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URANIUM BIOGEOCHEMISTRY: A BIBLIOGRAPHY AND REPORT ON THE STATE OF THE ART

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URANIUM BIOGEOCHEMISTRY: A BIBLIOGRAPHY AND REPORT ON THE STATE OF THE ART

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FOREWORD

The NEA/IAEA Joint Group of Experts in R+D in Uranium Exploration Techniques was formed in 1976 to encourage and facilitate international collaboration and co-operation in the development of uranium exploration technology. One of the projects carried out under the Joint Group was Project 5, "Biogeochemical Exploration for Uranium".

Project 5 met first at Lulea, Sweden, in September 1979. At that meeting it was decided to compile a "State of the Art" report and bibliography on the use of biogeochemical methods in uranium exploration as a guide and aid to workers contemplating the application of these methods. The task was entrusted to Colin E. Dunn of the Saskatchewan Geological Survey (Canada) and Jan Byman of the Swedish Geological Survey. They were later joined by John Ek, also of the Swedish Geological Survey.

The task of obtaining copies of all pertinent papers on the subject and translating them from a variety of languages proved to be a formidable one, and resulted in some delay in producing the document. The results of these efforts are presented in the main body of the report. At a meeting of Project 5, held in conjunction with the 12th International Geochemical Exploration Symposium at Helsinki in August 1983 the authors were fortunate to obtain an additional extensive list of references from Dr. Alexander Kovalevsky (USSR). These references, mostly of papers in Russian previously unknown to them, were added to the report as Supplement A. Since the authors had no access to these papers, they are listed as references only, with no comment on content. The authors took the occasion to compile an additional list of references, some previously unknown to them, and include papers published in 1983. These are included in Supplement B.

The subject of biogeochemical prospecting for uranium is complex and many conflicting results have been obtained. However, a firm data base is emerging and answers are being found to the many questions that have arisen. This encourages the feeling that biogeochemistry has much to offer to a uranium exploration programme.

The authors wish to thank Drs. Brooks, Erdman and Sheppard for providing copies of papers they had been unable to obtain. They especially wish to thank Dr. Kovalevsky for his important contribution. Many individuals provided information of help in assessing the state of the art. Finally, the authors wish to thank their organizations, the Swedish Geological Survey and the Saskatchewan Geological Survey, for support in the project.

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INTRODUCTION

This report comprises a compilation of the world literature published up to the end of 1982, that is classified under the general heading of 'Uranium Biogeochemistry'. This subject examines the distribution of U within natural organic systems. To the exploration geologist the study is concerned mainly with the analysis of plant material in an attempt to identify variations in U concentrations which may be attributed to concealed U mineralization. In addition, references are included on geobotany; on U in peat, coal, and fossil wood; on the migration and fixing of U in the natural environment and results from laboratory experiments; and even one paper on the U content of some birds. A total of 153 papers and books were identified, of which nine proved to contain no relevant information on the subject, and a few others (mainly from obscure Russian journals) proved unobtainable.

Information included in 130 papers (comprising several thousand pages of text, tables and figures) is summarized in tabular form following the list of references. Our task has been complicated by the fact that many papers are in Russian, and others are in Spanish, German, French, Rumanian and Japanese, but we have attempted to outline the main findings incorporated in each paper that are pertinent to biogeochemical prospecting for U.

Following the tabular summary there is an index of the common plant names, then an index of the scientific names of plants referred to in the publications. Within the report, numbers in square brackets [] identify the references in the bibliography and summary table.

HISTORICAL DEVELOPMENT

The earliest reports of U in plants appear to be the early 1940's data of Hoffman [58, 59] which gave the U content of algae, grasses, fruits and vegetables in Austria. A major advance took place in the 1950's when Cannon (especially her 1952 and 1964 papers) and her co-workers recognized selenium (Se) indicator plants on the Colorado Plateau (USA), and related their presence to the Se association with U in sandstones. A wealth of data on geobotany and the U content of plants was published following this discovery. During the late 1950's and 1960's many papers on U biogeochemistry appeared in the Russian literature, and other reports came from Australia, Great Britain, Scandinavia, France, Rumania, Japan, USA and New Zealand. Since the mid-1960's several compilation and review papers have been published on the migration and accumulation of U in organic substances [49, 64, 72, 104, 108, 111, 117].

In recent years the literature has contained papers on chemical disequilibrium [41, 78, 115, 127], and there has been a greater emphasis on case histories e.g. Spain [7], Canada [8, 17, 30, 35, 36, 40, 41, 109, 122], USA [46, 47, 95, 107], Sweden [43, 79], Finland [130], Israel [78], and USSR [116].

By far the greatest proportion of investigations have been conducted in cool or cold northern climates. A number of studies are reported from dry regions (especially the southern USA), but very little is known (or at least published) about the application of U biogeochemistry in tropical terrains.

GEOBOTANY

No plants have been recognized that are direct indicators of U mineralization, although in Alaska it has been noted that lupine tends to favour U-rich soil [42]. Several indirect indicators are known (notably Astragalus spp.) which have an affinity for selenium, and therefore are actually selenium indicators. U is associated with Se in the sandstone roll-front type deposits of the mid-western USA, where Se indicator plants have been used successfully in the discovery of U mineralization [19, 24, 25, 63].

Another geobotanical indicator of U mineralization is the development of abnormal growth patterns, which have been observed in the field and in laboratory experiments [19, 24, 25, 75, 113, 120]. Such morphological changes are not, however, a reliable guide to U mineralization, since many other physical and chemical parameters may effect similar changes.

Three studies have noted changes from normal flower colours near U mineralization. Shacklette [106] noted a paling in the pink hue of fireweed; Kovalsky and Vorotnitskaya [75] noted albinism and vari-coloured flowers of Caragana; and Brooks [14] indicated that U anthocyanins may give a bluish tint to flowers which are typically red or pink.

THE CHOICE OF SAMPLE FOR BIOGEOCHEMISTRY

Data are recorded on the U content of about 200 plant genera. These range from the fruit and vegetables consumed by man, to the indigenous mosses, grasses, shrubs and trees which represent the sample media appropriate for biogeochemical prospecting.

Obviously, environment is the primary control on the choice of sample, but in general conifers are suitable for northern climates; juniper and oak for temperate climates; eucalyptus for hotter climates; and sagebrush and catclaw mimosa for arid regions.

Many studies demonstrate the great variation of U content that occurs, within a given area, from one species to the next. Thus, a prime rule of biogeochemical investigations applies: that analytical data from different species must not be mixed, unless a very thorough study is made of the relative element concentrations of those species in a specific environment.

Not only must an appropriate species be selected for sampling, but also it is vital to identify which part of the plant is the most effective U accumulator, and is most practical to collect. For example, within a spruce tree the U content of the roots differs greatly from that of the trunk, bark, cones, twigs or needles. Some studies have concluded that by far the greatest amount of U is concentrated in the plant roots [e.g. 7, 19, 22, 24, 25, 71, 87, 98, 112, 113, 130], and Kovalevsky [71] found the bark of the roots to highly concentrate U. Other studies have found that twigs usually contain more U than leaves or needles, which both have more than trunkwood [6, 34, 35, 36, 37, 118, 122, 130]. In some species the aerial parts of plants have more U than the roots [10, 25, 36]. Some surveys have combined the twigs with the needles [8, 43, 51, 62] and still obtained meaningful results. Other studies known to us have obtained interesting but uninterpretable numbers and therefore were not published.

These, and many other observations quoted in the literature, indicate the complexity of the U distribution in plants, and emphasize the crucial need to obtain information on the distribution of U within a given species before attempting to conduct a biogeochemical survey using that species. Variation of U content occurs within a single twig: studies have shown more U in the 3-4 yr-old growth of birch and larch, than 1-2 yr-old growth [129]. Similarly the U content of black spruce twigs is highest in the 2-4 yr-old growth, and decreases in older growth [35]. In red beech the highest U concentrations were found in the 1-3 yr-old and 20-30 yr-old trunk growth [126].

Cannon and Kleinhampl [27] recommended collecting the latest year's growth of needles or branch tips from the entire periphery of a tree. Kovalevsky [70] suggested that the 2-8 yr-old growth of branches is to be preferred, and Dunn [36] concluded that the latest 10 yrs growth of black spruce twigs provided the most effective, consistent and practical sample medium to collect in the boreal forests of Canada.

Once the complexity of the situation is understood, steps can be taken to solve the problem and identify a sample medium which is simple, effective and practical to collect. By sifting through the literature it is possible to ascertain the problems surrounding a particular species in a particular environment, and the limitations of the biogeochemical method can be quantified. For example, it is found that natural variations influencing black spruce in Canada (e.g. age of tree, seasons, terrain) accounted for 15%, on average, of the data variability of U concentrations in the latest 10 yrs growth of black spruce twigs [35, 39]. No doubt for other species in other environments this percentage will differ, but a carefully planned orientation survey can readily determine the appropriate precautions and limitations that must be considered both in conducting the survey and interpreting the data.

LEVELS OF U CONCENTRATION

Exceedingly high U concentrations in plants are recorded. Data quoted in this section are from the U content of ashed sample, unless otherwise stated. The highest is 16.5% U in fossil wood from the Colorado plateau [12]. Dry peat has been reported with up to 3.1% U [6]. In living plants the highest level is 2.5% U from a moss in New Zealand [126], and several studies report U concentrations in moss between 0.1 and 0.5% [44, 55, 107, 123, 130].

By far the highest concentration in the higher order plants is 7400 ppm U in the roots of greasewood (Sarcobatus, [19]). In Alaska a combined sample of twigs and needles from a lodgepole pine yielded 2396 ppm U and a similar sample of western red cedar contained 2127 ppm U [42]. In Saskatchewan 2270 ppm U is recorded from black spruce twigs [37].

The roots of juniper which penetrated U ore in Colorado yielded 1600 ppm U [25].

All these values are extreme. Normal background levels of U in plant ash are of the order of 0.5-2 ppm [9, 10, 19, 25, 29, 37, 65, 121]. Cannon [19] considered that U concentrations greater than 2 ppm were anomalous, and determined that the optimum concentration for plant growth was 1.3-2.0 ppm U [25]. The Russian literature sometimes cites unusually low levels (less than 0.2 ppm) of U in plant ash as representative of background [65, 66, 118].

A unique area occurs in northern Saskatchewan, where "background" exceeds 10 ppm U in spruce twig ash over an area of 10,000 sq. km [40].

Low-order plant forms (especially mosses, lichens and aquatic bryophytes) readily accumulate U, whereas high-order forms only accumulate U in certain parts of their structures, and under certain physicochemical and hydrological conditions.

In general it appears that background levels of U in plant ash are less than 2ppm, and plant material which contains much in excess of this amount is indicative either of local U mineralization, or the presence of high background levels of U in the substrate, i.e. a uranium province.

CHEMICAL AND PHYSICAL CONTROLS ON U UPTAKE

Many papers have examined the chemical components which govern the absorption, and fixation of U by plants and organic matter in general. Plants grown in soils spiked with U accumulated more U in their roots than in their aerial parts [22, 23, 113], although the amount of U in the branch tips was found to bear a definite relationship to that available in the soil [22]. Roots with a high cation exchange capacity can absorb the most U [24]. Another study suggested that U compounds in plants probably form as a result of ion-exchange reactions between metal-bearing solutions and plant tissues [5].

Organic compounds can bind and transfer U [89]. Studies have shown that U occurs as oxonium complexes in cellulose and lignin [4], and as chelates [101]. Humic and fulvic acids are the dominant concentrators and transporters of U [18, 104, 110, 111, 119], and they are believed to play a significant role in the formation of secondary U deposits [104].

In a study of leaves of Coprosma australis [128] it was shown that 65% of the U occurred as a RNA complex, 25% as a protein complex, and 10% in low molecular form. At least 50% of the total U was found to be bound to cell wall proteins.

Low levels of soil phosphate greatly increase the ability of plants to accumulate U [1], whereas high levels of carbonate have a similar effect [19]. U is effectively absorbed by plants that take up very little potassium (e.g. rose and pine families [21, 22]). Where formation waters have a high salt content U tends to stay in solution [84], and in the presence of salts and calcium, U can migrate considerable distances [117].

Important observations for biogeochemical prospecting are: 1) U is absorbed best by plants which have a fairly acid cell sap and a high cation exchange capacity in the root [21, 25, 76]. This acidity is estimated to be pH 5 [4], pH 4-5 [18] and less than pH 5.2 [95]. One Russian study found the highest U uptake to take place in peat at pH 6 [115]; and 2) plants with high transpiration rates transport most ions to their upper parts [25].

Work by Kovalevsky [70,71] indicated that plants in the boreal forests of Siberia appeared to have a physiological barrier to U uptake, whereas Ra migrated readily from the soils to the plants and no barrier seemed present. He noted that physiological barriers are much more significant in the aerial portions of plants than their roots, and that the barriers are absent in the roots of high-order plants and of low significance in the lower plants. A later study [72] defined U as a "low barrier" element (i.e. only small quantities can be taken up by the high-order plants), but noted that element absorption by plants is, on average, 3000 times more vigorous from aqueous solutions than from the solid phase of soils. Thus where U is dissolved in groundwaters, much higher U concetrations in plants may result than where U is present in the soils. This observation may be valuable in explaining the situation that occurs in Saskatchewan, where far greater U concentrations are present in the aerial parts than the roots [36, 39]. This study [39] concluded that the "barrier" exists not in the roots but in the twigs, where U dissolved in fluids passing up the xylem tissues precipitates due to a change in pH that occurs during photosynthesis. U is in low concentrations in the soils, but available in the formation waters that the roots are tapping.

RELATIONSHIP OF U IN SOILS AND BEDROCK TO U IN PLANTS

A recurring observation in the literature is that there is a good correlation between U in soil or bedrock, and U in plants [1, 5, 7, 30, 52, 57, 69, 126]. Conversely, other studies report no discernible relationship between U in the soils and bedrock and that in plants [17, 34, 36, 37, 46, 84]. Work in the USSR found U levels to be usually 10-100 times lower in plants than in soils [67]. An observation was made that the correlation between U in plants and U in soils was only good up to 10 ppm U in soil, and a further U increase in soils did not result in an increased uptake by plants [70]. In Saskatchewan, however, soils consistently yielding about 2 ppm U support spruce containing from 5-886 ppm U in twig ash [37, 39]. A study in European Russia found an inconsistent relationship between U in plants and U in soils.

Thus there is a wide spectrum of results from a good to poor correlation, perhaps dependant upon the porosity, permeability and hydrologic regime of the substrate. Each study area must be treated on its own merits. If a better geochemical profile is obtained from soils than plants, then the soils should be collected. If a similar response is found in both sample media, then whichever is more practical should be collected. Bearing in mind that the extensive root system of a tree integrates the geochemical signature of several cubic metres of soil, the trees may, therefore, provide a more representative geochemical picture of the environment than a handful of soil. The latter holds particularly true where the soil is allochthonous, such as in glaciated terrains.

If the U in the bedrock is incorporated in the crystal lattices of resistate minerals, there is likely to be no more than a subtle biogeochemical response to the mineralization, despite the highly corrosive micro-environment established around rootlets. However, if the U is labile (e.g. as pitchblende or other U oxides in fractures and at crystal boundaries) then it can be readily assimilated by some plants and a strong biogeochemical response may result.

PEAT

The literature contains a large number of papers that deal with the chemistry of peat bogs, and many of these papers refer to U. We have not attempted to compile a complete bibliography of U in peats; instead we have selected a few of the classic studies, most of which deal also with U biogeochemistry.

Peat bogs are potential 'sinks' for U precipitation because their organic acid components readily absorb and adsorb the element. A bog in northern Sweden with up to 3.1% U in dry material concentrated U 9000-fold from the levels in the spring waters feeding it [5, 6]. In the USA [11] waters with up to 110 ppb U produced 2880 ppm U in dry material (a 26,000-fold concentration). This is greater than the maximum concentration factor of 10,000 obtained by experimental studies [110] on humic acids in peats. Furthermore, it has been observed by others [64] that waters with little more than background levels of U may provide concentrations of U in peat equivalent to an enrichment factor of 2 million, indicating that other factors may interact and locally give rise to extreme concentrations. An important difference between the experimental study and the field study, is that the experimental conditions were static whereas the field environment was dynamic and time could play a vital role in permitting U to concentrate.

In Sweden stream bank peats have been used successfully in outlining uraniferous areas [79]. Peats, comprising decaying grasses, sedges and roots, are collected immediately below lowest stream levels. Reconnaissance surveys by this method have found enhanced U levels to occur in regions underlain by granite, and have provided targets for follow-up work. Several prospects have been found directly by this biogeochemical method.

It would appear that because of the physicochemical nature of peats they may be of use in establishing the proximity of U mineralization.

However, false anomalies may occur in situations where slight enrichments of U in bedrock are leached by groundwaters, and low levels of dissolved U are supplied to a restricted basin containing a peat bog. The contained organic matter than continuously absorbs U over a long period of time.

BACTERIA

The role of bacteria in mobilizing U has been examined in several papers. Thiobacillus ferrooxidans can survive at a pH of zero and in an oxidizing environment where the Eh is up to 760 mv [99]. An increase in microbial activity greatly increases the dissolution of U [86]. It has been noted [50] that Desulfovibrio desulfuricans in groundwaters associated with U deposits is instrumental in controlling redox reactions, and thus can assist in mobilizing and subsequently immobilizing U. Some bacteria have a mechanism which inhibits successive uptake of U into the cells. These adapted strains play an important and more active role in the biogenic migration of U than unadapted strains [74]. As a result of these capabilities of bacteria, there is a bacterial zoning associated with metal zoning across the edge of U roll-front deposits [99].

The implication for biogeochemical exploration for U hinges upon the ability of bacteria to develop resistance to U toxicity. If bacteria that are normally intolerant to U are found to have adapted to U (i.e. if they are present in uraniferous soil samples), then a U deposit should be nearby. Researchers in this new field of experimentation (e.g. J. Watterson, USGS) suggest that there is the potential for the metal resistance of restricted groups of metal-sensitive organisms to be tested more easily than the analysis of the soils themselves.

DEPTH OF BURIAL OF U ORE DETECTABLE BY BIOGEOCHEMICAL METHODS

Biogeochemical methods can readily detect U mineralization at or close to the surface. So can many other exploration techniques, rendering biogeochemistry redundant for such occurrences. The object of using biogeochemistry is to assist in providing a "window" through surficial material to U mineralization that is not readily detectable by other means.

On the Colorado Plateau biogeochemical surveys have effectively detected U mineralization that occurs at depths up to 25 m beneath the surface [21, 25, 27, 63]. Similarly, in the USSR high U concentrations in plants were found where ore was at a depth of 20 m [10]. In Spain there was a good correlation between U in oak leaves and mineralization, especially down to 10 m [7].

An unusual situation occurs in Saskatchewan where high grade pods of pitchblende that occur beneath 150 m of Precambrian Athabasca Sandstone are reflected in the overlying vegetation [36]. In this environment it seems that the near vertical fracture system, coupled with an upward hydraulic gradient is responsible for producing the biogeochemical anomalies [36, 39].

NATURAL VARIATIONS

If the roots on one side of a tree penetrate U mineralization, the U content of leaves and twigs will be higher on that side of the tree [25]. If, however, the U source is disseminated throughout the soil, bedrock or groundwaters, then no systematic difference occurs around the periphery of the tree [35]. As a general rule it is better to collect samples from branches around a tree.

The age of the plant can make a difference on the amount of U taken up: some plants increase their U content with age, others decrease [1]. Within limits of ± 15% it was found [35] that the latest 10 yrs growth of black spruce twigs showed no systematic difference from young to old trees, and local variation fell within the same limits. Twigs taken from a spruce tree on three successive years showed no appreciable difference in U concentrations, whereas considerable differences were noted for the needles. A similar pattern was found in sampling a tree in June and again in August: U levels did not show consistent changes in the twigs, but a pronounced decrease occurred in the needles. Several workers have noted seasonal changes in U concentrations and found that each species responds differently [2, 19, 25, 37, 53, 65]. Cannon [25] found that in general, U levels increase during the growing season in evergreens, but decrease in deciduous species.

Another feature which has been considered is whether there are differences between the U content of dead and living twigs. Observations are again inconsistent, but there seems to be a tendency for dead organs to contain more U than live [28, 42].

SAMPLE SPACING

For detailed sampling over a U prospect, sample spacing of 5, 15, 20 and 30 m has been variously suggested as adequate for outling mineralization [27, 36, 51, 63, 65]. Obviously, this will depend upon the depth of the mineralization and the fracture system through which uraniferous waters may pass.

For rapid reconnaissance surveys, sample intervals of 75 m [27] and 200 m [37] have been suggested. The 10,000 sq. km Wollaston anomaly in Saskatchewan was outlined by sampling at 1 km intervals near its centre, and progressively increasing the sample intervals to 2 km, 5 km and 10 km [37, 39].

For reconnaissance level stream bank peat surveys in Sweden one sample is taken per 5 sq. km; for regional survevs the sample density is 2-3 per sq. km; and for detailed surveys the density is about 20 samples per sq. km.

Another sample medium appropriate for the preliminary assessment of the U potential of an area is aquatic bryophytes [107, 124]. In this instance no specific sample interval can be recommended, since their occurrence is not ubiquitous. They should, however, be sampled as close to springs as possible.

UNPUBLISHED INFORMATION

During discussions with various researchers and exploration geologists, several facts have come to light which have not been published in professional journals. Some pertinent observations are outlined in this section.

In Australia eucalypts and spinofex grass have both been used to successfully outline uraniferous zones. Leaves of eucalypts were found to contain considerably more U than dead twigs, which in turn had more than live twigs. There are unconfirmed reports that eucalypt trunkwood from the Rum Jungle area contains over 1000 ppm U. In northern Canada (Saskatchewan, Yukon, and the Northwest Territories) jack pine and black spruce are suitable and effective sample media in areas of permafrost and discontinuous permafrost. One study in the Yukon suggested that black spruce twigs (about the latest 3-4 yrs. growth) with over 1.3 ppm U in their ash represented a bedrock source of U. In northern Sweden all known major areas of mineralization give rise to enhanced U levels in neighbouring stream bank peats, commonly in association with Cu and Y enrichments.

Studies by French geologists in France and Africa have been disappointing, and although anomalous concentrations of U have been found in plants the soils have proved to be cheaper and more rapid to sample. It has been found that in all areas examined, U concentrations are consistently higher in roots than aerial parts over granitic terrains. Over sedimentary rocks U anomalies occur in twigs, leaves and roots of oak, but again soils have provided similar information. In Mediterranean climates pines have provided positive results, but only very close to mineralization. Trees in Nigeria indicate U up to 5 m below the surface, and in the equatorial climate of Gabon the trees give the same indications as the soils. In Madagascar some positive results have been obtained.

RECOMMENDATIONS

No universal guidelines can be laid down for conducting a biogeochemical survey for uranium. This is evident from the diverse results that appear in the literature. However, careful observation of the field environment, plus a rapid orientation survey to ascertain the most appropriate sample medium may provide the geologist with an important additional tool to his exploration program. It is imperative that sampling is undertaken in a thorough and systematic manner, and that summary field notes are taken at each sample site. It is not a technique which can usually be effectively undertaken by an untrained field assistant. Once the limitations of a particular sample medium have been identified and quantified by a competent biogeochemist, then a routine sampling program can be carried out by lesser qualified personnel.

The positive biogeochemical response of plants to concealed uranium mineralization is a well-established and well-documented fact. In addition there must be many studies which have not been published because results were negative: the examination of government assessment files bears witness to this. It seems that interesting U accumulations in plants have often been recorded but not interpreted. Sometimes this is because insufficient effort has been put into sample collection. For example, all too frequently random lengths of twigs have been collected and ashed without separating the needles. As indicated in the literature, twigs usually contain greatly different concentrations of U from needles and U concentrations vary with age along the length of some twigs [35]. As a result such data are uninterpretable.

In conclusion it is considered that biogeochemistry can provide a useful aid to the exploration for U, particularly in areas where the U is labile and not structurally incorporated in crystal lattices. Careful orientation surveys must be carried out before embarking upon a major sampling program. Samples must be collected carefully and systematically, and in order to be cost-effecitive a technique must be chosen and refined so that it is practical and rapid. Biogeochemistry is likely to be most effective and superior to other techniques where allochthonous soils cover the bedrock (e.g. desert and glaciated terrains). Roots can penetrate this overburden and integrate the geochemical signature of the bedrock or the formation waters, thereby providing a "window" through the overburden.

LIST OF REFERENCES

Reference numbers are placed alongside the papers which are summarized in the Table. They correspond, also, to the references quoted in the report on the state of the art.

References marked with an asterisk (*) indicate papers that contain little or no data on uranium biogeochemistry, yet appear in world lists under that general heading.

References which have no number or asterisk are those which we were unable to obtain.

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SUMMARY OF
INFORMATION CONTAINED IN THE PUBLICATIONS ON URANIUM BIOGEOCHEMISTRY

EXPLANATION OF ABBREVIATIONS

Column Heading:

Ref. No. and Code	Ref. No. is the reference number listed alongside the reference in the bibliography, and referred to in the text. 'Code' refers to the subject matter of the publication. Abbreviations are:

A = Analytical methods
B = Biogeochemistry - terrestrial plants
Ba= Biogeochemistry - aquatic plants
Bb= Biogeochemistry - bacteria
C = Coal and carbonaceous matter
G = Geobotany
L = Laboratory studies
OC= Organic Chemistry
P = Peat
R = Review paper

Species Investigated:
Part of Plant

B = bark
C = cone
F = flower
Fr= fruit
L = leaf
N = needles
R = root
S = stem
T = twig
W = trunkwood
X = undifferentiated
All = entire plant
Var.= various organs

Tech. Analytical technique employed:

A = alpha activity
B = beta activity
D = delayed neutron counting
F = fluorometry
MS = mass spectroscopy
NAA = neutron activation
UA3 = "scintrex" laser spectrometer
XRF = X-ray fluorescence

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
1 L	Anderson, Kurtz	1954	USA							A		Laboratory studies on U uptake by plants. Different species vary markedly in their ability to accumulate U. U accumulation seems to be a linear function of U in soils. Some plants increase U content with age, whereas in others U decreases. Low levels of soil phosphate greatly increase the accumulation of U.
2 B	Anderson, Kurtz	1955	USA, Arizona	Hot desert and oak woodland	Quercus emoryi	Emory oak	L	9-177 cph	Ash	S	Mesozoic clastics & carbonates; rhyolites containing pitchblende	Pitchblende at a depth of 2 m, with secondary U minerals closer to surface. Fracture from mineralization to surface - radioactive travertine. Seasonal difference observed - higher radioactivity in leaves in Nov. than June. Conclusion: Positive response to mineralization.
					Q. oblongifolia	Mexican blue oak	L					
					Prosopis juliflora	Mesquite	L	0-235 "	"	S		
					Mimosa dysocarpa	Velvet pod mimosa	T	26-886 "	"	S		
					" "		L	8-64 "	"	S		
3 A,B	Anderson, Kurtz	1956	USA, Arizona	Hot desert and woodland	Artemisia sp.	Sagebrush	X	1.7-29ppm	Ash	F		Scintillation alpha counting, adapted to the determination of the radioactivity of plant ash, is sufficiently sensitive to be used in biogeochemical surveys when more than 10 ppm U is present in the ash. The method has the limitation that it cannot distinguish between U, Th, or their decay products. Furthermore, the method is limited to the analysis of species of relatively great U absorption ability.
								(=45-209 cph)	"	S		
					Pinus ponderosa	Ponderosa pine	X	1.2-1.5 ppm	"	F		
					Juniperus deppeana	Juniper	X	10-32 cph	"	S		
					Prosopis juliflora	Mesquite	X	28-500 cph	"	S		
					Pinus sp.	Pinyon pine	X	0.7 ppm	"	F		
4 L	Andreyev, Andreyeva, Rogozina	1962	USSR			Conifers (dead)	X					Laboratory investigation on dead tissues - mainly conifers. Maximum absorption of U (~1%) at pH 5. Best absorbents are lignin and wood flour. Mechanism involves the formation of oxonium complexes in cellulose or lignin
5 B,P	Armands	1967	Sweden, Norrbotten	Peat bog (dwarf spruce and birch)	Alnus sp.	Alder	X				Granite, gneiss, skarn, iron ore	Twigs much richer in U than leaves. U compounds probably formed as a result of ion-exchange reactions between metal-bearing solutions and plant tissues. Good correlation between U in plants and in peat. Willow twigs proved the best concentrators of U. Ratios of U + Ra in twigs to leaves are: - Betula alba 3.9; Betula nana 2.5; Salix sp. 2.5; Alnus sp. 1.9. Rate of leaching from the rocks is dependent upon the bicarbonate content of the waters. Hydrogeologic follow-up is necessary to locate the U source.
					Betula alba	Birch	X					
					Betula nana	Birch, dwarf	X					
					Salix sp.	Willow	T	max. 860 ppm	Ash	A+F		
					"	"	L	" 450 "	"	"		
					"	"	F	" 450 "	"	"		
						Peat		" 3.1%	Dry	F		
6 P	Armands, Landergren	1960	Sweden, Norrbotten	Peat bog (dwarf spruce and birch)		Peat		$\bar{x}$ = 600 ppm	Dry	F	Granite, gneiss, skarn, iron ore, pegmatite	U was derived from four water sources, the most radioactive of which emanated from fractures. The ratio of U in peat to U in spring waters was about 9000:1. A total of 445 samples of peat yielded a mean concentration of 600 ppm U (dry weight).
								(= 900 ppm)	Ash	F		
7 B	Arribas, Herrero-Payo	1979	Spain	Semi-arid, warm	Quercus ilex	Oak ("Live-oak") 'Encina' in Spanish	L	Locally over 1500 ppm (= about 12ppm)	Ash Dry	F	Cambrian schists	Generally a good correlation between U in oak leaves and U in bedrock (especially down to 10 m). U content of the oak leaves was similar to that of the trunks and roots, but higher than in the fruits.

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8 B	Barakso	1979	Canada, B.C.	Temperate forest; glacial cover	Betula papyrifera	White birch	T	160 ppm	Ash	F	"Rexspar" U deposit; trachyte & schists	600 ppm U in B horizon soils
					Abies lasiocarpa	Balsam fir	T+N	280 ppm	"	F		
					Thuja plicata	Cedar	T+N	140 ppm	"	F		
					Abies lasiocarpa	Balsam fir	T+N	25 ppm	"	F	"Tyee lake" U deposit; gravels & clays	about 2 ppm U in B horizon soils, and about 5 ppm U in 30 m thick C horizon.
					Pinus contorta	Lodgepole pine	T+N	10 ppm	"	F		
					Picea englemanni	Engelman spruce	T+N	20 ppm	"	F		
					Pseudotsuga menziesii	Douglas fir	T+N	45 ppm	"	F	"Day Creek" U deposit; arkose	50 ppm U in C horizon.
					Populus tremuloides	Trembling aspen	T	15 ppm	"	F		
												Results indicate that plant geochemistry is a possible exploration aid in areas of heavy overburden owing to the high selectivity of certain plants for specific elements.
9 B	Boua, Grigorian	1977	General									Notes that the mean concentration of U in the ash of plants is 0.5 ppm. Points out that the Th/U ratio may be used successfully in the search for U deposits; its decrease in the ash of plants usually indicates the presence of U mineralization in the bedrock.
10 B	Botova, Malyuga, Moiseyenko	1963	USSR	Arid	Artemisia terrae albae	Sagebrush	All	1.7 – 5.5 ppm	Ash	F	Sandstone and argillite (Permian)	Background U in plant ash is 2 ppm. Maximum concentration is 80 ppm in the ash of Astragalus. In all but 3 samples U in the plant ash was higher than in the soils. High U in plants only corresponds to high gamma activity in rocks and soil where mineralization reaches the surface. High U in plants found where ore lies at depth of 20 m. U content of different parts of plants: a) Haloxylon: bark > roots > leaves wood b) Astragalus: bark > leaves > roots c) Anabasis: wood > leaves Oldest organs are richest in uranium. Conclusion: *method is successful*, and superior to radiometric surveys.
					Salsola subaphylla	Saltwort	All	3.1– 20.5 ppm	Ash	F		
					Anabasis aphylla	Itsegek	All	3.9– 75.0 ppm	Ash	F		
					Astragalus villosisimus	Poison vetch	All	12 – 80 ppm	Ash	F		
					Haloxylon aphyllum	Black saxaul	All	5.6 ppm	Ash	F		
					Annuals (undiff.)		All	5.2 ppm	Ash	F		
11 P	Bowes, Bales, Haselton	1957	U.S.A.	High-level meadow		Peat bog		Up to 0.34% U_3O_8	Dry		Jurassic(?) quartz diorite	Bog is fed by spring waters with 110 ppb U. Very low gamma activity suggesting recent U emplacement. Ore is confined largely to the peat bog, and is probably derived entirely from the spring waters.
12 C	Breger	1974	U.S.A., Colorado and Wyoming		Araucarioxylon Kraus	(Fossil conifer)		Max. 16.5%	Dry		Triassic to Eocene clastics	Deals with U in coalified logs. U is present mainly in colloidal form, and probably introduced in an alkaline solution as a complex uranyl carbonate. Increase in U content of coal is generally accompanied by an increase in its reflectance. Paper is a comprehensive discussion of the relationship between U and coalified substances.
13 B	Breger, Deul	1956										Data from Hoffman (1941 and 1942) are quoted, and a conclusion drawn is that plants absorb extremely small amounts of U. Mechanisms of U transport and concentration in dead organic substances are discussed.

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					Scientific Name	Common Name						
14 B	Brooks	1972	General									Excellent account of biogeochemical procedures with abundant data – numerous references to literature on U biogeochemistry. *Anthocyanins can form stable complexes* with U (and other elements), and may therefore produce a blue tint in flowers that are normally red or pink. Generally, the longer the root system of a plant, the less the enrichment of U in the upper part of the plant.
15 R,G	Brooks	1979a	General									Good review paper of geobotanical indicators. No new data on U.
16 R,B	Brooks	1979b	General									Good review paper of the biogeochemistry of many elements. No new data on U, but a useful update of workers and work being undertaken throughout the world.
17 B	Brooks, Holzbecher, Robertson, Ryan	1982	Canada, Nova Scotia	Temperate forest	Picea rubens	Red spruce	T	1.5-106 ppm (near U mineralization)	Ash	NAA	Granodiorite	Red spruce was the only plant to show a positive response to U mineralization. Very high degree of correlation between U levels in spruce ash and scintillometric readings; however, latter has limitations. *U in soils* shows no correlation with mineralization or radiometry or U in plant ash. *Conclusion: positive response to mineralization.*
					Picea rubens	Red spruce		.15-.97 ppm (distant from mineralization)	Ash	NAA		
					Acer pensylvanicum	Striped maple	T	*<5 ppm*	Ash	NAA		
					Acer rubrum	Red maple	T					
					Betula lutea	Yellow birch	T					
18 OC	Calvo	1974	Spain									Discusses the role of humic acids in precipitating U. Most effective when pH is 4 to 5. Does not deal with living plants, only the relationship of U to organic matter, pointing out their geochemical affinity (but lack of chemical affinity) due ultimately to pH and Eh.
19 B	Cannon	1952	U.S.A. a) Colorado	Temperate, semi-arid	*min. = near U mineralization – = no U mineralization						Jurassic sandstones	Indirect recognition of U ores by the Se indicator plant <u>Astragalus</u> and S indicators. Leaves of plants rooted in ore contain 2 to 100 ppm U; those rooted in barren sandstone and shale have less than 1 ppm U. Important references to early works by plant physiologists: small additions of U stimulate plant growth, and very small concentrations are essential for higher plants. Levels of toxicity and abnormal growth patterns are cited. Amount of U absorbed by plants varies with the species, time of year, part of plant, availability of U in the soil, and composition of underlying rocks. U content of any species growing in non-mineralized ground rarely exceeds 1 ppm. Plants rooted in U-bearing rock commonly have over 2 ppm U. Twelve valuable tables list U,V,Se,Pb and Mo contents of many species, and different parts of those species, from plants growing on mineralized and non-mineralized ground. The influence of carbonate is noted from the higher U content of plants growing above deposits of Ca-U carbonates. Generally, more U occurs in the roots of ricegrass, sagebrush, oak, juniper, vetch and ash than in their aerial parts.
					Astragalus sp.	Poison vetch	X	38-70ppm(min)	*Ash	F		
					" "	" "	X	0.8ppm(–)	"	F		
					Oryzopsis hymenoides	Ricegrass	X	30ppm(min)	"	F		
					Atriplex confertifolia	Shadscale	X	2-6 ppm(min)	"	F		
					" "	"	X	0.2ppm(–)	"	F		
					Atriplex canescens	Saltbush	X	0.7ppm(–)	"	F		
					Bahia nudicaulis		X	8ppm(min)	"	F		
					Chrysothamnus viscidiflorus	Rabbitbrush	X	7ppm(min)	"	F		
					" "		X	<1ppm(–)	"	F		
					Artemisia sp.	Sagebrush	X	3ppm(min)	"	F		
					" "		X	0.9ppm(–)	"	F		
					Haplopappus armeriodes	Goldenweed	X	40ppm(min)	"	F		
					Fraxinus anomala	Single leaf ash	X	0.7ppm(min)	"	F		
					" "	" "	X	0.5ppm(–)	"	F		
					Juniperus monosperma	Juniper	X	2-8ppm(min)	"	F		
					" "	"	X	<1ppm(–)	"	F		
					Quercus gambelii	Scrub oak	X	10ppm(min)	"	F		
					" "	" "	X	0.5ppm(–)	"	F		

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
	Cannon (cont.)											Higher U concentrations occur in May than in August. Junipers adjacent to a U mill contain up to 1100 ppm U; those 250-400 m away have 150 ppm U; and from 600-1200 m distant the content is 40 ppm U.
			b)Wyoming	Temperate, semi-arid	Sarcobatus vermiculatis	Greasewood	L+S	14ppm(min.)	Ash	F	Alluvium	
					" "	"	R	7400ppm(")	"	F	"	
					Eleocharis palustris	Spikerush	L+S	1.7ppm(")	"	F	Black mud	
					Spirogyra	Alga		39ppm(")	"	F	" "	
					Stanleya arcuata	Prince's plume	L+S	0.6ppm(")	"	F	Lignite	
					Cleome integrifolia	Angusta	L+S	1.2ppm(")	"	F	"	
					Apocynum androsaemifolium	Dogbane	L+S	0.5ppm(")	"	F	P_2O_5 shale	
					Smilacena stellata	Wild spikenard	L+S	0.3ppm(")	"	F	" "	
					Oryzopsis hymenoides	Ricegrass	L+S	4.3ppm(")	"	F	" "	
					Artemisia tridentata	Sagebrush	L+S	0.8-1.8(")	"	F	" "	
					Chrysothamnus parryi	Rabbitbrush		1.0ppm(")	"	F	" "	
			c)Utah	Temperate, semi-arid	Juniperus monosperma	Juniper	L+S	0.7ppm(")	"	F	Kaolinite	
					Atriplex confertifolia	Shadscale	L+S	4.8ppm(")	"	F	"	
					Juniperus monosperma	Juniper	L+S	66-100 (")	"	F	Asphalt.ore	
					Oryzopsis hymenoides	Ricegrass	L+S	20ppm(")	"	F	" "	
					Stanleya pinnata	Prince's plume	L+S	37ppm(")	"	F	" "	
			d)New Mexico	Hot, semi-arid	Pinus edulis	Pinyon	L+S	33ppm(")	"	F	Limestone	
					Juniperus monosperma	Juniper	L+S	49ppm(")	"	F	"	
20 B	Cannon	1953	U.S.A., New Mexico	Hot, semi-arid	Juniperus monosperma	Juniper	N	7-112 ppm	Ash	F	Jurassic Todilto Limestone	Positive response of juniper and pine needles to underlying uraniferous limestone. Slight airborne contamination of the needles. Trunk wood averaged 10 ppm U in ash of trees on limestone with <0.1% U_3O_8. Trunk wood averaged >20 ppm U in ash of trees on limestone with >0.1% U_3O_8.
					" "	"	T(p)	up to 44 ppm	"	F		
					" "	"	R(p)	up to 97 ppm	"	F		
					" "	"	W	6 -48 ppm	"	F		
					Pinus edulis	Pinyon	N	5 -41 ppm	"	F		
					" "	"	W	3 -30 ppm	"	F		
							(p = peeled)					
21 B	Cannon	1957	U.S.A., Colorado	Temperate, semi-arid							Sandstone	Plants reflect U mineralization at depth of 20 m. Paper is 50% geobotany, 50% biogeochemistry. Generally, U is best absorbed by plants with a fairly acid cell sap and high cation exchange capacity in the root. U absorbed better by plants that take up very little K (e.g. rose and pine families), than those that take up relatively high amounts of K. Recommended that branch tips be collected from all sides of a tree. 100 figures of plants are listed in order of their importance in prospecting.
22 L	Cannon	1959	U.S.A., Colorado	Temperate, semi-arid	Juniperus sp.	Juniper	X	1.74 ppm (min)	Ash	F		Experimental work involving growing plants in plots of desert soil with controlled U concentrations showed that more U was taken up by Descurainia (tansy mustard) than Grindelia than Verbesina (goldweed). There was a negative correlation between U and K. Generally more U in the roots than tops of plants; however, the amount of U in the branch tips bears a definite relationship to that available in the soil.
					" "	"	X	0.33 ppm (-)	"	F		
					Pinus sp.	Pinyon	X	1.31 ppm (min)	"	F		
					" "	"	X	0.56 ppm (-)	"	F		
					Abies sp.	Fir	X	2.18 ppm (min)	"	F		
					" "	"	X	0.35 ppm (-)	"	F		
					Pinus ponderosa	Ponderosa pine	X	1.28 ppm (min)	"	F		
					" "	" "	X	0.63 ppm (-)	"	F		

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23 R	Cannon	1960a										Review paper - no new data on U.
24 B	Cannon	1960b	U.S.A., Colorado, Utah	Temperate, semi-arid	Astragalus pattersoni	Vetch	X	up to 38 ppm	Ash	F		Roots with high cation exchange capacity can absorb the most U. U found to precipitate near the point of intake in the roots of juniper. Data are given on the U content of roots of several species, compared to U in branch tips of the same plants. Useful information is given on experimental work on the relative amounts of U taken up by different plants, and the physiological effects observed. In general, growth was stimulated by the addition of carnotite to the soil. Unusual growth (extra branching, imperfect flowers) resulted from the addition of strongly radioactive substances to the soil. Discussion on prospecting by means of indicator plants points to Astragalus (a Se indicator) as an indirect indicator of U deposits due to the U/Se association. Only certain species of Astragalus absorb substantial quantities of Se; notably A. pattersoni and A. preussi.
					" preussi	"	X	up to 70 ppm	"	F		
					" albulus	"	X	up to 1.2 ppm	"	F		
					" cobrensis	"	X	up to 0.8 ppm	"	F		
					" thompsonae	"	X	up to 3.6 ppm	"	F		
					" aculeatus	"	X	up to 2.7 ppm	"	F		
					" nuttallianus	"	X	up to 0.6 ppm	"	F		
25 B	Cannon	1964	U.S.A., Utah	Semi-arid	38 species within the genera:			*R=root; A=aerial part Maxima in mineralized ground			Mesozoic sandstones	Comprehensive information on the composition of mineralized and unmineralized bedrock, soils, waters and vegetation. Useful discussion on physiological processes (p. 42): an important conclusion is that plants with high-transpiration rates will transport most ions to their upper parts, whereas plants with high cation exchange capacities at their roots will accumulate most metals at the roots. All plants rooted in mineralized ground contained more uranium than those rooted in unmineralized ground. Data are presented (Table 16) on U, V, Se, Mo and Pb in 241 samples comprising 38 species (roots and aerial parts) collected over mineralized and unmineralized ground. Highest value is 1600 ppm U from deep roots of *Juniperus monosperma* penetrating U ore. U more concentrated in roots than aerial parts in all species except Atriplex, Chrysothamnus, and Ephedra. A summary (Table 17) shows average concentrations of U in classes of *vegetation growing over mineralized and unmineralized* ground to be: Grasses 4.1 ppm U (unmineralized) 34 ppm U (mineralized) Herbs 1.9 ppm U (unmineralized) 21 ppm U (mineralized) Trees and shrubs 0.9 ppm U (unmineralized) 8.7 ppm U (mineralized) Unpublished data from R. E. Gilbert (Utah): Sagebrush 1.7 ppm U (unmineralized) 9.7 ppm U (mineralized) Juniper 1.6 ppm U (unmineralized) 5.2 ppm U (mineralized) Pinyon 2.1 ppm U (unmineralized) 2.2 ppm U (mineralized)
					Artemesia	Sagebrush	R	20 ppm* (R, nd)	Ash	F		
					Atriplex	Shadscale	A	100 ppm (A>R)	"	F		
					Chrysothamnus	Rabbit brush	A	40 ppm (A>R)	"	F		
					Coleogyne		A	10 ppm (R,nd)	"	F		
					Cowania	Cliffrose	A	51 ppm (R,nd)	"	F		
					Ephedra	Mormon tea	A	120 ppm (A>R)	"	F		
					Fraxinus	*Ash*	R	9 ppm (R>A)	"	F		
					Juniperus	Juniper	R	1600 ppm (R>A)	"	F		
					Quercus	Oak	R	190 ppm (R>A)	"	F		
					Sarcobatus	Greasewood	R	39 ppm (R>A)	"	F		
					Tamarix	Tamarisk	A	16 ppm (R,nd)	"	F		
					Yucca	Yucca	R	10 ppm (R>A)	"	F		
					Elymus	Wild rye	A	5 ppm (R,nd)	"	F		
					Hilaria	Galleta grass	A	2 ppm (R,nd)	"	F		
					Oryzopsis	*Ricegrass*	A	82 ppm (R>A)	"	F		
					Allium	Wild onion	All	200 ppm	"	F		
					Aster	Aster	A	7 ppm (R,nd)	"	F		
					Astragalus (5 species)	Vetch	R	370 ppm (R>>A)	"	F		
					Bahia		R	20 ppm (R > A)	"	F		
					Castilleja		A	12 ppm (R,nd)	"	F		
					Cryptantha	Cryptanth	A	3 ppm (R,nd)	"	F		
					Eriogonum	Buckwheat	R	80 ppm (R > A)	"	F		
					Grindelia	Gumweed	A	20 ppm (R,nd)	"	F		
					Gutierrezia	Snakeweed	A	52 ppm (R,nd)	"	F		
					Hedysarum		A	3 ppm (R,nd)	"	F		
					Lepidium		R	76 ppm (R > A)	"	F		
					Solidago	Rock goldenrod	A	10 ppm (R,nd)	"	F		
					Sphaeralcea		A	15 ppm (R,nd)	"	F		

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	Canon (Cont.)				Stanleya Townsendia Zygadenus Spirogyra	Prince's plume Camus lily Algae	A A A All	5 ppm (R,nd) <1 ppm (R,nd) 2 ppm (R,nd) 54 ppm	" " " "	F F F F		Information is given on anomalous growth effects due to U and daughter products (p. 58); optimum U concentration for growth is 1.3-2.0 ppm U. Salsola, gladiolas and sedums are the most tolerant to irradiation, whereas gymnosperms are the least. Vegetables, fruits and cereals exhibit stimulated growth when irradiated. U content of leaves can vary greatly from one side of a tree to another (if roots on one side of a tree penetrate mineralization). Analyses suggest that during the growing season U content probably rises in some evergreens, but falls in most deciduous species. Juniper roots found at depths "much greater" than 12 m. Juniper and shadscale appear to accumulate similar amounts of U, and are therefore considered interchangeable for locating shallow ore. Ore at depths >6 m was better detected by Juniper. Juniper on barren ground contains generally 0.5 ppm U. " " mineralized ground contains generally >2 ppm U. Se indicator plants (Astragalus) successfully outlined U mineralization. The biogeochemical method was ineffective at locating U mineralization deeper than 50 m.
26 R	Cannon	1971	General									Review of plants indicative of water conditions, soil conditions, bedrock, and mineralization. No new specific information on U.
27 B, G	Cannon, Kleinhampl	1956	U.S.A., Colorado, New Mexico	Semi-arid								Plant ash normally contains 0.2-1.0 ppm U, but may range from 1-100 ppm U when rooted in ore. Major ore deposits up to 25 m below the surface may be detected by biogeochemistry. Generally more U in roots than aerial parts. Several conifers absorb about the same amounts of U: Pinus ponderosa, Pseudotsuga taxifolia, Abies concolor, Pinus edulis, Juniperus scopulorum, J. utahensis, J. monosperma. Most consistent results obtained from sampling the last year's growth of needles or branch tips collected from the entire periphery of the tree. For rapid reconnaissance, sample spacing of 75 m is adequate; 15 m spacing recommended for anomalous areas, and 4 1/2 - 9 m across talus-covered outcrop. Lists of Se indicator plants are given.
28 B	Cannon, Starrett	1956	U.S.A., New Mexico	Arid to semi-arid	Pinus sp. Juniperus sp.	Pinyon pine Juniper		0.1-2.3 ppm	Ash	F	Cretaceous coals (uraniferous)	Pinyon and juniper branches contain 0.1-2.3 ppm U (in ash). Dead branches contain more U than live:- 12 cm unpeeled sections from 4 quadrants of the tree were collected. Tree assays indicate that areas of uraniferous coal may be fracture controlled and of relatively small magnitude. Conclusion: branch tips of pinyon and juniper show a positive U concentration response to uraniferous coals.
29 B	Dean	1966	Great Britain	Temperate	Pinus sylvestris	Pine	N	0.6 ppm (unmin Range = 0.06-2.0 ppm	Ash "	NAA		New and old needles or leaves were collected in autumn; average age of the sample was 1.5 yrs. Uraniferous and non-uraniferous areas sampled. Data given for vegetation

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	Dean (Cont.)				Prunus laurocerasus	Laurel	L	0.2 ppm (unmin.)	Ash	NAA		in mineralized area are from an old Cornish U mine. Ashed pine needles from 37 localities scattered throughout the British Isles all yielded < 2 ppm U. Conclusion: Plants growing in debris from a Cornish U mine contained U 63-180 times higher than background. Highest values were in oak leaves.
					Rhododendron ponticum	Rhododendron	L	0.04–0.6 ppm)	"	"		
					Cupressus sp.	Cypress	N	0.5 ppm	"	"		
					Picea sp.	Spruce	N	0.1 ppm	"	"		
					Taxus sp.	Yew	N	1.0 ppm	"	"		
					Salix sp.	Willow	L	64 ppm (min.)	"	"		
								1 ppm (unmin.)	"	"		
					Quercus sp.	Oak	L	160 ppm (Min.)	"	"		
								0.9 ppm (unmin.)	"	"		
						Bracken	L	15 ppm (Min.)	"	"		
								0.5 ppm (unmin.)	"	"		
30 B	DiLabio, Rencz	1980	Canada, N.W.T.	Arctic	Vaccinium uliginosum	Bog blueberry	L	0.4–980 ppm	Ash	F	Precambrian metamorphics	Very strong positive correlation between U in leaves and U in tills (< 2 µm). Highest values obtained from shrubs collected close to a mineralized fault. Conclusion: Vaccinium uliginosum can successfully be used for prospecting for U.
31 OC	DOE News (summary of report by J. Schmidt-Collerus)	1979	U.S.A., Colorado	Temperate		Peat						Separation of organic acids shows that most U resides in humic acid, with less in fulvic acid.
32 Bb	Duncan, Bruynesteyn	1971	Canada, Elliott L.	Uranium mine	Thiobacillus ferrooxidans	Bacterium						Discussion of the bacterium Thiobacillus ferrooxidans in acidic mine waters, and its role in solubilizing uranium. By promoting bacterial growth there was an increase in uranium leaching.
33 B	Dunn	1979	Canada, Saskatchewan	Boreal forest	Ledum groenlandicum	Labrador tea		<1– >100 ppm	Ash	D	Precambrian Athabasca	Preliminary results of major project: see Dunn, 1981a.
					Chamaedaphne calyculata	Leather leaf						
					Picea mariana	Black spruce						
34 B	Dunn	1980a	Canada, Saskatchewan	Boreal forest	Picea mariana	Black spruce	T	up to 154 ppm	Ash	D	Precambrian Athabasca Sandstone	Abstract of paper given at symposium (see 1981a). U mineralization 150 m beneath sandstone appears to be reflected in the plants. No discernible relationship between U in plants and U in soils.
					" "	" "	W	~1 ppm	"	D		
					Ledum groenlandicum	Labrador tea	S	~100 ppm	"	D		
					" "	" "	R	<5 ppm	"	D		
					Chamaedaphne calyculata	Leather leaf	S	~100 ppm	"	D		
35 B	Dunn	1980b	Canada, Saskatchewan	Boreal forest	Picea mariana	Black spruce	T	up to 800 ppm.	Ash	D	Precambrian Athabasca Sandstone	a) Spruce twigs proved easiest to collect and prepare, and contained more U than any part of any species. 10 years growth was practical amount to collect (2-4 year old growth contains the highest U concentrations). b) Traverses over an area of several hundred square km did not reach the expected background of a few ppm U in spruce twig ash; 20 km west of the highest concentrations the mean concentration was 70 ppm U. All trees within an area of several hundred sq. km contain >100 ppm U in their twigs.
					Pinus banksiana	Jack pine	T	All contain about 50% less U than spruce at the same sites.	"	D		
					Alnus sp.	Alder	T					
					Larix laricina	Tamarack	T					
					Betula sp.	Birch	T					
					Salix sp.	Willow	T	90% less U than spruce.	"	D		
					Grass		All	80% less U than spruce.	"	D		
					Equisetum	Horsetail	All	1 ppm	"	D		

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated Scientific Name	 Common Name	Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
	Dunn (Cont.)											c) Eight biogeochemical profiles across EM conductors did not help define drill targets. d) Detailed sampling indicated that local variation of U in spruce twig ash is about + 15%. e) No systematic difference between U in twigs from short and tall spruce at adjacent sites. f) No systematic difference between U in live and dead twigs. g) 20 - 100% more U in twigs at the top of a spruce than those near the bottom. h) No systematic difference in U content of twigs on the north and south sides of trees. i) Spruce twigs usually contain about 10 times more U than needles, and 100 times more than trunk wood. j) No apparent correlation between U in twig ash and U in groundwaters. k) Anomalies transect terrains from wet muskeg to open woodland.
36 B	Dunn	1981a	Canada, Saskatchewan	Boreal forest	Picea mariana	Black spruce	T	($\bar{x}$ = 84 ppm) 50-154 ppm	Ash	D	Precambrian Athabasca Sandstone	Aerial parts of Labrador tea have much more U than roots. Spruce twigs are most pronounced accumulators of U, and contain twice as much as jack pine twigs. Conversely, the jack pine needles contain twice as much U as spruce needles. Apparent relationship between U beneath 150 m of sandstone and U anomalies in all vegetation, although anomalies are above but laterally displaced from known mineralization. U tends to vary sympathetically with Track-Etch data, Fe, Pb, Sm, and sometimes Cd, Be and Zn. Commonly an inverse relationship between U and Mn. No relationship between U in plants, and U in peat or soils. Conclusion: Positive relationship of U in vegetation to deeply buried U mineralization (150 m).
					" "	" "	N	($\bar{x}$ = 14 ppm) 9-22 ppm	"	D		
					" "	" "	W	($\bar{x}$ = 0.5 ppm) <.4-9.5 ppm	"	D		
					Pinus banksiana	Jack pine	W	($\bar{x}$ = 0.9 ppm) <.4-1.9 ppm	"	D		
					Ledum groenlandicum	Labrador tea	S	($\bar{x}$ = 56 ppm) 36-83 ppm	"	D		
					" "	" "	L	($\bar{x}$ = 32 ppm) 17-51 ppm	"	D		
					" "	" "	R	($\bar{x}$ = 3 ppm) 0.8-5.8 ppm	"	D		
					Chamaedaphne calyculata	Leather leaf	S	($\bar{x}$ = 70 ppm) 51-100 ppm	"	D		
					" "	" "	L	($\bar{x}$ = 51 ppm) 31-83 ppm	"	D		
						Peat		($\bar{x}$ = 6.2 ppm) 1-24 ppm	"	D		
37 B	Dunn	1981b	Canada, Saskatchewan	Boreal forest	Picea mariana	Black spruce	T	1-2270 ppm	Ash	D	Precambrian Athabasca Sandstone	Detailed and regional surveys. Spruce twigs contain up to 1260 ppm U in virgin forest (no known mineralization). Massive "Wollaston biogeochemical U anomaly" extends over an area of at least 3600 sq. km. Twigs show no systematic seasonal variation in U uptake " " " " annual " " " " Needles do show seasonal variation in U uptake (lower in summer than spring). Needles do show annual variation in U uptake. No relationship between U in twig ash and U in soils. Moderately good relationship between U in twig ash and scintillometer and Track Etch data. Across the Athabasca Basin background levels of U in spruce twig ash are about 3 ppm. In the Black Lake area the range is 3 - 18 ppm; near Uranium City the range is 1 - 120 ppm, and in the Carswell Structure 4 - 1480 ppm.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
	Dunn (Cont.)											Twigs appear very sensitive to changes in dissolved U in groundwaters. Suggested that spruce twigs may provide a "window" through surface sediments to the U potential of underlying rocks.
38 B	Dunn	1982a	Canada, Saskatchewan	Boreal forest	Picea mariana	Black spruce	T	up to 2270ppm	Ash	D	Precambrian Athabasca Sandstone	Describes a large U biogeochemical anomaly. The latest 10 yrs. growth of spruce twigs contains up to 2270 ppm U, and the 10 ppm contour (U in spruce twigs) extends for at least 3600 sq. km. Intense local anomalies occur within this region.
39 B	Dunn	1982b	Canada, Saskatchewan	Boreal forest	Picea mariana	Black spruce	T				Precambrian Athabasca Sandstone	Summarizes data compiled by same author between 1979-1981, and adds new information. The Wollaston Uranium Biogeochemical Anomaly found to extend for at least 7000 sq. km (>10 ppm U in ashed twigs). Discussion on possible origins of the anomaly - concluded that it is probably a hydrobiogeochemical effect.
40 B	Dunn	1982c	Canada, Saskatchewan	Boreal forest	Picea mariana	Black spruce	T				Precambrian Athabasca Sandstone; Aphebian metasediments	Results of investigations conducted during 1982. The 'JEB' zone of U mineralization found to have a positive biogeochemical expression. Regional study shows that the Wollaston U Biogeochemical Anomaly (>10 ppm U in ashed twigs) encompasses an area of 10,000 km^2. Within this the 50 ppm U contour extends for 3000 km^2, and the 100 ppm U contour covers an area of 1000 km^2. The composition of underlying Aphebian bedrock is shown to have a marked influence upon U concentrations in the trees.
41 B	Dyck, Boyle	1980	Canada, Saskatchewan	Boreal forest	Sium sp. Betula sp. Salix sp. Potamogeton sp. Equisetum sp. Alnus sp. Nostoc sp. Hippuris sp.	Water parsnip Birch Willow Pondweed Horsetail Alder Alga Marestail	All T+L T+L All All T+L All All	30 ppm 40 " 36 " 150 " 5 " 850 " 130 " 63 " 805m from U mineraliz'n	Ash	F	Precambrian metamorphics	First-year twigs and leaves were collected from all trees studied. Marked radioactive disequilibrium occurs. The ratio of eU/U increases greatly on approaching U mineralization. Study reflects the relatively high Ra content of plants growing close to mineralization. Conclusion: High radioactive disequilibrium in plants indicates the proximity of U mineralization.
					Betula sp. Alnus sp. Salix sp.	Birch Alder Willow	T+L T+L T+L	31 " 30 " 52 " 91 m from U	Ash	F		
					Betula sp.	Birch	T+L	3-78 " 6-61m	Ash	F		
					Betula sp.	Birch	T+L	185 ppm (4.6 m from U)	"	F		
					Salix sp.	Willow	T+L	75 ppm (9 m from U)	"	F		
					Salix sp.	Willow	T+L	900 ppm (0.6 m from U)	"	F		

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
42 B	Eakins	1970	U.S.A., Alaska	Boreal forest - high precipitation	Pinus contorta	Lodgepole pine	T+N	1-2396 ppm	Ash	F	Peralkaline granite and monzonite (Hydrothermal U)	Lupine appears to favour U-rich soil in the area. Samples comprised 12-20 cm lengths of twigs plus leaves or needles, weighing 100-200 g. Generally more U in dead than live twigs of pine [Compiler's note: this may be because needles and cones seem to have been included with the live twigs, and each plant part may be expected to contain different concentrations of U]. High values were all within a few hundred m of mine workings and outlined well the region of known U mineralization. <u>Conclusion</u>: Lodgepole pine proved the most sensitive plant to U mineralization, and was the most suitable medium for the area.
					Picea sp.	Spruce	T+N	2-315 ppm	"	F		
					Thuja plicata	Western red cedar	T+L	1-2127 ppm	"	F		
					Tsuga heterophylla	Western hemlock	T+N	2-901 ppm	"	F		
					Juniperus sp.	Juniper	T+N	2-159 ppm	"	F		
					Vaccinium sp.	Blueberry	T+L	20-30 ppm	"	F		
					Algae		All	2-1833 ppm	"	F		
					Luketkea pectinata		All	923 ppm	"	F		
					Lycopodium	Club moss	All	<20-374 ppm	"	F		
						Crowberry	All	<20-832 ppm	"	F		
					Alnus sp.	Alder	T+L	<20 ppm	"	F		
43 B	Ek	1982	Sweden	Boreal forest				$\bar{x}$ Max. U				Three mineralized areas chosen as test areas. At each, samples were taken above mineralization, boulder trains, and background. All ashed vegetation had lower U concentrations than C-horizon of the till and forest litter. No sample type showed a clear tendency to have higher U concentrations above mineralization or boulders than above background terrain. <u>Conclusion</u>: in this area the biogeochemical technique shows no positive response to mineralization.
					Picea abies	Norway spruce	T+N	0.4 0.8 ppm	Ash	D		
					" "	" "	B	0.2 0.8 ppm	"	D		
					Pinus sylvestris	Scotch pine	B	0.5 1.7 ppm	"	D		
					Betula alba	Birch	B	0.9 1.9 ppm	"	D		
					Vaccinium myrtillus	Blueberry	All	0.6 2.7 ppm	"	D		
					Vaccinium vitis-idaea	Lingonberry	All	0.9 7.4 ppm	"	D		
					Calluna vulgaris	Heather	All	0.8 2.3 ppm	"	D		
44 B	Erämetsä, Yliruokanen	1971	Finland	Boreal forest	Cladonia arbuscula	Lichen		6.1 ppm	Ash	MS		Short paper describes the content of several metals in mosses and lichens. Brief reference is made to the content of U in plants recorded by others.
					" "	"		4.8 ppm	"	MS		
					C. alpestris	"		24 ppm	"	MS		
					Stereocaulon paschale*	"		200 ppm	"	MS		
					S. saxatile			1.8 ppm	"	MS		
					Nephroma arcticum	"	All	3.9 ppm	"	MS		
					Cladonia arbuscula	"		2.1 ppm	"	MS		
					C. rangiferina	"		0.31 ppm	"	MS		
					C. alpestris	"		3.6 ppm	"	MS		
					C. arbuscula	"		4.2 ppm	"	MS		
					Stereocaulon paschale	"		1.3 ppm	"	MS		
					Cladonia rangiferina	"		3.1 ppm	"	MS		
					Pleurozium Schreberi	Moss		2.1 ppm	"	MS		
					" "	"		3.2 ppm	"	MS		
					Dicranum polysetum	"		65 ppm	"	MS		
					Rhacomitrium lanuginosum	"		4900 ppm	"	MS		
					Ptilidium ciliare			7.1 ppm	"	MS		
					Hylocomium splendens	"		4.3 ppm	"	MS		
					Dicranum fuscescens	"		1.7 ppm	"	MS		
					Pleurozium Schreberi	"		4.5 ppm	"	MS		
					Dicranum fuscescens	"		3.5 ppm	"	MS		
					D. scoparium	"	All	6.4 ppm	"	MS		
					Polytrichum	"		3.2 ppm	"	MS		
					juniperinum	"		& 7.1 ppm	"	MS		
					P. piliferum	"		0.74 ppm	"	MS		
					Hedwigia ciliata	"		4.5 ppm	"	MS		
					Rhacomitrium lanuginosum	"		4.2 ppm	"	MS		
					Hylocomium splendens	"		1.9 ppm	"	MS		

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					Scientific Name	Common Name						
	Erämetsä and Yliruokanen (Cont.)				Pleurozium Schreberi	"		2.0 ppm	"	MS		
					Hylocomium splendens	"		1.6 ppm	"	MS		
					Polytrichum commune	"	All	1.3 ppm	"	MS		
					Pleurozium Schreberi	"		5.0 ppm	"	MS		
					Rhacomitrium lanuginosum	"		4.6 ppm	"	MS		
					" "	"		3.7 ppm	"	MS		
					* Other samples from this site:							
					Cladonia alpestris	Lichen	All	350 and 500 ppm	"	XRF		
					Dicranum scoparium	Moss		400 and 670 ppm	"	XRF		
					Polytrichum piliferum	"		1700 ppm	"	XRF		
					" juniperinum	"	All	760 and 2400 ppm	"	XRF		
					Rhacomitrium lanuginosum	"		350 and 1700 ppm	"	XRF		
					Brachythecium rutabulum	"		4800 ppm	"	XRF		
45 B	Erdman, Harrach	1980	U.S.A. (West)	Semi-arid	Artemisia tridentata	Big sagebrush	S+L	< 0.4-3.2 ppm	Ash	F	Mainly Tertiary	Abstract of 1981 paper by same authors.
46 B	Erdman, Harrach	1981	U.S.A. (West)	Semi-arid	Artemisia tridentata	Big sagebrush	S+L	< 0.4-3.2 ppm	Ash	F	Mainly Tertiary	Composite samples of stem and leaf tissue of the current year's growth were analyzed. Frequency distributions of U concentrations were positively skewed. Basin and Range, Colorado Plateau, and Columbia Plateau physiographic provinces: only 9 of the 90 samples had U concentrations above 0.4 ppm, the upper-limit threshold for normal concentrations in sagebrush (max. 1.4 ppm). Highest values occurred near the Uravan mineral belt and in the Owyhee Mtns., the latter an area of little previously-demonstrated U potential. Powder River Basin: only 7 of the 64 samples had U concentrations above 1.6 ppm, the upper-limit threshold for normal concentrations in sagebrush (max. 3.2 ppm). The anomalous samples were collected in or near known U districts. No obvious correlation between eU in the soils and U in sagebrush.
47 B	Erdman, McCarthy	1981	U.S.A. (West)	Arid	Artemisia tridentata	Big sagebrush	S				Volcanics	Increase in U content of sagebrush wood over the Aurora U occurrence. No discernible increase of U in soils or soil gases, nor in gamma activity along same profiles.
48 B	Erdman, McNeal, Pierson, Harms	1979	U.S.A. (Texas)	Semi-arid	*Mimosa biuncifera*	*Catclaw mimosa*	L+FR				Tertiary volcanics	Abstract of paper given at symposium. U concentrated more in the leaves than in the fruit, but no specific data cited. Strong differences in U levels observed in plants growing over different geologic formations. Mimosa considered a potentially useful plant for exploration of U.
49 R	Faust Bondietti	1976	Worldwide									Bibliography (with abstracts) of publications concerning U and Th in the environment.
50 Bb	Fisher	1978	U.S.A.		*Desulfovibrio desulfuricans*	*Bacterium*						*Bacteria found in groundwaters associated with U deposits* are instrumental in controlling redox reactions, which can mobilize and subsequently immobilize U.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
51 B	Froelich, Kleinhampl	1960	U.S.A., Utah	Semi-arid	Juniperus sp. Pinus cembroides Shepherdia rotundifolia	Juniper Pinyon pine Roundleaf buffaloberry	T+N T+N L+S	0.6-77 ppm 0.6-71 ppm up to 9 ppm [N.B. more U in buffaloberry than other species at same site.]	Ash " "	F F F	Permo-Trias clastics	Plants sampled had comparable U content; except locally, the buffaloberry had much more U. Analyses are listed of U in 246 samples from 6 localities. Sampling was at 60 m intervals over outcrop and 5 m intervals where rocks not exposed. About 11 of branch tips (twigs + needles) collected at each of 2000 sites. Samples containing >1 ppm U in plant ash were considered anomalous (approx. 12% of the total population). In areas remote from mines, anomalous concentrations were 1.0-5.4 ppm, compared to a background of <0.6 ppm U. Near mines values of 8-115 ppm U were considered due in part to windblown contamination by absorption through roots or leaves. Conclusion: biogeochemical anomalies occur at all major known deposits, plus some anomalies elsewhere. Buffaloberry absorbs more U than the other species sampled.
52 B	Goldsztein	1957	France (South)	Warm temperate semi-arid	Pinus sp. Calluna sp. Cistus sp.	Pine Heather Rock rose	N All All	1.4 - 260 ppm 0.3 - 75 ppm 0.7 - 75 ppm	Ash " "	F F F	Permian volcanics	Pine proved to be the best sampling medium. The ashed rose and heather contained similar amounts of U, whereas the pine needles (with a much higher LOI) contained substantially higher concentrations. There was a good correlation between U in vegetation and U in soils (1 - 38 ppm), and the mineralized zone was strongly reflected by all sample media. Conclusion: Positive response to mineralization.
53 B	Gough, Erdman	1980	U.S.A. (Wyoming)	Semi-arid	Artemisia tridentata	Big sagebrush	S+L	0.008-0.045 ppm	Dry	F	Tertiary	Young tissue (< 2 yr. old) shows appreciable seasonal differences in U concentration, with lowest values recorded in the summer. This affect is much less pronounced in older tissue. The seasonal variability appears, in part, to be associated with variations in ash yield.
54 B	Gough, Severson	1981	U.S.A., New Mexico (San Juan Basin)	Desert	Hilaria jamesii Atriplex canescens Gutierrezia sarothrae	Galleta grass Fourwing salt bush Broom snakeweed	All All	0.6-1.8 ppm < 0.4-0.6 ppm < 0.4-3.6 ppm	Ash " "	F F F	Cretaceous clastics and coals	Discusses background values of many elements in three species sampled from a 38,000 km^2 area. The terminal 10-20 cm of stems and leaves of the saltbush were collected. Samples were collected from one plant at each site, except for the galleta. U data are from 20 galleta, 18 snakeweed and 10 saltbush samples; data quoted here are for U in ash. They are given on a dry-weight basis in the publication. U and Mo were the only 2 (out of the 35) elements to show regional trends in galleta grass).
55 B	Grodzinsky	1959	USSR, Ukraine			Moss	All	up to 4400 ppm	Ash			Notes that ashed mosses have been recorded with up to 4400 ppm U, but the range is usually 0.065-3.5 ppm U.
56 B	Grodzinsky, Golubkova	1964	USSR, Ukraine									Deals mainly with U and Ra in soils - discusses U uptake of plants in general.
57 A, B	Harms, Ward, Erdman	1981	U.S.A., Texas	Semi-arid	Mimosa biuncifera	Catclaw mimosa	L	< 0.05-2.6 ppm	Ash	F	Tertiary volcanics and lacustrine sediments	Method by laser-induced fluorometry found to be substantially more sensitive than by conventional fluorometry. Only 6 of 74 plant samples (mostly catclaw mimosa) contained U in amounts above the detection limit of the conventional method (0.4 ppm in the ash).

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
	Harms, Ward and Erdman (Cont.)											The detection of limit for U by the laser method (0.05 ppm) is about an order of magnitude lower than by the conventional method; this resulted in all but one of the plant samples having detectable U. A highly significant correlation was found between the U content of the soils and the associated plants. The laser-induced fluorescent method is described.
58 B	Hoffman	1941	Austria			Algae	All	9.1 ppm	Ash	F		Short description of U content of living freshwater algae.
59 B	Hoffman	1942	Austria			Apricot	W	7 ppm	Ash	F		Non-uraniferous region near Vienna.
						Birch	W	.06 ppm	"	F		
						Plum	W	.008 ppm	"	F		
						Grapevine	W	.005 ppm	"	F		
						Tobacco	All	.03 ppm	"	F		
						Cornstalk		.11 ppm	"	F		
						Corn kernels		.007 ppm	"	F		
						Beans		.014 ppm	"	F		
						Grasses		.08 ppm	"	F		
60 A,B	Huffman, Riley	1970	U.S.A.		Artemesia sp.	Sagebrush	X	0.8-51.2 ppm	Ash	F		Description of the fluorometric method of analysis applied to plant ash. Locations of plant samples and parts analyzed were not specified.
					Pinus edulis	Pinyon pine	X	0- 6.4 ppm	"	F		
					Pinus ponderosa	Ponderosa pine	X	0- 6.4 ppm	"	F		
					Juniperus sp.	Juniper	X	0-12.8 ppm	"	F		
61 Bb	Jayaram, Dwivedy, Bhurat, Kulshrestha	1974	India			Bacteria						Study concludes that considerable reconcentration of U can be brought about by bacteria. Ore samples showed a prolific growth of anaerobes and scanty growth of chemautotrophic bacteria. Host rock showed the reverse.
62 B	Kleinhampl	1962	U.S.A., Utah	Moist, high dissected plateau	Pinus ponderosa	Ponderosa pine	T+N	<.2 - 8.5 ppm	Ash	F	Permo-Trias clastics	Biogeochemical prospecting was restricted to the uraniferous Triassic Chinle Fm. About 11 of branch tips(including needles) was collected at each site. Different geometric means of U data exist for the species studied (juniper and white fir were the same). Pines appear to have a greater range in background amounts of U than the other species, and anomalous values begin at a higher level. An inverse relationship exists between U and ash content. Background values for oak leaves have an upper limit of 0.6 ppm U; for ponderosa pines the level is 0.9 ppm; for pinyon pines 0.8 ppm, and for the firs and junipers it is 0.7 ppm. Colluvium 0.5 m thick restricts the effectiveness of prospecting by the radioactivity method more than by plant analysis. Nine areas were sampled and later resampled for confirmation of results. Drilling confirmed the presence of U at many of the biogeochemical anomalies. It proved impossible to predict reliably the grade and precise extent of U deposits by plant analysis prospecting.
					Pinus edulis	Pinyon pine	T+N	<.2 - 3.2 ppm	"	F		
					Pseudotsuga menziesii	Douglas fir	T+N	<.1 - 6.0 ppm	"	F		
					Abies sp.	White fir	T+N	<.1 - 1.5 ppm	"	F		
					Juniperus sp.	Juniper	T+N	<.1 - 7.1 ppm	"	F		
					Quercus gambelii	Scrub oak	L+S	<.2 - 1.3 ppm	"	F		
63 B,G	Kleinhampl, Koteff	1960	U.S.A., Utah	Moist, dissected plateau	Juniperus sp.	Juniper	T+N	0.4 - 16 ppm	Ash	F	Permian to Jurassic clastics and	Discusses the use of Se (hence U) indicator plants (esp. *Astragalus* and *Stanleya*). U values greater than 1 ppm in the ash of branch tips are proposed to define mineralized ground in the area.
					Pinus edulis	Pinyon Pine	T+N	0.2 - 7 ppm	"	F		

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
	Kleinhampl, Koteff (Cont.)							(upper values may have been due to contamination)			limestones (mainly Triassic s/stns)	It is shown that the ratio of pinyon to juniper increases as the uraniferous *Shinarump member thickens.* Biogeochemistry appears effective where U mineralization occurs up to a maximum depth of 20 m, and a sample interval of 15 - 30 m appears adequate for outlining mineralization.
64 P	Kochenov, Zinev'yev, Lovaleva	1965	USSR	Humid forest		Peat						Discusses U in peat bogs. Data suggest that Szalay's(1958) conclusions are not all correct. U distribution is irregular. Close correlation between U and Fe. 70% of U-bearing peats come from sedge/wood and sedge/Hypnum varieties that are frequently found at the base of peat deposits. U content of waters feeding peat deposits of this study is 2 to 3 ppb. These waters contain bicarbonates of Ca and Mg, and all U in true solution. However, colloidal U occurs in weakly acid peat waters, by $UO_2(OH)^+$ and UO_2^{++} being adsorbed upon organic and organometallic compounds. The high content of dissolved organic matter is related to the oxidation of peat and is often accompanied by high concentrations of U. Experimental work shows that U in peats can only be in excess of 1000 ppm if the circulating water is not less than 10 - 100 ppb U. However, investigations show that high U concentrations may occur when circulating waters have about background levels of U (i.e. enrichment factors of 2 million). The importance of oxidation-reduction reactions in the fixation of U is emphasized - the theoretical Eh for U precipitation from peat water is -70mv. At pH 7.5-7.8 U dissolves 3 times faster than at pH 5.5-6.0. The conditions required for U accumulation in peat vary with climate and botanical composition.
65 B	Konstantinov	1963	USSR	Arid, temperate	Stipa hessingriana Carex ripariaeformis Artemisia sp. Ephedra intermedia Happula microcarpa Achyrophus	Feather grass Sedge Sagebrush Mormon tea	All " " " " "	100%* 100% 116% 100% 110% 143% } up to 60 ppm above deeply-buried U ore body (Background is 0.5 ppm) *Above percentages are concentrations relative to Feather Grass	Ash	F	<u>Area 1</u> Faulted & metamorphosed Lower Cambrian felsite-porphyry & tuffs. <u>Area 2</u> Caledonian porphyritic granodiorite with U in qtz-carbonate veins	<u>Area 1</u>: Hilly (relief up to 50 m): U ore 50-100m beneath surface. Plants sampled at 5m intervals, and soil taken from depth of 15-20cm. Soils contained background levels of U (0.18ppm) over the ore, but plants (300) contained background levels of 0.5 ppm U which increased to 60 ppm above and immediately surrounding the ore body (for 60m). There is a wide biogeochemical halo (extending 400m from the orebody) with concentrations 3-10 times background. <u>Area 2</u>: Rolling hills (relief up to 30m): Biogeochemical background is 0.18 ppm U. An aureole with 3-10 times background U extended for 10 times the width of the ore body in May, and 20 times the width in August at which time two new low-relief anomalies (3-100 times background appeared. <u>Conclusion</u>: The biogeochemical method showed a strong positive response to U mineralization at depth. In early summer the technique was a closer indicator of U mineralisation than in late summer. At that time the biogeochemical halo became diffuse and U concentrations were higher

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
66 B	Kovalevsky	1962	USSR		Betula sp.	Birch	T	.05-.35ppm	Ash	F		Plants analyzed came from close to a radioactive source. Discusses radioactive disequilibrium (between U and Ra) in plants and shows that equilibrium varies greatly from one species to another. This is because some plants (e.g. birch) absorb more Ra than U, and others (spiraea, pine) tend to favour U There is a large shift in equilibrium close to U mineralization. In general, the selective absorption of Ra causes the radioactive equilibrium in plants to be upset in the direction of an excess of Ra isotopes and their decay products. Concentrations of U and Ra in various species, relative to birch, are given. The coefficient of radioactive equilibrium depends not only on the species of plant, but also on the radium content: coefficients are usually >100, but may be much lower where U in groundwater is absorbed by the plants. Studies show that U is taken up by cones>branches>leaves or needles [N.B. only two cones were analyzed]. Comparisons are given of K, U, Ra, Th, Ac isotopes in several plants. Most gamma and beta activity in plants is caused by K; most alpha activity is from Ra. Discussion also includes an evaluation of the relative ionization due to radioactive elements absorbed by plants: alpha radiation (i.e. almost entirely Ra) is responsible for 90% of the ionization.
					Larix sp.	Larch	T	.10-.45 "	"	F		
					Larix sp.	Larch	N	.45 "	"	F		
						False spiraea	S	.10-6.0 "	"	F		
						False spiraea	L	7.0 "	"	F		
					Populus sp.	Poplar	T	.05-.15 "	"	F		
					Salix sp.	Willow	T	.1 "	"	F		
								Concentrations Relative to Birch:				
					Betula sp.	Birch		100%				
					Populus sp.	Poplar		90%				
					Lonicera sp.	Honeysuckle		75%				
					Filipendula			100%				
					Ribes sp.	Currant		200%				
					Larix sp.	Larch		400%				
					Pinus sp.	Pine		550%				
						False spiraea		600%				
						Daurskiy rhododendron		500%				
								Concentrations in plants growing in uraniferous soils				
					Populus sp.	Poplar	L	.12 ppm	Ash	F		
					Larix sp.	Larch	T	1.6 "	"	F		
					Betula sp.	Birch	T	0.1 "	"	F		
					Filipendula		T	0.1 "	"	F		
						Grasses	All	24.0 "	"	F		
67 B	Kovalevsky	1964	USSR, Siberia	Boreal forest	Betula sp.	Birch						Discusses Ra and U in plants. Ra 1.3 - 3 times higher in plants of Group I than in soils, and 5 - 20 times higher in their rootlets. In plants of Group II the ratio of Ra in plants to Ra in soils is much lower. U usually occurs in concentrations 10 - 100 times lower in plants than soils, and does not migrate far from its source in the soils. U is not an essential element to plant growth. A table shows element concentrations in different size fractions of soils: most U is in the less than 5 micron fraction.
					Picea sp.	Spruce	Group I					
					Abies sp.	Fir						
						Meadow-sweet						
						Yernik						
					Populus sp.	Aspen						
					Salix sp.	Willow						
					Populus sp.	Poplar						
						Acanthus						
					Pinus sp.	Pine	Group II					
					Thuja sp.	Cedar						
					Quercus sp.	Oak						
					Fraxinus sp.	Ash						
					Acer sp.	Maple						
68 B	Kovalevsky	1965	USSR	Boreal and temperate forests.								Discusses the relative alpha activity of various trees, shrubs and lower plants from boreal and temperate forests. Concentrations of U are not given: most data refer to Ra. Filipendula, rhododendrons and ledum have the highest alpha activities.
69 B	Kovalevsky	1966	USSR								Quartz porphyry	96p. book of which only the preface was obtained; this notes the high radioactivity (20 times background) in both plants (grasses and others) and soils overlying a U ore body. Good correlation between U and soils.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
70 B	Kovalevsky	1972	USSR Siberia	Boreal forest	Pinus sp. Rhododendron sp. Sorbus sp.	Pine Rhododendron Mountain ash plus others (not listed)	X X L	max. 100 ppm	Ash			Figure 1 shows that the correlation between U in plants and U in soils is good only up to 10 ppm (in ash); further increase of U in soils does not result in an increased uptake in plants. Plants (in this region) appear to have a physiological barrier to U uptake. [However, Ra retains a perfect correlation between Ra in soils and Ra in plants up to at least 1% Ra]. Therefore, it is considered that U should be rejected as a basic biogeochemical indicator of U mineralization; it is only a secondary indicator. U and Ra are at their highest levels (esp. 2 to 8 yr. old growth) from the fall to the spring. It is recommended that in prospecting for U the following should be collected: 1. 2 - 8 yr. old cuttings of branches, bark and wood; 2. leaves, cones and green shoots. for determination of Pb, As, Ag, Bi. Ra, U and thoron should also be determined. <u>Conclusions</u>: Biogeochemical prospecting for U is most effective when: 1. Ra (and not U) is used as the basic element indicator, whilst U in association with non-radioactive element indicators in plants is used as a secondary indicator. 2. The U minerals sought are readily soluble (e.g. pitchblende). 3. Overburden is thin (usually less than 10 m, but may be considerably more). 4. There are leached lithogeochemical haloes.
71 B	Kovalevsky	1973	USSR									Discusses the "physiological barriers to absorption of elements by plants" (FBPR), which are much more significant in the aerial portions of plants than roots. FBPR is absent in roots of higher plants and of low significance in the lower plants. Ra is unaffected by FBPR, whilst U and K are moderately affected. Ra is concentrated mainly in the bark of the roots. Plants growing in soils with 0.3-3.0 ppm U have the U quite evenly distributed, whereas in soils with 10-100 ppm U, the higher plants exhibit an insignificant increase of U in their aerial portions, and the lower plants and <u>roots</u> of higher plants may have 10 to 100s times the content of U in the soils. Within the roots U distribution is uneven, being enriched up to 1000 times in the bark. Mosses, lichens and roots of higher plants in contact with U ore and its halo may differ in their U concentrations from background values to 10,000 times greater.
72 R	Kovalevsky	1978										Review paper which stresses the role of "physiological barriers" to biogeochemical prospecting in general. U is considered a "low barrier" element (i.e. only small quantities can be taken up by the higher plants). Element absorption by plants is, on average, 3000 times more vigorous from aqueous solutions than from the solid phase of soils.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
73 R	Kovalevsky	1979										Good review of fundamental theories and techniques followed in biogeochemical prospecting for a wide range of ore deposits. Summarizes a great deal of research and case histories (world-wide, but with an emphasis on the Russian literature). Limited discussion of U, but some useful summary data in tables.
74 Bb	Kovalsky, Letunova	1970	USSR	Cool temperate		Bacteria						Study of the adaptation of micro-organisms to different contents of U in lake sediment oozes. Some bacteria have a mechanism which inhibits successive uptake of U into the cells ('adapted' strains), whereas in others the mechanism is absent thus inhibiting growth and decreasing their biomass. The adapted strain plays an important and more active role in the biogenic migration of U than the unadapted strains.
75 B	Kovalsky, Vorotnitskaya	1966	USSR, Khirghiz	Arid	Caragana laeta		All	max. 23 ppm	Ash			Compares the U province of Khirghiz and Tyan-Shan with normal background for the area and black soils of Kurskii; U in the plants of the uraniferous area is 5-85 times greater than background, and causes morphological changes (e.g. albinism and vari-colored flowers in *Caragana laeta* with 23 ppm U). Refers to numerous plants, organisms and fish with reference to the passage of U through the food chain. There is a decrease in U accumulation as the food chain is ascended, due to barrier mechanisms.
76 B	Kovalsky, Vorotnitskaya, Lekarev	1966	USSR									Covers some of the information given in the paper in Russian by Kovalsky and Vorotnitskaya (1966) - e.g. morphological changes and increased U content in plants of uraniferous areas. U accessible to plants can readily penetrate into them as a result of ion exchange, or in a complex combination with organic acids given off by the plant roots. The amount of U taken up from a soil is related to the nature of the soil. Some plants may accumulate U without showing any morphological change.
77 B	Kovalsky, Vorotnitskaya, Lekarev	1973	USSR, Issyk-kul									Short note discussing the passage of U through the food chain. No U data
78 B	Kronfeld, Zafrir	1982	Israel	Arid, hot	Phoenix dactylifera	Desert palm	L	0.12 ppm	Dry	A	Granite	Highest U concentrations were found in palms growing in granitic terrains. The palms reflect the U isotopic disequibria of their associated water sources, and the ratios of U-234 to U-238 in defining target areas for prospecting. In the southern Sinai the leaves do not closely reflect the waters' U concentration, but do mirror the U isotope ratios.
79 B,P	Larsson	1976	Sweden, Pajala	Temperate forest		Dead organic material		$\bar{x}$ = 22 ppm;	Ash	XRF	Mainly granitic	Organic stream bank sediments (dead organic debris and roots of *Carex*) comprised the material collected for a regional survey. Enhanced values of U all occurred in areas underlain by granite. Multi-element analysis of the samples was performed, and the data then subjected to computer manipulation.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
80 B	Lecoq, Bigotte, Hinault, Leconte	1958	Africa N.Central	Desert, Savanna, Equatorial forest	Compositae Chenopodiaceae Cornuca	Grass, crucifer	X				Granite with U veins	No specific data on U biogeochemistry. Only reference is p.761: of 21 species recognized none seemed peculiar to uraniferous zones, but Cornuca seemed capable of accumulating a little U.
81 B	Leroy, Koksoy	1962	USA, Colorado	Temperate	Parmelia conspersa Umbilicaria hyperborea Lecanora rubina Caloplaca elegans	Lichen " " "	All " " "	Max. 20 ppm " 31 ppm " 10 ppm " 3 ppm	Ash " " "	S S S S	Sandstone	Four species of lichen collected from Mesozoic sandstone outcrops yielded from 1 - 31 ppm U, whereas the s/stns all had less than 1 ppm U.
82 B	Lexow, Maneschi, Sa	1948	Argentina	Semi-arid, warm	Larrea divaricata Schinopsis lorentzii	Creosote bush	X X					Cannon (1964, p.55) quotes this paper, and notes that these species have unusually high U contents.
83 P	Lisitsin, Kruglov, Panteleev, Sidel'nikova	1967	USSR	Peat bog		Peat						Fixation of U on organic matter is discussed, as well as hydrogeochemical factors. The possibility of peat to bear U is not regional, but local. U accumulation is directly related to the conditions of peat formation. Oxidation and reduction factors are important controls.
84 P,L	Lopatkina	1967	USSR	Peat bogs in humid regions (low moors)		Peat		Max.6000 ppm	?	?	Various	200 marshy areas were sampled, plus 4 bogs in detail. U concentrations are governed by the composition of the peat, the U content and pH of the groundwaters, rates of groundwater flow, and the total dissolved salt content of the water. Where the salt content is high, the U tends to remain in solution and not be absorbed by peat. Laboratory experiments showed that from pH 6 to 7.2 nearly all the U in solution was precipitated by the peat. At pH 8.3 none was precipitated.
85 B	Lopatkina, Komarov, Sergeyev, Andreyev	1970	USSR E.Siberia	Humid, Cool Temperate. Marshy flood plains and terraces	Betula sp. Ledum sp. Alnus sp. Salix sp. Larix sp. Betula nana Carex Eriophorum sp. " "	Birch Ledum Alder Willow Larch Dwarf birch Sedge Herbs Cotton grass " " " " Mosses	T+L T+L T+L T+L T+L T+L All All Upr. Lwr. Roots All	0.1–0.9 ppm 0.1-1.4 " 0.4 " 0.2-2.0 " 0.6–0.9 " 0.2-2.5 " 0.2-1.0 " 0.2-19.5 " 2.5 " 10.5 " 45.0 " 1.7-210. "	Ash " " " " " " " " " " "	?	Granite	The U content of the plants bore no relationship to the U content of the soils. The soils ranged in content from 1 - 2000 ppm U, whereas only the herbs, mosses, and cotton grass had over 3 ppm U. Highest U contents tended to occur in roots; it is believed that U is adsorbed upon root surfaces. Mosses (8 species examined) accumulated more U than the higher plants. Dead larch needles contained more U than live. Conclusions: exposed parts of trees and grasses contained one tenth to one thousandth of the U absorbed by the hydromorphic soil in which the plants grew, regardless of the U content of the groundwaters. Highest concentrations of U occur in plant roots, dead plants and mosses.
86 L,Bb	Magne, Berthelin, Dommergues	1974	France	Laboratory tests	Thiobacillus	Bacterium (and other micro-organisms)						Laboratory tests of bacterial cultures show that microbial activity increases the solubilization of U by 2 to 97 times. The processes are biosyntheses of complexing or chelating compounds involving soil microflora and bacteria. U attached to organo-compounds is released by biodegradation. Thus bacteria may be instrumental in mobilizing U deposits.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
87 B	Malyuga	1964	USSR	Various (U in deserts)	Artemisia	Sagebrush	All					Book which describes the controls of internal factors of dispersion of chemical elements above ore deposits; external factors of migration; conditions required for the accumulation of heavy metals in plants; and gives a critical evaluation of the biogeochemical method of prospecting. One chapter deals with the biogeochemical exploration for U under desert conditions. It was found that higher accumulations of U occur in roots than in aerial parts.
					Salsola	Thistle	"					
					Astragalus	Vetch	"					
					Anabasis	Itsegek	"					
					Haloxylon	Saxaul	"					
88 B	Mamulea, Buracu	1967	Rumania	Temperate forest	Quercus sp.	Oak	X	100-320 ppm	Ash	?		Results indicate that beech accumulates U more strongly than oak, and elm is better than ferns. It is concluded that the biogeochemical method may be superior to radiometric, hydrogeochemical and lithogeochemical methods in the exploration for U. Results obtained are interpreted as a function of local geology.
					Fagus sp.	Beech	X	160-320 ppm	"			
					Ulmus sp.	Elm	X	140 ppm	"			
						Fern	X	72- 84 ppm	"			
89 P,OC	Manskaya, Drozdova Emelianova	1956	USSR	Laboratory tests		Peat						Deals with the binding and transfer of U by different natural organic compounds - fulvic acids, humic acids, and melanoidines; pH levels govern the formation of uranyl fulvates and humates from uranyl salts and fulvic and humic acids. U is probably bound to peat and coal as an organic complex. U accumulates in the chitin envelope of organisms.
90 C	Manskaya, Drozdova	1968	USSR	Various								Chapter 6 describes the association of U with fossil organic matter, and summarizes the biogeochemical studies conducted by other workers.
91 G	Massingill	1979	USA, Colorado	Semi-arid, temperate	Astragalus pattersoni	Poison vetch					Clastics	Summary of geobotanical prospecting for U using Se indicator plants (based mainly upon Cannon's work). No new data. Common Se indicators are illustrated. Notes that the best indirect indicators of U are Astragalus pattersoni and A. preussi: these develop best where ore contains more than 0.001% Se and lies at less than 70 ft (20 m) beneath the surface. Botanical studies made in 10 districts of the Colorado Plateau have located 5 ore bodies.
					Astragalus preussi	" "						
92 B	Moiseenko	1959	USSR (European)	Boreal forest, taiga and bogs.	Scorpidium scorpiodes	Moss	All	Max. 189 ppm	Ash	F	U mineralization	Samples were taken from an area with radioactive soils over known ore bodies. Area was 0.25 km x 0.5 km x 2.5km. Relates the U content of the ashed plant to the U content of the soils. Most mosses had similar U content to the associated soil. Herbs had consistently lower U levels of U than the soils in which they grew. Trees had similar U content to the soil, except for local enrichments in spruce needles and willow leaves. Many of the 1105 samples collected had greater than normal U contents for plants, with 70 samples containing more than the designated 'anomalous' level for the area of 5 ppm. The study showed that in a given area, mosses concentrate more U than grasses and trees, and herbs contain more than the trees. It is noted that there is an inconsistent relationship between U in soils and U in plants.
					Calliergon giganteum	"	"	" 115 ppm	"	F		
					Drepanocladus fluitans	"	"	" 54 ppm	"	F		
					Polytrichum commune	"	"	" 19 ppm	"	F		
					Sphagnum centrale	"	"	" 9 ppm	"	F		
					Carex caespitosa	Sedge	"	" 99 ppm	"	F		
					Aegopodium podagraria	(Herb)	"	" 67 ppm	"	F		
					Lycopodium annotinum	Club moss	"	" 20 ppm	"	F		
					Filipendula ulmaria		"	" 11 ppm	"	F		
					Crepis paludosa		"	" 9 ppm	"	F		
					Deschampsia caespitosa		"	" 7 ppm	"	F		
					Prunella vulgaris		"	" 7 ppm	"	F		
					Aconitum excelsum		"	" 6 ppm	"	F		
					Picea excelsia	Spruce	N*	" 400 ppm	"	F		
					" "	"	T*	" 7 ppm	"	F		
					" "	"	R*	" 10 ppm	"	F		

*Probably not from the same tree

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
	Moisseenko (cont.)				Frangula alnus	Buckthorn	X	max. 36 ppm	Ash	F		
					Alnus incana	Alder	L	" 43 ppm	"	F		
					Salix caprea	Willow	L	" 400 ppm	"	F		
					Betula pubescens	Birch	L	" 6 ppm	"	F		
					Sorbus aucuparia	Mountain ash	L	" 6 ppm	"	F		
93 L,C, P	Moore	1954	USA	Laboratory tests		Coals, wood and peat						Describes the fixing of U by peat, lignite and coal. Low rank coals were more effective at extracting U in solution than any other material tested. The association of U and organic material in nature may result from the ability of these substances to remove U from natural solutions by the formation of a chelate. Discusses the possibility of using coal, lignite and peat to extract U from solutions derived from U-processing industrial plants.
94 B	Murakami, Fujiwara, Sato, Ohashi	1958	Japan	Temperate forest (mountainous)	Pinus sp.	Pine	X	93 ppm (mineralized area) 2 ppm (barren area)	Ash "	F F	Conglomerates	Pine, cypress and Cryptomeria were (in decreasing order) effective in accumulating U. They showed a good positive response to U mineralization. The other species were less effective.
					Cupressus sp.	Cypress	X	23 ppm (mineralized area) 0.4 ppm (barren area)	" "	F F		
					Cryptomeria Shibu Sasa albo-marginata							
95 B	Nash, Ward	1977	USA Washington State	Temperate forest	Pinus ponderosa	Ponderosa pine	N	0.4-200 ppm	Ash	F	Precambrian Togo Fm.	First year growth of needles was collected from mineralized and barren areas. Table lists all U analyses: 358 pine needle, 29 Douglas fir, 35 cone and 4 pine needle duff (i.e. forest litter) samples. Some samples may have been contaminated from 5 open pit U mines, but investigations suggest that contamination was not a major problem. It is believed that pine needles take up similar amounts of U to the fir needles (data are not conclusive). Plants with cell sap of less than pH 5.2 absorb relatively large amounts of U. Cones and duff appeared to have more U than needles. U concentrations were relatively high near mineralized zones.
					" "	" "	C	6.0-440 ppm	"	F		
					Pseudotsuga menziesii	Douglas fir	N	<0.4- 26 ppm	"	F		
96 R,C	Norris, Edmond	1973	General	Sandstone-type U deposits								Review paper of the distribution of micro- and macroplant fossils in the vicinity of sandstone-type U deposits. Discusses the role of palynomorphs, lignin, humic substances and carbonaceous sediments in mobilizing and fixing U. Extensive bibliography.
97 R	Peterson	1971										General information on the accumulation of chemical elements by living organisms. Herbs, mosses, lichens and others are included. Common accumulator plants for U are quoted.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
98 L	Prister, Prister	1970		Laboratory tests		Corn Beans						Results showed that U is accumulated in plant tissues, especially in the roots. 50 ppm U in water proved fatal to beans and corn.
99 Bb	Rackley, Shockey, Dahill	1968	General	Roll-front deposits	Clostridium cellulosedossolvens Desulfovibrio Thiobacillus ferrooxidans	Bacterium " "					Sandstone	Biochemical reactions caused by these bacteria are discussed, with particular attention to the pH/Eh changes which take place. Thiobacillus can survive at pH of zero, and thrives in a highly oxidizing environment (up to 760 mv). Due to these reactions there is bacterial zoning associated with metal zoning across the edge of a roll-front deposit of U.
100 C	Robertson	1975	United Kingdom (Wales)			Plant debris						A theoretical situation is described where granite is overlain by clastic sediments. The relationship between U and the humic components of coals and clastic rocks is described. By using palynological techniques the lateral persistence of organic concentrates can be accurately predicted. In a U province where free circulation of groundwaters can take place, accumulation of prospective urano-organic complexes may be predicted.
101 R	Rogers, Adams	1969										Brief account of work by others. Mentions that U is not known to be of importance for the life process of any organism. The concentration of U in plants is not easily understood. U may occur as chelates.
102 B	Rowntree, Mosher	1976	Australia N.Territory	Tropical scrub		Eucalypts (gum, mallee and stringybark)					Sandstones and metasediments	Results showed a wide variation in the U content of the species sampled, even within known anomalous areas. The eucalypts showed encouraging results and could be useful. In this environment, however, augur drilling was preferred to biogeochemistry.
103 A,B	Schiller, Skalova	1975				Wild sour cherry Grass "	X All "	29 ppm (mineralized area) 14 ppm (mineralized area) 0.5 ppm (barren area)	Ash " "	NAA NAA NAA		Discusses NAA of plant material and includes data on the analysis of two species.
104 R,OC	Schmidt-Collerus	1979	General									Report (available on microfiche only) of investigations and an extensive literature survey and compilation of information concerning the relationship between organic matter and U ore formation. The emphasis is on humic and fulvic acids and their U complexes in uraniferous peat bogs. Both acids play a significant role in the formation of economic secondary U ore deposits.
105 C	Scott	1961	USA, Utah, Colorado	Temperate grasslands	Araucarioxylon	Fossil conifer		up to 8.5%	Ash		Sandstone	U in deposits of Mesozoic age on the Colorado plateau is often associated with fossil wood and other organic debris. The U content of organic matter varies in a single mineralized zone, hence the possibility that woods of differing systematic affinities might have different capacities for localizing U is examined. Various organic materials have the ability to effect fixation, and evidence does not suggest that different plants had a significant bearing on the localization of ore.

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					Scientific Name	Common Name						
106 G	Shacklette	1964	N.America	Temperate to Arctic	Epilobium angustifolium	Fireweed	F					Discusses geobotanical aspects of fireweed (Indian brush) which is found in large numbers in temperate and arctic regions (particularly disturbed areas). Studies of fireweed populations in many areas show that variation in colour is rare. However, there is a distinct change in colour of plants growing close to a U mine: the plants are paler than elsewhere. Factors causing mutations are briefly discussed.
107 Ba	Shacklette, Erdman	1982	USA, Idaho	Temperate forest	Pohlia sp.	Moss	All	11-1600 ppm*	Ash	UA3	Volcanics & clastics	Bryophytes were collected from sites where springs (22) emerge at rock-unit contacts. The pH of the spring waters ranged from 7.4-8.4, and the U content of the waters ranged from 0.08-6.5 ppb. The water with 6.5 ppb U gave rise to the moss with the highest U content (1800 ppm). Spectrographic analysis of the 28 moss samples and one liverwort indicated unusually high concentrations, locally of As, Be, Cd, and Pb. Conclusion: Mosses absorb U from spring waters, but are better indicators of mineralization than the waters because 1) they concentrate the U; 2) they integrate the fluctuating U values of the waters over a long period of time.
					Brachythecium rivulare	"	"	11-1800 ppm	"	"		
					Mnium punctatum	"	"	31 ppm	"	"		
					Marchantia polymorpha	Liverwort	"	8 ppm	"	"		
					Cratoneuron filicinum	Moss	"	8 ppm	"	"		
					Philonotis fontana	"	"	45- 67 ppm	"	"		
					Bryum sp.	"	"	18 ppm	"	"		
					Brachythecium lamprochryseum	"	"	61- 180 ppm	"	"		
					Aulacomnium palustre	"	"	11 ppm	"	"		
					Drepanocladus fluitans	"	"	16- 700 ppm	"	"		
					Cratoneuron falcatum	"	"	87 ppm	"	"		
					Dichodontium pellucidium	"	"	400 ppm	"	"		
								*All data normalized to a "sediment-free" basis.				
108 R	Sheppard	1980	General									A review of the literature on U and Th. Many aspects are discussed e.g. concentrations in plants, soils and organisms, and analytical methods. Information is given on U and Th in nature, as well as on the chemistry of the two elements. U and Th concentrations in plants, plant transfer coefficients, concentrations in soil organisms, and methods of detection are summarized.
109 B	Sheppard, Olchowy, Mayoh	1981	Canada (Ontario & Manitoba)	Cool temperate forest	Lycopodium obscurum	Club moss (ground pine)	All	<3-150 ppm	Ash	NAA	Precambrian Shield	Three uraniferous areas were studied to determine the relationship of U, Th, Ra, and As in rocks and soils to that in plants and animals. U in 48 samples from 34 plant species show concentration factors (compared to soils) of 0.03 - 3.0. Preliminary data indicate that the lower plant forms were able to accumulate U better than the higher plants. Around the Bancroft U mine plants contained from <3 - 150 ppm U. Near the Bruin Lake/Edison Lake mine all plants had concentrations of U at or below the detection limit of 3 ppm. The Black Lake occurrence, which has not been mined, has U in plants from <3 - 60ppm
					Polytrichum sp.	Moss	"	60 ppm	"	"		
					Sphagnum sp.	"	"	3.5 ppm	"	"		
					Pleurozium sp. & Dicranum sp.	"	"	<3 ppm	"	"		
					Cladonia sp.	Lichen	"	3- 30 ppm	"	"		
					Carex sp.	Sedge	"	<3 ppm	"	"		
					Gramineae	Grass	"	<3 ppm	"	"		
					Pteridium aquilinum	Bracken fern	"	32 ppm	"	"		
					Epilobium angustifolium	Fireweed	"	<3 ppm	"	"		
					Typha sp.	Cattails	"	3 ppm	"	"		
					Solidago canadensis	Goldenrod	"	3 ppm	"	"		
					Thuja occidentalis	White cedar	L+T	40 ppm	"	"		
					Acer sp.	Maple	L+T	40 ppm	"	"		
					Acer sp.	Maple	W	20 ppm	"	"		
					Alnus rugosa	Speckled alder	L+T	<3- 40 ppm	"	"		
					Alnus rugosa	" "	W	<3 ppm	"	"		
					Betula papyrifera	Paper birch	L+T	<3- 25 ppm	"	"		
					Picea glauca	White spruce	L+T	<3 ppm	"	"		
					Larix laricina	Larch	L+T	<3 ppm	"	"		

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
	Sheppard et al. (cont.)	1981			Rhus sp.	Sumac	L+T	< 3 ppm	Ash	NAA		
					Rubus idaeus	Red rasberry	L+T	< 3 ppm	"	"		
					Prunus virginiana	Chokecherry	L	< 3 ppm	"	"		
					" "	"	W	< 3 ppm	"	"		
					Malus sp.	Apple	Fr	< 3 ppm	"	"		
					Populus balsamifera	Balsam poplar	L+T	< 5 ppm	"	"		
					Populus tremuloides	Trembling aspen	L+T	3-10 ppm	"	"		
					Salix sp.	Willow	L+T	3 ppm	"	"		
					Anaphalis margaritacea	*Pearly everlasting*	L+T	< 3 ppm	"	"		
					Fragaria banksiana	Strawberry	All	< 3 ppm	"	"		
					Vaccinium myrtilloides	Blueberry	L+T	3 ppm	"	"		
					Pinus banksiana	Jackpine	L+T	3-10 ppm	"	"		
					Arctostaphylos uva-ursi	Bearberry	L+T	< 3-10 ppm	"	"		
					Abies balsamea	Balsam fir	L+T	3 ppm	"	"		
					Picea mariana	Black spruce	L+T	3 ppm	"	"		
					Juniperus communis	Juniper	L+T	< 3 ppm	"	"		
					Ledum groenlandicum	Labrador tea	L+T	< 3 ppm	"	"		
					Chamaedaphne calyculata	Leatherleaf	L+T	< 4 ppm	"	"		
110 P,OC	Szalay	1958	Hungary			Humus, peat and coal						Experiments showed that humic acids are responsible for the enrichment of U in coals and other decayed organic matter. This fixing of U is a reversible cation-exchange process with a geochemical enrichment factor of about 10,000: 1. Comparison is given between laboratory experiments and U enrichment in nature.
111 L,P	Szalay	1968	Hungary			Peat						Laboratory experiments and field tests. Humic acids derived from peat and plant residues were found responsible for the geochemical fixation of U.
112 B	Talipov, Khatanov	1974	USSR	Mountainous, Temperate	Ephedra shobilaceae Rhamnus coriacea	Wormwood	All				Schists and intrusives (Precambrian)	U was found to be preferentially concentrated in roots. The distribution and concentration of other elements is discussed.
113 L	Thibault, Sheppard	1980	Canada	U mine tailings	Pinus sylvestris	Scots pine (seedlings)	R	$\bar{x}$ 346 ppm	Dry	NAA		Laboratory experiments in which seedlings of pine were planted in soil from U tailings, and also in a non-uraniferous control soil. There was a distinct acropetal (tipward) gradient for U and Th. U showed a strong concentration in roots, with up to 609ppm U in one dry root sample. It is concluded that the seedlings growing in treated soils eventually died by chemical and/or radiological toxicity. High levels of U and As seemed to cause stunting.
							S	" 9 ppm	"	"		
							N	" 4 ppm	"	"		
114 B	Timperley, Brooks, Peterson	1970	New Zealand	Temperate forest	Nothofagus fusca	Red beech	L	$\bar{x}$ 5.6 ppm	Ash	F		Investigations showed that trace elements essential to plants gave different statistical distribution patterns to non-essential elements (e.g. U). The latter tend to have a wider spread in values. High plant/soil ratios of elements indicate non-essentiality and consequent suitability for biogeochemical prospecting.
					Quintinia acutifolia	Five fingers	L	" 7.8 ppm	"	F		
					Weinmannia racomosa	Kamahi	L	" 3.3 ppm	"	F		
115 P	Titaeva	1967	USSR	Humid, cold (taiga, permafrost)		Peat						U is more mobile than Ra in surface waters containing small amounts of calcium bicarbonate. In peat, U is associated with the alkali-soluble fraction (humic and fulvic acids). Laboratory experiments showed that U is sorbed

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
	Titaeva (cont)											better than Ra for weakly acid solutions under static conditions. The uptake of U is highest at pH 6. In waters with a low salt and Ca content U can migrate considerable distances, and can be concentrated from water in a suitable geochemical setting.
116 B	Titaeva, Taskaev, Ovchenkov, Alexakhin, Shuktomova	1978	USSR	Humid zones								Describes the migration of isotopes of U, Th, Ra, and Po and their radioactive decays in the soil-plant chain. A separation of isotopes of an individual element was observed. Data are given on isotope concentrations in numerous high and low-order plants.
117 P	Usik	1969	General	Peatlands		Peat						Review of geochemical and geobotanical prospecting methods in peatlands. An extensive compilation of references is given.
118 B	Verkhovskaya, Vavilov, Maslov	1967	USSR, north	Taiga	Betula sp.	Fluffy birch	B	x̄ 0.11 ppm	Ash	F		The radioelement data of Gruzdev (1965), from a radioactive occurrence, are quoted.[N.B. data given on an ashed basis are more in accord with levels usually found on a dry basis above U mineralization]. It appears that twigs preferentially concentrate U. The accumulation coefficient (plant:soil) is from 0.05-0.01, whereas in moss the coefficient is close to 1. Data are given on the radioelement content of 4 species of *Lyrurus*-type birds. U concentrations up to 18.6 ppm (raw body weight, excluding craws and gizzards) are recorded. Mineral particles extracted from craws and gizzards contained up to 510 ppm U in the summer. It is emphasized that the content of radioelements entering plants does not correspond to their ratios in soil. All plants show an acropetal gradient in the distribution of radioelements.
					"	" "	W	" 0.08 ppm	"	F		
					"	" "	T	" 0.41 ppm	"	F		
					"	" "	L	" 0.10 ppm	"	F		
					Picea obovata	Siberian spruce	B	" 0.09 ppm	"	F		
					" "	" "	W	" 0.07 ppm	"	F		
					" "	" "	T	" 0.33 ppm	"	F		
					" "	" "	N	" 0.05 ppm	"	F		
					Sorbus aucuparia	Mountain ash	B	" 0.16 ppm	"	F		
					" "	" "	W	" 0.05 ppm	"	F		
					" "	" "	L	" 0.09 ppm	"	F		
119 C,OC	Vine, Swanson, Bell	1968	USA			Carbonaceous matter						Distinguishes 4 types of carbonaceous matter: indigenous humic matter (oxygen-rich plant remains); redeposited humic extracts; indigenous sapropelic matter (hydrogen-rich plant and animal remains); redeposited bitumens. Only the first two are commonly associated with U deposits. Humic acids in solution readily assimilate U to form uranyl humates, which can be precipitated by lowering the pH or increasing divalent cation concentrations.
120 R	Vostokova	1957	USA, USSR									Brief review of the work of Cannon and others on U geobotany and U biogeochemistry. Deformities of vegetation due to high U concentrations are discussed. Geobotany as an exploration tool is recommended to be used on a reconnaissance scale.
121 B	Walker	1976	Canada, Saskatchewan	Boreal forest								Preliminary outline of study conducted over known U mineralization. 19 species collected, but analytical data not given (see Walker, 1979 for details).Values of 4 - 7 ppm U in ashed plants over the ore zone, compared to less than 1 ppm U local background.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
122 B	Walker	1979	Canada, Saskatchewan	Boreal forest	Pinus banksiana	Jack pine	Var.	0.1-162 ppm	Ash	D	Precamb. Athabasca Sandstone	Data on 12 elements are given for various plant organs and soil horizons. Woody parts of the plants contain the most U. There are enhanced concentrations of U in plants above a U orebody. Trunkwood is considered a useful sampling medium.
					Picea mariana	Black spruce	"		"	"		
					Vaccinium myrtilloides	Blueberry	"	0.5-32.4ppm	"	"		
					Ledum groenlandicum	Labrador tea	"	0.5-71.6ppm	"	"		
123 B	Wenrich-Verbeek	1979				Moss	All	1500 ppm	Ash			Mosses concentrate U more strongly than algae.
						Algae	"	70 ppm	"			
124 Ba	Whitehead, Brooks	1969a	New Zealand	Temperate rain forest; mountainous		Moss	All	0.7 - 86 ppm	Ash	F	Granitic breccia	Eight species of bryophyte present; on average 5 species at each of the sampling sites. Species were not separated. Data are presented for U, Be, Cu, and Pb. Conclusion: High U in bryophytes occurs in radioactive areas, hence it is considered that the analysis of bryophytes may be useful as a preliminary assessment of a new area.
125 B	Whitehead, Brooks	1969b	New Zealand	Temperate rain forest; mountainous						F A B S		100 specimens of leaves and older wood were collected from 4 representative species, then dried and ashed. Analytical analyses of the plants are not given (see Whitehead and Brooks, 1969c). Comparison is made of the fluorometric method of analysis with radio-article counting, and results are discussed. It is concluded that fluorometry is superior to the other methods.
126 B	Whitehead, Brooks	1969c	New Zealand	Temperate rain forest; mountainous	Marchantia berteroana	Liverwort	All	670* ppm	Ash	F	Granite breccia	In addition to the analysis of several "non-ubiquitous" species, four common species (Weinmannia, Nothofagus, Quintinia and Coprosma australis) were tested to assess their suitability for biogeochemical prospecting. There was a highly significant correlation between the alpha activity of the leaf ash of each plant and the alpha activity of the corresponding soil. A similarly strong correlation was observed between the U in leaf ash and U in soil. Dissection of a 90 yr-old trunk of Nothofagus into a series of tree rings showed that most U was in new (1-3 yr-old) and 20-30 yr-old trunkwood. Zn in dried wood of Q. acutifolia corresponded to the presence of U mineralization.
					Blechnum capense	Fern	"	705* "	"	F		
					Dicksonia lanata	Fern	"	238* "	"	F		
					Cordyline banksii		L	18* "	"	F		
					Uncinia leptostachya	Sedge	All	25100 "	"	F		
					Carpodetus serratus		L	291* "	"	F		
					Coprosma arborea		L	987 "	"	F		
					C. australis		L	150* "	"	F		
					Cyathodes fasciculata		L	495 "	"	F		
					Myrsine salicina		L	68 "	"	F		
					Nothofagus fusca	Red beech	L	20* "	"	F		
					Pseudowintera colorata		L	26 "	"	F		
					Quintinia acutifolia	Five fingers	L	30 "	"	F		
					Weinmannia racemosa	Kamahi	L	20 "	"	F		
								*single value; others are means of 2 to 6 samples				
127 B	Whitehead, Brooks, Coote	1971	New Zealand	Temperate rain forest; mountainous								A similar suite of plants to those listed under Whitehead and Brooks (1969c) were isotopically analyzed by gamma-spectrometry. Isotopes included those of Pb, Ra, Bi, and U. Data obtained were used to calculate the contribution of each radionuclide and its daughters to the alpha-activity of the plants.
128 B,O	Whitehead, Brooks, Peterson	1971	New Zealand	Temperate rain forest; mountainous	Coprosma australis		L	1.4-146 ppm	Ash	F	Granite breccia	65% of U in leaves was present as a U-RNA complex; 10% of U was in the low molecular form; 25% of U was present as a U-protein complex. At least 50% of the total U was bound to cell wall proteins.

Ref. No. & Code	Reference	Year	Location	Environment	Species Investigated		Part of Plant	U Conc.	Ash or Dry	Tech.	Underlying Rocks	Summary
					Scientific Name	Common Name						
129 B	Yakovleva	1963	USSR	Cool temperate	Larix sp.	Larch	T	0.2- 5.2 ppm	Ash	F		Table shows that the one and two yr-old growth has considerably less U than the 3-4 yr-old growth.
					Betula sp.	Birch	T	0.2- 6.0 ppm	"	F		
						Wild rosemary	T	1.5-110 ppm	"	F		
						Rowan	T	2.0- 60 ppm	"	F		
130 B	Yliruokanen	1975	Finland	Boreal forest	Polytrichum commune	Moss	All	max. 160 ppm	Ash	MS	Granite, pegmatite, mylonite	Samples were collected from scattered granitic localities that were rich in U and REE. Highest concentrations were found in mosses and shrubs. One 10 yr-old spruce growing in a mylonitic ore pile had (in ash) 700 ppm U in its roots, 50 ppm U in the trunk, 80 ppm U in twigs (plus needles) and 16 ppm U in the youngest shoots.
					Sphagnum	Moss	"	900-2800 ppm	"	MS		
						Lichen	"	max. 30 ppm	"	MS		
					Vaccinium vitis-idaea	Blueberry	T+L	90 ppm	"	MS		
					V. myrtilloides	Blueberry	T+L	3-150 ppm	"	MS		
					Calluna vulgaris	Heather	T+L	30-270 ppm	"	MS		
					Betula alba	White birch	T+L	1- 3 ppm	"	MS		
					Picea abies	Spruce	T+N	max. 15 ppm	"	MS		
					Pinus sylvestris	Pine	T+N	max. 5 ppm	"	MS		

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SUPPLEMENT

Preface

At a meeting of the Project 5 Study Group in Helsinki (31 August 1983), Dr. Alexander Kovalevskii kindly presented us with a list of additional references on uranium biogeochemistry. Many of these papers are in Russian, and were previously unknown to us. We thank Dr. Kovalevskii for his important contribution which we have reproduced here as Supplement "A", edited to conform with the main compilation. We do not have access to these papers; hence, they are listed as titles and references only, with no comment on content.

Supplement "B" is a list of additional papers in languages other than Russian. Again, most were in a list presented to us by Dr. Kovalevskii, but we have taken this opportunity to include a few other papers recently brought to our notice, plus those published in 1983.

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December, 1983

SUPPLEMENT A

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[1] In the main text of this report, we have adopted the spelling Kovalevsky -- in this supplement Dr. Kovalevskii has used the optional spelling, which we have maintained throughout this section.

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