BOTANICAL METHODS OF PROSPECTING FOR URANIUM

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ABSTRACT

Botanical methods of prospecting are based on the premise that concealed mineral deposits may be reflected chemically in surface vegetation. Results indicate that ore bodies under a cover of barren sandstone many feet thick may be detected by testing plants growing above them for uranium and associated elements. Two methods of such prospecting for uranium have been developed.

The first method is based upon the presence of uranium in all plants in small but measurable amounts. The uranium content of plants rooted in ore, however, is detectably greater than the uranium content of plants rooted in barren ground. In semiarid country, similar parts collected from identical species of trees or deep-rooted shrubs show differences in uranium content, which may indicate mineralized ground buried to a maximum depth of 60 feet. Plant ash is analyzed directly for uranium by the fluorimetric method. The uranium content of the ash of plants rooted in unmineralized sandstone is generally less than 1 part per million. A content of several parts per million is common in the ash of plants rooted in ore.

A second method of prospecting, that of mapping the distribution of indicator plants, has been used in ecologically favorable areas. A plant may be used as an indicator plant in prospecting if its distribution is controlled by any factor related to the chemistry of the deposit. Carnotite ore and other oxidized uranium ores contain appreciable amounts of available selenium and sulfur. The distribution patterns of plants requiring one of these elements in quantity may indicate favorable ground. Which species of plants are useful as indicators in an area depends directly upon the chemical composition of the ore and the position of the ground-water table.

Experimental studies show that the availability of selenium is greatly increased in the presence of carnotite. *Astragalus pattersoni*, the most reliable indicator of uranium ore, is deep rooted and capable of extracting selenium directly from ore bodies as deep as 75 feet. In some ores soluble salts have migrated upward into the surface soil and there become available to plants that have shallow roots. Ore has been found as much as 25 feet below the surface in ground indicated as favorable by the distribution of onions and other sulfur-absorbing ephemerals. Prospecting by both plant analysis and indicator-plant mapping in widely separated areas of the Colorado Plateau has shown a positive correlation between botanically favorable ground and major ore deposits.

Botanical prospecting in advance of drilling for shallow ore deposits substantially reduces the number of holes required and may be used in unprospected country to suggest areas worthy of intensive geologic study.

INTRODUCTION

Prospecting for mineral deposits at depth by observing unusual growth characteristics or distribution patterns in surface vegetation has been used through the ages in the search for many metals. Botanical methods of prospecting are dependent upon the absorption and accumulation of metals and associated elements by plants growing over metalliferous deposits.

Two methods of botanical or biogeochemical prospecting have been developed and used by the Geological Survey to locate uranium deposits on the Colorado Plateau, which includes parts of Colorado, New Mexico, Utah, and Arizona. The deposits are chiefly of the carnotite type and occur as irregular tabular masses in rocks of Triassic and Jurassic age. The ore commonly contains about 2 percent V_2O_5 and 0.25 percent U_3O_8 with minor amounts of selenium, sulfur, arsenic, cobalt, and copper, and with traces of other metals. One method of botanical prospecting currently used is based upon the uranium content of plants; another is based upon the distribution of indicator plants—those that are dependent either directly or indirectly upon the presence of abnormal amounts of uranium and associated elements. Basic studies in the development of the methods have been described by Cannon (1952, 1953). Subsequent laboratory and experimental plot studies have supplemented field observations.

During the past 5 years, nearly 10,000 samples have been analyzed for uranium, and distribution studies of indicator plants have been made along 50 miles of outcrop. A positive correlation between botanically favorable ground and major ore deposits, has been demonstrated, and preliminary results indicate that ore may be found at depths to 80 feet by botanical methods of prospecting.

PROSPECTING BY CHEMICAL ANALYSIS OF TREES

Prospecting by analysis of tree material is based on the uranium content of plants growing in the area to be prospected. Uranium occurs in all plants in small but measurable amounts. Plant ash normally contains 0.2 to 1.0 ppm (parts per million) uranium. The uranium content of plants rooted in ore, however, may range from 1 to 100 ppm uranium. Therefore, the uranium content of plants rooted in ore or within the chemical halo of the ore body may be used as an indication of mineralized ground.

The uranium content of vegetation varies for many reasons, which should be understood and evaluated before a project of plant analysis is undertaken. The uranium content of trees and herbaceous plants varies slightly with the seasons and the amount of rainfall, but in an area being prospected by day-to-day sampling, this small variation can be discounted. A large part of the uranium absorbed by the plant root is precipitated within the root cells. A lesser amount is transported to the leaves and branches and is present in direct proportion to the total uranium absorbed by the roots, so that the presence or absence of mineralized ground may be inferred from leaf or twig analyses. Of importance in prospecting is the variation in uranium content from one side of the tree to another. As the roots of one side of the tree are directly connected to a particular set of branches, the uranium content of the branches may vary depending upon the position of the mineralized ground. It is important, then, to sample a tree on all sides to obtain a representative sample.

Some plant species absorb much more uranium than others. The mechanism by which plants absorb uranium is not a matter of ion transport in a water solution but of ion exchange. Plant families differ in regard to the amounts of the various ions absorbed because they have different and characteristic buffer systems and resulting variations in cell-sap pH. Studies of experimental plots indicate that those plants that readily absorb large amounts of sodium, sulfur, selenium, and calcium but small amounts of potassium will also absorb uranium readily. These plants generally have a low cell-sap pH. For this reason, conifers and desert shrubs of the rose family that have these characteristics and are common in uranium districts of the Colorado Plateau can be used successfully in sampling programs.

The amount of uranium absorbed by plants is dependent also upon the percentage of water-soluble uranium in the vicinity of the plant roots. The amount of water-soluble uranium present is due in part to the interaction of uranium with other ions present in unusual amounts and does not necessarily reflect the total amount of uranium present. For instance, the percentage of water-soluble uranium in the soil is increased when gypsum, selenium, or lime is added. The addition of carnotite increases the percentage of water-soluble sulfur and selenium. The latter relationship is important in the localization of sulfur- and selenium-bearing indicator plants. The described changes in solubility of uranium take place under oxidizing conditions, and important differences in the relative absorption of uranium by deep-rooted trees and shrubs have been observed only in areas of oxidizing ore.

The depth to which ore can be detected by plant analysis depends upon the root habits of the species sampled and upon the availability of water. In semiarid country, shrubs and trees commonly have root systems 50 to 75 feet in length. In many uranium districts of the Colorado Plateau, the ore-bearing rock is an aquifer. The roots of junipers, pinyons, and many desert shrubs penetrate long distances through cracks and crevices connecting with the water-bearing zone, and act as phreatophytes or ground-water plants Mineralized areas of a coal bed on La Ventana Mesa, N. Mex., were outlined by analysis of pinyon and juniper whose roots penetrated an 80-foot sandstone capping the mesa (Cannon and Starrett, 1955). It is probable, however, that plant analysis is not generally effective in prospecting at depths of more than 75 feet.

In prospecting by the plant-analysis method, a preliminary study must first be made of the geologic relations. This should include observations on the extent, depth, and inclination of the ore-bearing strata, the size and habits of the ore bodies, the probable grade of the ore, the presence or absence of a chemical halo in the surrounding barren rock, and the relation of the ore-bearing bed to the water table and the plant roots. Botanical studies should be made of the growth habits of species available for sampling. Preliminary samples should be collected on both mineralized and barren ground and then analyzed to determine the amount of uranium absorbed by trees in the area under study. Finally, from this geological and botanical information, the sampling medium, the sampling pattern, and sampling interval may be determined.

Several coniferous species have a wide range on the Colorado Plateau, have deep roots, and absorb about the same amounts of uranium. The species listed below have been used as the sampling medium on several projects.

Tree	*(Altitude, feet)*
Pinus ponderosa Doug. (Ponderosa, pine)	7,000 to 9,000
Pseudotsuga taxifolia Britt (Douglas-fir)	
Abies concolor Lindl. (White fir)	
Pinus edulis Engelm. (pinyon)	6,000 to 7,000
Juniperus scopulorum Sarg. (Rocky Mtn. juniper).	
Juniperus utahensis Sarg. (Utah juniper)	4,000 to 6,000
Juniperus monosperma Engelm. (oneseed juniper).	

Samples of the last year's growth of needles or branch tips collected from the entire periphery of the tree have given the most consistent results.

In areas where the ore-bearing bed occurs in a broad flat bench with a uniform vegetative cover, systematic tree sampling on a grid pattern may be used. Favorable areas may be found by establishing isograms based on uranium content. In areas where the ore-bearing bed crops out in sharp cliffs, line traverses with special emphasis on close-spaced samples collected on talus-covered areas may prove to be the best collecting pattern.

The distance between trees sampled depends in part upon the objective of the project. For rapid reconnaissance, an initial spacing of 250 feet is usually adequate, and in anomalous areas later fill-in samples with 50-foot spacing may be desirable. An interval of 15 to 30 feet is useful for sampling across talus-covered rim or cliff outcrops.

ANALYTICAL METHODS

A fluorimetric method of analysis is used by the Geological Survey for the determination of uranium in plant ash; the method has been described by Grimaldi and others (1952, 1954). A portable fluorimeter, powered by batteries, has been designed for field use, and a chromatographic field test for uranium in soils and in plant ash has also been used in Survey laboratories. A method of analyzing the radioactivity of plant ash by α-ray count has been developed at the University of Arizona and has been described in a recent paper by Anderson and Kurtz (1955).

A pint container of fresh plant material is collected for fluorimetric analysis under present laboratory procedure. The precision to be expected from the method is 0.5 ppm uranium in the range from 0.3 to 5.0 ppm uranium. The chromatographic and α-ray count methods require much less sample, but are not so accurate in the low ranges as the fluorimetric method.

INTERPRETATION OF RESULTS

Although the amount of uranium absorbed by plants rooted in ore varies slightly with the type of ore and the species of plant sampled, contents above 1 ppm uranium in the ash are considered to indicate favorable and possibly mineralized ground in many areas sampled on the Colorado Plateau. This figure was arrived at empirically from early plant analysis studies and from a statistical analysis of 2,000 tree samples. Trees rooted in barren ground were found to average 0.3 ppm uranium in the ash; trees rooted in mineralized ground averaged 1.5 ppm uranium.

Statistical study verifies the conclusions of other workers that a sampling program should be restricted to one kind of tree. However, when it is necessary to use more than one species of tree, special factors relating the different species to one another could be employed. These factors would be obtained by relating the statistical measures of the assay data of each population to the other populations used. The results thus obtained would define anomalously high values more exactly and make the results obtained from the different species comparable.

PROSPECTING BY CHEMICAL ANALYSIS OF INDICATOR PLANTS

A plant may be used as in indicator plant in prospecting for metalliferous deposits if its distribution is affected by the availability of chemical constituents present in the ore. The plants used in prospecting for a particular type of deposit may not all be controlled by the same factor. They are usually common rather than unusual plants. Indicator plants for uraniferous sandstone deposits are controlled not only by the presence of unusual amounts of selenium and sulfur but by an increased availability of these elements in water-soluble form and by the increased availability of the major plant nutrients calcium and phosphorous. Selenate and sulfate were found by plot experiments to be more readily absorbed by plants in the presence of carnotite, and uranium to be more readily absorbed in the presence of selenate and sulfate. The availability of calcium and phosphorous was also increased in the plots to which carnotite has been added. In addition, each indicator plant, depending upon the specific metabolic processes inherent in the species, reacted differently to the excess materials available for absorption. These experiments explain many irregularities in plant distribution noted in the field.

A correlation between the distribution of selenium indicator plants and carnotite deposits of the Morrison formation was first noted by O. A. Beath (1943) in conjunction with toxicity studies of range land. The Geological Survey has since established the use of selenium indicator plants in prospecting for uranium In general the plants are perennials with long tap roots; roots of *Astragalus* have been traced to a depth of more than 30 feet in mine workings. Under favorable conditions the use of *Astragalus* has led to the discovery of ore bodies 75 feet below the surface. *Astragalus* (pl. 17) and other seleniferous genera have distinct distribution patterns depending upon the amount of selenium in the ore and the amount required by the plant. Preliminary studies are mandatory in advance of prospecting in each new area to determine the species best correlated in distribution with mineralized ground.

Astragalus pattersoni, A. Gray, belonging to the vetch group is the most useful indicator plant on the Colorado Plateau (pl. 17). The plant requires large amounts of selenium and commonly absorbs several thousand ppm selenium from uranium ores. Experimental plot results indicate that the presence of carnotite increases the absorption of selenium by this plant many fold.

The following species of *Astragalus* are also useful in some areas of the Plateau:

A. preussi A. Gray
A. thompsonae S. Wats
A. confertiflorus A. Gray
A. bisulcatus (Hook) A. Gray
A. lonchocarpus Torr.
A. dodgeanus M. E. Jones

Other selenium indicator genera that require only small amounts of selenium may act as indicators of uranium ore containing less than 2 ppm selenium. These include:

Aster venustus, M. E. Jones (woody aster)
Grindelia spp. (gumweed)
Oryzopsis hymenoides, (R. and S.) Rick (Indian-ricegrass)
Stanleya spp. (princesplume)

Many uranium ores contain sulfides that commonly form gypsum upon weathering. Sulfur- and calcium-absorbing ephemeral plants occur where this gypsum moves upward into surface soil within reach of shallow plant roots. Sulfur- and calcium-absorbing ephemerals include:

Allium spp. (wild onion)
Calachortus spp. (Sego lily)
Zigadenus spp. (Camas lily)
Sisymbrium spp. (tumblemustard)
Lepidium spp. (pepperweed)
Eriogonium inflatum Torr. (desert trumpet)
Cryptantha spp. (cryptanth)
Oenothera caesiptosa Nutt. (tufted evening primrose)
Oenothera albicaulis Pursh. (white-stemmed evening primrose)
Stipa comata Trin. and Rupr. (needle-and-thread)
Elymus salina Jones (Salina wildrye)
Aplopappus armeriodes A. Gray (goldenweed)
Senecio longilobus Benth (threadleaf groundsel)
Mentzelia multiflora Nutt. A. Gray (desert blazingstar)

The plants used as indicators in prospecting may be common roadside weeds in other areas of the country. The chemical elements that control their distribution around metalliferous deposits, particularly selenium and sulfur, are present in all rocks but their concentration differs greatly in different stratigraphic units. The plants may be useful prospecting tools where the difference in chemical composition between barren parts of the ore-bearing bed and the ore itself is enough to affect the flora.

The effectiveness of indicator plants as a guide to uranium deposits depends largely on the depth to mineralized ground and the availability of selenium and sulfur to the plant roots. In turn, species of indicator plants differ in their root habits and in their capacity to absorb selenate and sulfate ions. Much depends on whether the elements in question are present only at ground-water level or have migrated to the soil surface along fractures or through permeable beds.

The distribution of indicator plants can be plotted directly on maps or photographs as a result of field observation without the necessity of collection or analysis. Indicator-plant prospecting is rapid and inexpensive and therefore if conditions permit is preferable to prospecting by plant analysis.

Preliminary studies are necessary in each area to be prospected to determine what plants in the area correlate most closely with the extent of the mineralized ground. An initial mapping of several dozen plants may eventually resolve itself into a final mapping of 2 or 3 species which may be plotted by symbol on maps or on airphotos. From a study of the resulting plant maps, favorable areas may be delineated for detailed geologic evaluation and possibly for exploration.

For the most effective use of plant distribution maps, a careful study should also be made of the sedimentary features, direction of ground-water movement, joint fracture patterns, folding, and other topographic and geologic features. Many drill holes have been inauspiciously placed in a futile attempt to test plant information without due regard to the probable origin and migration of water-soluble ions.

RESULTS OF BOTANICAL PROSPECTING ON THE COLORADO PLATEAU

Botanical prospecting studies have been made in advance of exploration in five districts of the Colorado Plateau. Of these only one area has subsequently

ASTRAGALUS PATTERSONI, PATTERSON'S LOCO, A SELENIUM-INDICATOR PLANT USEFUL IN PROSPECTING FOR URANIUM

completely explored by diamond drilling. Pre-
nary drilling programs have been started in two
r di ' icts. Results indicate that prospecting by
cato. lants is advantageous in areas of the plateau
re uranium ores average about 0.01 percent selenium
are at an average depth of not more than 40 feet
eath the ground surface. Prospecting by tree
lysis is advantageous in areas where the tree cover
continuous and the ores are not more than 80 feet
depth. It is also important that the ore-bearing
mation be an aquifer.

Prospecting by indicator plants has been tested in
Yellow Cat area, Grand County, Utah, where
nts were mapped over an area of about 6 square
les and nearly 2,000 holes were subsequently drilled.
ie ore in this area occurs in the Salt Wash sandstone
mber of the Morrison formation and contains
nadium, uranium, selenium, and sulfur. The distribu-
on patterns of 9 species of plants were originally
apped on a scale of 1:6000. Final maps of the dis-
ibution of four species were compiled.

An analysis has been made of the relation of plant
stribution patterns to results of the first 1,000 holes
rilled in the area. Holes ranged in depth from 10 to
50 feet. A total of 26 holes were in ore in the first
,000 holes drilled, and all 26 penetrated ore at a
elatively shallow depth. Twenty-one of the holes
ontaining ore were in areas of indicator plants. Five
re l es out of a total of 10 were found entirely on
lant data. Indicator plants were found to reflect
nineralized ground to an average depth of 68 feet but
roved to be a more dependable ore guide where ore is
confined to depths of less than 50 feet. Ten percent
of the barren holes, 50 percent of the mineralized holes,
and 80 percent of the ore holes were drilled in areas of
indicator plants.

A comparison of the effectiveness of indicator species in the area showed that the selenium indicators *Astragalus pattersoni* and *A. preussi* are the most reliable indicators of mineralized ground and that the sulfur plants *Allium acuminatum* and *Eriogonum inflatum* may act as competent indicators where the ore lies at depths of no more than 33 feet.

Several ore bodies have also been found in the Grants district, McKinley County, N. Mex., as a result of indicator-plant prospecting. A project of prospecting by plant analysis was conducted during 1952–54 on the ore-bearing Jurassic Todilto limestone. About 5,000 pinyon and juniper samples were collected from the Todilto bench west of Grants. Results of the program show that botanically defined anomalies delimit areas that are favorable for the discovery of uranium deposits, and preliminary drilling information indicates that bo‑‑nical anomalies correlate with mineralized ground.

On Elk Ridge, Utah, the analyses of 3,000 tree samples have defined areas where physical exploration for uranium may be warranted, as a study of the outcrop near botanically defined anomalies shows a positive correlation with geologically favorable criteria such as secondary copper and iron staining, carbonaceous trash, pyrite, and channel fillings. A drilling program is in progress.

On La Ventana Mesa, Sandoval County, N. Mex., a uranium-bearing coal bed is capped by a 65-foot sandstone through which the roots of a pinyon-juniper forest penetrate. More than 200 tree samples have been analyzed, and the resulting uranium values plotted to indicate probable areas of mineralized coal (Cannon and Starrett, 1955). A private company is drilling in the area.

SUMMARY

Two methods of botanical prospecting have been used in prospecting for uranium on the Colorado Plateau; first by analyzing for uranium content the foliage of trees collected on a grid or linear pattern; second by mapping the distribution of indicator plants.

Analysis of tree material depends on the absorption of anomalous amounts of uranium by trees rooted in ore. In general trees rooted in barren ground average less than 0.5 ppm uranium but trees rooted in ore average 1.5 ppm or more. The uranium content of a plant varies with the organ of the plant sampled, the season, the amount of rainfall, the species, and the form in which the uranium occurs in the soil. The solubility of uranium has been shown experimentally to increase in the presence of selenium, sulfur, and calcium. The depth to which ore can be detected depends on the root habits of the plant and on groundwater conditions. Plants have been used effectively in outlining mineralized ground at depths of 80 feet.

Samples of plant ash may be analyzed by fluorimetric, radiometric, or chomatographic methods. At the present time fluorimetric analysis is the most satisfactory method for uranium detection in low ranges. The results may be plotted on maps of the area with suitable isopleths showing areas of anomalously high uranium content.

The indicator plant method is dependent on changes in the distribution pattern of individual species in the vicinity of ore deposits. The factors controlling indicator plants for uranium deposits are the presence of anomalous amounts of available selenium, sulfur, calcium, and phosphorus in the surface soil. The most useful indicator plants on the Colorado Plateau, species of *Astragalus*, are able to concentrate large quantities of selenium from the ore deposits. Locally, plants of the lily, mustard, and buckwheat family, indicative of gypsum, are also useful. Areas favorable for geologic investigation can be delineated from maps of indicator plants in areas where the deposits lie at shallow depths and where the geologic setting is thoroughly understood.

Results of botanical prospecting on the Colorado Plateau suggest that prospecting by indicator plants is advantageous where the uranium content is 0.01 percent or more and the selenium content is also at least 0.01 percent, if the upper limits of the ore bodies are at an average depth of not more than 40 feet beneath the ground surface. Prospecting by analysis of tree material is advantageous in areas of continuous vegetative cover where the average depth to the ore-bearing stratum is no more than about 60 feet. Physical exploration of several areas prospected by botanical methods has shown a positive correlation between botanically defined favorable areas and mineralized ground and suggests that this technique has much promise as a method of finding worthwhile mineralized areas elsewnere.

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