HYDROGEOCHEMISTRY OF URANIUM
IN THE BANCROFT-HALIBURTON REGION,
ONTARIO

The field hydrogeochemical laboratory

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By

J. A. Chamberlain

PREFACE

The amount of uranium present in natural waters is to some extent a reflection of the uranium content of associated rocks. The intimate penetration of such rocks by circulating waters suggests a technique in prospecting for uranium deposits that may have been overlooked.

The Bancroft-Haliburton region, with its hundreds of known radioactive occurrences, was chosen as the site to test the technique of Canadian waters. This report gives the uranium content of over 1,100 water samples and discusses its significance. Conclusions reached regarding the great influence of chemical environment on the hydrogeochemical dispersion of uranium are probably applicable over much of the Canadian Shield.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, August 15, 1962

Bulletin 118: Die Hydrogeochemie des Urans im Gebiet Bancroft-Haliburton, in Ontario. Von J. A. Chamberlain

Bericht über die Ergebnisse chemischer Untersuchungen auf Uran in den Gewässern eines als uranhaltig bekannten Gebiets in Zentral-Ontario und Schlussfolgerung, daß diese Methode bei der Suche nach Uranlagerstätten auf dem Kanadischen Schild nur von begrenztem Nutzen ist.

Бюллетень 118 — .Гидрохимия урана в районе Банкрофт — Халибэртон, провинция Онтарио. Автор: Дж. А. Чэмберлэн.

Статья сообщает результаты химических исследований на уран в водах одного известного ураноносного района центральной части провинции Онтарио, и заключает, что этот метод имеет только ограниченное применение в поисках ураноносных месторождений в пределах Канадского Щита.

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HYDROGEOCHEMISTRY OF URANIUM IN THE
BANCROFT-HALIBURTON REGION, ONTARIO

Abstract

Over 1,100 samples of surface and underground waters from the Haliburton-Bancroft region were collected and analysed in a field laboratory. Analyses were completed using a colorimetric method sensitive to 1 ppb (1 part per billion). Consistent with chemical considerations, the average uranium content of creek, lake, and swamp waters varies from 1.7 to 1.5 to 1.1 ppb, respectively. Owing to limitations of the analytical method, these values are calculated to be high by a factor of about 35 per cent.

On a local scale, anomalously high uranium values in waters associated with orebodies generally decrease to near-background level within a few hundred feet. Results indicate that uranium is extracted from solution by the reducing effects of decaying organic materials. In the investigated area, and presumably over much of the Canadian Shield, uranium hydrogeochemistry thus offers only restricted guides to specific ore targets.

The regional plot of the hydrogeochemical data outlines successfully the general configuration of the belt of uranium mineralization. Changes in background levels are spatially related to changes in character of bedrock, with syenitic rocks showing the greatest affinity to waters of high uranium content. The greatest potential use of the method appears to be in outlining broad zones for which additional exploratory work in search of uranium, or other metals believed to be associated with uranium, may be warranted.

Résumé

On a prélevé plus de 1,100 prises d'eau superficielle et souterraine dans la région de Bancroft-Haliburton. On les a analysées dans un laboratoire-remorque, à l'aide d'une méthode colorimétrique sensible à une partie par milliard. La teneur moyenne en uranium des eaux de ruisseaux, de lacs et de marais concorde avec les données chimiques et s'établit à 1.7, 1.5 et 1.1 ppb, respectivement. La méthode analytique étant d'une application restreinte, les calculs démontrent que ces teneurs sont trop élévées d'environ 35 p. 100.

A l'échelle régionale, les teneurs extraordinairement élevées en uranium des eaux aux environs des gîtes diminuent en général, dans un intervalle de quelques centaines de pieds à une teneur presque normale. Les résultats indiquent que l'uranium dissous est extrait par l'effet réducteur des substances organiques en décomposition. Ainsi, dans la région étudiée et sans doute sur une grande partie du Bouclier canadien, l'hydrogéochimie de l'uranium ne donne que des indications incomplètes dans la recherche de gîtes de minerai.

Le schéma régional des données hydrogéochimiques permet de délimiter la forme générale de la zone uranifère. Les variations des teneurs normales en uranium sont liés dans l'espace aux variations de la nature de la roche de fond; les syénites présentent la plus grande affinité pour les eaux riches en uranium. Il semble que cette méthode puisse s'appliquer surtout à délimiter de grandes zones, dans le cas desquelles il y aurait lieu de pousser plus avant les travaux d'exploration à l'égard de l'uranium ou des autres métaux associés avec l'uranium.

INTRODUCTION

As the name implies, hydrogeochemistry is concerned with the migration and distribution of elements in the hydrosphere. The present hydrogeochemical study was directed to the element uranium and was restricted to that part of the hydrosphere lying within an area of 2,000 square miles centred on Bancroft, Ontario. Its purpose was to obtain information regarding concentrations of uranium in natural waters with a view to testing the practicality of the hydrogeochemical method as a prospecting technique in the search for uranium or associated metals. Its usefulness depends in part on the concept that if known zones of mineralization are used as controls in determining the dispersion pattern of uranium in adjacent waters, the information so gained can be applied in the exploration of new areas.

The investigated area was originally selected for study because it contains many known uranium occurrences and because much of it has been mapped geologically (Adams and Barlow, 1910; Satterly, 1957; Hewitt, 1959).[1] Furthermore, most of the stripped areas and prospect trenches, as well as some underground workings, have lain undisturbed for the past six years. This was deemed advantageous because in a study of this kind it is desirable that the results be based as much as possible on natural rather than artificially created conditions.

No previous hydrogeochemical studies have been made on uranium in Canada. In Russia, however, preliminary investigations were undertaken as early as 1941, followed by extensive regional work there from 1948 to 1958 (Starik, et al., 1958; Germanov, 1958). Based on data accumulated since 1952, attempts were made in the United States to evaluate the uranium-discovering potential of the hydrogeochemical method (Fix, 1956) and to relate the uranium content of natural waters to local geology (Denson, et al., 1956) as well as to various tectonic regions, including the southern part of the Canadian Shield (Scott and Barker, 1958). Since 1957 various hydrogeochemical studies on uranium have been conducted in Austria, England, Japan, Israel, and Sweden. For details of these the reader is referred, respectively, to papers by Hecht, et al. (1958), Smith and Chandler (1958), Murakami (1958), Mazor (1961), and Armands (1961).

A summary of the hydrogeochemical behaviour of uranium was given by Adams, et al. (1959), and a review of the subject with reference to the formation of marine black shales was presented by Swanson (1961). A treatise on radiohydrogeology by Tokarev and Shcherbakov (1956), comprises both a synthesis of fundamental concepts and a discussion of investigational procedures. It includes a detailed classification of natural radioactive waters of Russia.

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[1] Names and dates in parentheses refer to publications listed in the *References*.

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Field Work

Over eleven hundred samples were collected and analysed from surface and underground waters in the investigated area from August to November 1961. Six water samples for chemical analysis were collected on a subsequent trip to the area in January 1962.

Where possible, a station wagon or four-wheel drive vehicle was used to approach the sample-site. Time did not permit going on foot more than a mile unless several bodies of water could be sampled on the same traverse. Access to the more remote areas was gained with a single-engine, float-equipped aircraft. Ninety-eight samples were collected in this way using approximately 17 hours flying time.

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ANALYTICAL METHOD

Water samples were brought daily to a semi-mobile field laboratory (*see* Frontispiece) where uranium analyses were carried out using a colorimetric method described by Smith and Chandler (1958) with additions by Hunt (1958). The method was found to be well suited to field requirements as no heat is needed for evaporating or fusing. Whenever possible, the likelihood of human error was reduced by the use of such items as automatic reagent dispensers and pre-weighed reagent ampules. It was found that analyses could be performed satisfactorily by relatively unskilled workers after a training period of two weeks. Two men experienced in the method could complete thirty analyses in a normal work day.
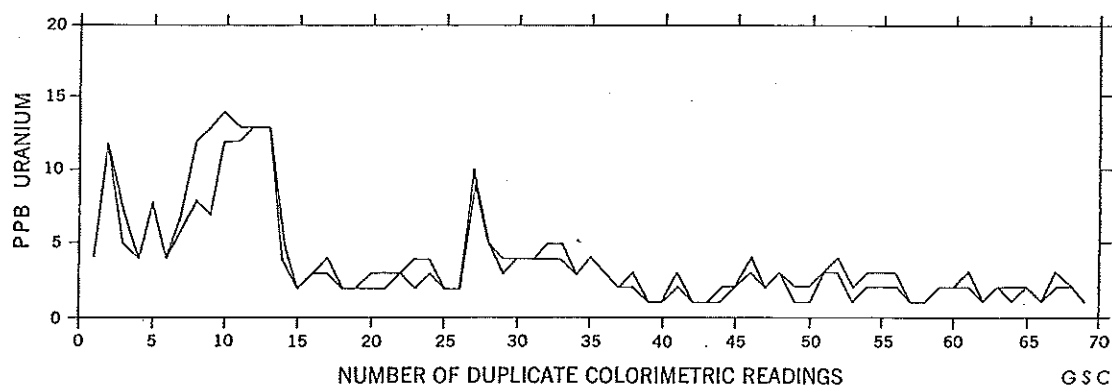
FIGURE 1. Comparative spread of colorimetric readings made by two different persons.

Analyses are made by extracting as a dibenzoylmethane complex the uranium contained in a litre sample of water into 10 ml of carbon tetrachloride. The colour of the organic phase is compared visually with previously prepared standards and uranium values are recorded directly in parts per billion (ppb)[1]. Variations in analyses made in this way by different persons taking readings from the same samples are indicated on Figure 1. Readings differed between persons, on the average, by 16 per cent. The maximum difference recorded was 46 per cent. This is thought to be fairly good agreement, particularly as the comparisons were made on samples read during the first few days of field testing.

Duplicates of twelve water samples were sent from the field to Ottawa for fluorimetric analysis in the Analytical Chemistry Section of the Geological Survey. This was done as a general check on the accuracy of the colorimetric method relative to the less qualitative results produced by fluorimetry.

Comparison of assays from the two methods is shown on Figure 2. The diagram suggests that the lower limit of sensitivity of the colorimetric method is 1 ppb uranium, and this was found to be so. It is interesting to note that con-

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[1] One part per billion is equivalent to 1×10^{-9} grams per millilitre.
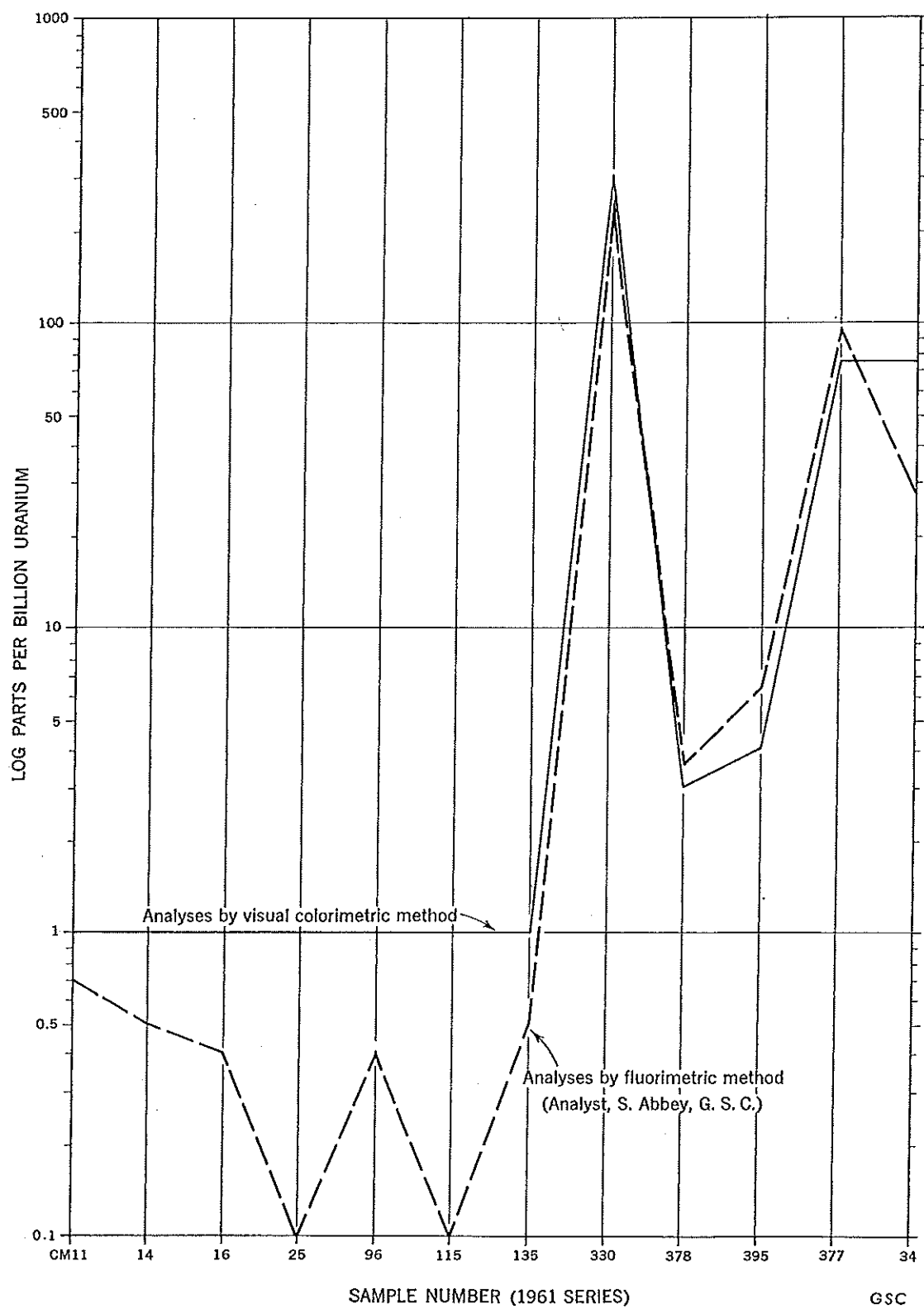
FIGURE 2. Comparison of analyses by colorimetric and fluorimetric methods.

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siderable variation below this figure is revealed by fluorimetric analysis. This is recognized as a drawback to the usefulness of the colorimetric method in establishing background levels in regions of low uranium concentration. The two sets of results are sufficiently close to establish good confidence in the accuracy of the colorimetric method in the range above 1 ppb.

Several minor departures from the original method were found to be expedient under field conditions. These are listed in the Appendix.

HYDROGEOCHEMICAL RESULTS

General Considerations

The location and uranium content of approximately 1,110 water samples are shown against a background of the general drainage of the investigated area on Figure 3. This corresponds to a sampling density of one sample per 2 square miles. Also indicated are the distribution of radioactive occurrences, syenitic rocks, and major structural breaks or lineaments, largely from Satterly (1957).

No attempt has been made on Figure 3 to distinguish between the various types of water sampled. However, it is generally apparent from the location itself whether the sample in question represents a creek, lake, or swamp. Special cases such as wells or waters issuing from underground workings are not identifiable as such.

The average uranium concentrations for the three major types of water sampled are (1) creeks and rivers 1.7 ppb, (2) lakes 1.5 ppb, and (3) swamps 1.1 ppb. A fourth group comprising 76 samples averages 15.1 ppb, or nearly ten times the average uranium content of the first three types. This group represents samples taken from special localities such as mine shafts or adits, open pits, tailings ponds, and so on. Although they comprise less than 10 per cent of the total number of samples, their inclusion with the rest of the data raises the average concentration of uranium from 1.6 to 2.5 ppb, an increase of over 50 per cent.

The regional trend lines on Figure 3 are intended to express shifts in hydrogeochemical levels of uranium across the area. The lines were derived by calculating the percentage of samples within each grid square (as defined on the map legend) that shows assays greater than 1 ppb uranium. The percentages were then contoured directly. This treatment of data has the advantage of not being influenced by extreme values and, for this reason, is useful in outlining general trends. The method, however, may also have application in pointing up specific target zones: the highest contoured value on Figure 3 falls midway between the two largest uranium producing mines in the area—Faraday and Bicroft.

Sampling Bias

Although attempts were made to keep the density of sampling fairly uniform, it was not feasible to take samples on a pre-arranged grid. Areas containing abundant water naturally tended to be sampled more heavily than dry areas. Similarly, areas in which waters showed high concentrations of uranium were often re-visited and sampled more extensively in an effort to establish the origin of the apparent anomaly. No doubt, other factors such as location of roads and trails, size of lakes, and nature of the topography all affected in some way the overall pattern of sampling.

The greatest source of bias, however, was in the prior knowledge that rocks of certain localities contain uranium in above-normal concentrations. Many of these localities, ranging in size from minor uranium occurrences to producing mines, were sought out and sampled. There is little doubt that the restricted nature of some such sites would preclude their being sampled on a routine hydrogeochemical reconnaissance of the area. As mentioned in the preceding section, 76 samples of this kind were taken, with an average uranium content of nearly ten times average for the remaining 1,034 samples.

Statistical Discussion

Curve A on Figure 4 is a plot of the raw analytical data. The curve indicates that 837, or 75 per cent of the total number of samples gave uranium values of 1 ppb. The large proportion of samples giving values of the lower limit of sensitivity of the analytical method (i.e., 1 ppb as discussed previously) suggests that a considerable variation in uranium content exists below 1 ppb. The results of fluorimetric analyses on seven samples that gave colorimetric values of 1 ppb (*see* Fig. 2) bear this out. Their average uranium content, determined fluorimetrically, is 0.4 ppb with a range between 0.1 and 0.7 ppb.

Curve A: actual analytical data
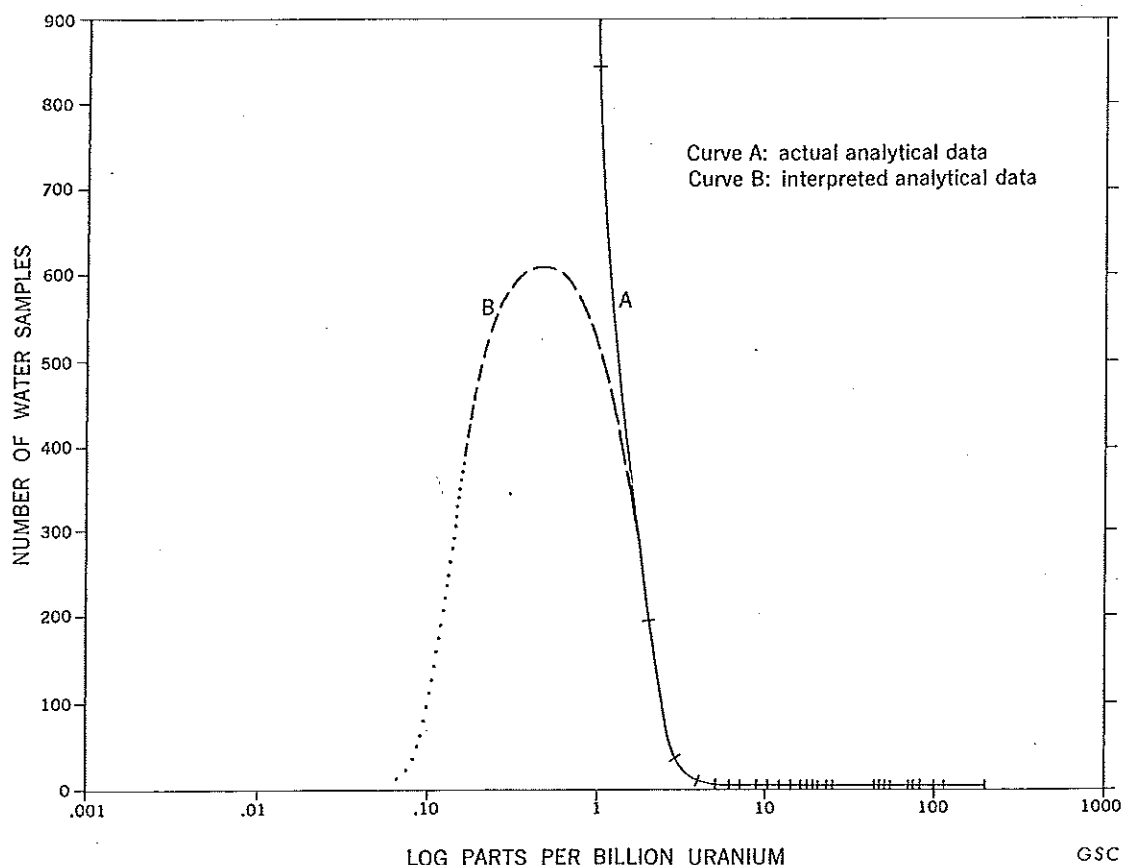Curve B: interpreted analytical data

FIGURE 4. Frequency diagram for 1,110 water samples.

Curve B on Figure 4 is an interpretation of how the data might appear if the analytical method had been sufficiently sensitive to give values below 1 ppb. The position of the crest of the curve relative to the abscissa is taken at 0.4 ppb. The crest of the curve relative to the ordinate is located slightly above the 600 sample level so that the entire curve may accommodate the total number of samples.

The actual curve may be quite different from that suggested by curve B on Figure 4. It is not possible, for example, to predict polymodal distribution or skew below 1 ppb. Nevertheless, relative to the plot of the raw data as shown by curve A, the interpreted curve must be a closer approximation to the truth. Adoption of curve B means that average values for various groups of samples are lowered by a factor proportional to the number of samples in those groups containing 1 ppb uranium. Thus a group of samples all formerly assaying 1 ppb now has a distribution of values below this figure, with an average taken at 0.4 ppb. A breakdown of samples into groups, with averages calculated on both raw and modified data is given in Table I.

Table I

Type of Water Sample	Number of Samples	Raw Data (curve A, Fig. 4) Average Uranium Content in ppb	Modified Data (curve B, Fig. 4) Average Uranium Content in ppb
Creeks (and rivers)	620	1.7	1.2
Lakes	375	1.5	1.0
Swamps	39	1.1	0.6
Subtotal	1,034	1.6	1.1
Special group[1]	76	15.1	14.5
Total	1,110	2.5	2.1

[1] This group is described under the heading *General Considerations.*

As shown on Figure 4, the combined curve A and B in the range of uranium values above 8 ppb is essentially parallel to the abscissa and has a longer extension than would be anticipated in a log normal distribution. (In a plot of normal distribution the curve in question would, of course, have an even more abnormal extension.) Visual inspection of the curve suggests that samples assaying much over 10 ppb are not likely to be part of the log normal population; that is, such samples are anomalous.

The lack of sensitivity of the analytical method below 1 ppb uranium precludes direct calculation of a value for the regional background level. Data presented above suggest that the more reliable figure in this connection is the modified average of 1,034 samples, namely 1.1 ppb (Table I).

Factors Influencing Regional Distribution of Values

Lithology

In the investigated area, most uranium deposits occur near the margins of dome-like granitic intrusions and are associated in some way with syenitic rocks. One might therefore expect waters overlying syenitic rocks to carry higher than average quantities of uranium. Figure 3 shows the distribution of these rocks relative to the analytical data furnished by the study as well as to regional trend lines.

The pattern of the regional trend lines reveals that the belt of syenitic rocks is associated with waters carrying a higher general level of uranium than elsewhere in the area. Exceptions to this occur at the southwest end of the syenitic belt where it is transected by a strong negative trend, and in the south-central part of the area where a positive trend is developed in the absence of large areas of syenitic rocks.

A spatial relationship between higher uranium values and syenitic rocks is indicated on Figure 5. Here it is shown that 60 per cent of the sampled waters overlying syenitic rocks assays more than 1 ppb uranium as opposed to only 25 per cent for those of the non-syenitic association.

It should be pointed out that although the spatial relationship of the regional hydrogeochemical anomaly to syenitic rocks is reasonably well established, it need not be a genetic relationship as well. For example, water in many places must leach uranium from granites or from quartz-rich pegmatites that replace or are intrusive into syenitic country rocks. Although there is no direct genetic link between uranium-rich waters and the syenitic rocks in such cases, the spatial relationship remains valid. More work is required on the geochemical distribution of uranium in rocks of the area before the specific cause of regional variations in uranium content of waters can be determined.

Structure

No apparent spatial relationship exists between faults and uranium content of nearby or associated waters. Major faults and lineaments of the area are shown on Figure 3. These structural elements are as common in regions of low uranium content—such as the northwestern part of the area—as they are elsewhere.

Climate

It has been noted that the uranium content of certain waters shows fluctuations that can be related to effects of rainfall (Peacock, 1961). Peacock (p. 1190) stated that the amount of uranium in natural water "reaches a maximum when rain follows a dry spell during which normal weathering processes in the zone of oxidation have made available abnormal quantities of uranium in a readily soluble form".

Time was not available in the present study to re-take samples periodically in order to study such possible effects on given bodies of water. Instead, an attempt was made to determine whether any sympathetic variation exists between rainfall

LEGEND

● Sample group containing all types of water sampled in the stated area, including waters issuing from mine adits, diamond-holes, springs etc.

× Sample group limited to the stated source of water over the entire map-area: ie, creek, lake or swamp

Water samples overlying syenitic rocks

Water samples overlying non-syenitic rocks

× Creek and river water

× Lake water

× Swamp water

PERCENT OF SAMPLES ASSAYING OVER ONE P P B

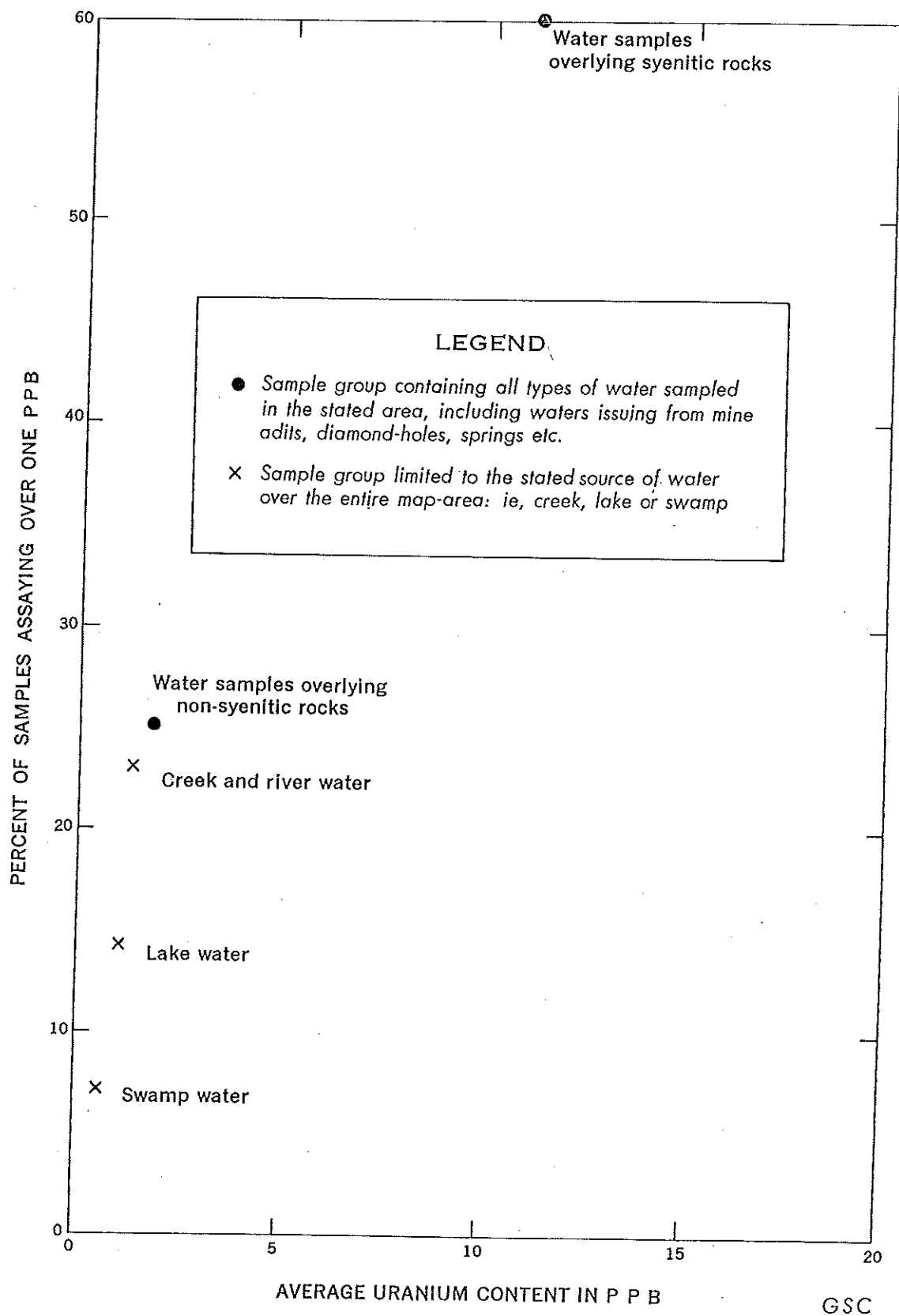AVERAGE URANIUM CONTENT IN P P B

GSC

FIGURE 5. Per cent of various sample groups assaying over one ppb uranium plotted against their average uranium content.

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and uranium concentrations generally. Figure 6a is a graph showing the percentage of samples assaying higher than 1 ppb uranium plotted against date of collection. Figure 6b is a graph of the rainfall in the area plotted on a daily basis. Comparison of the diagrams reveals little apparent sympathetic variation and it is probable that any such variation has been masked by lithological effects or by other factors as mentioned below.

Type of Water

The results of the present study indicate that creeks, lakes, and swamps exhibit a systematic variation in uranium content. Figure 5 shows that creek (and river) waters have 64 per cent more samples assaying above 1 ppb than lake waters, and that lake waters in turn have 87 per cent more samples assaying above 1 ppb than swamp waters. These variations agree in principle with results described by Krylov and Shats (1958) in which rivers in the northwestern U.S.S.R. were found to have an average uranium content of 0.5 ppb whereas lakes averaged 0.27 ppb. Variations of this type are governed by chemical factors and are discussed more fully in the sections that follow.

Other Factors

Numerous other factors are capable of influencing the regional hydrogeochemical dispersion pattern of uranium. Among these are nature of topography, depth of overburden, drainage pattern, and abundance and type of vegetation. Insufficient data are available to assess the importance of these; however, it is worth emphasizing that the character of the dispersion pattern is primarily influenced by *variations* of the controlling factors. Where variations are not large— as is so with most of the above factors—correspondingly small variations in dispersion pattern can be attributed to them. Thus, although the possible effects of the factors may not be understood, they can be to some extent de-emphasized in the area under consideration.

Factors Influencing Local Distribution of Values

High concentrations of uranium in waters of the investigated area are characterized by two features: first, they are of limited areal extent with high values decreasing to background levels within a few hundred feet of the peak anomaly; second, such anomalies are spatially and genetically related to bedrock zones of uranium enrichment. These patterns of distribution occur repeatedly on a local scale and it is necessary to have some understanding of their development before the potential usefulness of uranium hydrogeochemistry can be estimated.

Tory Hill Case Study

The features already described as being typical of the local distribution of uranium values are exemplified at the Amalgamated Rare Earth property 4 miles south of Tory Hill. The somewhat detailed discussion that follows is justified on the basis that similar principles and processes seem to have application in the area studied wherever local high anomalies are observed.
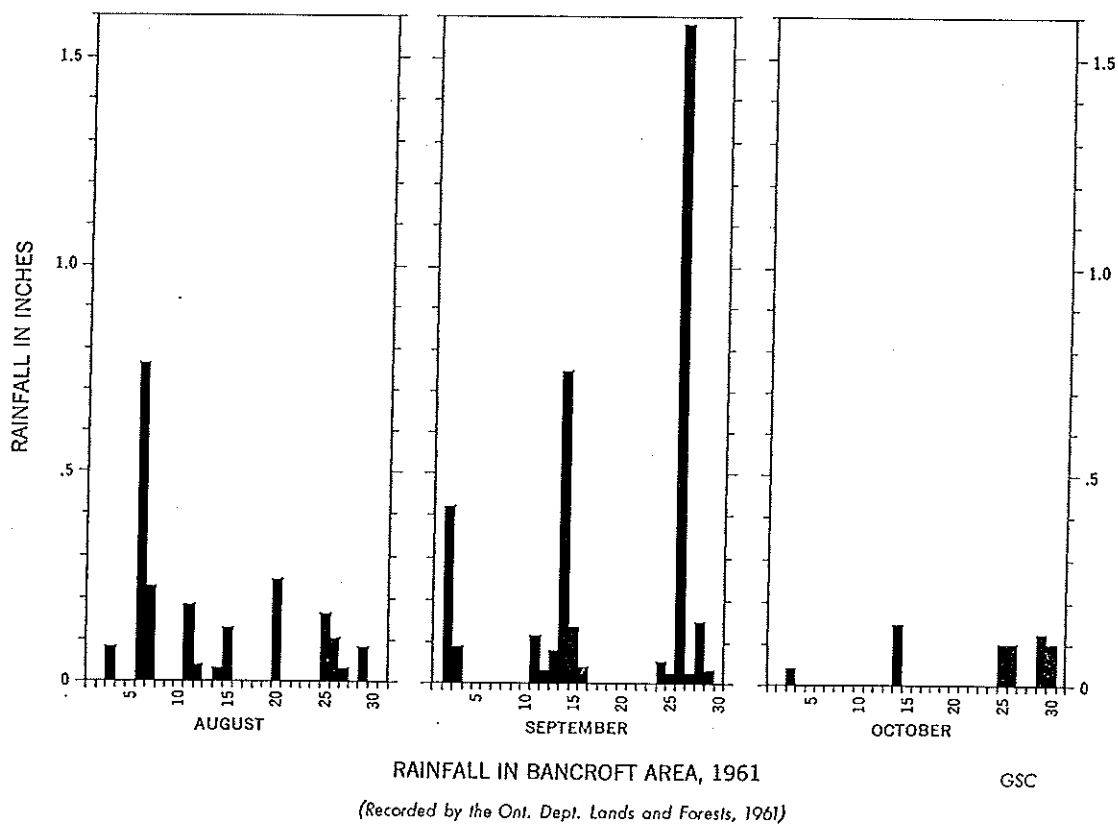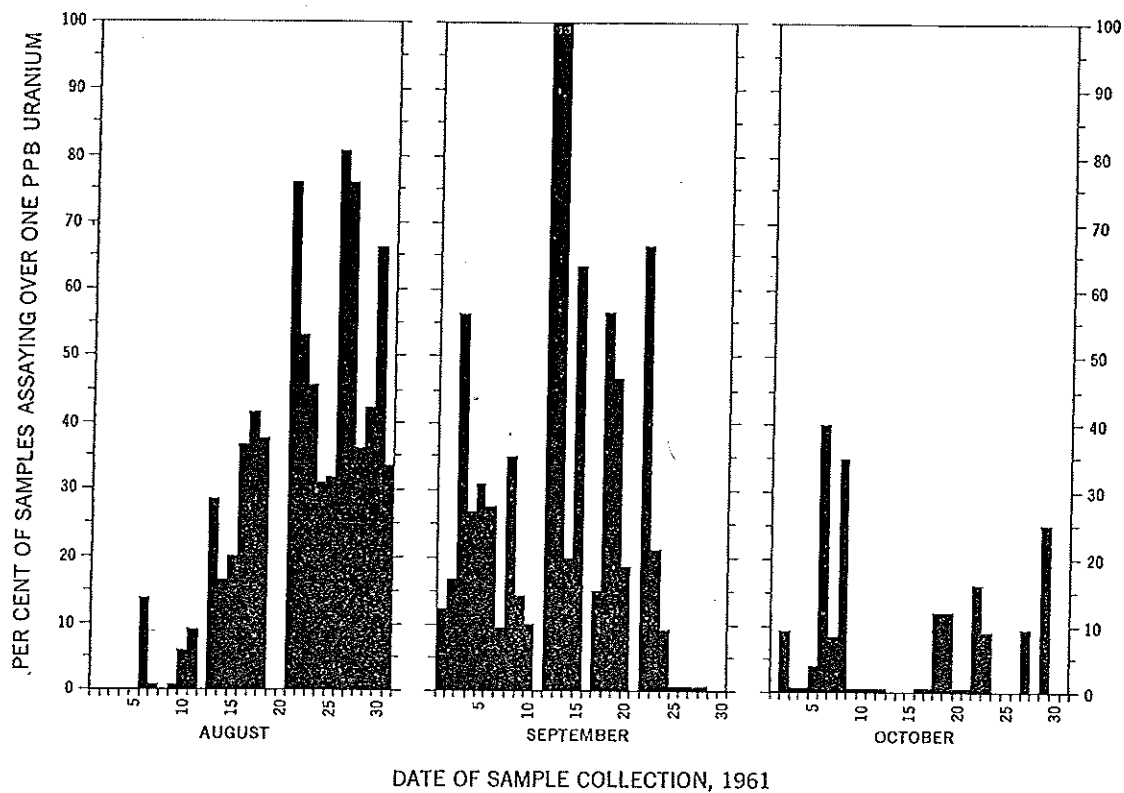
FIGURE 6. Daily comparison of per cent of samples assaying higher than one ppb uranium with rainfall in inches.

At the Rare Earth property, waters issuing from the main adit (Fig. 7) contain between 200 and 500 ppb uranium. Similar and greater values are obtained downstream for 400 feet at which point the drainage enters a lake. In the lake, 10 feet from the junction of lake and mine water, the uranium content decreases to 20 ppb. Fifteen additional lake samples taken within 250 feet of this locality contain only normal, or near-normal, background levels of uranium. Chemical analysis of the lake water (Thomas, 1962) shows it to be typical of others in the area for which analytical data are available.

LEGEND

Water sample, number indicates ppb Uranium.......... ●¹
Mud sample (dried), number indicates percent of U_3O_8... ▲.⁷¹
Water sample, taken for chemical analysis.............. ✕

Note: Fluorimetric analyses of bottom muds done by Control Analysis Section, Mines Branch, Department of Mines and Technical Surveys, under direction of J. C. Ingles. Analyses based on dry weight of samples

FIGURE 7. Distribution of uranium in waters and muds at Amalgamated Rare Earth Mines Ltd., No. 2 shaft area near Tory Hill.

The uranium content of water can be reduced either by simple dilution, or by removal of the uranium from solution by such processes as precipitation or adsorption. Although the processes of both dilution and removal undoubtedly operate in the case under consideration, evidence points to the latter as being of primary importance.

Waters issuing from the mine adit, shown on Figure 7, flow into the lake at a constant yearly rate of about 20 litres per minute. Taking the uranium content of these waters conservatively to have been 300 ppb over the past five years—that is, since underground development ceased at the mine—the amount of uranium carried in solution by the mine water would be about 15,700 grams in a total volume of water equal to about 5 per cent of that of the lake. Thus, if no processes operated to reduce the uranium content of the lake water, the lake would now be expected to contain about 15 ppb.

The mine drainage is the main source of water and the only surface inlet to the lake, for the lake's outlet flows at a similar rate to that of the inlet except during periods of heavy rainfall or run-off. Direct rainfall and local run-off could not account for more than 50 per cent net dilution of the lake since 1956, which would reduce its uranium content to about 7 ppb. Whereas it is recognized that other variables such as groundwater movements and the existence of stagnant or poorly mixed zones together may cause large-scale changes in these estimates, it seems clear that dilution cannot be the principal factor in explaining the near-absence of uranium in the lake.

As shown on Figure 7, the adit drainage crosses a waste dump, disappears underground for 50 feet, then emerges at the base of the dump where it winds through a swamp area to the lake. Six samples of bottom muds, rich in organic material, were taken from the swamp at the locations shown, and analysed for uranium. The first of these samples assayed 0.71 per cent U_3O_8 (based on dry weight of sample) whereas values for the remaining samples decreased systematically with increasing distance from the base of the dump. The conclusion seems unequivocal: conditions are such that virtually all the uranium is extracted from the mine drainage as it moves through the swamp and as it enters the lake. We are apparently witnessing the first stage in the formation of what could ultimately become a uraniferous lignite or related rock.

Walton (1960) found similar conditions to those described in central Wyoming and concluded that precipitation of the uranium is caused by decaying vegetation, the products of which reduce hexavalent uranium to the tetravalent form. This same phenomenon has been observed and discussed in detail by other workers, both from experimental evidence and from field relations (Krylov and Shats, 1958; Vine, et al., 1958; Swanson, 1961).

Observations by Fix (1956) do not appear to agree with the conclusions reached here regarding restricted dispersion patterns and the de-emphasis placed on dilution as a factor in lowering uranium concentrations. Fix found that the aura of large uranium deposits "is easily detected downgradient as far away as several kilometers in ground water, and probably at least a hundred kilometers in streams"

and that the concentration of uranium in streams "usually drops off downstream chiefly because of dilution . . ."

These conclusions were based mainly on dispersion patterns observed by Fix in waters of arid and semi-arid regions of the United States. The apparent conflict is reconciled by the fact that arid regions are deficient in natural organic material, and in such regions dilution becomes by default the chief mechanism for lowering the uranium content of waters. In the Canadian Shield, on the other hand, where dilution must be much greater than in arid regions, it plays a subordinate role relative to the powerful reducing action of organic precipitants.

Throughout the investigated area and, in fact, over much of the Canadian Shield there are abundant sources of decaying organic material. In waters, these are more commonly associated with swamps and lakes of restricted circulation than they are with fast moving creeks or rivers. Thus, on a statistical basis, we would expect to find less uranium in swamp waters than in creeks, with the uranium content of lakes falling somewhere between. These relations are well borne out in the present study, as mentioned in the preceding section and summarized on Figure 5.

Bow Lake Case Study

Bow Lake, 6 miles southwest of Bancroft, provides the single exception to the generalization that high positive anomalies are of limited areal extent. Bow Lake is 2 miles long (Fig. 3) and contains a relatively uniform uranium concentration of 50 ppb. It is a clear body of water, containing little or no organic material. The Faraday mine, plant, and tailings pond are at the northeast end of the lake.

Chemical analysis of Bow Lake water shows it to be greatly enriched in sulphate and chloride over waters considered typical for the area. The well-known tendency of uranium to form soluble ionic complexes with sulphate no doubt explains why uranium remains in solution in Bow Lake.

Bow Lake drains to the southwest beneath highway 28 through two swamp-like ponds and joins the Crowe River about 4 miles downstream. The uranium content of the water of the first pond is reduced by a factor of 80 per cent and of the second pond by a factor of 90 per cent over that of Bow Lake. As at Tory Hill, dilution appears to be a negligible factor in explaining the uranium loss because the inflow to the ponds from Bow Lake is approximately matched by the outflow to the south. Precipitation of uranium by the reducing effects of decaying organic material is again indicated, by analysis of bottom muds from the ponds. Two samples taken from the first pond average 0.011 per cent U_3O_8 based on dry weight of sample, showing significant increase in uranium over normal muds of the area. Consistent with this, a single bottom sample taken from Bow Lake itself was found to contain only 0.003 per cent U_3O_8, which appears to be within the normal range.

CONCLUSIONS

The regional plot of the present hydrogeochemical data successfully outlines the many known occurrences and deposits that together form the belt of uranium mineralization in the investigated area. Changes in background levels are spatially related to changes in character of bedrock, with syenitic rocks showing the greatest affinity to waters of high uranium content.

Strong influences of chemical environment on the dispersion of uranium in water are indicated by the fact that natural waters contain less uranium with increasing availability of decaying organic material. Creeks are estimated to average 1.2 ppb, whereas lakes and swamps show reductions of 18 and 50 per cent, respectively, over this figure. Accordingly, under non-anomalous conditions in most parts of the Canadian Shield, groundwaters and creeks fed by watershed basins would be expected to contain more uranium than lakes or lake-fed creeks. Lowest quantities of uranium would be anticipated in swamp waters, where reducing conditions predominate.

The influence of chemical environment is also demonstrated locally in areas where waters are associated directly with uranium deposits. There, waters are generally found to contain anomalously high uranium values for only a few tens, or a few hundreds, of feet before decreasing to near-background levels. Results again indicate that uranium is extracted from solution by the reducing effects of organic precipitants. Dilution, although of some importance in other regions low in natural organic material, plays a relatively less important role in the investigated area and, presumably, in much of the Canadian Shield.

It seems probable that uranium orebodies will escape direct detection by routine hydrogeochemical studies in the Canadian Shield because of the restricted nature of their dispersion patterns. The greatest potential economic use of the method appears to be in outlining broad zones for which additional exploratory work in search of uranium, or other metals believed to be associated with uranium, may be warranted. On the basis of the present study, such zones would be indicated by repeated assays of as little as two or three times background value for the region. Trend lines of the type used here are effective aids in recognizing and assessing areas in which small changes in background may exist.

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APPENDIX

The following minor departures were made from the standard analytical method in the present study:

1. Water samples were filtered through cellulose floc prior to acidification. This procedure removes uranium adsorbed on solid matter and allows determination of the uranium content of only the aqueous phase.

2. In order to prevent brown coloration and emulsification of the final extract, every sample was scrubbed, at least once, with carbon tetrachloride and treated with potassium dichromate before addition of dibenzoylmethane to the aqueous phase. This was recommended in the original method for troublesome cases, but in the present study, it was found propitious to treat all samples in the same way, i.e., on a production basis.

3. The dibenzoylmethane used in the present study did not require purification. The reagent was obtained from Eastman Organic Chemicals, Rochester 3, New York, as 1, 3-diphenyl-1, 3-propanedione, number 2197.

4. One fresh standard, at least, was made daily and substituted for the corresponding old standard. This procedure afforded a relatively continuous check on the stability of colours of standards and on other laboratory problems such as contamination.