only background levels of uranium and helium. The second anomaly gives increasing concentrations of radon, uranium and helium with depth, indicating greater uranium potential than the first. Both locations have a rapid turnover of water as indicated by the relatively high oxygen content. The presence of oxygen may also explain the lack of radium and hydrogen sulphide in the water samples; radium becomes extremely immobile and hydrogen sulphide is oxidized in an oxidizing environment. Only four samples contained less than 2 per cent oxygen; these were also the only samples with measurable contents of hydrogen, ranging from 0.1 to 1 per cent.

A drillhole in radioactive pegmatitic rock in the Gooderham, Ontario area was sampled twice in order to confirm the exceptionally high radon content in the water. The radon level was the highest encountered to date by the author, including drillholes on the old Bicroft Mine property near Bancroft, Ontario, and waste water and drillhole water in the Elliot Lake uranium mines. Yet the uranium concentration of bulk samples from this drill core did not exceed 350 ppm. In pc per litre of water the values range around

500 000. To maintain this radon concentration requires as many picograms of radium or 1500 ppm uranium in solution in equilibrium with its decay products. In actual fact the water samples contained not more than 160 ppb uranium and 170 pc per litre radium. So practically all the radon in the water originated from the radium in the rocks. To explain the high radon content in the water one can postulate (1) the existence of rich uranium ore within range of the drillhole and porous rock permitting the radon to diffuse onto the water; or (2) the accumulation of radium on the walls of the hole or in cracks nearby through which radon can move onto the drillhole with the groundwater. The relatively low helium content of the water samples seems to preclude the existence of large amounts of high grade ore unless one further postulates rapid loss of helium by diffusion. If that were the case in this drillhole, however, a helium gradient should be evident. Even though the helium content in the dissolved gas is relatively low (12 to 42 ppm) it is 6 to 21 times larger than that in surface waters.

A weaker radioactive zone nearby drilled many years ago gave much lower radon and helium values in the drillhole waters reaching a maximum of 420 pc per cc and 20 ppm helium in the dissolved gas.

On a third radioactive showing in the same general area as the above two, 8 drillholes were sampled. Drill core analyses for uranium give a maximum of 0.18 per cent U_3O_8 . The relatively high helium and radon and radon contents (up to 384 ppm and 6000 pc per cc in the dissolved gas or 12 ppm helium and 160 000 pc per litre radon in the water) also suggest near ore grade material comparing these values with values found in drillholes of known uranium mines. It should be pointed out though that the highest values of helium and radon came from the same drillhole but the higher U_3O_8 content from another. More detailed correlative investigations are required to evaluate the usefulness of helium in detailed uranium exploration.

Conclusions

Geochemical surveys and field tests over the past six years have shown that uranium, radium, and radon are useful pathfinders for uranium ore deposits. The techniques employed are based on sound radiochemical and geochemical principles.

Uranium, because of its high mobility in the oxidized state, moves relatively large distances in the surficial environment along drainage sheds, making possible regional surveys of large tracks of land. Major geochemical provinces or larger near surface uranium deposits may be outlined with lake water or sediment sample densities as low as one per 10 square miles. In regions of dense vegetation sample densities of one per 3 to 5 square miles may be required because of the strong adsorption of uranium by the organic rich sediments.

Radium and radon, because of their much shorter ranges than uranium in the surficial environment, are more suitable for detailed or semidetailed exploratory work. In swampy, wet terrain radon in streams or

groundwaters may be used; in dry porous soils radon is suitable.

Recent tests with helium and radon in well and drillhole waters indicate that they will become useful regional tracers for uranium ore deposits in flat-lying sedimentary strata. Cost of analysis and difficulty of interpretation of helium results are the main deterrents to its wider use in uranium exploration at the present time. The potential of helium as a tracer for underground structure seems good.

Although any one of the four elements uranium, radium, radon, and helium can, under favourable conditions, reveal the existence of an ore deposit, it is usually a matter of probabilities. This probability increases every time another indicator over a prospect is positive.

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