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Soil and Vegetation Geochemistry

THE BIOGEOCHEMICAL EXPRESSION OF DEEPLY BURIED URANIUM MINERALIZATION IN SASKATCHEWAN, CANADA

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ABSTRACT

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Ten kilometres from the eastern edge of the Athabasca Sandstone, near McClean Lake, uranium mineralization (locally up to 27% U_3O_8) lies 150 m beneath the surface at the unconformity between the Athabasca and crystalline basement.

A biogeochemical survey of the area sampled A_H and B_F soil horizons, peat moss, and plant organs from the dominant species, viz. black spruce (*Picea mariana*), jack pine (*Pinus banksiana*), labrador tea (*Ledum groenlandicum*), and leather leaf (*Chamaedaphne calyculata*). Uranium concentrations in the ash of various media are surprisingly high: spruce twigs up to 154 ppm U; labrador tea and leather leaf stems around 100 ppm U. Conversely, labrador tea roots yield < 5 ppm U and spruce trunk wood usually < 1 ppm U. Soils give values of 1—3 ppm U. Contoured U values reveal that highest concentrations occur in plants growing above, but laterally displaced from the mineralization. Track-Etch data show a similar pattern. Upward migration of ions along steeply inclined fractures is invoked to explain the phenomenon. Other elements are present in varying concentrations, depending upon the plant species and the plant organ. High concentrations of several elements are recorded, most notably Cd and Ag in the conifers.

INTRODUCTION

Biogeochemistry has a chequered history of success and failure in its application to mineral exploration. The literature on the subject is extensive, but relatively few studies have dealt with uranium.

Plants were successfully used in the search for uranium in the Colorado plateau (Cannon, 1960), using both geobotany (the visual approach) and biogeochemistry (the chemical approach). The Swedish Geological Survey has successfully used organic-rich stream bank peats to outline uraniferous regions and help focus on ore deposits (Larsson, 1976). In the United States the catclaw mimosa shows interesting potential as a biogeochemical exploration tool (Erdman et al., 1979). Studies in Canada by Walker (1979) and Barakso (1979) have documented U uptake of plants growing over U ore deposits in Saskatchewan and British Columbia, respectively. The work by Walker (1979) in the Key Lake area indicates that the woody parts of conifers and vascular shrubs are the best concentrators of U. A list of additional references pertaining to U biogeochemistry is given in Brooks (1972).

The present study concerns the biogeochemical expression of high-grade U mineralization (locally over 27% U_3O_8) buried beneath 150 m of barren Precambrian Athabasca Sandstone, near McClean Lake (Fig. 1). Canadian Occidental Petroleum Ltd. and its partner, Inco Metals Company, announced the discovery in the spring of 1979, and this biogeochemical study was conducted six weeks later when there had been little disturbance of vegetation by drill rigs and heavy equipment. The study shows that abnormally high U concentrations are present in some of the vegetation, and that the highest values are from plants growing above, but laterally displaced from, the known extent of deeply buried mineralization. No other geochemical or geological surface expression of mineralization is discernible.

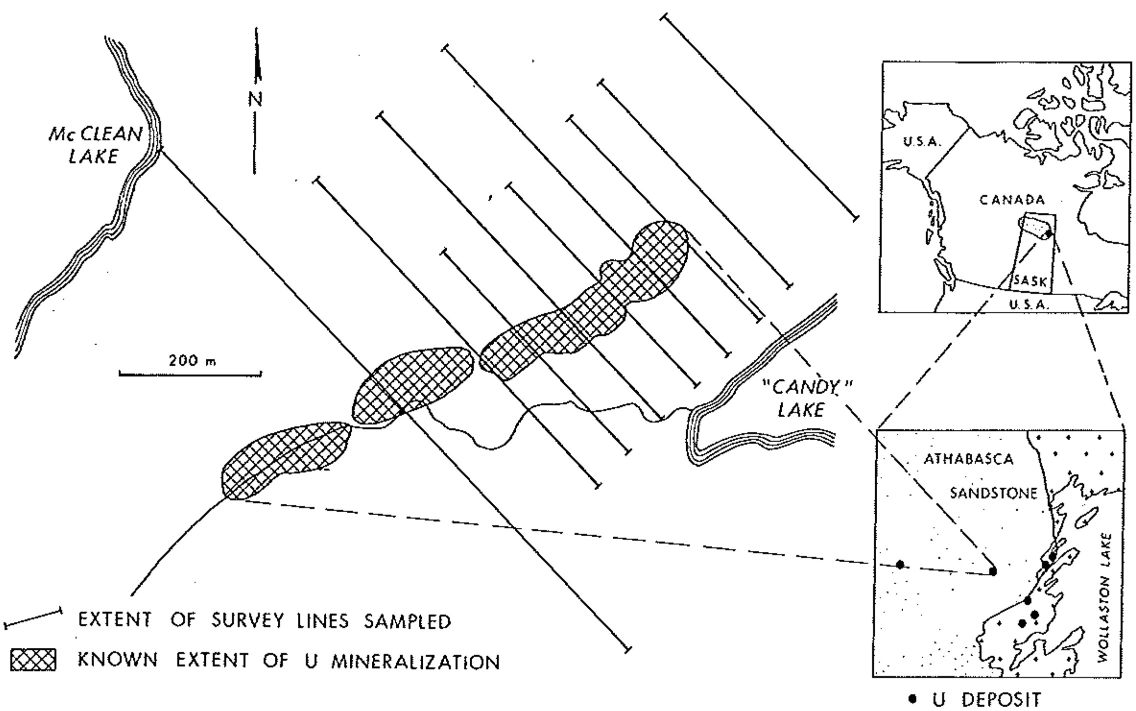

Fig. 1. Location map.

GEOLOGY, PHYSIOGRAPHY, AND VEGETATION

The northern half of Saskatchewan comprises Precambrian Shield covered with Pleistocene glacial deposits. One third of this area consists of unmetamorphosed Helikian fluviatile and marine sandstones of the Athabasca

Group (1350 ± 50 m.y., Ramaekers and Dunn, 1977). Recent work (P.P. Ramaekers, pers. commun., 1980) suggests that the sediments are molasse, and they may be around 1420 m.y. old. Several major uranium deposits have been discovered in the last twelve years near the unconformity between the Athabasca Sandstone and underlying crystalline basement (e.g. Rabbit Lake, Cluff Lake, Key Lake, Midwest Lake). The McClean Lake mineralization is in the same geological setting (Fig. 2).

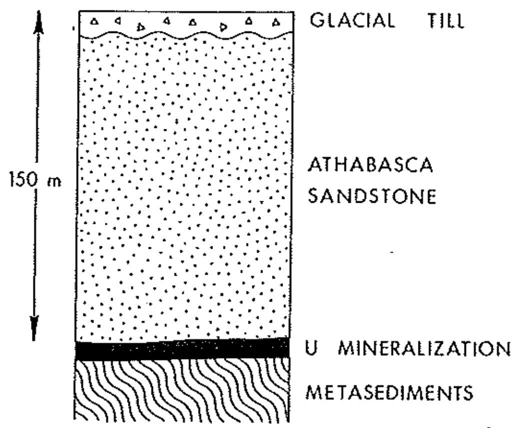

Fig. 2. Stratigraphic section.

Outcrops of Athabasca Sandstone are extremely sparse: no outcrop occurs in the McClean Lake are, although frost-heaved slabs are locally present. The flat topography is relieved by drumlins and eskers. Glacial drift ranges in thickness from zero (in frost-heaved areas) to several metres in thickness. Thin podzols are present in the drier areas, and peat moss in the widespread wet regions. The severe continental climate of northern Saskatchewan gives rise to a boreal forest within which few species are ubiquitous, thus making the choice of sample media relatively simple.

The ground in this area is, for the most part, damp to wet, so that black spruce (*Picea mariana*) is the most common tree. On drier ground, such as eskers and drumlins, jack pine (*Pinus banksiana*) is dominant. Of the vascular plants labrador tea (*Ledum groenlandicum*) predominates, with leather leaf (*Chamaedaphne calyculata*) present in very wet areas, especially bordering peat bogs. Lichens and mosses cover the ground.

METHODS

The fieldwork was conducted during the first half of June, 1979. Ice had disappeared from the small lakes, but the ground was still frozen a few centimetres beneath the surface due to an exceptionally long winter. Hence, the vegetation was still fairly static, with very little new growth. Because of seasonal variations in plant chemistry (e.g. Robinson, 1943; Guha, 1961), the static state of the plants was considered important for inter-site comparison of element abundances. Similarly the age of the plant and plant organ can affect the amount of element uptake (Warren et al., 1968) so these factors were kept as consistent as reasonably possible for an exploration survey, by sampling trees of similar height and twigs of similar length. In this environment, spruce twigs grow about 2.5 cm per year on mature trees, making it impractical to collect only the latest growth because of the relatively large sample (> 100 g of fresh twig) needed to provide the 1 g of ash desired for this study. Thus, twig lengths of about 25 cm (representing ten years growth) were collected, permitting the accumulation of sufficient material at each site within 30 sec.

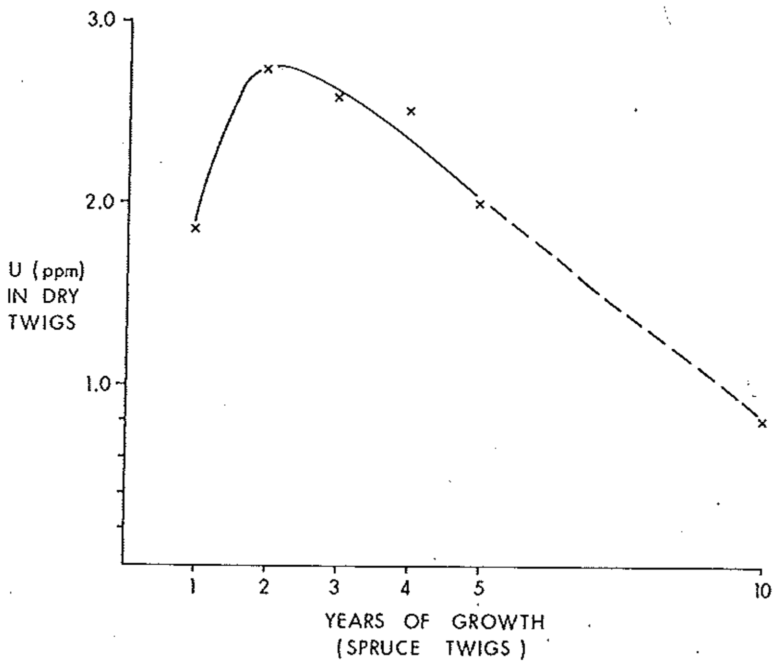

Fig. 3. Variation in U concentration of spruce twigs according to age.

The U distribution within individual twigs was checked on a few samples (Fig. 3), and results show that the 2 to 4 year old growth contains the highest concentrations of U, with older growth having progressively less. The implication is that U ions are continuously transported through the tree to accumulate in its extremities. Another test suggests that twigs at the top of trees concentrate more U than those lower down.

Samples were collected along survey lines at 30 m intervals. At each site black spruce trunk (without the bark), labrador tea stems and leaves, and A_H and B_F soils were sampled. Where no soil profile was developed the peat moss was sampled. In addition, at every fifth site spruce twigs and needles, and labrador tea roots were collected. Leather leaf stems and leaves were sampled at the few sites where they were present. The entire above ground portion of the shrubs was collected. The amount of oven-dry material needed for 1 g of ash is about 400 g of pine wood, 300 g of spruce wood,

TABLE I

Types and numbers of samples

Type		No.
At each site (30 m spacing):		
Black spruce (*Picea mariana*)	Trunk	117
Labrador tea (*Ledum groenlandicum*)	Leaves	117
	Stems	117
Soils: A_H		46
B_F		46
or Peat (*Sphagnum sp.*) where soils absent		93
plus		
At every 5th site:		
Black spruce	Twigs	22
	Needles	22
Labrador tea	Roots	13
Leather leaf (*Chamaedaphne calyculata*)	Leaves	21
	Stems	21
(Jack pine (*Pinus banksiana*) Trunk, where spruce absent		15
	Total	650

100 g of labrador tea roots, 70 g of spruce twigs or shrub stems, and 30 g of spruce needles or shrub leaves. From the 140 sites visited, 650 samples were prepared for analysis (Table I).

The A_H soil horizon is present beneath the forest litter to a depth of 2—3 cm. The B_F horizon is a few cm thick, at a depth of 5—10 cm. The soils were oven-dried at 105°C and sieved to obtain the —80 mesh fraction for analysis.

The plant preparation procedure was to partially air-dry the samples (1—2 weeks), then dry them to constant weight in a microwave oven (at 80°C). The dried samples were then easily separated into twigs and needles, and with a little more difficulty into leaves and stems. A pottery kiln was used to ash the samples at 475°C. Tests indicated no significant variation in U content of the ash within the temperature range of 450—550°C.

The ashes were first analyzed for U by neutron activation/delayed neutron counting, then returned for atomic absorption spectrophotometry following a hot concentrated acid digestion (4 parts HCl: 4 parts HNO_3: 1 part $HClO_4$) for Pb, Ag, Cd, Cu, Co, Zn, Be, Fe, and Mn (with background correction for interferences where appropriate). The solution was analyzed next by an inductively coupled argon plasma spectrometer (ICAP) for Ni, Mo, Ba, Ca, Mg, P, V, Y, Sr and Ti. Thirty-three dry samples were analyzed by neutron activation analysis for Au, Sc, As, Sb, La, Ce, Sm, W, Th and Br, and a further 22 ashes for Au and Sm only.

RESULTS

Uranium

The background concentration of U in plant ash is estimated to be 0.6 ppm (Hawkes and Webb, 1962; Brooks, 1972). Cannon (1964) reports 0.5 ppm U in the ash of junipers growing over barren ground in Utah, increasing to 2 ppm U over mineralized areas. In the light of these reports the data in Table II are highly anomalous. The only type of vegetation with U values close to the above-mentioned figures are the trunks of the conifers; concentrations in the shrubs are dramatically higher, and are highest in the spruce twigs (up to 154 ppm U).

TABLE II

U content (ppm) of soils and ashed vegetation

Sample		Range	Mean (≅ Median)
Black spruce	Twig	50 —154	84
	Needle	9 — 22	14
	Trunk	<0.4— 9.5	0.5
Jack pine	Trunk	<0.4— 1.9	0.9
Labrador tea	Stems	36 — 83	56
	Leaves	17 — 51	32
	Roots	0.8— 5.8	3
Leather leaf	Stems	51 —100	70
	Leaves	31 — 83	51
Soils (dry)	A_H	1.0— 3.6	1.8
	B_F	0.8— 2.2	1.4
Peat		1 — 24	6.2

It is noteworthy that the soils within which the plants are growing have only background concentrations of U. There is no significant correlation between the U content of the ashed plants and the soils or peat within which they are growing. For example the ratio of U in spruce twig ash to U in peat ash varies from 6:1 to 77:1, and a plot of these values from individual sites (Fig. 4) shows no apparent relation, perhaps because the plant roots extract trace elements from an area of several square metres, thus giving a more homogeneous representation of element distributions than is obtained by taking a single localized soil or peat sample. It should be noted, also, that even the highest concentrations of U in vegetation are only a little higher than those found in the soils, when data are converted to a dry-weight basis.

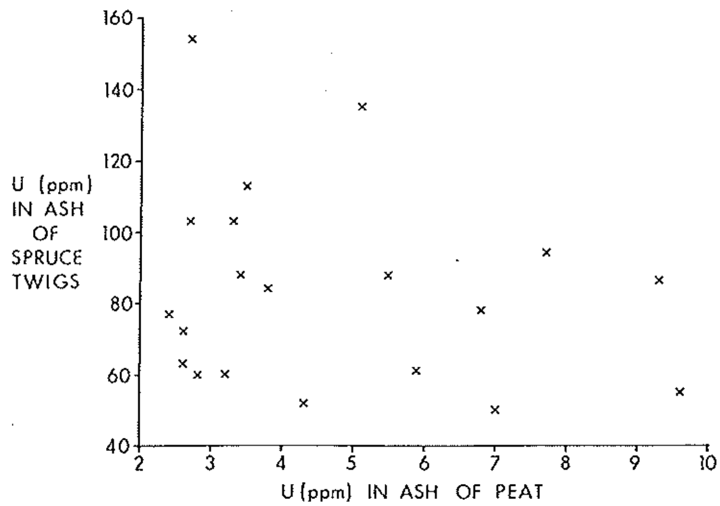

Fig. 4. U in the ash of spruce twigs vs. U in the ash of peat at the same site.

By ashing the plants U is highly concentrated, so that otherwise subtle variations in the dry material are enhanced and more readily discerned.

The labrador tea roots contain much less U than the parts growing above ground. This is surprising in that roots commonly have much higher concentrations of trace elements (including U, cf. Cannon, 1960) than other plant organs. It is possible that the fine rootlets do, indeed, retain more U; in this study the bulk of the root pulled out of the ground was relatively thick (5—8 mm diameter) woody material. The conifers show low U concentrations in their thick portions (i.e. trunks) so by analogy a similar situation may prevail in the labrador tea.

It appears (Table II) that the most pronounced accumulators of U are spruce twigs, followed by leather leaf stems, and labrador tea stems; thus the woody extremities of the plants form the best sample media. A few labrador tea and leather leaf samples collected from the same sites show that the leather leaf U content of both stems and leaves is 30 to 40% higher than that of the labrador tea. Two samples of jack pine twigs and needles indicate that the twigs contain only half to one-third of the U of the spruce twigs, and conversely the needles contain two to three times more U than the spruce needles. These findings serve to confirm what others have demonstrated — that in a biogeochemical survey, data from different species and different plant organs must not be mixed.

The highest concentration of U in spruce twigs (Fig. 5) occurs just south of the mineralized zone, and apparently extends southward into an area where no drilling results are yet available.

Spruce needle U data (Fig. 6) show a distribution pattern similar to the twigs, but with lower values. Given sufficient U in the environment, it seems that either plant organ is suitable for outlining anomalous areas.

An additional observation is that the ratio of U in twigs to that in needles is highest directly over the eastern extension of U mineralization. In general

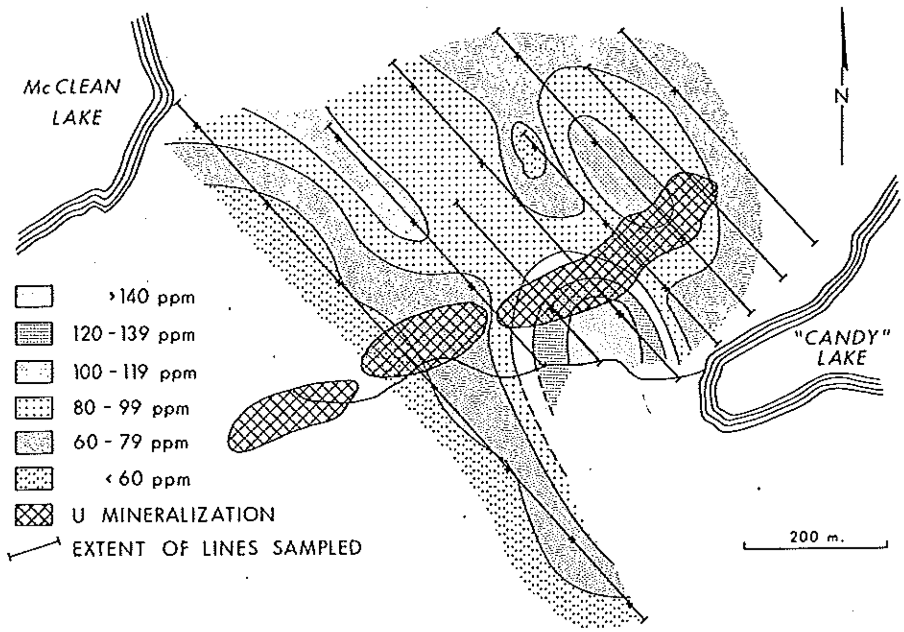

Fig. 5. U in the ash of spruce twigs. Crosses indicate sample sites.

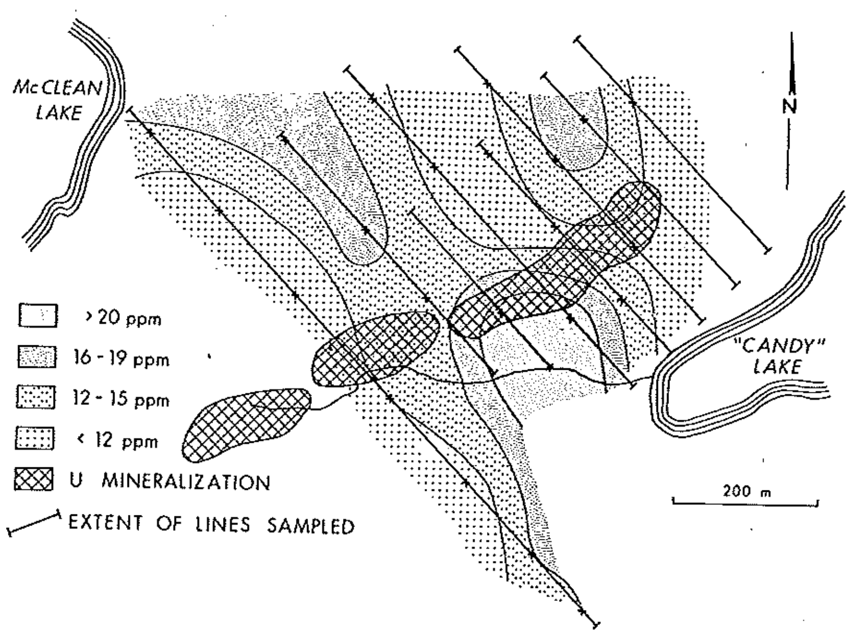

Fig. 6. U in the ash of spruce needles. Crosses indicate sample sites.

it appears that both here, and further west at Midwest Lake, the higher the U concentration the higher this ratio becomes.

Although the spruce trunks contain very little U, the data appear meaningful. If they are contoured at 0.5 ppm and 1 ppm, a relationship of these subtle variations to the underlying mineralization is evident (Fig. 7). There were five times more spruce trunk samples than samples of twigs and needles,

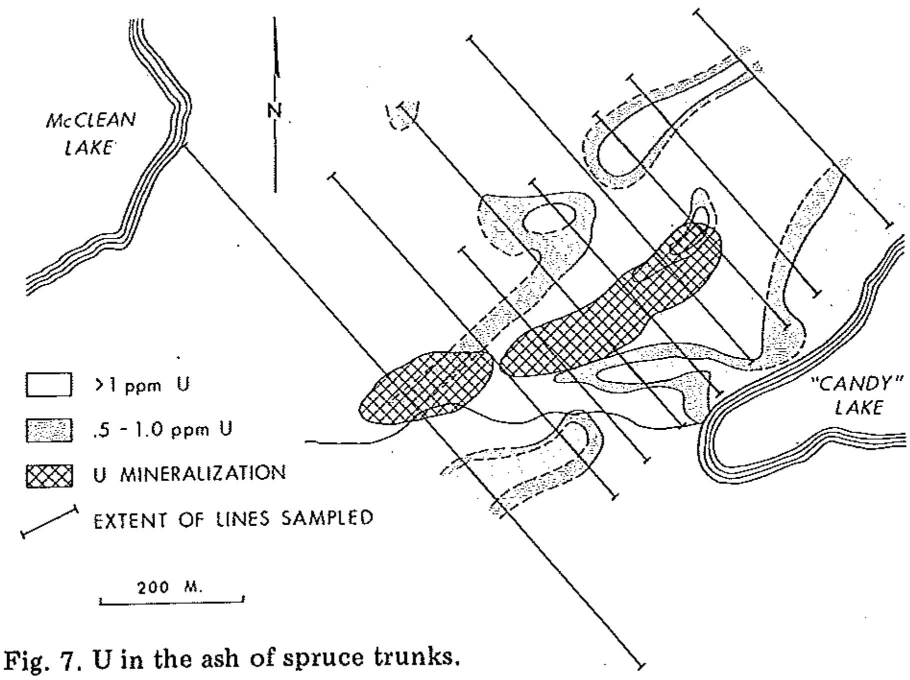

Fig. 7. U in the ash of spruce trunks.

thereby providing closer control on contours and a better defined picture of U anomalies, which are seen to surround the underlying mineralization.

Thoron-filtered Track-Etch data (Fig. 8) show a picture broadly similar to that of the spruce trunk anomalies, again with the higher values surrounding the mineralized zone.

U contents of labrador tea stems and leaves are a little more variable, but patterns of U anomalies are similar to the spruce trunk and Track-Etch plots. U anomalies do not coincide with the distribution of wet areas: the anomalies transgress terrains from wet bog to dry open woodland.

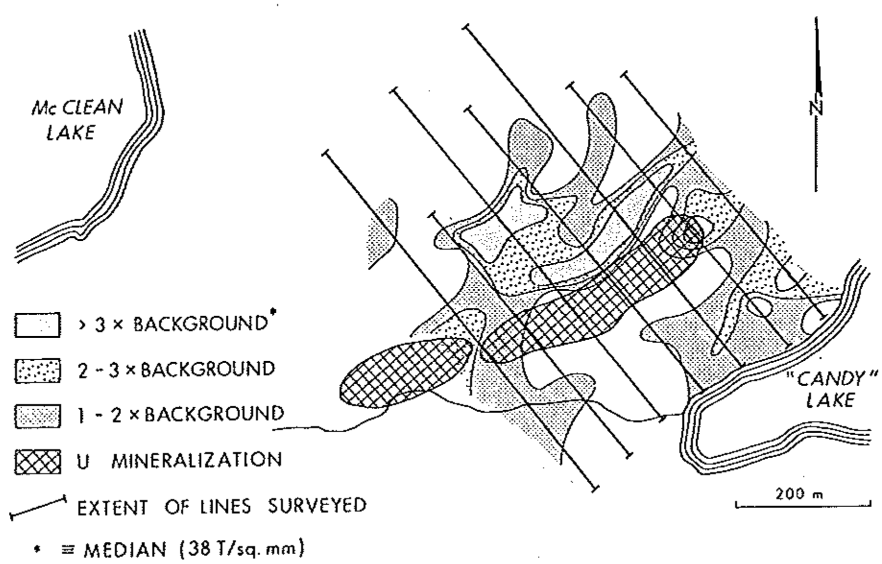

Fig. 8. Thoron-filtered Track-Etch data.

Other elements

Table III summarizes the contents of other elements in the various sample media. The right-hand column shows the normal concentrations to be expected in plant ash (Brooks, 1972). The plant organs which contain highest concentrations of each element are:

(1) Spruce twigs: U, Pb, Ba, V.
(2) Labrador Tea roots: Ni, Cu, Co, Be, V, P, Fe, Ti.
(3) Jack Pine trunk: Cd, Zn, Ca, Mg, Sr, Ag (Ag similar in spruce trunk).
(4) Leather Leaf stems: Mn, Mo (Mo similar in labrador tea leaves and roots).

The most notable concentration is that of Cd in the trunk of jack pine, for which the mean value exceeds by 520 times the published estimate of background value. Jack pine trunk consistently has high Cd with low Mn; in the black spruce this association is reversed. Another considerable enrichment is that of Ag in the trunks of both conifers. Iron is enriched in the labrador tea roots, and Mn concentrations are high in most plant organs. Tests indicate that little or no U and Co volatilize during the ashing process up to at least 550°C. However, about 50 percent of the Zn is lost during ashing.

Twenty-nine dry samples of spruce needles and twigs were made into briquettes and run through the nuclear reactor at McMaster University for NAA analysis of fourteen elements. Elements not detectable in any sample (with detection limits in parentheses) are As (1 ppm), Sb (0.2 ppm), La (0.5 ppm), W (1 ppm) and Th (0.2 ppm). The Sc content of twigs ranges from 600 to 900 ppb, and of needles from 100 to 300 ppb. Ce ranges from 1 to 3 ppm with more in the twigs than needles, whereas Br is higher in the needles (7 to 14 ppm) than twigs (1 to 5 ppm). Most samples returned gold assays below the detection limit of 1 ppb, with no sample having over 2 ppb; one *ashed* labrador tea stem returned an assay of 75 ppb Au.

Samarium is preferentially concentrated in the spruce twigs (40 to 80 ppb in the dry material) compared to the needles (20 to 50 ppb), and shows an almost perfectly linear relationship with U (1 part Sm to about 12 parts U). Tests carried out to verify these results confirm that this is a natural relationship and that it is not interference caused by creation of Sm as a fission product during irradiation of the sample.

ELEMENT RELATIONSHIPS

Inter-element correlations in the various sample media are generally weak, and each medium has a different suite of related elements. In the plant organs U tends to vary sympathetically with Fe and Pb, and sometimes with Cd, Be and Zn: there is frequently an inverse relationship between U and Mn. The U-Cd relationship is most prevalent in the labrador tea, and to a lesser degree in black spruce trunk and leaves of the leather leaf. The U-Be association occurs in the spruce twigs, and that between U and Zn in the leaves of both shrubs.

TABLE III

Mean concentrations of elements in the sample media

Element	Soils		Spruce			Pine	Labrador tea			Leather leaf		Ave. conc. in plant ash (Brooks, 1972)
	A_H	B_F	Twigs	Needles	Wood	Wood	Stems	Leaves	Roots	Stems	Leaves	
U	1.8	1.4	84	14	0.5	0.9	56	32	3.0	70	51	0.6
Pb	4.0	3.9	161	9	10	12	94	31	72	94	44	70
Cu	5.3	5.3	134	24	85	136	259	127	300	229	98	180
Co	1.7	2.5	14	12	14	16	14	15	24	12	14	9
Ag	0.1	0.1	2.4	0.9	23	24	0.6	0.4	0.6	1.2	0.3	1
Cd	0.2	0.1	4.3	0.3	1.2	52	2.8	1.2	4.2	4.8	2	0.1
Zn	8	5	2880	1814	3600	3981	1701	924	1942	1669	911	1400
Be	0.3	0.3	0.4	0.1	0.1	0.2	0.3	0.3	0.7	0.3	0.2	0.7
Ni	3	4	32	14	14	25	25	31	42	27	17	65
Mo	0.8	0.6	7	7	7	9	10	16	15	16	10	13
Ba	71	19	492	162	297	253	261	390	297	376	291	280
V	9	16	23	9	7	9	17	18	23	17	14	22
Y	2.7	3.3	5	3.6	3.5	4	4	4	4	4	4	*
Sr	NA	NA	329	184	482	1013	337	221	327	178	135	30
Ti	NA	NA	90	15	9	11	56	43	101	60	38	*
Fe	3804	6250	5200	765	967	501	3540	4320	22600	4700	2780	6700
Mn %	25 ppm	25 ppm	2.9	5.3	3.2	1.1	7.1	3.1	6.8	9.9	6.7	0.5
P %	550 ppm	430 ppm	2.4	2.0	0.4	0.9	3.4	3.8	4.1	3.1	3.2	*
Ca %	780 ppm	0.1	13.6	17.4	19.4	21.8	13.0	14.8	10.9	9.0	14.1	*
Mg %	460 ppm	0.1	2.5	3.4	3.2	4.9	2.6	3.0	3.0	3.1	2.8	*
Ash %	—	—	1.9	3.2	0.4	0.3	1.1	2.8	0.9	1.1	2.7	—
LOI %	24.7	5.8	—	—	—	—	—	—	—	—	—	—

NA = not analyzed; * = data not quoted. All values in ppm unless otherwise indicated; values in soils are quoted on a dry weight basis (—80 mesh fraction); values for plants are concentrations in ashed material.

Metal associations in the soils are different: in the B_F horizon LOI is the only parameter to show a strong positive correlation with U (r = 0.46), whereas in the A_H horizon U shows strong affinity with Y, Be, Pb, Fe, V and Mg (all significant at the 99% confidence level), and to a lesser degree with P and Cu.

Sample media with sufficiently large populations were subjected to factor analyses (Table IV). Results demonstrate the considerable difference in element associations within the soil fractions and plant organs.

TABLE IV

Factor analysis summary (after Varimax rotation) of elements in several sample media

A_H soils

Factor No.	Percent. of variation	Factor loadings		
		>0.75	0.50—0.74	0.25—0.49
1	50.2	Be, P	LOI, Co, Cr, Y	Mg, Fe, Ni, Ca, Pb
2	19.0	Zn, Cd	Mn, Ca, Ba, LOI	Pb, P, Fe
3	11.1	V	Mg, Co, Fe	Zn, Ca, Mn, Cr, Ni
4	6.7	U	Cr, Y, Pb	Fe, Be, V
5	6.5	Cu	Ni	Co, Fe
6	4.1		*Ag*	Mg, Mn, Ca

B_F soils

Factor No.	Percent. of variation	Factor loadings		
		>0.75	0.50—0.74	0.25—0.49
1	51.9	Mg, Mn, Zn	Ni, Co, Cr	Be, Cu, Pb, V, Fe, Mo
2	13.2	V, Fe	Cu, Cr, Be, Co	P, Pb, Zn
3	12.0	LOI	U, P	Cu, Be, Zn
4	7.4	Ca, Y		P, Mn
5	5.4	Ba		V, Co, Fe
6	4.2		Mo	P

Spruce woods

Factor No.	Percent. of variation	Factor loadings		
		>0.75	0.50—0.74	0.25—0.49
1	28.2	Fe	Pb, Ti, Cd	P, U, Co, Ni, Cu
2	18.6	Mn		Cd, *Ag*
3	13.3	Be, *Ash*		
4	10.2		Co, Sr, Cu	Ag
5	6.6		Mg, Zn, Ag	Mo
6	5.4	V	Mo	
7	4.5		Ca	*Cu*, Co
8	3.4		U	Ti, *Mo*

Labrador tea stems

Factor No.	Percent. of variation	Factor loadings		
		>0.75	0.50—0.74	0.25—0.49
1	39.4	Fe, Pb, Ti	V, Cd	Ni, Cu, Be, Mo, Zn
2	15.4	Mn	*Sr*	V
3	12.2	P	Mg	Mo, Ca, V
4	8.7	Be, *Ash*		V
5	7.4	Cu, Co		Mo, Cd
6	5.3		U	Cd, Ni, Ca
7	4.0	Ba		Mo

Labrador tea leaves

Factor No.	Percent. of variation	Factor loadings		
		>0.75	0.50—0.74	0.25—0.49
1	53.6	*Mn, Ca,* Ag, U, Cu, *Zn*	Y, Pb, V, *Fe*, Cd, *P*	Mg, Co, *Ba*, Sr
2	18.8	Fe	Co	Pb
3	7.8		Be, *Ash*	Co, V, Cu
4	4.9	Ti		Fe, Ni, V, Zn
5	3.8	Mg		*P*, V, Pb, Y, Ag, Cu
6	3.3	Ba		Be, Mo, Ca

Data included in the factor analysis were for the elements listed in Table III, plus Cr for both soil horizons.
Factor numbers listed are those with eigenvalues > 0.5.
Elements are listed in order of decreasing factor loading from left to right.
Negative loadings are in italics.

DISCUSSION AND CONCLUSIONS

The Athabasca Sandstone in this region shows no sign of U mineralization: only locally do drill core samples of the sandstone contain more than 5 ppm U. There are, however, subtle variations of U in the sandstone which may be reflected in the vegetation. For example, a plot of areas where Athabasca core contains 5 ppm or more U at depths of less than 60 m shows anomalies laterally displaced from the mineralized zone in a manner similar to vegetation and Track-Etch anomalies, (Canadian Occidental, pers. commun., 1979).

At Midwest Lake, 14 km to the west, U mineralization is present beneath 200 m of Athabasca Sandstone with secondary U oxidation products occurring close to the surface, above the ore zone. Recent work at the Saskatchewan Research Council (J. Hoeve, pers. commun., 1980) has identified a change in clay mineralogy and associated elements for 200 m above this ore zone. These observations furnish strong evidence for upward migration of ions at some undetermined time since the Athabasca sediments became lithified.

The same process of upward migration of ions is envisaged for the McClean Lake area, perhaps driven by radiogenic heat from the U mineralization causing convective rise of surrounding fluids. Convection may only be effective for a short distance above the mineralization, but could have triggered off a movement of ions which have slowly diffused upward, preferentially along the abundant steeply inclined fractures of the sandstone: core sections of Athabasca Sandstone from the eastern side of the basin show sub-vertical fractures, commonly coated with veneers of limonite. The hydrologic regime at McClean Lake has not yet been determined, but the water-table is sufficiently close to the surface so that the root systems have constant access to the water-table, either directly or by way of its capillary fringe (normally extending up to 3 m above the water table, Wisler and Brater, 1959). Thus there is a continuum of water, between mineralization and the surface, through which ions can diffuse. Artesian flow has been reported from the general vicinity.

It is noteworthy that above the U ore-bodies of the Athabasca region, fracture zones commonly contain veinlets of pitchblende penetrating the sandstone. Because these fractures are typically sub-vertical, and upward migration of ions may preferentially follow their trend, the ions that reach the surface will be concentrated not directly above mineralization, but displaced to one or both sides, or in the case of radial fracturing perhaps surrounding an ore-body. Fig. 9 presents a diagrammatic idealized situation showing twin peaks of U concentration reflected by the vegetation. If the thickness of the sandstone is known and two or three drill holes encounter slight "kicks" in gamma-ray logs, it may be possible to extrapolate down-

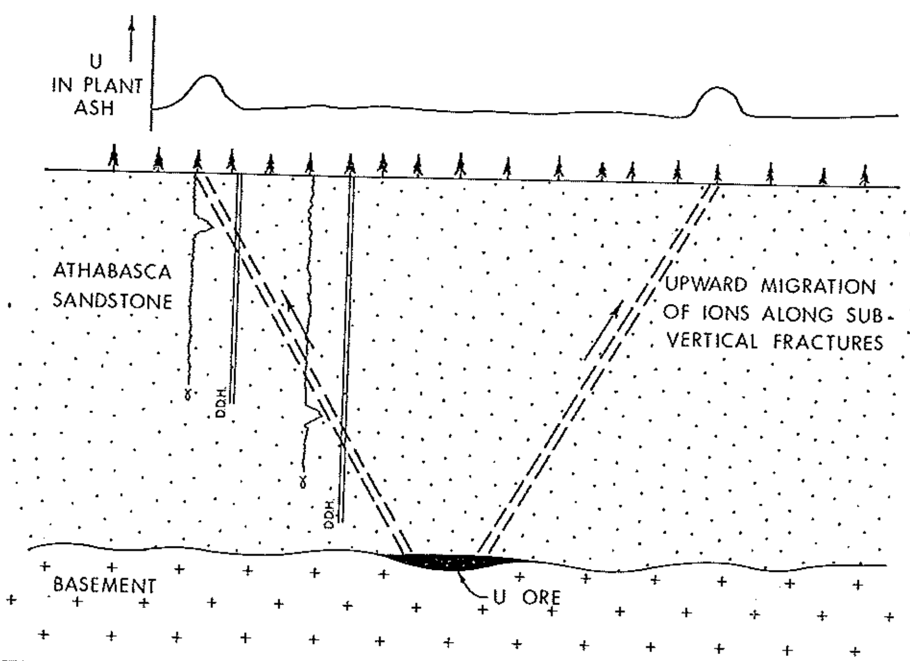

Fig. 9. Idealized section to show upward migration of ions and the biogeochemical relationship to mineralization.

ward and thus reduce the number of drill holes necessary to intercept mineralization.

In conclusion, careful use of the biogeochemical method has the potential of providing an additional exploration tool to be used in conjunction with other geological, geophysical and geochemical evidence, particularly with respect to detailed surveys. In the boreal forest environment of the Athabasca Sandstone it may become possible to use biogeochemistry to map areas of high U potential, and to map fracture zones which act as conduits for the upward migration of elements, and which are themselves sites of mineralization and therefore exploration targets.

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