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This document consists of 40 pages,
Series A

CATEGORY VII (Colorado Plateau geology)

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THE EFFECT OF URANIUM-VANADIUM DEPOSITS ON THE VEGETATION OF THE COLORADO PLATEAU

By

Helen L. Cannon

October 1951

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Trace Elements Investigations Report 160

USGS - TEI Report 160

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CONTENTS

TABLES

THE EFFECT OF URANIUM-VANADIUM DEPOSITS ON THE VEGETATION OF THE COLORADO PLATEAU

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Helen L. Cannon

ABSTRACT

A research study has recently been made by the Geological Survey of the relation of plants to carnotite deposits in several districts of the Colorado Plateau. The deposits occur as lenses or pods of ore along the bedding of the Salt Wash sandstone member of the Jurassic Morrison formation. The ore contains unusual concentrations of uranium, vanadium, and selenium; and, in some cases, plants growing near ore deposits accumulate small amounts of these metals. Basic geobotanical studies were made largely in the Yellow Cat district, near Thompsons, Grand County, Utah.

Three lines of investigation have been pursued. The pathologic effects on the plants of these concentrations of metals have been observed, methods of analyzing plant ash for uranium and vanadium have been developed and the absorption of uranium and vanadium by plants investigated, and the ecology of the plants in uranium districts has been studied. Because of the association of selenium-indicator plants with the uranium deposits of the Yellow Cat district, the distribution of various species of indicator plants was mapped in detail.

Four important conclusions have been drawn from this work to date. First, the plants growing on dumps and areas of mine seepage where the metals are oxidized show chlorotic symptoms and dwarfing, but the vegetation in general, growing in carnotite districts, is not noticeably affected. Second, it has been demonstrated that plants absorb small amounts of uranium and vanadium that can be detected by sampling a given part of the plant. The amount of uranium is consistently greater where

the plants are rooted in ore than where rooted in barren sandstone. Third, a uranium-tolerant flora has been recognized and compiled from a study of 13 areas. The flora is characterized by selenium-indicator plants, and by sulfur-accumulating members of the mustard and lily families. Fourth, where selenium-bearing ores lie at shallow depth and where the geography and rainfall are favorable for plant growth, it has been shown that the distribution of selenium-indicator plants is accordant with that of the carnotite ores. Certain species of selenium plants, depending on the quantity of selenium in the ore, can be mapped in a given area as a guide to exploration. The information gained from this study is being used in the development of geobotanical methods of prospecting for uranium ores in sandstones of the Colorado Plateau.

INTRODUCTION

The Geological Survey is conducting at the present time a long-range program of exploration and geologic studies of uranium deposits in the Colorado Plateau under the auspices of the Atomic Energy Commission. A special research project has been in progress since the spring of 1949, as a part of this program, to determine whether geobotanical methods of prospecting could be used as tools in the search for this type of ore. In particular, methods of prospecting by plant analysis as reported to be used in Sweden (personal communication from Josef Ekland, Swedish Geol. Survey) for locating a vanadium-bearing shale, and the use of selenium-indicator plants as suggested by Beath (1943) have been investigated.

In the course of this study, considerable data have been acquired on the effects of these uranium ore bodies on plant growth. Ecological studies have been made of the tolerance of various species for large amounts of uranium, vanadium, and selenium in the soil, and conclusions have been drawn from several thousand analyses of plant material on the absorption of these elements by plants. Information in less detail on the absorption by plants of uranium and selenium from other geologic types of uranium deposits has been collected for comparison. These data, of interest to botanists as well as to geologists who may wish to use plants in prospecting, are presented in this paper. The application of these relationships to prospecting will be discussed separately.

The author gratefully acknowledges the suggestions and criticisms of R. P. Fischer, geologist in charge of the Geological Survey's Plateau exploration program, and of H. E. Hawkes, in charge of the Survey's Geochemical Prospecting Unit. Samples were collected, and plants and geology were mapped by the author and four assistants, John R. Harbaugh, Mary E. Durrell, Richard Stillman, and Louis C. Rove, Jr. The chemical analyses of the plants and rocks on which these studies were based were made by members of the Trace Elements Laboratories in the Geochemistry and Petrology Branch, of the Geological Survey. Ruth Kreher, Fred Ward, and Claude Huffman, are responsible particularly for developing chemical techniques, and for ashing and analyzing large numbers of the samples.

GEOLOGY AND GEOGRAPHY

The uranium deposits of the Colorado Plateau are of wide areal distribution and occur in sandstones of similar lithology in several formations of Triassic and Jurassic age. The deposits under immediate geobotanical study are restricted to the Jurassic Morrison formation which can be divided into two lithologic units of about equal thickness. The lower unit, the Salt Wash sandstone member, consists of massive lenses of medium-grained, rather porous sandstone, interbedded with red and gray mudstone.

These sandstones crop out as a series of cliffs, and in places the harder beds form conspicuous benches or mesas. The upper unit, the Brushy Basin shale member, forms a steep slope beneath the overlying Cretaceous Burro Canyon formation and is composed of variegated shales and thin beds of hard sandstone. Locally, thick lenses of sandstone and chert-pebble conglomerate occur in the basal part of this member.

Most of the uranium deposits are in the sandstone beds near the top of the Salt Wash member or in the basal conglomerate of the Brushy Basin member. The ore bodies are extremely spotty in distribution and form irregular, elongate, tabular masses that lie essentially parallel to the sandstone beds. The bodies range from 1 to 60 feet in thickness and from a few feet to several miles in length. Those of the Yellow Cat district, where most of the botanical studies were made, are comparatively small. Uranium- and vanadium-bearing sandstone averaging about 0.25 percent U_3O_8 and 2 percent V_2O_5 constitutes ore. Carnotite, which is yellow, is the principal uranium mineral. Minor amounts of selenium, molybdenum, lead, cobalt, nickel, chromium, and copper are associated with the ore. The red mudstones that normally are interbedded with the sandstones have been altered to blue green where they underlie a bed containing ore. More detailed descriptions of the uranium-vanadium deposits are contained in reports by R. P. Fischer (1942, 1950) from which this brief description largely has been taken.

The Yellow Cat district is 10 miles southeast of Thompsons, Grand County, Utah. The altitude of this area is about 4,900 feet, and the climate is arid with an average rainfall of less than 7 inches per year. The erosion of the mudstones interbedded with the sandstones has produced a typical badland topography. The vegetation is of the desert type with blackbrush and saltbrush predominating and taller shrubs, scrub oak, and junipers on certain of the higher mesas. The ecological environment is ideal for the development of selenium-indicator plants of the *Astragalus* group that abound in the district. The distribution of these plants is controlled by the occurrence of selenium, which is associated with the uranium ore bodies. The Carrizo district in northeastern Arizona, where additional plant data were acquired, has a similar ecology and geographic setting.

Plant studies were made on some of the higher mesas of southwestern Colorado in a somewhat different environment. These mesas range from 6,000 to 8,000 feet in altitude and receive around 15 inches of rainfall per year. The vegetation is predominantly juniper and pinyon pine with an undergrowth of Rosaceous shrubs and tender herbaceous annuals. There is sagebrush and saltbush in the drier areas. Selenium-indicator plants of the *Astragalus* group do not grow at much over 6,000 feet altitude. *Stanleya pinnata*, however, is unaffected by altitude.

RELATION OF PLANTS TO ORE DEPOSITS

The chemical environment of an ore deposit affects the plants growing on the deposit in three ways. First, the metabolism of the plants can be affected by the unusual amounts of certain elements available to the roots, so that the plants acquire recognizable pathologic symptions. Second, certain species of plants will absorb and accumulate available ore elements in detectable quantities. Third, the chemical environment can restrict the distribution of certain plants so as to create an indicator flora. Under favorable circumstances, these three effects on plants can be used in prospecting for ore bodies.

Pathologic symptoms

Drobkov (1937, 1940) and Hoffmann (1942) indicate that the radioactive elements, radium, uranium, and thorium, are necessary nutrient substances for plant growth. The amount needed is infinitesimal, and concentrations above a very low level are retarding or even toxic. In the beneficial range, growth and seed germination are stimulated and maturing is accelerated according to Gleditsch (1942), Bevilotti (1945), and Stoklasa (1912). Preliminary experimental work done under the direction of Dr. L. W. Durrell of the Department of Agriculture experiment station at Fort Collins, Colo., confirms these observations. Acqua (1912) and Bambacioni-Mezetti (1934) have reported injury to the roots of plants absorbing uranium compounds. Jacobson and Overstreet (1947) experimented with the radiation effects of a series of activated elements and demonstrated that radiation injury to the roots is severe with only a mean activity of 0.1 microcurie per gm soil at the region of contact. Verducci (1945) has demonstrated that the radiation effects on seed germination from uranium sulfate are greater than from uranium nitrate in the soil. Kayser (1921) indicates that uranium nitrate increases nitrogen fixation in the soil by Azotobacter, a genus of soil bacteria, and Drobkov (1945) has shown that the development of root-nodule bacteria in legumes is likewise affected. This fixation of atmospheric nitrogen in the soil is beneficial to all plant growth.

Bortels (1930) first demonstrated that molybdenum is necessary to nitrogen-fixing bacteria, (1933) that vanadium can be substituted for molybdenum to fulfill this requirement, and (1936) that vanadium and molybdenum are necessary to higher plants in catalyzing nitrogen-fixation. This work has been confirmed by Burk and Horner (1935, 1942, 1944). Suzriki (1903), Ducloux and Cobanera (1911-12), and G. Bertrand (1931) showed that small amounts of vanadium are stimulating to plant growth but that large amounts are toxic. Free and Trelease (1917) found 20 ppm vanadium toxic to wheat, and Brenchley (1932) that 40 ppm are toxic to barley. Gericke and von Rennenkampff (1940) have also shown that vanadium as an anion is more favorable for plant growth than as a cation.

The amounts of uranium and vanadium present in the soils associated with the carnotite deposits are commonly in the range retardative or even toxic to plant growth, and, as expected, the effects are noticeable in the field. Near mines, on dumps, and in poorly drained areas, plants have been observed to set fruit and mature early in the season with a marked reddening of the stem and seed, and a yellow chlorosis of the leaves results in early death of the plants. The fine roots are commonly decayed and fragmental, and the large roots less commonly contain deposits of a greenish-yellow powdery material not yet identified. Where the plants are rooted in undrained pockets of soil containing a large percentage of soluble salts, they are dwarfed, exhibit indications of frenching, and die before reaching maturity. The red and yellow coloration of the stems and leaves as described by Warington (1937), however, is possibly due to molybdenum which occurs in large quantities in certain of the sandstone beds.

Absorption of ore elements by plants.

The uranium ores of the Colorado Plateau contain not only uranium but also considerable quantities of vanadium and selenium. These elements are absorbed in unusual amounts by vegetation rooted in mineralized ground. Little information is available in the literature on the absorption of uranium in quantity by naturally growing plants, although experimental work is described by Baranov (1939) on the assimilation of this element from nutrient solutions. Hoffmann (1942) investigated the average content of uranium in plants. In 1943 he reported fluorimetric determinations of uranium in the ash of various parts of plants. These determinations are similar in range to those made in the Geological Survey's Trace Elements Laboratories and are given here.

Plant material	Uranium (parts per million)	
Apple seed	5.06	
Grape stem	0.008	
Grape skin	1.6	
Grape seed	2800.0	
Quack grass leaves	0.179	
Quack grass root	0.573	
Potato tuber	0.0318	
Dill roots	1.54	
Dill leaves	2.95	
Dill seeds	0.956	
Celery rootlets	7.91	
Celery tap root	2.96	
Celery root bark	0.039	
Celery leaves	26.5	(contaminated?)
Garlic rootlets	41.07	
Garlic bulb skin	4.38	
Garlic bulblets	2.47	
Mistletoe branch	3.73	
Mistletoe leaves	5.25	
Mistletoe berry	2.16	
Mistletoe seed	6.78	
Pine branches	0.425	
Pine needles	2.54	

Although his results are variable, perhaps owing to differences in the soil, the uranium content of the feeder roots in most plants is noticeably higher than of the leaves. The analyses of some of the seeds show that there is a greater concentration of uranium in the seeds than in the whole berry or fruit. Hoffmann also analyzed pear, apricot, and birch leaves in the spring and fall and found a consistent decrease in uranium content in the fall.

A much higher content of uranium has been reported by the Canada Department of Mines (Informal communication from S. C. Robinson, Geological Survey of Canada, Ottawa, 1951) in plants growing in the vicinity of pitchblende deposits. Plants growing on the asphaltic sandstone deposits at Temple Mountain, Utah, and on limestone deposits at Grants, N. Mex., also absorb uranium readily (table 8). The maximum values are considerably higher than those found in plants associated with carnotite deposits of the Colorado Plateau.

Ter Meulen (1931) first discovered unusual amounts of vanadium in a species of Amanita, a poisonous mushroom. D. Bertrand (1941, 1942) analyzed 62 species of plants which ranged from 0.152 to 4.2 ppm vanadium in the dry weight of leaves, 0.01 to 1.2 ppm in the roots, and less than 0.01 ppm in the seeds. The plants averaged 1 ppm in the dry weight of the plant or 7.1 ppm in the ash. Robinson and Edgington (1945) report 20 ppm in the dry weight of several species.

Robinson (1933), Beath and others (1934), and Byers (1935) have shown that certain plants in Wyoming, because of their selenium content, were poisonous to cattle. A considerable amount of selenium is also absorbed by vegetation growing on the Morrison formation of the Colorado Plateau. Some plants of the Astragalus group growing on the uranium deposits near Thompsons, Utah, were reported by Beath (1943) to accumulate up to 8,512 ppm selenium in the dry weight of the plant. The Geological Survey's Trace Elements Laboratories have found 2,200 ppm selenium in the ash of similar plants from the same district. The analyses, however, were restricted to a few check samples, because the selenium content of these plants is not as important in prospecting as their distribution.

The absorption of vanadium and more particularly uranium from sandstone deposits of the Plateau has been investigated by the Geological Survey in some detail. Uranium and vanadium analyses reported by Beath (1943) from deposits near Thompsons, Utah, have been duplicated in the systematic analytical work of the study described in this report. Vegetation believed to be free of artificial contamination in mining areas averages 40 ppm V_2O_5 and 1.5 ppm uranium in the ash and contains maxima of 300 and 100 ppm respectively where rooted in ore.

All plants were air-dried, ground, and carefully ashed at about 500° C. The vanadium content was determined by an adaptation of the phospho-tungstate method. The uranium content was determined photofluorimetrically on a 5-mg sample of ash, using a mixed fluoride-carbonate flux to prepare the phosphor. This method has recently been described by Grimaldi and others (1950). The limit of detection is about 1×10^{-9} g uranium, using the instrument described by Fletcher and others (1950). The vanadium and uranium contents of the soils were determined by the same methods that were used for plants. It should be pointed out that only the total metal contents of the soils were determined and that the amount of these metals soluble in water and directly available to the plants in different types of soils is not known. The availability of these metals to plants is probably influenced by (1) the clay content, (2) the organic content, (3) the acidity of the soil, and (4) the combination in which the elements occur.

The amount of uranium and vanadium absorbed by plants varies with the species, time of year, part of plant, availability of these elements in the soil, and chemical composition of the country rock. The uranium content of ashes of species of plants growing on various materials and the uranium content of the underlying rocks are shown in table 1. The variation between contents of ashes of species growing on the same soil is shown horizontally, and the content of the ash of a given species growing in different soils is shown vertically. It is rare for the uranium content of any species growing in nonmineralized ground to be greater than 1 ppm. A content of 2 or more ppm is common in plants rooted in uranium-bearing rock. The V_2O_5 content of ashes of species of plants growing on various materials and the V_2O_5 content of the underlying rocks are shown in the same manner in table 2. Although excessive amounts of vanadium are sometimes absorbed when a large percentage of available vanadium is present around the roots, lesser variations are masked by the normal requirements of the plant.

Table 1.—Uranium content of ashes of plants and underlying rocks**

	Formation	Material	Uranium content (ppm)	*Astragalus Pattersonii (milkvetch)	*Astragalus Preussii arctus (milkvetch)	*Astragalus confertiflorus	*Oryzopsis hymenoides (ricegrass)	*Atriplex confertifolia (shadscale)	Atriplex canescens (saltbush)	Bahia nudicaulis	Chrysothamnus viscidiflorus (rabbitbrush)	Ephedra viridis (mormon-tea)	Artemisia spinescens (bud-sage)	Artemisia bigelovii (sagebrush)	Haplopappus sp. (goldenweed)	Fraxinus anomala (singleleaf ash)	Juniperus monosperma	Quercus gambelii (scrub oak)
Mineralized	Salt Wash member of Morrison formation	colluvium	3070					3.0		8.0	7.0							
		secondary oxide deposit	2400	38.0				5.9										
		shale	11															10.0
		shale	80		70.0										40.0	0.7		
		sandstone	290					2.0				2.0	3.0					
		sandstone	540														7.8	
		sandstone	20				30.0											
		sandstone	400														2.0	
Nonmineralized		sandstone 3 samples (averaged)	3					0.2			0.6	1.0		0.87		0.5	0.1	0.5
	Dakota sandstone	sandstone	0.6						0.75		0.9						1.0	
	Mancos shale	shale	4.0			0.8												
		sandstone	0.9					0.26	0.68								0.0	

* Selenium indicator plants

**Ruth Kreher, Jesse Greene, and Norma Guttag, analysts

Table 2.—V_2O_5 content of ashes of plants and underlying rocks

Formation	Material	V_2O_5 content (ppm)	*Astragalus Pattersonii (milkvetch)	*Astragalus preussii arctus (milkvetch)	*Astragalus confertiflorus	*Oryzopsis hymenoides (ricegrass)	*Atriplex confertifolia (shadscale)	Atriplex canescens (saltbush)	Bahia nudicaulis	Chrysothamnus viscidiflorus (rabbitbrush)	Ephedra viridis (mormon-tea)	Artemisia spinescens (budsage)	Artemisia bigelovii (sagebrush)	Haplopappus sp. (turpentine bush)	Fraxinus anomala (singleleaf ash)	Juniperus monosperma	Quercus gambelii (scrub oak)
			V_2O_5 content of ash of plants (ppm)														
Salt Wash member of Morrison	colluvium	180					10		70	200							
	secondary oxide deposit	300	12				15									30	
	shale	320															90
	shale	26000		3000										260	5		
	sandstone	23000					50				20	70					
	sandstone	2000														20	
	sandstone	2200				70											
	sandstone	5400														50	
	sandstone (3 samples averaged)	216					90			50	50		70		5	10	5
Dakota sandstone	sandstone	300						25									
Mancos shale	shale	180			90		60	30									
	sandstone	1200														60	

* Selenium-indicator plants
**Ruth Kreher, Norma Guttag, and Jesse Greene, analysts

Table 3 shows the uranium and V_2O_5 contents of ashes of various parts of several plants collected in mineralized areas.

Table 3.--Uranium and V_2O_5 contents of ashes of various parts of the same plant*

	Uranium in ash (ppm)				V_2O_5 in ash (ppm)		
Plant	Stems	Fruits	Tops	Roots	Fruit	Tops	Roots
Juniper		1	2	8	5	5	80
Juniper		0.6	2	2	5	40	70
Juniper		0.5	10	20	30	30	50
Juniper			3	5 (peeled) 3 (bark)		20	70 (peeled) 30 (bark)
Saltbush	0.48	0.96	1.98 leaves				
Juniper	11 (peeled)		24 (washed)	49 (peeled)			
Pinyon pine	26 (peeled)		30 (washed)	74 (peeled)			

*Ruth Kreher, Jesse Greene, and Norma Guttag, analysts

Because uranium and vanadium are largely precipitated within the root near the point of intake, a root sampled at the surface will have a lower content of uranium and vanadium than the same root sampled in the ore-bearing sandstone, as shown in table 4. Contamination of the roots need not be considered because the roots contain more of these metals than the sandstone. Furthermore, as shown in table 3, the peeled roots contain more uranium and vanadium than the contaminated root bark.

Table 4.--Distribution of uranium and V_2O_5 in ashes of parts of a Juniper tree and in rock underlying plant*

Plant	Uranium (ppm)	V_2O_5 (ppm)
Juniper tops (ash)	7.8	20
Juniper root (ash) at surface	8.4	200
Juniper root (ash) in mineralized sandstone at 4-foot depth	1,600	3,000
Rock underlying plant		
Mineralized sandstone at 4-foot depth	540	2,000

*Ruth Kreher, Jesse Greene, and Norma Guttag, analysts

A root on one side of the tree reaching into barren sandstone will not be of the same composition as one on the opposite side of the tree growing in mineralized rock. This variation is transmitted in a lesser degree to the tops and is illustrated in the analyses in table 5 of the end branches of a juniper tree.

Table 5.— Uranium content of ashes of branches of four sides of a juniper tree growing on east side of an ore body*

	Uranium (ppm)
Juniper branches (ash), north side of tree	0.51
Do. do. do. south side of tree	0.29
Do. do. do. east side of tree	0.53
Do. do. do. west side of tree	3.20

*Ruth Kreher, Jesse Greene, and Norma Guttag, analysts

Analyses of samples taken in different months of the summer from the same trees indicate that the vanadium content rises during the growing season, and that the uranium content probably rises through the growing season in some evergreens but falls in most deciduous species. These findings agree with those of Hoffmann (1943).

Junipers are known to penetrate 20-30 feet of sandstone in certain areas of the Colorado Plateau. The depth to which the roots will penetrate depends not only on the species but also on water conditions and on the composition of the rocks penetrated. Many desert plants or xerophytes possess deep-seated root systems able to draw water from moist beds at a considerable depth. Although the roots commonly penetrate to the water table, sufficient moisture may be retained in a sandstone bed above the water table to satisfy the plant's requirements. The moisture content of the ore bed and of the intervening sandstones and shales is the prime controlling factor in the absorption of metals from ore bodies at depth. Tables 6 and 7 show analyses of plants and soils for U, V_2O_5, Se, MoO_3, and Pb. The samples were collected to show the relation of different species to various types of mineralized soil, the seasonal variations in content, and the relative variations of these elements and oxides in plant parts. In addition to samples taken in uranium districts, plant samples for comparative purposes were collected on nonmineralized parts of the Salt Wash member, and on the Mancos shale and Dakota sandstone, both of Cretaceous age.

The differences in amounts of metals absorbed in plants growing on shales and those growing on sandstones are not great, as shown in tables 6 and 7. A more significant variation in amounts of metals absorbed appears to be associated with differences in the amount of calcium in the ore. A rough comparison of the uranium, V_2O_5, and selenium contents of various types of ores from other districts is shown in table 8. Considerably more uranium is absorbed from the deposits of calcium-uranium carbonates and from deposits occurring in limestones than from calcium-poor sandstones and shales. The absorption of uranium from the carbonate mineral schroeckingerite by the plants at Wamsutter, Wyo., is particularly noteworthy and compares favorably with the absorption, by plants, of the carbonate in the Yellow Cat district. The absorption of uranium by plants is considerably greater from the asphaltic deposits of Temple Mountain, Utah, and the limestone deposits of Grants, N. Mex., than from the Plateau carnotite deposits studied. Although the cause of the variation may be due to the solubility of the secondary minerals in each type of ore, it is also possible that uranium is absorbed by plants along with calcium which has a similar ionic radius and that vanadium is absorbed along with phosphorus. The latter is suggested by the analyses of plants growing on the Permian Phosphoria formation.

Table 6.—Analyses of plants growing on uranium-bearing rocks and soils of the Colorado Plateau 1949-50**

Locality and sampled rock and plant material	Month sample collected	Ash (per-cent)	U		V_2O_5		Se	MoO_3		Pb	
			(parts per million)								
			Soil or rock	Plant ash	Soil or rock	Plant ash	Plant ash	Soil or rock	Plant ash	Soil or rock	Plant ash
Sta. 1 Yellow Cat district, Thompsons, Utah											
S. 2 Sandstone near carnotite ore			20		2200			10		30	
*P. 8 *Oryzopsis hymenoides* tops	May	7.3		30		70			30		10
Do. roots	May	35.2		40		1600			<10		30
S. 3 Surface soil 5 ft. above carnotite ore			2		180			<10		<10	
S. 4 Shale layer in ore			290		23000			20		30	
P. 10 *Ephedra viridis* tops	May	14.7		2		20			<10		10
*P. 12 *Atriplex confertifolia* tops	May	31.3		2		50			20	<10	
P. 56 *Artemisia spinescens* tops	May	18.4		3		70			<10		<10
Do. roots	May	13.2		5		100			n.d.		<10
Sta. 2 Yellow Cat district, Thompsons, Utah											
S. 5 Sandstone ore at depth of 10 ft.			730		3500			20		<10	
S. 6 Shale layer containing roots			80		2600			10		40	
P. 14 *Fraxinus anomala* leaves	May	7.8		0.7		5			10		40
Do. leaves	Aug.			0.98		40			n.d.		n.d.
Do. roots	May	5.4		9		30			10		110
*P. 16 *Haplopappus* sp. tops	May	8.3		40		260			190		50
Do. roots	May	14.7		20		180			160		30
P. 18 *Astragalus Preussii arctus*	May	19		70		3000			30		<10
Do. roots	May	5.8		70		2600			70		<10
S. 7 Colluvium at base of cliff			7		180			10		<10	
P. 20 *Bahia nudicaulis* tops	May	20.9		8		70			10		<10
Do. roots	May	10.2		20		180			10		<10
P. 22 *Chrysothamnus viscidiflorus* tops	May	17.3		7		200			30		<10
Do. roots	May	16.8		10		200			80		20

*Selenium-indicator plants   n.d. not determined.

** F.S. Grimaldi, Ruth Kreher, Claude Huffman, and F.N. Ward, chief analysts.

Table 3.—Analyses of plants growing on uranium-bearing rocks and soils of the Colorado Plateau 1949-50 (continued)

Locality and sampled rock and plant material	Month sample collected	Ash (percent)	U		V_2O_5		Se	MoO_3		Pb	
			(parts per million)								
			Soil or rock	Plant ash	Soil or rock	Plant ash	Plant ash	Soil or rock	Plant ash	Soil or rock	Plant ash
Sta. 2 Yellow Cat district, (con't.)											
S.7 Colluvium at base of cliff (con't.)											
*P.24 <u>Atriplex confertifolia</u> tops	May	22		3		10			10		<10
Do. roots	May	13.8		5		90			<10		<10
Sta. 3 Yellow Cat district, Thompsons, Utah											
S.8 Clay layer containing roots 1 ft. depth			3		320			10		10	20
P.26 <u>Quercus gambelli</u> leaves	May	4.0		10		90			20		20
Do. leaves	Aug.			40		200			n.d.		n.d.
Do. roots	May	10.8		190		1700			20		10
Sta. 1 McCoy group, Thompsons, Utah											
S.106 Uranium carbonate in mudstone			2400		300			n.d.		n.d.	
*P.636 <u>Astragalus Pattersonii</u> tops	July	11.6		38		12	1280		150		20
*P.637 <u>Atriplex confertifolia</u> tops	July	22.8		5.9		15	1260		150		<20
S.108 Altered mudstone in Windy Point rim			20		800			n.d.		n.d.	
*P.640 <u>Astragalus Preussii arctus</u> tops	July	9.0		20		14	110		60		20
Sta. 2 McCoy group, Thompsons, Utah											
S.18 Carnotite ore at 18 ft. depth containing roots			57		3000			6			
P.214 <u>Juniper monosperma</u> (collected in mine) roots	July	5.5		7.4		80			15		
Sta. 3 McCoy group, Thompsons, Utah											
S.19 Surface soil			3.1		100			n.d.		n.d.	

* Selenium-indicator plants
n.d. not determined

Table 6.—Analyses of plants growing on uranium-bearing rocks and soils of the Colorado Plateau 1949-50 (continued)

Locality and sampled rock and plant material	Month sample collected	Ash (percent)	U (parts per million) Soil or rock	U Plant ash	V_2O_5 Soil or rock	V_2O_5 Plant ash
Sta. 3 McCoy group, Thompsons, Utah (cont'd)						
S.20 Ore at 9 ft. in which roots are imbedded			440		5400	
P.38 *Juniper monosperma* tops	May	4.9		2		50
Do. in mine roots	May	6.5		20		140
Do. do. roots	July			140		4000
Do. do. berries	May	4.7		0.2		5
Sta. 4 McCoy group, Thompsons, Utah						
S.22 Ore at 4 ft. depth containing roots			540		2000	
P.217 *Juniper monosperma* tops	July	5.0		7.8		20
Do. surface roots	July	2.5		8.4		200
Do. in mine roots	July			1600		3000
Sta. 7 McCoy group, Thompsons, Utah						
S.28 Surface soil (carnotite ore at 10 ft. depth)			170		800	
*P.223 *Oryzopsis hymenoides* tops	July	3.9		82		200

Locality and sampled rock and plant material	Se (parts per million) Plant ash	MoO_3 Soil or rock	MoO_3 Plant ash	Pb Soil or rock	Pb Plant ash
Sta. 3 McCoy group, Thompsons, Utah (cont'd)					
S.20 Ore at 9 ft. in which roots are imbedded		n.d.		n.d.	
P.38 *Juniper monosperma* tops			40		80
Do. in mine roots			30		10
Do. do. roots			130		
Do. do. berries			10		<10
Sta. 4 McCoy group, Thompsons, Utah					
S.22 Ore at 4 ft. depth containing roots		n.d.			
P.217 *Juniper monosperma* tops			24		
Do. surface roots			30		
Do. in mine roots			15		
Sta. 7 McCoy group, Thompsons, Utah					
S.28 Surface soil (carnotite ore at 10 ft. depth)	14.0				
*P.223 *Oryzopsis hymenoides* tops					

* Selenium-indicator plants
n.d. not determined

Table 7.--Analyses of plants growing on nonmineralized rocks and soils of the Colorado Plateau**

Locality and sampled rock and plant material		Month sample collected	Ash (percent)	U Soil or rock	U Plant ash	V_2O_5 Soil or rock	V_2O_5 Plant ash	Se Plant ash	MoO_3 Soil or rock	MoO_3 Plant ash	Pb Soil or rock	Pb Plant ash
				(parts per million)								
Sta.5 Yellow Cat district, Thompsons, Utah												
S.11 Surface soil over nonmineralized (?) Salt Wash				1		220			<10		<10	
P.49 <u>Juniper monosperma</u>	tops	May	5.3		2		40			<10		<10
Do.	tops	Aug.			0.1		10			n.d.		n.d.
Do.	roots	May	17.2		2		70			<10		40
Do.	berries	May	5.2		0.6		5			10		<10
Do.	berries	Aug.			0.04		30			n.d.		n.d.
P.52 <u>Fraxinus anomala</u>	tops	May	8.4		0.5		5			<10		10
Do.	tops	Aug.			<0.01		30			n.d.		n.d.
Do.	roots	May	4.8		1		30			<10		10
P.54 <u>Artemisia bigelovii</u>	tops	May	9.7		2		50			10		<10
Do.	tops	Aug.			0.87		70			n.d.		n.d.
Do.	roots	May	11.3		2		5			<10		30
Sta.6 Yellow Cat district, Thompsons, Utah												
S.13 Surface soil over nonmineralized (?) Salt Wash				6		200			<10		10	
P.67 <u>Ephedra viridis</u>	tops	May	12.5		1		50			<10		20
Do.	roots	May	8.1		1		50			<10		40
P.69 <u>Chrysothamnus viscidiflorus</u>	tops	May	11.7		0.6		50			10		40
Do.	roots	May	14.7		1		30			<10		30
*P.71 <u>Atriplex confertifolia</u>	tops	May	34.3		0.2		90			<10		<10
Do.	roots	May	10.6		0.2		50			10		40

* Selenium-indicator plants
n.d. not determined
**F. S. Grimaldi, Ruth Kreher, Claude Huffman and F.N. Ward, Chief Analysts

Table 7.--Analyses of plants growing on nonmineralized rocks and soils of the Colorado Plateau (continued)

Locality and sampled rock and plant material		Month sample collected	Ash (percent)	U Soil or rock	U Plant ash	V_2O_5 Soil or rock	V_2O_5 Plant ash	Se Plant ash	MoO_3 Soil or rock	MoO_3 Plant ash	Pb Soil or rock	Pb Plant ash
				(parts per million)								
Sta.7 Yellow Cat district, Thompsons, Utah												
S.12 Surface soil over nonmineralized (?) Salt Wash				2		230			<10		10	
P.58 *Quercus gambelli*	tops	May	4.3		0.5		5			<10		10
Do.	roots	May	12.3		2		50			<10		<10
Sta. 1 Mancos shale 10 miles east of Thompsons, Utah												
S.14 Surface soil				4		180			<10		<10	
*P.73 *Astragalus confertiflorus*	tops	May	14.7		0.8		90			50		20
Do.	roots	May	18.8		30		70			120		<10
Mancos shale 40 miles east of Thompsons, Utah, along Highway 50												
Sta.1 450' N. of highway												
P.1 *Atriplex canescens*	tops	Aug.	15		1		30			60		
*P.2 *Atriplex confertifolia*	tops	Aug.	30		0.04		60			30		
P.3 *Juniperus monosperma*	tops	Aug.	4.5		1.1		60			15		
P.4 *Sarcobatus vermiculatus*	tops	Aug.	27.5		0.15		20			30		
Sta.2 70' NW of Sta.1												
P.5 *Atriplex canescens*	leaves	Aug.	15		0.12		20			15		
*P.6 Do. *confertifolia*	leaves	Aug.	30		0.10		40			30		
P.7 *Juniper monosperma*	tops	Aug.	5		0.01		50			15		
P.8 *Sarcobatus vermiculatus*	tops	Aug.	26		0.17		10			30		
Sta.3 210' N of Highway												
S.1 Surface soil				0.9		1200		<0.7**	n.d.		2.0	
P.9 *Atriplex canescens*	leaves	Aug.	15		0.68		<10			30		

* Selenium-indicator plants
** Analysis of soil sample
n.d. not determined

Table 7.—Analyses of plants growing on nonmineralized rocks and soils of the Colorado Plateau (continued)

Locality and sampled rock and plant material		Month sample collected	Ash (percent)	U		V_2O_5		Se	MoO_3		Pb	
				(parts per million)								
				Soil or rock	Plant ash	Soil or rock	Plant ash	Plant ash	Soil or rock	Plant ash	Soil or rock	Plant ash
Sta.3 210' N of Highway (continued)												
S.1 Surface soil												
*P.10 Atriplex confertifolia	leaves	Aug.	33		0.26		40			15		
P.11 Juniper monosperma	tops	Aug.	5		0.01		40			30		
P.12 Sarcobatus vermiculatus	leaves	Aug.	25		0.19		20			30		
Sta.1 Dakota sandstone, Harley Dome, Utah												
S.20 Sandstone residuum				0.6		300		<0.7**	n.d.		1.0	
P.20 Juniperus monosperma	tops	July	4		1		30			10		20
P.21 Chrysothamnus viscidiflorus	tops	July	7.6		0.9		n.d.			10		20
P.22 Atriplex canescens	tops	July	14.4		0.75		25			10		20

* Selenium-indicator plants
** Analysis of rock sample
n.d. not determined

Table 8.—Comparative collections from other uranium districts**

Locality and sampled rock and plant material		Ash (percent)	U (parts per million)		V_2O_5 (parts per million)		Se (parts per million)		P_2O_5 (percent)	
			Soil or rock	Plant ash	Soil or rock	Plant ash	Soil or rock	Plant ash	Soil or rock	Plant ash
Wamsutter, Wyoming										
Uranium carbonate in alluvium			270		100					
Sarcobatus vermiculatus, greasewood	tops	25.0		14		0				
Do.	roots			7400		400				
Black muck from mineralized spring			10		40					
Eleocharis palustris, spikerush	tops			1.7		0				
Spirogyra-type algae				39		500				
Uraniferous lignite bed			20		1500		2			
*Stanleya arcuata, Prince's Plume	tops	15.0		0.6		65		15		
Uraniferous lignite bed			50		400		2			
Cleome integrifolia angusta	tops	5.3		1.2		70		<1		
Marysvale, Utah										
Kaolinized vein deposit			1000		600		0.8			
*Atriplex confertifolia, shadscale	tops	23.0		4.8		n.d.		n.d.		
Juniperus monosperma	tops	4.0		0.7		n.d.		n.d.		
Temple Mountain, Utah										
Asphaltic ss. ore, Shinarump deposit			760		1500		0.8			
Wood in ore			4900		7800		3.0			
Juniperus monosperma	tops	4.0		66		350		n.d.		
Do.	tops	4.0		100		470		n.d.		
*Oryzopsis hymenoides, ricegrass	tops	5.5		20		260		10		
*Stanleya pinnata, Prince's Plume	tops	10.0		37		120		190		
Buck Creek, Wyoming										
Phosphate rock in shale, Phosphoria formation			120		3600		46.0		9.0	
Apocynum androzaefolium, dog-bane	tops	9.0		0.45		n.d.		n.d.		1.10
Smilacena stellata, wild spikenard	tops	10.0		0.25		n.d.		n.d.		1.30

* Selenium-indicator plants

** Claude Huffman, J. W. Harbaugh, R. G. Havens, Ruth Kreher, analysts.

n.d. not determined

Table 8.—Comparative collections from other uranium districts (continued)

Locality and sampled rock and plant material		Ash (percent)	U (parts per million)		V_2O_5 (parts per million)		Se (parts per million)		P_2O_5 (percent)	
			Soil or rock	Plant ash	Soil or rock	Plant ash	Soil or rock	Plant ash	Soil or rock	Plant ash
Cokeville, Wyoming										
Phosphate rock in shale, Phosphoria formations			210		5600		12		28.0	
*<u>Oryzopsis hymenoides</u>, ricegrass	tops	8.0		4.3		690		<1.0		0.18
Phosphate rock with fluorine			60		2400		4		31.0	
<u>Artemisia tridentata</u>, sagebrush	tops	5.0		1.8		150		15.0		0.65
Calciferous shale			20		800		52		1.3	
<u>Chrysothamnus parryi</u>, rabbitbrush	tops	6.0		1.0		93		n.d.		0.58
Vanadiferous mudstone			20		6200		96		2.0	
<u>Artemisia tridentata</u>, sagebrush	tops	5.0		0.75		110		n.d.		0.65
Grants, New Mexico										
Tyuyamunite in Todilto limestone			2200		3900		<0.01			
<u>Pinus edulis</u>, pinyon pine washed	tops	2.3		33		<10				
<u>Juniper monosperma</u> Do.	tops	3.6		49		<10				

* Selenium-indicator plants

Experimental plots are being established to test the influence of these elements on the absorption of metals from the ore minerals.

Artificial contamination is a considerable source of error in sampling areas of active mining (table 9.) Dust from an operating surface pit may

Table 9.—Contamination of trees near area of mining*

Plant	Ash (percent)	Uranium	V_2O_5
		(ppm in ash)	
Cowania mexicana			
During active mining 1949	5.3	51.0	400.0
During dormant period 1950, unwashed sample	5.0	8.4	75.0
During dormant period 1950, washed sample	5.0	6.4	50.0
Juniperus monosperma			
Sampled in 1949	5.0	7.8	20.0
Sampled in 1950			
unwashed sample	4.5	7.0	65.0
washed sample	4.5	5.3	50.0

*Claude Huffman, Ruth Kreher, analysts

raise the uranium content of nearby trees from 2 to 100 ppm. Contamination from the Uravan mill has substantially increased the content of uranium in juniper ash near the Club mine, 1 mile south of the mill at Uravan, Colo. Samples collected from between the Club mine and the mill show an increment of over 1,000 ppm uranium, as shown in table 10.

Table 10.—Contamination of junipers near a uranium mill*

Distance from mill	Number of samples	Uranium content (ppm)
2,000-4,000 ft.	6	40 (average)
800-1,500 ft.	4	150 (average)
Adjacent to the mill	2	700 and 1,100

*Claude Huffman, analyst

The need for guarding against contamination in any plant sampling cannot be emphasized too strongly. A regular routine has been established of checking surface soil and washing some samples to assure more representative analyses. Because the amount of contamination present in active areas was not realized during the preliminary sampling for basic information, many of the early Survey analyses have been rejected. Tables 6 and 7, however, summarize data on samples collected in inactive areas where contamination is probably at a minimum.

Indicator plants

Although an indicator plant has been defined by agricultural specialists as a plant restricted in distribution to soils containing unusually large quantities of a particular element, a plant can be used as an indicator in geochemical prospecting if its distribution is controlled by any factor related to the chemistry of the ore deposit. A plant can indicate mineralized ground by either its presence or absence; it can accumulate or not the element being sought; and, in different chemical environments, it can indicate various metallic deposits. No specific indicator plants of either uranium or vanadium are mentioned in the literature. The association of selenium-indicator plants with carnotite deposits near Thompsons, Utah, however, was early noticed by Beath (1943) of the University of Wyoming, and a major objective of the Survey's work in this area has been to establish the use of selenium-indicator plants as a method of prospecting.

Plant studies have also been made in the Yellow Cat and other uranium districts to determine the tolerance of various plant species for highly mineralized soils. The ecology of 13 mineralized and 11 nonmineralized areas have been studied in detail in the Yellow Cat district. In each area complete collections were made on a strip of ground 5 feet wide and 10 feet long directly over a mine entrance or known ore body. In each place the ore was not over 15 feet below the surface and in most places was less than 10. A study was made at the same time of the ecology of the dumps and colluvium along the base of the rim outcrop. To compare the resulting lists of plants with plants growing on nonmineralized ground, similar collections were made wherever possible on the same slope or rim at a distance of about 500 feet from the deposit. It should be noted that the studies of plants growing on nonmineralized ground were all made _within_ the uranium district, so that the difference is one of degree and is not as marked as if the studies had been made in an entirely barren region.

The flora of uranium-tolerant plants compiled from these lists is given in table 11. The commonest of these plants throughout the district are rabbitbrush, shadscale, Mormon-tea, milkvetch, and grasses, but junipers, scrub oak, serviceberry, and cliffrose are common on some of the higher mesas. The flora assemblage over ore is characterized particularly by the presence of the selenium-indicator plants and the replacement of _Atriplex canescens_, the common narrow-leafed saltbush, by the shadscale saltbush, _Atriplex confertifolia_. This change in saltbush species in uranium districts has not previously been recognized. Although _A. canescens_ is a selenium-indicator, it apparently cannot tolerate the increased quantity of salts in the soil. The change from the narrow-leafed desert shrub to the wider-leafed shadscale affects the appearance of the vegetation in a uranium district to a remarkable degree, and is probably subconsciously used by many prospectors. The plants unable to grow over shallow uranium deposits are likewise shown in table 11. Sagebrush and _Grayia_ are especially intolerant and can, in some places, be as useful in prospecting as positive indicators.

Table 11.-- Ecological variations in the desert flora of the Yellow Cat district, Grand County, Utah; compiled from a study of 24 areas 1/

Flora tolerant of mineralized ground**	Common name	Number of mineralized areas, out of 13 examined, in which species were observed	Number of nonmineralized areas, out of 11 examined, in which species were observed
Grasses:			
Graminae			
Aristida Fendleriana Steud.,	Fendler three-awn	10	9
Bromus tectorum L.,	cheatgrass	12	11
Elymus salina Jones	wild rye	8	7
Hilaria jamesii (Torr.)Benth.,	galleta	11	9
**Oryzopsis hymenoides* (R.&S.) Ricker,	Indian ricegrass	12	6
Sitanion hystrix (Nutt.)Smith,	squirreltail	4	5
Stipa comata Trin.& Rupr.,	needlegrass	2	0
Trees and shrubs:			
Ephedraceae			
Ephedra trifurca Torr.,	Mormon-tea	9	11
Pinaceae			
Juniperus monosperma (Engelm.) Rydb.,	oneseed juniper	5	4
Fagaceae			
Quercus Gambellii Nutt.,	Gambel's oak	2	1
Chenopodiaceae			
**Atriplex confertifolia* (T.&F.) S. Wats.,	shadscale	13	9
Rosaceae			
Amelanchier utahensis Koehen.,	serviceberry	1	0
Coleogyne ramosissima Torr.,	blackbrush	6	6
Cowania mexicana Don.,	cliffrose ("vanadium bush")	2	0
Oleaceae			
Fraxinus anomala Torr.,	singleleaf ash	1	1
Compositae			
Tetradymia spinosa H.& P.,	tetradymia	3	2

*Selenium-indicator plants

** *Pinus edulis*, pinyon pine, is also uranium-tolerant but occurs only on the higher mesas of the Plateau.

1/ Plants collected by R. Stillman and Mary Durrell
Identifications checked by A. Holmgren of Utah State Agricultural College

Table 11.--Ecological variations in the desert flora of the Yellow Cat district, Grand County, Utah; compiled from a study of 24 areas 1/ (continued)

Flora tolerant of mineralized ground	Common name	Number of mineralized areas, out of 13 examined, in which species were observed	Number of nonmineralized areas, out of 11 examined, in which species were observed
Browse:			
Liliaceae			
Calachortus Nuttali Torr.& Gray	mariposa-lily	2	0
Polygonaceae			
Eriogonum inflatum Torr.,	desert-trumpet	4	2
Eriogonum bicolor Torr.,	eriogonum	1	0
Cruciferae			
* Stanleya pinnata Greene,	Prince's Plume	1	0
Lepidium lasciocarpum A.Gray	peppergrass	2	1
Lepidium montanum Nutt.,	peppergrass	6	7
Leguminosae			
*Astragalus Preussii var. arctus Jones,	milkvetch	10	2
*Astragalus Thompsonae Rydb.,	milkvetch	5	1
*Astragalus Pattersonii A.Gray	milkvetch	2	0
Polemoniaceae			
Gilia pungens Benth.,	gilia	4	4
Gila congesta (A.Gray) Rydb.,	gilia	1	0
Boraginaceae			
Cryptantha flava (A Nels.) Payson,	cryptantha	4	0
Euphorbiaceae			
Euphorbia typica Rydb.,	sand spurge	6	5
Plantaginaceae			
Plantago Purshii R. & S.,	wooly indianwheat	1	1
Compositae			
*Aster venusta Rydb.,	woody aster	6	5
Chrysothamnus Greenei (A.Gray) Greene	rabbitbrush)		
Chrysothamnus viscidiflorus (Hook.) Nutt.	rabbitbrush)	12	11
Solidago Petridoria Blake,	goldenrod	4	4
Artemisia spinescens D.C.Eat.,	bud-sage	1	1
Grindelia squarrosa (Pursh) Dunal.,	gumweed	2	0
Senecio uintahensis (A.Nels.) Greene.,	ragwort	1	0
Haplopappus sp.	goldenweed	3	0

* Selenium-indicator plants

1/ Plants collected by R. Stillman and Mary Durrell.
Identifications checked by A. Holmgren of Utah State Agricultural College.

Table 11.—Ecological variations in the desert flora of the Yellow Cat district, Grand County, Utah; compiled from a study of 24 areas 1/ (continued)

Flora intolerant of mineralized ground	Common name	Number of mineralized areas, out of 13 examined, in which species were observed	Number of nonmineralized areas, out of 11 examined, in which species were observed
Shrubs:			
Chenipodiaceae			
*Atriplex canescens James,	fourwing saltbush	0	4
Grayia Brandegei A.Gray,	hop-sage	0	3
Compositae			
Artemisia Bigelovii A Gray,	sagebrush	2	6
Browse:			
Scrophulariaceae			
Castilleja angustifolia (Nutt.) G. Don.,	paintbrush	0	2
Compositae			
Bahia nudicaulis A. Gray,	Bahia	1	4

*Selenium-indicator plant in other areas.

1/Plants collected by R. Stillman and Mary Durrell. Identifications checked by A. Holmgren of Utah State Agricultural college.

Chemical analyses of channel samples taken through carnotite ore bodies and enclosing barren sandstones of the Salt Wash member show a close association of selenium and sulfur with uranium and vanadium in these deposits. A logical corollary of the geologic association of selenium with the uranium ores, is the affinity of selenium-indicator plants for carnotite deposits. The various species have distinct distribution patterns and have been mapped and studied separately. Of these, woody aster, rice-grass, and shadscale all have low selenium requirements and are common on alluvium and dune sands throughout the carnotite districts. Their prevalence is indicated in tables 8, and 11.

Astragalus confertiflorus, a small milkvetch with bluish folage, occurs on the altered mudstones, from which it extracts selenium and considerable ferrous iron. According to Trelease and Beath (1949) a very low percentage of the selenium absorbed is water soluble. It is possible that the insoluble fraction is bound with iron. The species is replaced by Astragalus Preussii var. arctus where the mudstones contain excessive amounts of selenium.

Astragalus P. arctus and closely related Astragalus Pattersonii, are the most useful selenium-indicator plants for carnotite deposits on the Colorado Plateau. They both absorb large quantities of soluble selenium and are found in conspicuous stands along the base of the ore-bearing sandstone, on the altered mudstones at the base of the sandstone, and, where there is sufficient moisture, on sandstone outcrops above the ore. Patches of these plants indicate selenium and possibly uranium in the nearest sandstone bed. Plants of the Astragalus group are limited by altitude and are not found on the Plateau much over 6,000 feet.

Stanleya pinnata or Prince's Plume, a tall yellow crucifer with a spike of conspicuous flowers, also requires considerable selenium. Unlike the Astragalus group, Stanleya is not limited by altitude but requires sulfur in addition to selenium, and access to larger amounts of water. These differences vary the patterns of distribution of the two genera considerably. Astragalus is commonest in low, hot, dry areas of the Plateau, and Stanleya is commonest near gypsiferous deposits at any altitude in areas of discharge or where the roots are in reach of ground water.

Other members of the lily and mustard families that accumulate sulfur grow around the deposits and can be used as indicators under favorable circumstances. For instance, Sisymbrium altissimum is abundant around deposits of the Spud Patch and Charles T groups in San Miguel County, Colo., at a higher altitude than the Astragalus group grows.

The restriction of Cowania mexicana to basal conglomeratic beds of the Brushy Basin member of the Morrison formation and its absence from similar beds of the Salt Wash member suggest a chemical control. The plant is not restricted in growth to the immediate environment of the ore deposits in this bed, but its presence, as well as that of the closely related Purshia tridentata at higher altitudes, may suggest favorable areas for prospecting.

Useful indicator plants and their observed occurrence are shown in table 12. To augment the information on distribution of these various indicator plants gained from studies of carnotite deposits, reconnaissance studies were made of other types of uranium deposits in the western states. The same suite of selenium accumulators was observed in the same ecological position on the uranium deposits of the Shinarump sandstone at Temple Mountain, Utah. Stanleya pinnata is an indicator of uraniferous lignites near Wamsutter, Wyo. Ricegrass and other indicator plants requiring less than 1 ppm of selenium are present on the altered hydrothermal deposits of Marysvale, Utah, and on shales of the Phosphoria formation of Idaho and Wyoming. Sulfur indicators, however, are more prevalent on the deposits of the Phosphoria formation in Idaho and Wyoming than selenium indicators.

Table 12.—Indicator plants useful over uranium deposits.

Plant	Element indicated	URANIUM: Carrizo Mountains Apache County, Arizona	Slick Rock, San Miguel County, Colorado	Thompsons, Grand County, Utah	Temple Mountain, Emery County, Utah	Marysvale, Piute County, Utah	Phosphoria formation Bear Lake Jounty, Idaho	Phosphoria formation Caribou County, Idaho	Phosphoria formation Teton County, Wyoming	Wamsutter, Sweetwater County, Wyoming
<u>Oryzopsis hymenoides</u>	Se	x	x	x	x	x	x		x	x
<u>Atriplex confertiflora</u>	Se		x	x	x	x				x
<u>Astragalus Pattersonii</u>	Se	x	x	x	x					
<u>Astragalus Preussii var. arctus</u>	Se	x	x	x	x					
<u>Astragalus Thompsonae</u>	Se	x		x	x					
<u>Aster venusta</u>	Se			x						
<u>Stanleya pinnata</u>	Se and S	x	x	x	x	x				x
<u>Grindelia squarrosa</u>	Se			x						
<u>Senecio uintahensis</u>	S	x	x	x				x		
<u>Sisymbrium altissimum</u>	S		x				x	x		
<u>Lepidium lasciocarpum</u>	S			x						
<u>Eriogonum inflatum</u>	S	x		x	x		x	x	x	
<u>Calachortus Nuttali</u>	S		x	x					x	
<u>Cowania mexicana</u>	?	x		x	x			x		
<u>Purshia tridentata</u>	?		x			x	x	x	x	
<u>Cryptantha flava</u>	?	x		x						

CONCLUSIONS

The relation of plants to uranium deposits of the Colorado Plateau has been studied over a period of two years. Three separate lines of investigation have been followed; the observable pathologic effects of mineralized soil on the vegetation; the absorption of uranium and associated ore elements by plants; and the ecologic distribution of plants around the ore deposits. Physiologic symptoms of ill health are observed mainly on dumps and disturbed ground where the ore metals have become soluble and available during weathering. Symptoms of uranium poisoning are masked by the excessive amounts of uranium, vanadium, selenium, and molybdenum present in the ore. Plants absorb considerable uranium and vanadium from soil, and a certain amount is transferred to the twigs and leaves where they can be detected by chemical analyses. The leaves of certain plants contain from 2 to 100 ppm uranium and from 40 to 200 ppm V_2O_5 where rooted in ore. The normal content of plants within the carnotite district studied is less than 1 ppm uranium and 20 to 40 ppm V_2O_5. Selenium and sulfur accumulators can be used as indicators of uranium ore under the proper circumstances. The distribution of selenium indicators near Thompsons, Utah, has been studied in detail and the distribution patterns for the various species have been determined. The same species have similar occurrences on other types of uranium deposits in the western states.

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