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SCIENCE

CURRENT PROBLEMS IN RESEARCH

Botanical Prospecting for Ore Deposits

How plant chemistry is being used to aid the geologist in his search for metals at home and abroad.

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The world with its expanding populations requires increasing supplies of metals. In the early days of this country, metalliferous deposits cropped out at the surface and needed only to be hauled to the mill. Today the search is under way for the big deposits that are yet to be found under valley fill, gravel pediments, glacial moraine, and other types of blanketing soil cover or thicknesses of barren rock. One answer to this search lies in geochemical means of prospecting the soils, waters, and plants for evidences of enrichment near ore deposits. Plant prospecting is being used increasingly on all continents, but the U.S.S.R. greatly surpasses all other countries in the development and use of botanical methods of prospecting in the world today. In this article (*1*) I shall consider the usefulness of plants in prospecting and the value of an increased domestic program of investigation in this field.

Research in the development of botanical methods of prospecting in this country dates only from 1946. Plants were used as indicators of economic deposits as early as 1828, but not until 1937 was this method strongly recommended, by Dorn in Germany (*2*). Owing to the complexity of trace element analytical techniques, plant analysis was not seriously suggested as a prospecting tool until it was described by the Russian Tkalich in 1938 (*3*). He discussed both the use of indicator plants and plant analysis in prospecting and checked his ideas in the area of the Unvashinsk arsenopyrite deposits in the Far East. There he found that the amount of iron in the leaves of beach grass and the distribution of the plants defined the veins of ore.

At the same time Palmqvist and Brudin of the Swedish Prospecting Company investigated methods of prospecting by spectrographic analysis of plant ash (*4*) and discovered a vanadium-bearing shale in Sweden and a tungsten deposit in Cornwall (*5*). These pioneer studies were followed by investigations of plant contents over nickel deposits in Finland (*6*), copper deposits in Norway (*7*), and chromite in Greece (*8*).

Systematic use of botanical methods of prospecting began in the U.S.S.R. A geobotanist was included on all major Russian geological expeditions after 1945, and in 1955 the Russian Ministry of Geology and Conservation made geochemical work of one sort or another mandatory for all geological exploration parties. Thus, many plants are analyzed and geobotanical maps are made for many areas studied geologically in the U.S.S.R. today. Under this intensive program plants have been used to map geology, structure, ground water, saline areas, and salt domes and to search for deposits of boron, nickel, cobalt, copper, iron, chromium, and molybdenum. On-the-ground mapping and sample collections are regularly combined with low-level air photo mapping along previously drawn grid lines. The color, shades, and pattern of the plant cover assist materially in mapping from a plane, but each type of vegetation must also be carefully checked on the ground (*9*). Similarly, a program of combined geochemical and geologic mapping has been set up by the Canadian Geological Survey. Muskeg sampling will be used as a prospecting tool in northern Ontario (*10*). Geochemical prospecting studies on a less ambitious scale are being made by the French, Australian, Indian, Japanese, and United States governments and in universities of England, Canada, and the U.S.

H. E. Hawkes reviewed the uses of vegetation in prospecting in 1957 (*11*). The principle of using plants in the search for economic deposits is based on the ability of plants to absorb and to be affected by high concentrations of metals from deposits at considerable depths or from a mineralized halo surrounding the ore. An area where there is a unique reaction of plant life in a region of ore deposits is called in the U.S.S.R. a biogeochemical province (*12*); within such a province endemic variations occur in distribution, species make-up, and chemical composition. Changes in plant chemistry commonly result in morphological and physiological changes. The following discussion illustrates the three ways in which plants are used in prospecting: (i) by the mapped distribution of particular species (indicator plants) most affected by the minerals sought; (ii) by the physiological and morphological changes in plants growing in mineralized ground (appearance); and (iii) by the differences in chemical composition (plant analysis). Hawkes also discussed the advantages and disadvantages of using plants as a medium in prospecting and the future of botanical prospecting.

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Prospecting by Indicator Plants

Plant species whose distribution is affected by the chemical constituents of an ore deposit are called indicator plants. Geobotanical prospecting, or prospecting by studying these indicator plants, was proposed and tried out by several workers in different countries between 1880 and 1946. Only in the past 13 years, however, have indicator plants been seriously evaluated and used in systematic prospecting. Indicator plants have been called "universal" if the given species always indicates the presence of a definite element and "local" if the plant acts as an indicator only within the limits of a given district (*13*). The species known to have been used in prospecting are listed in Table 1, and are labeled as universal or local. This list does not include the 60 or 70 additional plants that have been observed to prefer mineralized soil but for which no definite prospecting information is available, or the many more plants that are tolerant of mineralized ground but are not necessarily restricted to these soils.

Zinc indicators, such as certain mustards and pinks, are featured widely in the early literature as occurring on the zinc dumps of Aachen, Germany, and in other previously discovered mineralized areas, but there are no authentic records of the discovery of ore by use of these plants. The plant families in which the European zinc indicator plants occur tend to grow around mine dumps and tailings of high zinc content in the United States. This localization may be due, however, to differences in acidity, sulfur content, or availability of major plant nutrients rather than to zinc. At any rate the European indicator *Silene latifolia* or bladder campion grows on the zinc-bearing limestone dumps of Franklin, New Jersey, and also on the copper-bearing acidic schists at Ely, Vermont. *Lysimachia* or loosestrife, closely related to the *Anagallis* of Europe, grows on the zinc tailings at Friedensville, Pennsylvania. *Arabidopsis thalianum,* a cress closely related to *Thlaspi* of Europe, was also found there, growing on some old disintegrated sacks of pure ZnO. The plants contained 9000 parts of zinc per million (dry weight) or about 6 percent in the ash. *Amorpha canescens* was observed to grow in the Wisconsin zinc district but, contrary to reports in the literature, not in mineralized ground. *"Baptisia bracteata"* or wild indigo, on the other hand, was restricted locally to the old lead diggings and could probably be used as an indicator.

True copper indicators—those plants universally or locally restricted to copper-bearing soils—are considerably more abundant than zinc indicators and have been extremely useful in finding ore. The copper indicators belong mainly to three plant groups: the Caryophyllaceae or pink family, the Labiatae or mint family, and the mosses. Three copper deposits have been located in Sweden by simply examining localities from which the herbarium specimens

Table 1. Plants that have been used as indicators in prospecting.

Universal (U) or local (L)	Family	Genus and species	Common name	Locality	Reference
		Bitumen			
L	Goosefoot	*Anabasis salsa*		Caspian Sea	(20)
L	Goosefoot	*Salsola spp.*	Saltwort	Caspian Sea	(20)
L	Lily	*Allium sp.*	Onion	California	(44)
		Boron			
L	Goosefoot	*Salsola nitraria*	Saltwort	U.S.S.R.	(24)
L	Goosefoot	*Eurotia ceratoides*	Winter fat	U.S.S.R.	(24)
L	Plumbago	*Limonium suffruticosum*	Statice	U.S.S.R.	(24)
		Copper			
U	Pink	*Gypsophila patrini*	Karum	U.S.S.R.	(13)
L	Pink	*Polycarpea spirostylis*	Pink	Australia	(45)
U	Mint	*Acrocephalus roberti*		Katanga	(16)
L	Mint	*Elsholtzia haichowensis*	Elsholtzia	China	(15)
U	Mint	*Ocimum homblei*	Basil	Rhodesia	(17)
U	Moss	*Merceya latifolia*	Copper moss	Sweden and Montana	(14)
L	Poppy	*Eschscholtzia mexicana*	Calif. poppy	Arizona	(46)
L	Plumbago	*Armeria maritima*	Thrift	Scotland	(47)
		Gypsum			
L	Buckwheat	*Eriogonum inflatum*	Desert trumpet	Western U.S.	(18)
L	Loasa	*Mentzelia spp.*	Blazing star	Western U.S.	(18)
		Iron			
L	Birch	*Betula sp.*	Birch	Germany	(48)
L	Guttiferae	*Clusia rosea*	Copey clusia	Venezuela	(49)
		Lead			
L	Grass	*Erianthus giganteus*	Beardgrass	Tennessee	(50)
		Phosphorus			
L	Morning-glory	*Convolvulus althaeoides*	Bindweed	Spain	(48)
		Selenium			
U	Legume	*Astragalus bisulcatus*	Poison vetch	Western U.S.	(51)
U	Legume	*Astragalus racemosus*	Poison vetch	Western U.S.	(51)
U	Legume	*Astragalus pectinatus*	Poison vetch	Western U.S.	(51)
U	Sunflower	*Oonopsis spp.*	Goldenweed	Western U.S.	(51)
U	Sunflower	*Aster venustus*	Woody aster	Western U.S.	(51)
U	Mustard	*Stanleya spp.*	Princesplume	Western U.S.	(51)
		Selenium and Uranium			
U	Legume	*Astragalus pattersoni*	Poison vetch	Western U.S.	(18)
L	Legume	*Astragalus preussi*	Poison vetch	Western U.S.	(18)
L	Legume	*Astragalus sp.*	*Garbancillo*	Andes	(19)
		Silver			
L	Buckwheat	*Eriogonum ovalifolium*	Eriogonum	Montana	(47)
		Zinc			
U	Violet	*Viola calamineria (lutea)*	Zinc violet	Belgium and Germany	(52)
L	Saxifrage	*Philadelphus sp.*	Mock orange	Washington	(53)

Table 2. Physiological and morphological changes in plants due to metal toxicities.

Element	Effect	Reference
Aluminum	Stubby roots, leaf scorch, mottling	(54)
Boron	Dark foliage; marginal scorch of older leaves at high concentrations; stunted, deformed, shortened internodes; creeping forms; heavy pubescence; increased gall production	(54) (24)
Chromium	Yellow leaves with green veins	(31)
Cobalt	White dead patches on leaves	(30)
Copper	Dead patches on lower leaves from tips; purple stems, chlorotic leaves with green veins, stunted roots, creeping sterile forms in some species	(55) (16)
Iron	Stunted tops, thickened roots; cell division disturbed in algae, resulting cells greatly enlarged	(55) (56)
Manganese	Chlorotic leaves, stem and petiole lesions, curling and dead areas on leaf margins, distortion of laminae	(54)
Molybdenum	Stunting, yellow-orange coloration	(55)
Nickel	White dead patches on leaves, apetalous sterile forms	(30)
Uranium	Abnormal number of chromosomes in nuclei; unusually shaped fruits; sterile apetalous forms, stalked leaf rosette	(28) (32) (31)
Zinc	Chlorotic leaves with green veins, white dwarfed forms; dead areas on leaf tips; roots stunted	(31) (55)

of the "copper mosses" had been collected (*14*). The copper indicators *Elsholtzia haichowensis* from China (*15*), *Acrocephalus roberti* from Katanga (*16*), and *Ocimum homblei* from Rhodesia (*17*) all belong to the mint family and are very useful in prospecting. The blue-flowered *Ocimum homblei* will not grow in soil containing less than 100 parts of copper per million. The distribution of this plant has led to the discovery of several ore deposits and is currently being mapped in both Northern and Southern Rhodesia by the Rhodesian Selection Trust.

Selenium indicator plants of the *Astragalus* genus have been used in this country to find uranium ores on the Colorado Plateau (*18*, plate 1). An *Astragalus* is currently being mapped in the Peruvian Andes by government scientists to locate radioactive hydrothermally altered areas (*19*). As an aid in prospecting for oil, halophytes have been used as indicators in locating salt domes around the Caspian Sea where the salt domes are under a cover 500 to 800 meters thick (*20*).

Geobotanical prospecting does not require an advanced knowledge of plant taxonomy. It does require a systematic study of the species of plants growing over known ore deposits in the district to be prospected as compared to the species of a topographically similar area of nonmineralized ground. Once the indicator plants are established, recognition of the indicator plants on day-to-day traverse is comparatively simple. A plan for prospecting by indicators in the field has been outlined (*21*) as follows:

1) Drawing up of a complete geobotanical description of five or more standard sections (a small area where an intensive geologic study has been made), covering (i) abundance of plants; (ii) flowering period of species; (iii) vitality of plants; and (iv) species composition.

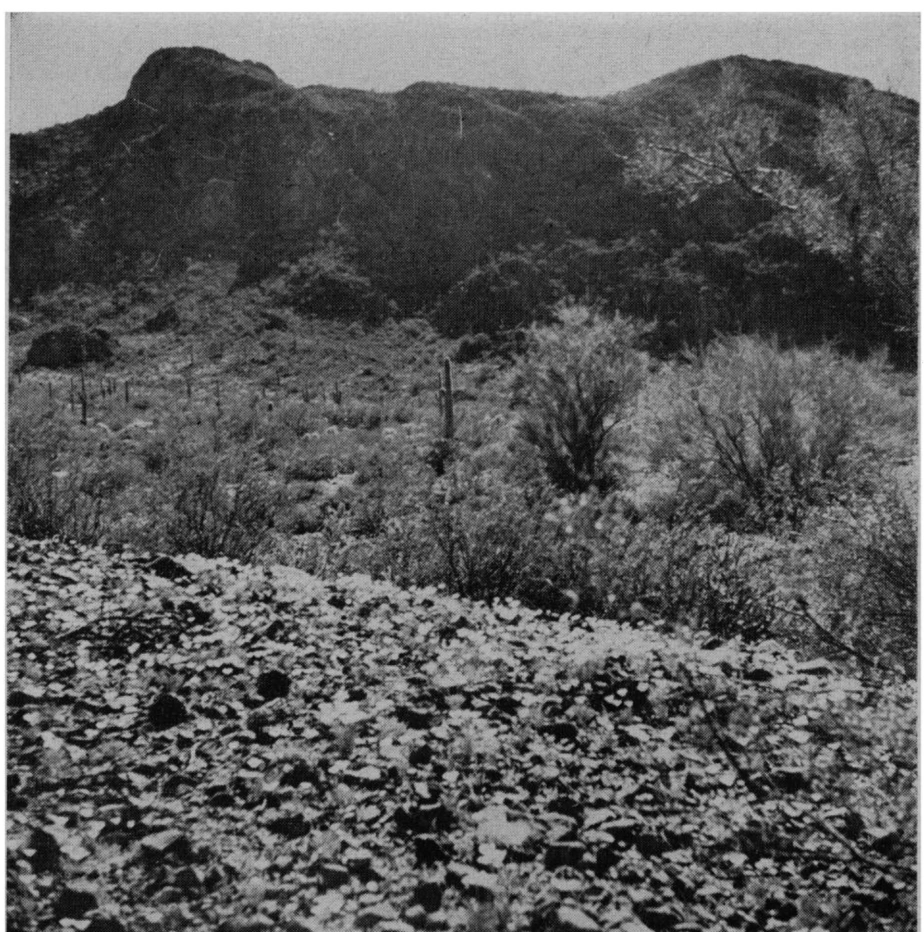
2) Compilation of tables to show the significance of plant communities as indicators.

Observation during low-level flights and the use of air photos can aid materially in the mapping. Reconnaissance flights commonly precede field studies on the ground (*9*).

Prospecting by Lack of Vegetation

Prospecting by bare areas might be considered a negative indicator of ore. At any rate some soils are so toxic that no vegetation can grow, and these bare

Chlorotic leaf pattern developed in a maple tree growing in copper-rich soil in Ely, Vermont.



California poppies (*Eschscholtzia mexicana*), indicating copper mineralization bounded by a fault, in San Manuel, Arizona.

or open areas are useful in prospecting. Soils containing 8 to 14 percent of copper in some generally forested districts of the Congo have no tree growth but form open glades covered by shrubs and grasses (*22*). Bare areas are also used in prospecting for copper in Armenia and in Rhodesia (*13*). A similar phenomenon is reported for areas of high iron content near pyrite deposits of upper Italy (*23*) and for rocks containing platinum in the Urals (*13*) and in the Transvaal (*2*). Bald spots are used in prospecting for boron where borates occur at the surface (*24*).

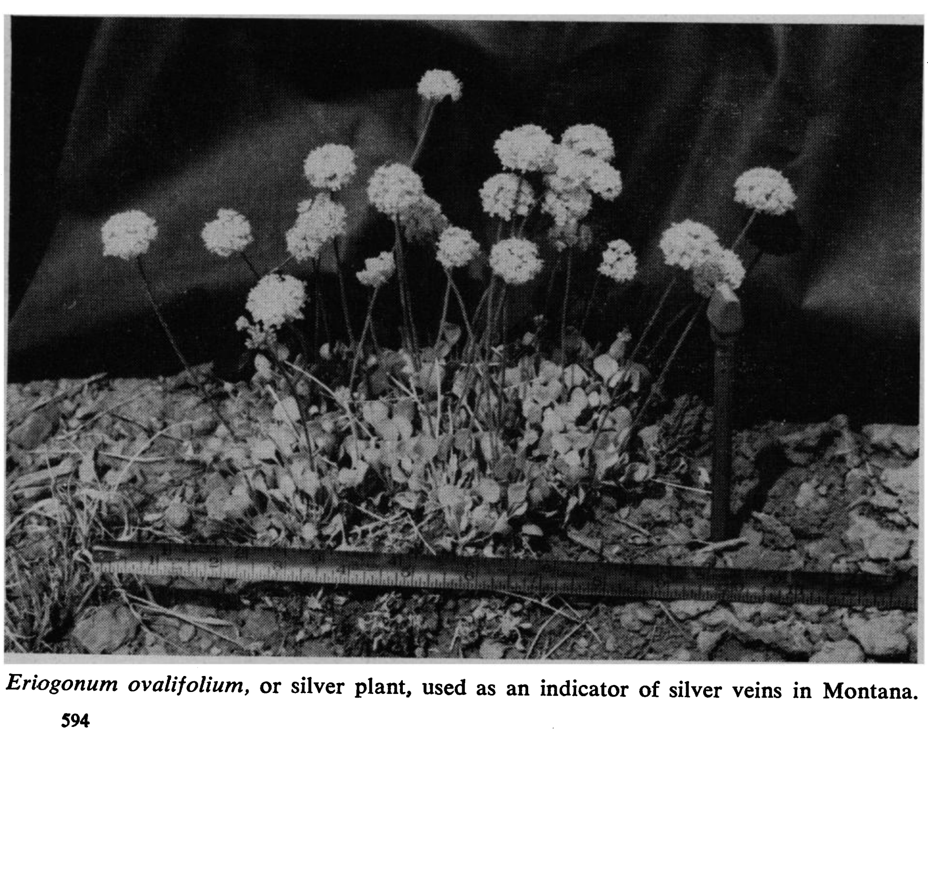
In this country Isaac Tyson, Jr., was led to the discovery of chromium ores in Maryland and Pennsylvania in 1818 by the comparative bareness of the serpentine area (*25*). Drained muck in New York State, in which no vegetation can be grown, contains 10 to 16 percent zinc (*26*) concentrated from ground water that drains nearby zinc-rich dolomites. Strontium sulfate was mined in Howard County, Arkansas, from areas devoid of trees in an otherwise heavily forested area (*27*).

Astragalus thompsonae, or Thompson's loco, an indicator of selenium and uranium in Utah.

Prospecting by Changes in Appearance

Morphological changes and symptoms of physiological diseases in plant species growing in mineralized ground are also used to discover economic deposits. Again, useful phenomena have been studied most thoroughly in the U.S.S.R. Variations may be observed (*28*) in vitality, completeness of development cycle, growth and flowering cycle, growth abnormalities, changes in growth form, sexual sterility, and so on.

On ground rich in boron many plants are two to three times their normal size and have a spherical shape and larger, greener leaves than normal (*24*). Some species acquire an abnormal creeping habit. These characteristics are used as a guide in prospecting for new boron deposits. Striking changes in plants growing over oil deposits were shown to be caused by bitumen in the soil (*29*). These included gigantism in 29 species, abnormal growth of either lateral or terminal shoots, and a two-cycle flowering habit. To study these differences, height and diameter measurements were made of 50 to 100 specimens of each species. Where the number of abnormalities was greater than 10 percent the soil was sampled for bitumen content.



Eriogonum ovalifolium, or silver plant, used as an indicator of silver veins in Montana.

Probably the most interesting morphological change observed in Russia is the effect on the vegetation of nickel-cobalt deposits in the southern Urals. Here an anemone, *Pulsatilla patens*, and a composite, *Linosyris villosa*, can be used as indicators because 60 percent of the plants on mineralized ground are abnormally white in color and produce apetalous forms (*30*). The change may be restricted to plants growing on serpentine rocks.

The effects of radiation on plants near uranium deposits have been studied in this country. In ground containing radioactive uranium or thorium ore, *Stanleya* plants of the mustard family (*31*) produce abnormal apetalous flower stalks with no stamens and consequently no seeds. H. T. Shacklette (*32*), in a study of the flora of Great Bear Lake, found blueberry plants with fruits of unusual and varied shape, each variation being limited to descendants of one plant. He also found fireweed flowers varying from pure white to magenta in the same small area over radioactive ore. These genetic differences might well be used as indicators in prospecting.

Nickel, copper, cobalt, chromium, zinc, and manganese in excess of normal concentrations interfere with a plant's assimilation of iron, and thereby with the formation of chlorophyll, and thus produce chlorosis, or a yellowing of the leaves. In addition, an excess of any one of these elements may produce a characteristic pattern of dead tissue on the leaf. In Katanga the gradient of copper concentration is estimated by the relative stunting of *Protea goetzeana*; on extremely toxic soils a creeping sterile form develops (*16*). Chlorosis in crops that is due to an excess of zinc on high-zinc peats in New York State was used to trace for 20 miles the extent of nearby zinc-bearing dolomites covered by a thickness of glacial till (*26*). The yellowing of trees rooted in soils of high zinc content has likewise been investigated in the Driftless area of Wisconsin and at Warren, New Hampshire, and has been used as a guide in prospecting for zinc in limestones of Missouri (*33*).

Prospecting by physiological or morphological changes may require the ability to distinguish genetic changes in otherwise normal species or merely to recognize variations in color, size, or shape. Table 2 summarizes the changes in plants, due to excess of metals, that may be useful in prospecting.

Prospecting by Plant Analysis

Prospecting based on the analysis of plant material for metal content and the delineation of favorable areas from the anomalous values obtained has been called the biogeochemical method of prospecting. Plant analysis has been used much more extensively than any of the other prospecting methods. Plant analysis was first used from 1938 to 1940 in prospecting for tungsten and tin in Cornwall, for nickel in Finland, and for vanadium and tungsten in Sweden. In the middle 1940's workers in the U.S.S.R., the United States, Cuba, Japan, the Far East, West Africa, and Canada began similar studies. Investigations by this method are summarized in Table 3. Deposits of uranium, zinc, tungsten, tin, arsenic, copper, and vanadium have been discovered by plant analysis; anomalous metal contents have been shown to correlate well with known deposits of lead, manganese, molybdenum, nickel, chromium, and cobalt and poorly with silver.

Copper is perhaps the most unpredictable metal, as can be seen from the following series of events. Warren and Delavault (*34*) studied extensively the sampling techniques and sampling media best adapted to prospecting for copper and zinc in glaciated country in British Columbia. They found good correlations between the copper contents in the plants and those in the soils, although most of their studies were confined to areas of known mineralization. The Quebec Department of Mines (*35*) carried out a biogeochemical survey over copper deposits in Gaspé and found copper anomalies in twigs of balsam over both known and previously undiscovered ore bodies.

Marmo (*36*) reported, on the other hand, that the concentration of copper in plants does not increase linearly. Small differences in the amount of

Table 3. Prospecting by plant analysis.

Locality	Metal sought	Element used	Plant sampled	Results*	Reference
Australia	U	U	*Xanthosteum paradoxus*	Good correlation	(57)
Canada	Cu, Zn	Cu, Zn	Birch	Good correlation	(58)
British Columbia	Cu	Cu/Zn	Sagebrush, juniper	Good correlation	(37)
British Columbia	Zn	Zn	Silver birch	Good correlation	(34)
British Columbia	Zn	Zn	Alder	Good correlation	(59)
British Columbia	Mn	Mn	Hemlock	Good correlation	(34)
British Columbia	Au	Au	Horsetails, trees	Good correlation	(60)
British Columbia	Ag	Ag	Horsetails, trees	No correlation	(60)
British Columbia	Ni	Ni	Fir, cedar	Good correlation	(61)
British Columbia	Mo	Mo	Balsam	Good correlation	(34)
British Columbia	Cu	Cu/Zn	Pine, fir	Good correlation	(38)
Eastern Canada	Cu, Zn	Cu/Zn	Alder, maple, birch, willow	Used in prospecting	(62)
Quebec	Cu	Cu	Balsam twigs	Anomalies discovered	(35)
Cornwall, Wales	W	W	Heather	Anomalies discovered	(4)
Cornwall, Wales	Sn	Sn	Heather	Anomalies discovered	(4)
Cuba	Ni	Ni	Vegetation	Good correlation	(63)
Estérel (Pyrenees)	U	U	Vegetation	Good correlation	(64)
Far East	As	Fe	Grass	Veins defined	(3)
Finland	Ni	Ni	Birch	Good correlation	(6)
Finland	Cu	Cu	Vegetation	Correlations at low concentrations, not at high	(36)
Germany	Ni	Ni	Birch, spruce, pine	Good correlation	(65)
Greece	Cr	Cr	Vegetation	Good correlation	(8)
Japan	U	U	Cypress, pine	Good correlation	(66)
Nigeria	Pb-Zn	Pb	Savannah trees	Good correlation	(42)
Norway	Cu	Cu	Birch, willow	Too erratic to be useful	(7)
Sweden	V	V	Birch, pine	V-shale discovered	(4)
Sweden	Pb, Zn	Pb, Zn, Cu	Birch, pine	Good correlation	(8)
Sweden	Pb-Ag	Pb-Ag	Tree cover	No correlation	(8)
Sweden	Mo	Mo	Tree cover	No correlation	(8)
Sweden	W	W	Tree cover	No correlation	(5)
United States					
Arizona	U	Alpha count	Oak	Good correlation	(67)
Arizona	Cu	Cu	Oak, mesquite	Good correlation	(68)
Arizona	Cu	Cu	Cresote bush, oak	Good correlation	(69)
Calif., Nevada	Ba	Ba	Fir, manzanita	Good correlation	(70)
Idaho	Zn, Pb, Cu	Zn, Pb, Cu	Fir, pine, spruce	Good correlation Zn, Pb, poor correlation Cu	(50)
Missouri	Zn	Zn	Oak	Good correlation	(71)
New Mexico	U	U	Juniper, pine	Anomalies discovered	(72)
New York	Zn	Zn	Willow	Defined Zn area	(26)
New York	Pb, Zn	Zn	Birch, maple, hemlock	Good correlation	(73)
Pennsylvania	Pb-Zn	Pb, Cu/Zn	Birch	Good correlation	(39)
Pennsylvania	Zn	Zn	Vegetation	Good correlation	(74)
Tennessee	Mn	Ni	Oak	Good correlation	(75)
Utah	U	U	Juniper	Anomalies discovered	(31)
Utah	U	U	Juniper, pinyon	Anomalies discovered	(76)
U.S.S.R.	Cu, Mo	Mo	Legumes	Two major Cu discoveries	(77)
U.S.S.R.	Cu, Fe	Fe	Birch, fir	Outlined Cu ore	(78)
U.S.S.R.	B	B	Phreatophytes	Good correlation	(79)
U.S.S.R.	Ni	Ni/Cu	Grasses, herbs	Good correlation	(12)
U.S.S.R.	Co	Co	Grasses, herbs	Good correlation	(80)
U.S.S.R.	Cu	Ni/Cu	Grasses, larch	New Cu discoveries	(12)
U.S.S.R.	Cr	Cr	Grass	Good correlation	(12)
U.S.S.R.	Pb	Pb	Vegetation	Good correlation	(12)
U.S.S.R.	Mo	Mo	Vegetation	Good correlation	(12)

* "Correlation" signifies correlation between plant content and soil content over known mineralization.

copper in rock are reflected in plants, but beyond a certain threshold (which differs for different species), the copper concentration in plants ceases to reflect the copper content of the bedrock. Further work (*37–39*) has shown that the copper-zinc ratio—rather than the zinc or copper values per se—outline anomalies most clearly for both zinc and lead deposits. Copper deposits have also been found in Europe by using the nickel-copper ratio and the molybdenum and iron content in vegetation. Probably pathfinder elements should be seriously considered in prospecting for copper.

In the United States, biogeochemical prospecting for uranium has been investigated by the U.S. Geological Survey in cooperation with the Atomic Energy Commission. Ten thousand trees were sampled in advance of drilling programs, much basic information was acquired, and several ore bodies were discovered by this method (*31*). In addition to governmental research, several private companies have tried prospecting by plant analysis for copper, zinc, and manganese. The U.S. Geological Survey has studied the movement of metallic elements into shallow colluvium, soils, and plants over the Phosphoria formation in Idaho (*40*) to provide basic information for prospecting. Similar research programs are being carried on at the present time in Alaska over various types of metallic deposits and in Maryland over a series of nonmineralized formations.

Table 4. Average metal content in the ash of vegetation growing in unmineralized ground.

Element	Average content (ppm)	No. of analyses
Al	8610	80
Fe	6740	482
Mn	4815	1023
Zn	1400	1763
B	700	394
Cu	183	2047
Pb	70	1908
Ni	65	858
V	22	180
Mo	13	616
Cr	9	462
Co	9	512
Sn	< 5	10
Be	< 2	34
Ag	< 1	308
U	0.6	610
Au	< 0.007	32

The plants that accumulate maximum amounts of ore metals were first used in prospecting because the threshold of analytical detection was necessarily high; but these unusual accumulators have not proved to be the most desirable media for prospecting by plant analysis. Species of plants that are best for sampling are ubiquitous, have a deep root system, and show a fairly constant correlation between plant composition and supporting medium. The average metal contents in plant ash are given in Table 4. The compilation was derived from information carded from the literature and from U.S. Geological Survey files on more than 1000 plant species. The number of analyses necessarily differs for each element. The values for mean content of the elements iron, manganese, aluminum, and boron are quite different from the figures commonly quoted in the literature because an attempt was made to include analyses from all classes of vegetation. Most averages previously given have been derived largely from edible herbaceous plants.

Of prime importance in prospecting is the accumulation ratio (content over ore: content over nonmineralized ground). Variation in the ratio depends largely on the exchange capacity of the soil, on its acidity and structure, and on the species of plant sampled. The choice of a plant species for sampling depends not only on the distribution of the plant and the depth of penetration of the roots but also on the element being prospected. Average amounts of eight metals in five general types of vegetation (compiled from the same source as Table 4) are shown in Table 5. Clearly, grasses might be preferable to trees if chromium is the element sought, whereas the reverse might be true for zinc. Generally the plant species to be chosen for extensive biogeochemical sampling can only be established by preliminary sampling in an area.

Sampling techniques have been considered most carefully by Warren, Delavault, and Fortescue (*41*), who point out that comparison should be made only between the same plant parts of the same age of the same species, and from the same height on the plant. They suggest further that second-year twigs may give more reproducible results than first year twigs and that anomalies may be more pronounced when results are expressed in terms of ash rather than of dry weight.

Most systematic sampling programs consist of sampling at 100- to 200-foot intervals after plants have been sampled over barren and mineralized ground to establish what species are useful and the cutoff above which values shall be considered anomalous. A safe maximum interval of sampling is considered by Webb (*42*) to lie between one-half and two-thirds the minimum dimensions of the detectable dispersion halo. For preliminary reconnaissance this interval is commonly exceeded. The values obtained may be plotted to outline mineralized ground.

Eriogonum inflatum, or desert trumpet, a fine indicator of gypsum.

Table 5. Average metal content in the ash of five types of vegetation growing in unmineralized ground, in parts per million. Figures in parentheses show the number of analyses used in the calculations.

Vegetation	Cr	Co	Ni	Cu	Zn	Mo	Pb	V
Grasses (above ground)	19 (30)	10 (30)	54 (28)	119 (102)	850 (62)	34 (32)	33 (29)	25 (4)
Other herbs (above ground)	10 (139)	11 (192)	33 (226)	118 (429)	666 (355)	19 (217)	44 (311)	23.5 (39)
Shrubs (leaves)	14 (67)	10 (70)	91 (182)	223 (853)	1585 (735)	15 (104)	85 (877)	25 (46)
Deciduous trees (leaves)	5 (100)	5 (101)	87 (209)	249 (293)	2303 (278)	7 (118)	54 (339)	16 (14)
Conifers (needles)	8 (120)	< 7 (119)	57 (213)	133 (370)	1127 (333)	5 (145)	75 (352)	21 (77)
Total	9 (462)	9 (512)	65 (858)	183 (2047)	1400 (1763)	13 (616)	70 (1908)	22 (180)

Methods of analysis depend upon the element, but those commonly used are fast and inexpensive. Present-day methods of the proper sensitivity for most elements are either spectrographic or colorimetric. A high degree of accuracy commonly is sacrificed in the interest of speed. Ideally, 30 samples or more should be collected and analyzed in a day with an accuracy of about ± 30 percent. Plant materials require the additional step of ashing, which can sometimes be done in small dishes on an ordinary charcoal broiler designed for backyard picnics.

Colorimetric quick tests have been developed by the U.S. Geological Survey for copper, lead, zinc, cobalt, tungsten, mercury, molybdenum, uranium, silver, and nickel in soils, and many of the tests have been modified for plant analysis. Both the Soviet Union and the United States have government-owned mobile spectrographic units for field use (*43*). This method of analysis is extremely useful for most common elements with the exception of tellurium, uranium, sulfur, selenium, and possibly zinc. A two-man crew can complete 30 determinations on 20 to 30 samples a day.

Comparison of Botanical and Other Geochemical Prospecting Methods

Botanical prospecting methods have some disadvantages not encountered in soil prospecting. The absorption of metals by plants is a very complex phenomenon and is dependent on many soil and plant factors that require interpretation. The depth to which prospecting by plants is effective depends upon the root penetration. The irregularity of distribution of the various species also makes sample collection difficult and requires, in many cases, the use of conversion factors from one species to another. Still other disadvantages of biogeochemical prospecting are the necessity for ashing the sample and the difficulty of obtaining a thoroughly mixed ash sample for analysis. Finally, a major disadvantage in geobotanical prospecting is the need for personnel with botanical training. A keen observer of plant differences who lacks such training may do a good job, but a man with botanical training usually does a better one.

In some situations, on the other hand, plant sampling is superior to soil sampling. The depth of penetration of the roots may permit the sampling of a deep horizon not accessible by surface soil sampling; and if there is an accumulation of metals in the ground water from a dispersion halo, phreatophytes whose roots penetrate to the groundwater table may be a very useful tool. Plant sampling also eliminates the possibility of interference from transported surface soils and permits prospecting in areas where residual soil is either nonexistent or varied. The amount of ground sampled both vertically and horizontally by a given tree represents a much larger area than that of a given soil sample. Finally, where indicator plants can be used, geobotanical prospecting is superior to all other methods because no analytical work is required and maps of mineralized ground may be drawn directly from observation of the plant's distribution.

Current Status

Rapid advances in botanical methods of prospecting for metals are being made in the U.S.S.R., and in several other countries at the present time. Because of a lack of organized research in this field, the methods are developing much more slowly in the United States. Several avenues of research concerning the relations between plants and ore deposits could be investigated profitably to further the search for buried ore deposits. The absorption of elements by various plant groups, and in various soil environments, should be studied in greater detail, and the information should be compiled and disseminated to those who are to sample plants. A systematic botanical search should be made around every type of mineral deposit for indicator plants, both universal and local, that can be used in prospecting. And last, we need to develop better and cheaper methods of plant analysis to aid the prospector in his search for hidden ore deposits.

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The Academic Scientist, 1940–1960

Much has changed, from the federal support scientists receive to the political responsibilities they accept.

Bentley Glass

Among academic subjects, the natural sciences and mathematics have come, since World War II, to occupy a favored position in the United States, in respect to the support received from the federal government and from industry. The trend began long before the sputnik era and was an outgrowth of the part played by scientific developments in winning the war. It gained added strength from the rivalry of the chief powers in the Cold War. This was the period that saw the establishment of the National Science Foundation in 1950, and growing attention to the utilization and training of American scientists. The past two years have seen a flurry of added excitement and anxiety as the American public came to perceive that in at least some scientific and technological respects the Russians have exceeded us, and that in advanced education they are far outstripping us in quantity of trained personnel if not in the quality. General concern has led to another unprecedented increase in the effort to hold our own by subsidizing scientific research and development and by improving the educative process that permits further growth. The National Defense Education Act, vast increases in appropriations to existing agencies for science education and scientific research, and new roles of science in the political sphere alike show what enormous concern about these problems now prevails in the executive and legislative branches of our government and in the political life of our people.

In late 1958, the President's Science Advisory Committee issued a highly significant report entitled *Strengthening American Science,* and last year followed it with recommendations for *Education for the Age of Science.* Curriculum studies in physics, mathematics, biology, and shortly in other sciences are revising secondary school courses and preparing textbooks and laboratory programs of novel kinds. Soon these efforts will lap over into the teach-

The author is professor of biology at Johns Hopkins University, Baltimore, Md., and chairman of the Biological Sciences Curriculum Study of the American Institute of Biological Sciences. This article is adapted from the presidential address given 8 April 1960 at the 46th annual meeting of the American Association of University Professors, in Detroit, Mich.