70-54

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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URANIUM IN STREAM SEDIMENTS IN CARBONIFEROUS ROCKS OF NOVA SCOTIA

(Report and 3 figures)

H.W. Little and C.C. Durham

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H.W. Little and C.C. Durham

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ABSTRACT

Samples collected in 1957 and 1958 during a regional geochemical study were re-examined for uranium using a fluorometric method developed in the Geological Survey laboratories. Samples were selected to cover the Carboniferous Basin and the authors discuss the uranium potential of each formation within this basin. Values are displayed on a contoured map derived through computer techniques.

URANIUM IN STREAM SEDIMENTS IN CARBONIFEROUS ROCKS OF NOVA SCOTIA

INTRODUCTION

During the field seasons of 1957 and 1958, some 4,400 samples of stream sediments were collected during a geochemical reconnaissance and the results of analyses of these samples for lead, zinc, and copper were published (Holman, 1959a, b, c, d; 1963). At the suggestion of A. Y. Smith, then of the Geological Survey of Canada, samples from the Carboniferous basin that he selected in 1968 from the stored material were analyzed for uranium in the geochemical laboratories of the Geological Survey by a fluorometric method described by Smith and Lynch (1969). The initial results were received from the laboratory just before the 1969 field season, and the writer visited Nova Scotia early in August in order to investigate some of the anomalies and resample the stream sediments at those localities for confirmatory analyses.

Acknowledgments

The authors are indebted to Dr. J. P. Nowlan and members of the staff of the Nova Scotia Department of Mines for their co-operation in providing information and for discussion of the problems, and to Dr. Vladimir Růžička, a post-doctorate fellow with the National Research Council, for similar discussion and for assistance in the field.

D. G. Benson and W. H. Poole were most helpful in clarifying problems of regional geology.

The competent analytical work performed by J. J. Lynch and Mrs. Sharon Lindsay is acknowledged and gratitude is expressed to Dr. E. M. Cameron and J. D. Hobbs for their assistance and advice on the contour program.

Physiography

The Carboniferous basin of Nova Scotia comprises mainly lowland which lies north of the Southern Upland (Goldthwait, 1924), more recently named Atlantic Upland (Bostock, 1970). This upland is underlain principally by metasediments of the Meguma Group of Early Ordovician and possibly earlier age, overlain unconformably by local remnants of volcanic and sedimentary rocks of Silurian and Carboniferous age. In the southern part these rocks are intruded by batholiths and smaller bodies of granitic rocks of Devonian and (?) earlier age.

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Final version approved for publication: 26 June, 1970

Table of Formations: northern region

Era	Period or Epoch	Formation	Lithology
Mesozoic	Triassic	North Mountain Basalt	Basalt
		Conformable contact	
		Wolfville and Blomidon Formations	Red conglomerate, sandstone, siltstone, and shale
		Relationship unknown	
Paleozoic or Mesozoic	Pennsylvanian or later		Diabase
Paleozoic	Pennsylvanian	Intrusive relationship with Horton Group	
		Pictou Group	Brown and grey sandstone, mudstone, and conglomerate; grey and red wacke; carbonaceous shale; coal
		Conformable to unconformable contact	
		Cumberland Group	Brown, red, green, and grey sandstone, shale, and conglomerate; coal
		Conformable to unconformable contact	
		Riversdale Group	Grey to black, locally red, shale, sandstone, siltstone, and, locally, conglomerate
		Conformable to unconformable contact	
		Canso (Mabou) Group	Red, green, and grey mudstone, sandstone, shale, siltstone, and argillite
	Mississippian	Conformable and disconformable contact	
		Windsor Group	Red and grey shale and limestone; gypsum, anhydrite, salt; minor limestone conglomerate

northern region continued-

Era	Period of Epoch	Formation	Lithology
Paleozoic	Conformable and disconformable contact		
	Upper Devonian (?) and Mississippian	Horton Group	Red and grey sandstone, shale, mudstone, siltstone; grit, conglomerate, arkose; locally volcanic tuff, breccia, and flows in lower part
	Unconformable contact with Devonian granite and older rocks		
	Middle (?) Devonian and (?) later	River John Group	Grey and red siltstone, sandstone, shale; minor reddish brown conglomerate, basalt, felsite, tuffaceous breccia
	Unconformable (?) contact		
	Devonian and earlier		Granite and related rocks
	Intrusive contact with Arisaig Group and older formations		
	Lower Devonian	Knoydart Formation	Red sandy slate, hard grey sandstone of continental origin
	Conformable contact		
	Silurian and Lower Devonian	Arisaig Group, and equivalents in west part of map-area	Grey, green, and red shale; siltstone greywacke, sandstone; minor quartzite, conglomerate, and limestone; locally graphitic schist
	Disconformable contact with Browns Mountain Group		
	Ordovician and (?) earlier		Diorite and gabbro
	Intrusive contact		
	Ordovician	Browns Mountain Group and Malignant Cove Formation	Greywacke, red and grey sandstone, siltstone, argillite, slate; locally includes andesite flows, agglomerate, and tuff; conglomerate, grit; rhyolite
Relationship unknown			
Paleozoic or Proterozoic	Cambrian and/or earlier		Andesite, rhyolite, felsite, chlorite schist, pyroclastic rocks

The lowland to the north is subdivided into the Annapolis Valley and Minas Lowland on the south and the Cumberland Lowland on the north, separated by the Cobequid Mountains. To the east are the Antigonish Highlands.

The Cobequid Mountains are underlain by a complex of sedimentary and volcanic rocks of Silurian and Early Devonian age that are intruded by granites of mainly Devonian age. Cobequid Mountains comprise broad, rounded summits that range in altitude from 850 to 1, 000 feet and were formed during the Acadian Orogeny. Antigonish Highlands are underlain by metavolcanic and metasedimentary rocks that range in age from Ordovician to Lower Devonian, and intruded by bodies of Ordovician diorite and Cambrian (?) to Devonian granitic rocks. These rocks are covered locally by onlapping Mississippian sediments.

The lowlands that surround the uplands described above contain some swampy areas and low, drumlinoid hills, having an average relief of perhaps 200 feet, but locally up to 600 feet. Deposits of glacial drift and soil are fairly thick. Bedrock is rarely exposed other than along streams and rivers and in sea cliffs.

The area is for the most part well drained by streams and rivers that flow nearly all year. The lower parts of many stream valleys are drowned, forming tidal estuaries. Except in the estuaries, and at flood time in the spring thaw, the waters are normally clear. Holman (1963, p. 2) stated that in boggy areas of the uplands where the waters are brown a pH of 4 or 5 is common; elsewhere the pH is normally 6 near the sources, gradually becoming neutral and then alkaline (pH8) near the sea.

The climate is humid continental, with daily mean temperatures ranging from 20°F. to 65°F. throughout the year and the annual precipitation ranging throughout the area from 38 to 55 inches.

GENERAL GEOLOGY

The area is divided into northern and southern parts by faults and intervening fault zones along a line between Minas Basin and Chedabucto Bay. The pre-Carboniferous geology differs markedly in these two regions.

The tectonic evolution of the Appalachian region has been synthesized by Poole (1967) and the reader is referred to his paper for a detailed account. In Hadrynian time the northern part of the map-area formed part of the Avalon Geosyncline, and from Cambrian to mid-Devonian time formed part of the Avalon Platform. The Taconian Orogeny, which had such a marked effect on the regions to the west and north, resulted only in epeirogenic movements and relatively minor extrusions and intrusions of intermediate to basic composition in the Avalon Platform. During the Acadian Orogeny some folding, faulting, and metamorphism occurred, but granitic intrusions were small and not numerous. Subsequent downwarping of the platform in Middle Devonian to Permian time resulted in the formation of the Fundy Geosyncline into which debris was fed northward from the Nova Scotia platform and southeastward from the New Brunswick platform.

The southern part of the map-area during the early Paleozoic was the site of the Meguma Geosyncline, upon which the Taconian Orogeny had little or no apparent effect. The Acadian Orogeny, however, caused close folding in the Meguma Geosyncline, major faulting, intrusion of many bodies of granite and related rocks, including several batholiths, and attendant metamorphism. Downwarping and graben faulting of the adjacent Avalon

Table of Formations: southern region

Era	Period or Epoch	Formation	Lithology
Mesozoic	Triassic	North Mountain Basalt	Basalt
		Conformable contact	
		Wolfville and Blomidon Formations	Red conglomerate, sandstone, siltstone, and shale
Unconformable contact			
Paleozoic	Pennsylvanian	Riversdale Group	Grey to black, locally red, shale, sandstone, siltstone, and, locally, conglomerate
		Conformable to unconformable contact	
		Canso (Mabou) Group	Red, green, and grey mudstone, sandstone, shale, siltstone, and argillite
		Conformable and disconformable contact	
	Mississippian	Windsor Group	Red and grey shale and limestone; gypsum, anhydrite, salt; minor limestone conglomerate
	Conformable and disconformable contact		
	Upper Devonian (?) and Mississippian	Horton Group	Red and grey sandstone, shale, mudstone, siltstone; grit, conglomerate, arkose, locally volcanic tuff, breccia, and flows in lower part
	Unconformable contact with Devonian granite and older rocks		
	Devonian and earlier		Granite and related rocks
	Intrusive contact with Meguma Group		
	Ordovician (?) and Silurian	White Rock, Kentville, and New Canaan Formations	Quartzite with interbedded slate; slate and minor quartzite; marine breccia and minor siltstone and slate
	Conformable, locally unconformable		
	Lower Ordovician and (?) earlier	Meguma Group	Greywacke, slate, schist, quartzite; minor gneiss, argillite, and conglomerate

Platform created the Fundy Geosyncline which lay mainly in the northern part of the map-area but extended some distance into the southern part. In discussing post-Acadian sedimentation, therefore, the entire area will be considered rather than the northern and southern parts separately.

Post-Acadian sedimentation

Syn- and post-Acadian sedimentation in the Fundy Geosyncline, within the map-area, began with the River John Group in which spores of probable Middle Devonian age have been identified by D. C. McGregor (oral communication, 1969). The more widespread Horton Group, however, is Tournasian (early Lower Mississippian) (Poole, 1967, p. 38), although a Late Devonian age is indicated by spores at Right River (M. S. Barss, oral communication, 1970). The Horton beds comprise continental sedimentary, and, locally, volcanic rocks. In the type area the lower part contains few red beds but in the upper part red beds are abundant. This subdivision of the Horton cannot be traced far, however. Granite roundstones, arkose, and feldspathic sandstone testify that the source area was a granitic terrain. Carbonaceous material and, locally, coal seams occur in the sediments.

The succeeding Windsor strata are marine, and consist largely of shale and limestone. Gypsum, anhydrite and salt occur in many places and testify to lagoonal restricted basins that existed there in Late Mississippian time, according to Bell (1929), but Schenk (1969) contended that the evaporites were formed within subaerial salt flats.

The marine beds are succeeded by a thick assemblage of red and grey strata of continental origin. These rocks range in age from earliest to latest Pennsylvanian. The rocks are subdivided from base to top into the Canso (Mabou), Riversdale, Cumberland, and Pictou "Groups". These units are not, however, mappable units that can be traced for great distances. As indicated in the Table of Formations, the contacts between these units range in character from conformable to, locally, unconformable. In many places they are sparsely fossiliferous, particularly in certain units, so that their boundaries cannot be accurately defined (Kelly, 1967b), and there has been some overlap in the units as previously mapped. The original definitions of the units depended upon floral assemblages; more recently spore determinations have done much to help to resolve the problem of correlation.

All four units comprise continental feldspathic clastics derived from granitic terrain, containing a large proportion of red beds, widespread carbonaceous material and, especially in the upper part, coal. No record of Permian sedimentation exists within the map-area but red beds of Early Permian age in Prince Edward Island in which uranium and vanadium minerals have been identified (Prest <u>et al.</u>, 1969) show that similar conditions of sedimentation persisted after the Pennsylvanian.

Uplift probably occurred at the close of the Early Permian followed by erosion until the Late Triassic, at which time a graben-like downfaulting and downwarping created a deep trough in which many thousands of feet of red terrestrial sediments were deposited about the Bay of Fundy. These beds were succeeded by widespread basalt flows.

SAMPLING AND ANALYTICAL PROCEDURES

Stream sediment samples collected by Holman in 1957 and 1958 were taken where streams intersected the network of roads in the region, but well upstream from the roads to avoid contamination. About one pound of the wet silt-sand sediment was collected from the active segment of the stream and bagged in a waterproof paper envelope.

The sediment was dried in the envelope and then sieved to -80 mesh, a procedure outlined by Lavergne (1965).

The analytical procedure of Smith and Lynch (1969), used for the determination of trace amounts of uranium, is based on the fluorescence of uranium salts. 0.25 grams of the -80 mesh material was leached in hot 4N nitric acid for two hours then an aliquot of this leach was diluted with 4N nitric acid and evaporated to dryness. After ashing the residue, a carbonate-fluoride flux was added and the mixture fused at 650°C. for ten minutes. The resultant fused wafer was then measured for fluorescence and compared to a standard curve computed from synthetically prepared standard solutions. The lower limit of detection was 0.5 parts per million (0.0005 per cent) uranium. The precision of the analytical method is ± 5 ppm at the 58 ppm level. The accuracy may be judged from the following data relating Geological Survey of Canada analytical results to those by the U.S. Geological Survey on the same samples.

Table I
Comparative Data

Sample No.	G.S.C.	U.S.G.S. (Flanagan, 1969)
G-2	2.4	1.99
GSP-1	2.6	1.98
AGU-1	1.5	1.9
BCR-1	1.7	1.5

Resampling of Stream Sediments

Most localities where high anomalies were obtained were resampled in August, 1969 by V. Růžička and Little. In most cases anomalies of similar magnitude were obtained. Exceptions are on a tributary of Black River near Oxford, Deep Hollow Brook which is a tributary of Wallace River, and upper Wallace Brook a few miles south of Malignant Cove. At the last locality two factors may account for the discrepancy, the high water at the time of the resampling, and the rerouting of roads so that a different locality may have been sampled. A short distance south of this locality, coaly beds occur in the Windsor strata, so the environment may be especially favourable for the occurrence of uranium.

DISTRIBUTION OF URANIUM

Because the samples were especially selected to assess the uranium content of the Carboniferous sediments, there are insufficient data to assess other formations. A rough tabulation showing number of samples of stream sediments derived from the various groups of Carboniferous age and their average uranium content is given in Table II.

This tabulation cannot be considered exact; samples taken a short distance downstream from a particular formation are assumed to be representative of that formation. Also the higher pH (alkalinity) of the streams near their mouths probably causes a greater quantity of uranium to be precipitated or adsorbed by organic material there, thus giving false values unrelated to the underlying formation.

The data in Table II are shown graphically in Figure 2. In comparing the Carboniferous units (solid line) it is evident that the Pictou Group is the most uraniferous, followed by the Canso (Mabou) and Riversdale Groups. The River John Group shows a high proportion of analyses 0.5 ppm uranium or greater but the average of these analyses is low. The equivalents of the Silurian and Lower Devonian Arisaig Group that occur in the west part of the map-area appear to be more uraniferous than the Pictou, but there are insufficient analyses of the former for such a conclusion to be valid. Stream sediments resting on the Wolfville and Blomidon Formations show a rather high proportion of analyses 0.5 ppm uranium or greater, but the average content of these is low.

From Table II the Devonian granites would appear to have a very high uranium content, but very few samples of such stream sediments were analysed.

ASSESSMENT OF URANIUM POTENTIAL OF FORMATIONS

Pegmatite Deposits

Pegmatitic uranium occurrences are known within the map-area near Georgeville and several miles southwest of the map-area near Lake Ramsay (Gross, 1957, pp. 21-23). Those near Georgeville occur in the Browns Mountain Group whereas those near Lake Ramsay are in Devonian granite. At neither of these localities is uranium of economic value. Similar occurrences may be found in most formations of Ordovician age or older or in granite of Devonian age or older.

Vein and Dissemination Deposits

Vein deposits are not known within the map-area. At New Ross, near Lake Ramsay, tin- and tungsten-bearing quartz veins in greisenized granite, of probable Devonian age, contain minute amounts of torbernite or meta-torbernite (Gross, 1957, p. 25). Similar veins might be found in the same map-unit within the map-area or in other pre-Silurian formations, one of the most favourable being grey slates of the Meguma Group. Such marine slates are commonly more uraniferous than the average sedimentary rock, and intrusion of granitic bodies into such rocks might result in concentration of uranium in veins or disseminations.

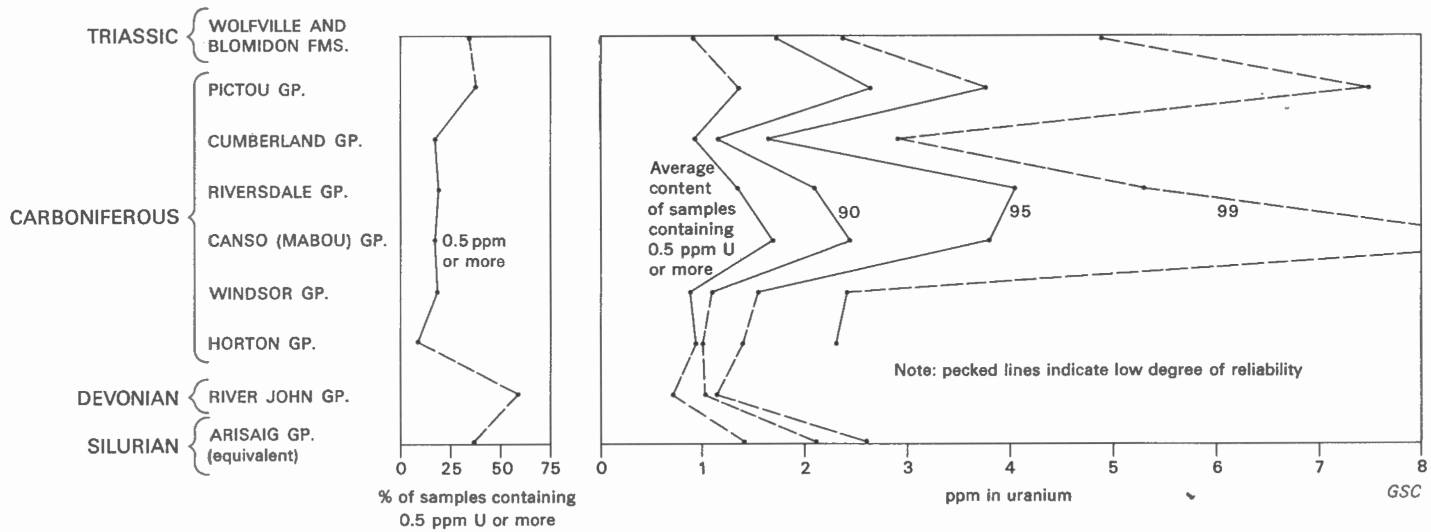

Figure 2. Graphs showing proportion of stream sediments that contain 0.5 ppm U or more, and average uranium content of samples containing 0.5 ppm or greater, 90th, 95th, and 99th percentile, plotted against sedimentary unit.

TABLE II

RELATIVE URANIUM CONTENTS OF STREAM SEDIMENTS DERIVED MAINLY FROM SPECIFIED FORMATIONS

FORMATIONS (see Figure 1)	No. of Samples	PER CENT OF TOTAL Samples that Contain 0.5 ppm U or more	AVERAGE CONTENT of Samples that contain 0.5 ppm U or more	90th Percentile	95th Percentile	99th Percentile
Meguma Group	170	90	0.78	0.80	1.1	1.4
Brown's Mountain Group	21	(86)	(0.6)	0.6	0.6	---
Arisaig Group Equivalents	53	64	1.4	2.1	2.6	---
Knoydart Formation	12	(92)	(0.8)	0.8	---	---
Granite (Devonian and (?) earlier)	18	(45)	(1.5)	2.8	3.3	---
River John Group	45	(42)	0.7	1.0	1.1	---
Horton Group	690	91	0.95	0.99	1.40	2.3
Windsor Group	475	80	0.88	1.09	1.45	2.4
Canso (Mabou) Group	118	82	1.70	2.42	3.8	9.8
Riversdale Group	326	80	1.38	2.10	4.05	5.3
Cumberland Group	247	83	0.91	1.15	1.62	2.9
Pictou Group	374	62	1.35	2.64	3.67	7.5
Wolfville and Blomidon Formations	181	65	0.91	1.74	2.4	4.9

Note: Figures in brackets should not be considered reliable. because too few samples were analyzed.

Epigenetic Uranium Deposits in Sandstones

Epigenetic uranium deposits in sandstones are of two types: lignitic deposits in which uranium is adsorbed by carbonaceous plant fragments, and roll-type deposits commonly composed of uraninite and coffinite and formed by lateral migration of uraniferous groundwaters. The former type is unlikely to be of importance but the latter is probably the foremost source of uranium in the world. Either type may occur in several formations each of which is discussed in turn, from oldest to youngest.

Meguma Group

Quartzitic rocks of the Meguma Group are of marine origin, are not arkosic, indicating a nongranitic source, and are not likely to contain sandstone uranium deposits. The small percentage of stream sediment samples that contain 0. 5 ppm or more of uranium, and the low average content of these samples give support to this statement.

Browns Mountain Group

Although red and grey sandstones exist in the Browns Mountain Group, and rhyolite of approximately equivalent age is present west of Malignant Cove, probably few or none of these beds were derived from a granitic source, and as they are of marine origin, the group is considered to be unfavourable as a source of uranium. Even less favourable is the locally distributed overlying Malignant Cove Formation. Geochemical data on stream sediments derived from these formations are too sparse to support or refute these conclusions.

White Rock Formation

The quartzites as described by Crosby (1962, p. 23) are well indurated and tough. The lack of porosity and the pre-granite age of the formation make it unfavourable.

Arisaig Group (and equivalents)

The coarse clastic rocks, particularly the red beds which are probably of nonmarine origin (Poole, 1967, p. 27) and may in part have been derived from Ordovician granites contain tuffs, and in Cobequid Mountains region abundant lavas, which are commonly acidic and are associated with beds of equivalent and younger age (Kelley, 1966, 1967a, 1968). Because carbonaceous material, other than in some shales, is not present in these sediments to act as a precipitant of uranium in solution, some other agent, such as pyrite, would be necessary. Despite this drawback, the uranium content of stream sediments derived from Silurian and Lower Devonian rocks in the Cobequid Mountains appears to be relatively high and these rocks are perhaps as favourable as the Pictou Group to the north. No samples were analyzed from the Arisaig Group near its type locality.

Knoydart Formation

In the eastern part of the map-area the Knoydart Formation comprises terrestrial red slates and hard grey sandstone, which may be favourable for the concentration of uranium. In Cobequid Mountains, however, Kelley (1966, 1967a, 1968) reported red beds and associated acidic to basic volcanic rocks, which appear to be more favourable. These units, as indicated in the previous section, appear to be comparatively uraniferous.

River John Group

The fluviatile origin, presence of red, feldspathic sandstones and conglomerate with granitic pebbles and carbonaceous plant remains are factors that favour the accumulation of roll-type uranium deposits. The widespread occurrence of uranium in the stream sediments above the group is encouraging. The low average uranium content may have resulted from leaching by circulating waters that could have carried the uranium to greater depths in the sandstones.

Horton Group

Like the River John Group the Horton Group is of fluviatile origin, was derived in large part from the erosion of granite, and contains red feldspathic sandstones and carbonaceous matter. Conditions are similarly favourable, but stream sediments derived from the group are singularly low in uranium content. This may be a result of leaching, causing enrichment at greater depth, but in Colorado Plateau and elsewhere, roll-type deposits are not usually present in basal beds, but mostly in beds higher in the section.

Windsor Group

Because the Windsor Group is of marine origin and the lithology is unsuitable it is not regarded as favourable for uranium deposits.

Canso (Mabou) Group

The more porous clastic members of the terrestrial Canso Group, some of which are red, may be favourable for uranium deposits. In general, though only a small proportion of samples contain 0.5 ppm uranium or more, those that do have a very high average content (see Fig. 2). Parts of the Canso Group are therefore considered favourable. King Mine, a copper-uranium occurrence, is in this formation.

Riversdale Group

Because this terrestrial assemblage is derived in part from a granitic terrain and contains sandstones that locally are red, it would appear to be reasonably favourable for uranium deposits. From Figure 2, however, it appears to be less so than the Pictou and Canso Groups. The most interesting anomalies within the group, and some of the most interesting within the map-area, occur along the Cobequid fault, extending easterly from Parrsboro. Whether these anomalies are related to mineralization along the Cobequid fault is not known at present. Gabelman (1968), however, suggested that in the Appalachian region base metal, barite-fluorite, and copper-uranium deposits were formed during the taphrogenic phase of orogeny in post-Triassic time. Traverses in which soil gas is tested for radon content, if done across the Cobequid fault might resolve the question of whether or not uranium mineralization is associated with the fault.

Cumberland Group

Despite the presence of red sandstones and conglomerate, and of coal, the Cumberland Group seems to be one of the least favourable of the Carboniferous units (see Fig. 2).

Pictou Group

Of the sedimentary units exposed within the map-area the Pictou Group appears to be the most favourable for the occurrence of epigenetic uranium deposits, being probably the most uraniferous of all. The region between River John and Cumberland Basin gives the highest anomalies. The presence of uranium has been reported in two sedimentary copper properties between River John and Philip River (Brummer, 1958, and Nova Scotia Dept. Mines, 1966). At the Black Brook occurrence local alteration of the ferric oxides to ferrous was noted, and selected samples tested as high as 0. 039 per cent U_3O_8 equivalent. Both copper and uranium were deposited from circulating waters.

Wolfville and Blomidon Formations

These terrestrial beds, which abound in feldspathic carbonaceous red sandstones and contain interbedded shales, are on theoretical grounds favourable for roll-type uranium deposits, but from Figure 2 these formations do not appear to be highly uraniferous. The samples, however, were taken almost entirely from the central and eastern parts of Minas Basin. The Triassic of the Cornwallis-Annapolis Valley was not sampled, but as the sediments there were derived mainly by the erosion of granites to the south they should perhaps be more favourable for uranium deposits.

RECOMMENDATIONS FOR URANIUM EXPLORATION

In order to assess the anomalies in stream sediments shown on Figure 1 it will be necessary to take check samples where none has been taken by the writer and to do more detailed sampling in the vicinity of the anomalies so that they may be more closely delineated. Surface samples of bedrock will in many places be difficult to obtain due to the paucity of outcrops. Such samples may not however be useful in tracing the source of an uranium anomaly because the transported uranium may already have been leached from the outcrop. If, however, an unusually uraniferous bed is discovered, drilling should be undertaken to intersect the bed at depths of the order 100 to 400 feet and perhaps more.

In an arid climate migration of groundwater along an aquifer to its outcrop is a common process so that uranium and its daughter products may be readily transported from a hidden deposit to the surface. In a humid climate, however, such conditions may occur only during periods of drought, but at other times the migration of groundwater is likely to be down the dip of the aquifer. Continued washing of the outcrops by rain dissolves both

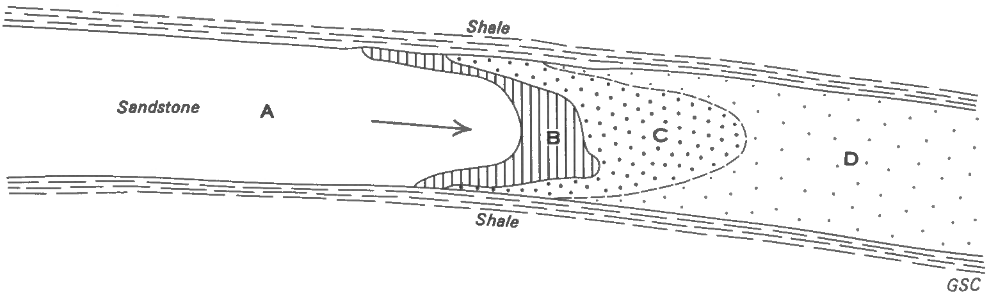

Figure 3. Diagrammatic representation of an idealized roll-type uranium deposit.

uranium and daughter products, so that the probability of either a uranium or a radiation anomaly being present is not great in the humid environment.

A comprehensive exploration program under such conditions may therefore require sampling of well waters from known aquifers, measuring the pH and Eh of the samples, and analyzing them for uranium and perhaps radium. From these values the position of the interface at which the pH and Eh are critical for the precipitation of uranium might be determined. It is probable that additional boreholes would have to be made to supplement the information obtained from water wells.

Samples of the aquifers should be obtained from boreholes and, if possible, from water wells for petrographic examination under a binocular microscope. The chemical processes that lead to the formation of roll-type deposits in aquifers leave their imprint upon the rocks (King and Austin, 1966). Figure 3 is a diagrammatic representation of a roll-type deposit and its environment. The arrow indicates the direction of migration of uranyl oxidic solutions, and the boundary between the roll (B) and barren sandstone (A) is the solution front. According to King and Austin the characteristics of each zone are as follows:

A. Grey-white, lacking in brown limonitic specks, feldspars notably altered, and pyrite in the form of individual euhedral crystals.

B. Dark ore with abundant carbonaceous matter and limonitic specks are obscured; radioactivity is very strong.

C. Brownish black ore with sparse limonitic specks; radioactivity is strong.

D. Light brownish grey protore, with sparse limonitic specks; pyrite forms clusters of tiny anhedral crystals.

These criteria will aid greatly in determining the position of the sample relative to a roll-type deposit.

Recent preliminary tests of stream sediments in New Zealand have indicated that copper-lead ratios of 0.80 or greater may be pathfinders in the search for uranium deposits (Cohen et al., 1969). It is not within the sphere of this paper to investigate this possibility, but as the data are available in Holman (1959a, b, c, d) the prospector may wish to try this approach as an additional tool.

CONTOUR MAP OF URANIUM CONCENTRATIONS BY COMPUTER TECHNIQUE

Uranium concentrations below the detection limit of 0.5 parts per million (ppm) were given an arbitrary value of 0.2 ppm, for purposes of computing contour levels. The method used to produce the contour map incorporated into Figure 1 was the "General Purpose Contouring Program" (GPCP), a proprietary program of California Computer Products, Inc. (Calcomp).

By means of contours, the program displays functions depending on two independent variables. The computer determines the contours and presents them for display on an incremental X-Y plotter.

In the contour map illustrated, the x and y co-ordinates and the corresponding uranium concentrations were read into an IBM 360/65 computer with 50K words of memory, 1 plotter tape, 1 system 'use' tape, card reader, printer and the contours plotted by a Calcomp 663 plotter.

The raw data were transformed to logarithms which reflect the lognormal distribution of uranium in the sediments. The contours plotted are the logarithmic levels but labelled as the raw data concentrations in ppm. For visual clarity only 6 levels of the concentrations are plotted, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 ppm. The 1.0, 2.0, and 3.0 levels are contoured as heavy bold lines. Most of the data fall within the range of less than 0.5 to 3 ppm. Those samples that contain greater than 0.5 ppm appear to be significant and the few that are greater than the 3 ppm level are obviously anomalous and contours for these individual highs were deemed to be superfluous.

The Calcomp program grids the specified random data by a procedure which analytically constructs a smooth surface passing through every data point but the method is neither a weighted mean of nearby points nor a least squares fit of the data. The grid values are generated by weighting the intersections of the gradient plane at the data points with the vertical line (Z axis vertical) at the grid point. Extrapolation of gradient planes a great distance from the data points may cause spurious trends. Taking derivatives of $\Sigma_{j=1}^{k} Wj(\vec{N}.\vec{Q}._j)^2$ with respect to x, y, z, gives three equations in three unknowns for the normal vector. The program subdivides each cell, refining the grid, to produce nearly smooth contours and interpolates within the sub-grid to define the contour. When interpreting the contour map of the uranium concentrations, consider that the targets are mathematical computations and do not necessarily indicate actual high concentrations, particularly if they are distant from data points. However, it may also be noted that for some of the areas outlined by the contours, Little has also shown that those areas are geologically favourable for uranium deposits.

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