Botanical Prospecting for Uranium on La Ventana Mesa, Sandoval County New Mexico

GEOLOGICAL SURVEY BULLETIN 1009-M

This report concerns work done on behalf of the U. S. Atomic Energy Commission and is published with the permission of the Commission

Botanical Prospecting for Uranium on La Ventana Mesa, Sandoval County New Mexico

By HELEN L. CANNON *and* W. H. STARRETT

A CONTRIBUTION TO THE GEOLOGY OF URANIUM

GEOLOGICAL SURVEY BULLETIN 1009-M

This report concerns work done on behalf of the U. S. Atomic Energy Commission and is published with the permission of the Commission

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1956

UNITED STATES DEPARTMENT OF THE INTERIOR

Douglas McKay, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 15 cents (paper cover)

CONTENTS

ILLUSTRATIONS

TABLES

A CONTRIBUTION TO THE GEOLOGY OF URANIUM

BOTANICAL PROSPECTING FOR URANIUM ON LA VENTANA MESA, SANDOVAL COUNTY, NEW MEXICO

By HELEN L. CANNON and W. H. STARRETT

ABSTRACT

A uranium-bearing coal of the Allison and Gibson members (undifferentiated) of the Mesaverde formation of Late Cretaceous age crops out in erosional remnants of La Ventana Mesa, Sandoval County, N. Mex. Analyses of the coal show the uranium to be concentrated locally, along with minor accumulations of sulfur, selenium, chromium, copper, lead, cobalt, molybdenum, and nickel. It is believed that the metals have entered the coal along fractures in the overlying La Ventana sandstone member and that the source of the metals may have been Pliocene(?) Bandelier tuff of Smith (1937).

Plant distribution studies indicate that selenium- and sulfur-indicator plants, including species of *Astragalus*, *Stanleya*, several Crucifers, and *Eriogonum*, which grow on the slopes below the coal outcrop, may be useful in prospecting along the base of other mesas in the area.

On the buttes of La Ventana Mesa the coal is capped by a well-fractured 65-foot sandstone bed through which roots of a pinyon and juniper forest penetrate. More than 200 samples of branches of trees growing on top of the mesa were collected and analyzed for uranium. The assays ranged from 0.1 to 2.3 parts per million of uranium in the wood ash. Dead branches, which were found to contain more uranium in the ash than live branches, were sampled whenever possible. The resulting uranium values have been contoured to indicate probable areas of mineralized coal. Parts of the north butte are recommended as favorable for physical exploration.

INTRODUCTION

Geological studies were made by the Geological Survey in advance of exploration in an area of uranium-bearing coal on La Ventana Mesa, Sandoval County, N. Mex., as described by Bachman, Vine, Read, and Moore (in preparation). Prospecting by botanical methods was suggested by C. B. Read of the Geological Survey and was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

The purpose of the present investigation was to prospect for uranium by botanical methods in an area in which the uranium-bearing bed is under cover. The bed, known to be mineralized along parts of the outcrop, is overlain by the La Ventana sandstone member of the Mesaverde formation, a massive flat-lying sandstone 65 feet thick, which caps the mesa. Botanical prospecting was planned to study the metal constituents of the uranium-bearing coal; the relation of these constituents to plant distribution; the absorption of uranium by trees rooted in the sandstone capping; and the use of this information in prospecting.

The area studied includes the north butte and part of the south butte of La Ventana Mesa. The mesa lies just east of New Mexico Highway 44, 15 miles by road south of Cuba, and 65 miles by road northwest of Albuquerque, in sections 28, 29, 32, 33, and 34 of T. 19 N., R. 1 W., New Mexico principal meridian (fig. 58). The two buttes are completely isolated from each other and rise about 1,400 feet above the valley floor. The shale and talus-covered slopes can be traversed only on foot except at the northwest corner of the north butte where it is possible to drive a jeep about one-third of the way up the slope. The area is drained and dissected by tributaries of the Rio Puerco, a part of the Rio Grande drainage system. The altitude ranges from 6,000 feet at the base of the mesa to 7,400 feet at the top. The climate is semiarid. The mean annual rainfall on La Ventana Mesa is 18 inches (Renick, 1931, p. 6–8).

La Ventana Mesa is composed of sedimentary beds and lies off the western flank of the granitic Nacimiento Mountains (fig. 58). Rocks exposed on the mesa belong to the Mesaverde formation of Late Cretaceous age. Uranium-bearing material is found in the upper carbonaceous shales and coal of the Allison and Gibson members (undifferentiated) of the Mesaverde formation; these form the body of the mesa. Overlying the Allison and Gibson members is 65 feet of porous, jointed La Ventana sandstone capping the buttes. According to Bachman, Vine, Read, and Moore (in preparation), a small flexure, the La Ventana syncline, plunges northwest, and its axis trends through the part of the mesa sampled. The flat-lying beds are steeply upturned within a few miles to the east where the more resistant beds form hogbacks which parallel the Sierra Nacimiento. The structure described remained almost unchanged in Tertiary time. The area was probably once covered by the mildly radioactive tuffs of the Pliocene(?) Bandelier tuff of Smith, (1937). It seems probable that uranium was dissolved by descending meteoric waters which percolated through the La Ventana sandstone member and was adsorbed by carbonaceous material in the underlying Allison and Gibson members. The geologic relations have been described by

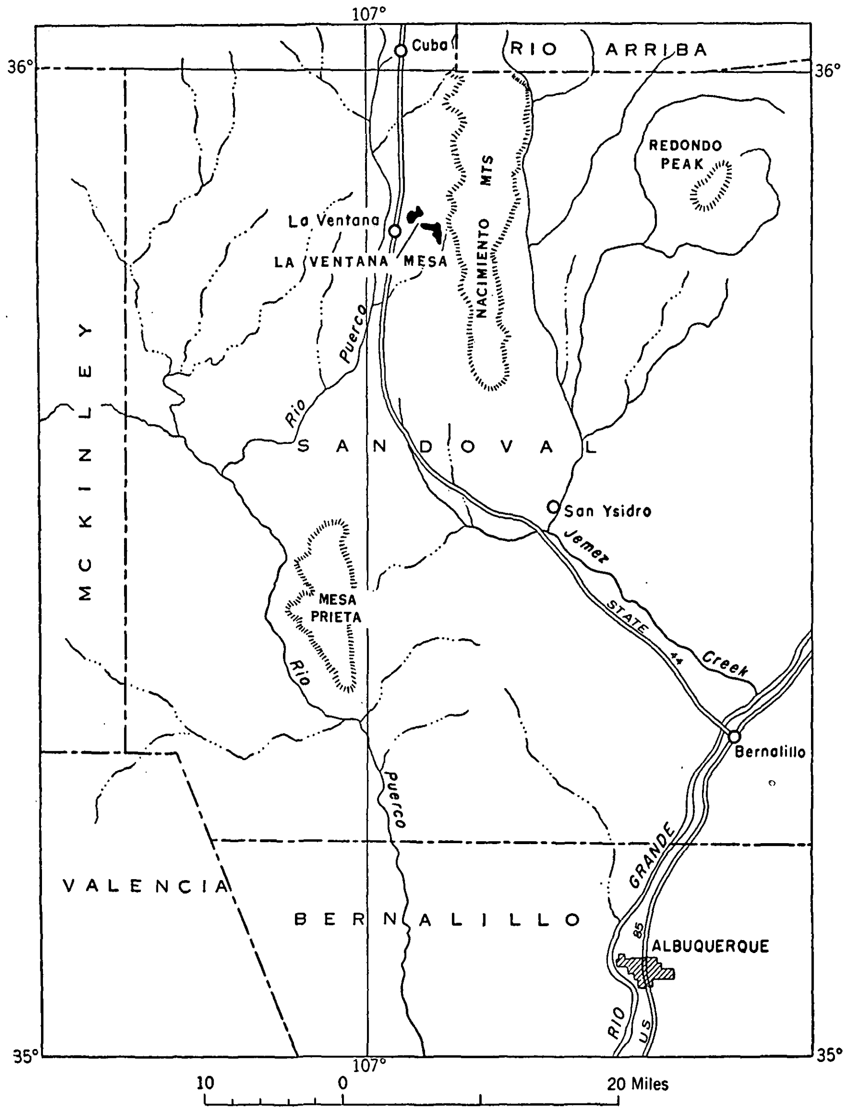

FIGURE 58.—Index map of part of New Mexico, showing location of La Ventana Mesa, Sandoval County, N. Mex.

Darton (1929), C. B. Read (written communication), and Bachman, Vine, Read, and Moore (in preparation), and are shown in a generalized way in figure 59. According to the last, the Bandelier tuff of Smith (1937) contains about 0.003 percent of uranium.

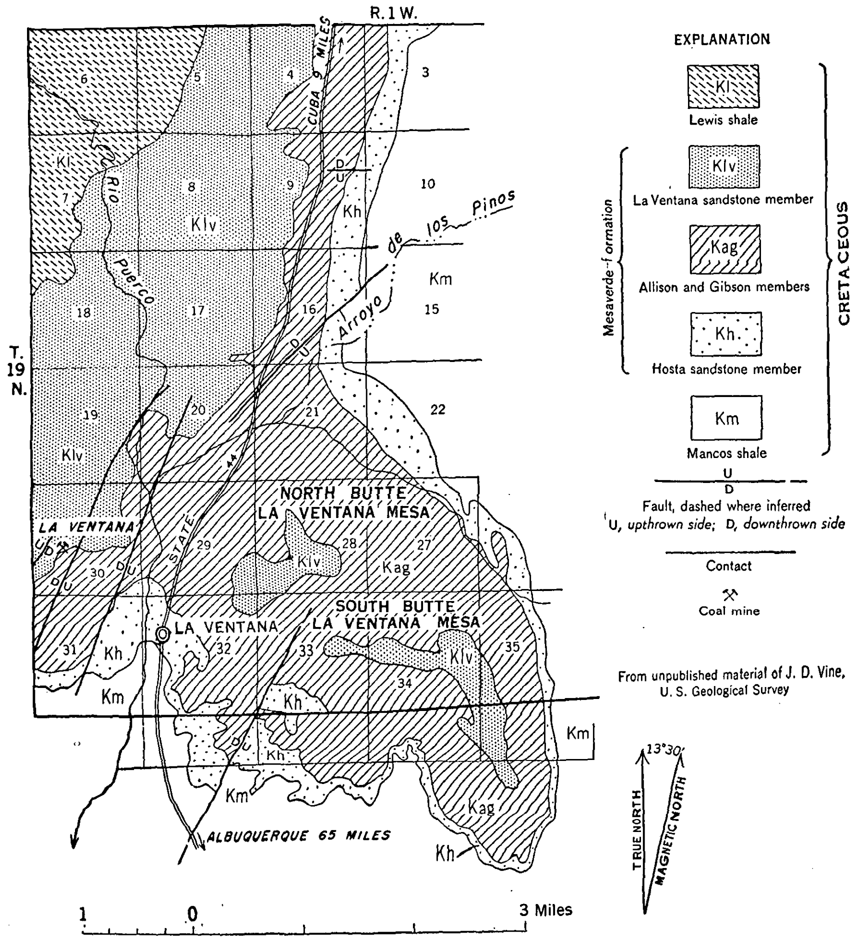

FIGURE 59.—Geologic map of the La Ventana area, Sandoval County, N. Mex.

METHODS AND EXTENT OF WORK

Plant distribution studies were made, and coal and preliminary plant samples were collected in the summer of 1952. Detailed sampling was begun in the fall of 1952 and completed in the spring of 1953 by Starrett.

Radioactive coal samples collected during previous studies made by Bachman, Vine, Read, and Moore (in preparation) were reanalyzed to determine the minor metal content, and, for comparison, a barren coal sample was collected from the same bed at a distance of several miles and analyzed.

Plants were collected at six stations: near the outcrop of uraniferous coal, on the talus slopes below the coal on each butte, and at the nonuraniferous La Ventana coal mine. E. F. Castetter of the University of New Mexico aided in plant identification.

The method of prospecting used was the collection of livewood and deadwood samples of branches of pinyon and juniper, and a few samples of mountain mahogany, for fluorimetric uranium analyses. The buttes of La Ventana Mesa are covered with a thick growth of pinyon and juniper, which are known to be excellent absorbers of uranium. These trees are phreatophytes; that is, they "habitually obtain their water supply from the zone of saturation either directly or through the capillary fringe" (Meinzer, 1923, p. 95). The uranium-bearing coal at the base of the sandstone acts as a perched zone of saturation and contains the water supply on which the trees depend. Live juniper roots have been observed in mines at depths of several hundred feet. Whether the tree roots on La Ventana Mesa actually penetrate to the coal or whether there is sufficient upward migration of water and soluble salts in the capillary fringe to support root growth is not known. At least the roots have worked down through joints and fractures of the La Ventana sandstone member and sufficient uranium has been absorbed by the trees to be detectable in the trunk, limbs, and branch tips (Cannon, 1952).

For this study, a sample consisted of 6-inch unpeeled sections of either livewood or deadwood branches collected from the quadrants of the tree. Detailed sampling on a grid pattern with a 100- to 200-foot spacing was originally planned on the advice of G. O. Bachman to cover only the western part of the north mesa which was considered to be most favorable for mineralized ground. Later it was decided to include widespaced and admittedly incomplete coverage of the rest of the mesa in order to round out the picture. In all, 90 livewood (fig. 60) and 103 deadwood (fig. 61) samples were collected to cover a large part of the north butte, and 13 deadwood samples were collected on a thin extension of the south butte known to be mineralized (fig. 62). The samples in secs. 29 and 32 were collected in November 1952, and the rest in April 1953. The assays for each tree were plotted on maps of the buttes, and the values contoured with an isogram interval of 0.5 ppm of uranium (figs. 60, 61, and 62).

The samples were analyzed by an extraction fluorimetric method by C. Huffman and G. Burrow of the U. S. Geological Survey. By this method, the samples are ground, ashed, digested in nitric acid, and the solution extracted in ethyl acetate. After evaporation, the residue is analyzed fluorimetrically for uranium.

355398—56——2

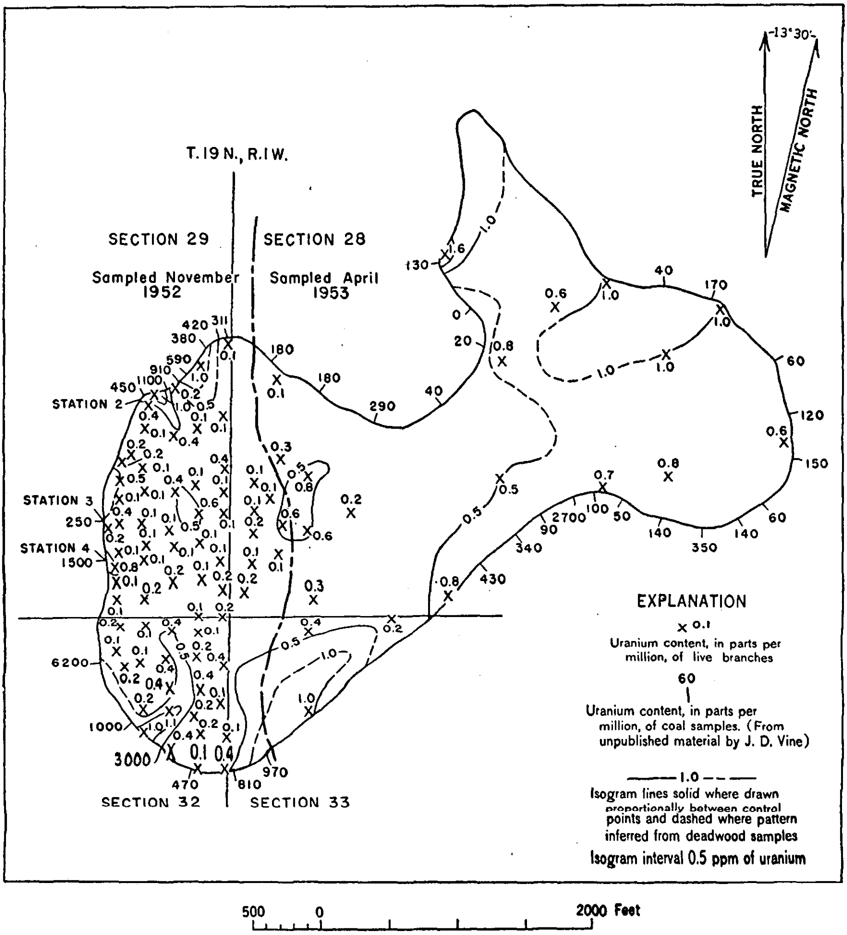

FIGURE 60.—Isogram map showing uranium content of live pinyon and juniper branches from north butte of La Ventana Mesa.

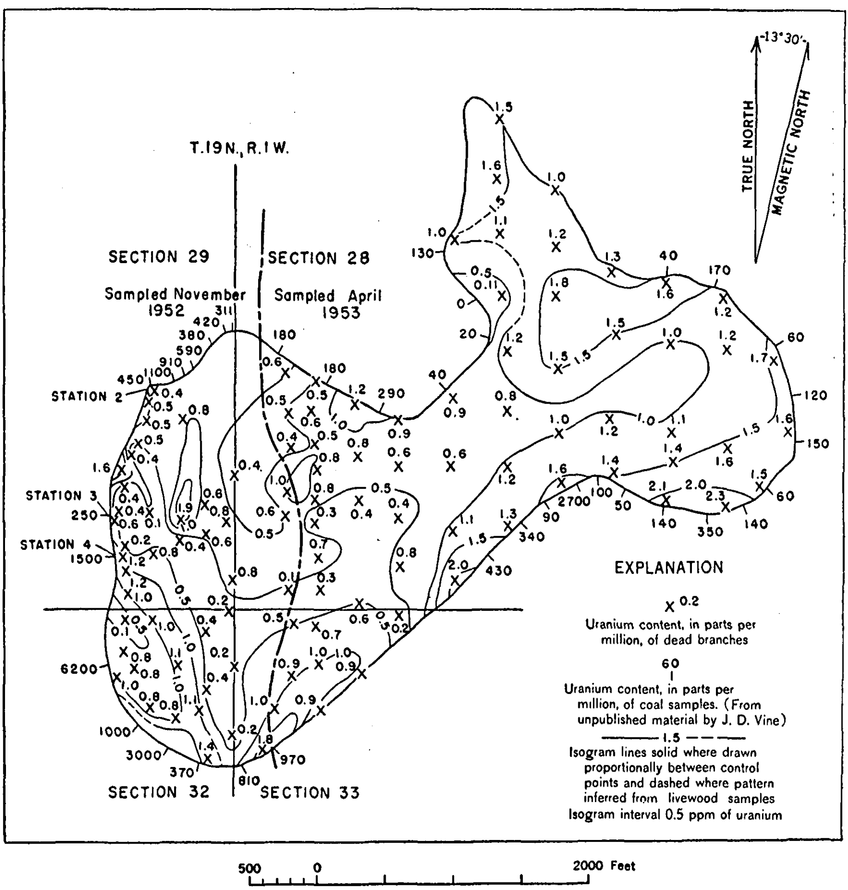

FIGURE 61.—Isogram map showing uranium content of dead pinyon and juniper branches from north butte of La Ventana Mesa.

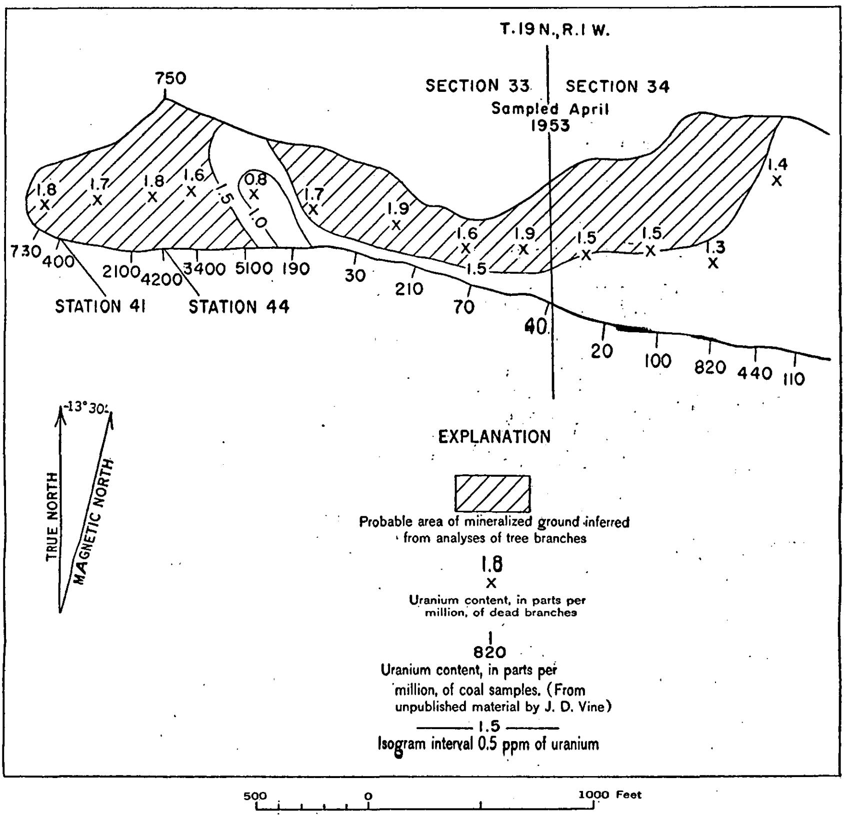

FIGURE 62.—Isogram map showing uranium content of dead pinyon and juniper branches from part of south butte of La Ventana Mesa.

RESULTS

The problem of prospecting La Ventana Mesa for uranium is one of prospecting a barren sandstone mesa top for favorable areas in an underlying coal bed which can only be sampled around the rim. Analysis of samples from the mesa top was therefore chosen as the primary method of prospecting, and only a cursory study of the coal and its effect on the plant ecology of the talus-covered slope was made.

CHEMISTRY OF COAL

Coal is considered by Bachman, Vine, Read, and Moore (in preparation) to be mineralized when it contains more than 100 ppm of uranium; the mineralized parts of the coal bed contain from 100 to 6,200 ppm (0.01 to 0.62 percent) of uranium and the barren parts of the coal average about 20 ppm of uranium. The elements associated with uranium in the mineralized coal compared to barren coal are shown in table 1. The ratio of selenium to uranium is very high in mineralized coal. Chromium, copper, lead, cobalt, molybdenum, nickel, and sulfur also occur in greater amounts in the uranium-bearing coal than in barren coal. Although these elements are concentrated in several types of deposits, the argument that they may be of volcanic origin is strengthened by the fact that anomalous amounts of the same suite of metals occur in three samples of glass collected in the Jemez volcanic field (R. S. Cannon, oral communication).

DISTRIBUTION OF INDICATOR PLANTS

The selenium and sulfur in the coal have affected the plant ecology of the slopes below the coal outcrop. Plants noted in study areas are listed in table 2. Few plants grow along the actual outcrop of uranium-bearing coal and these are limited to a few genera known to be tolerant of uranium ore deposits. *Euphorbia*, *Atriplex*, *Mentzelia*, and *Stanleya* were seen. *Aster tenacetifolius* is also abundant. In addition, two species of *Astragalus* associated with several Crucifers and an *Eriogonum* appear on the slopes and along the drainage channels below the uranium-bearing outcrop. Though these *Astragalus* species have not been proved to be selenium indicators, their presence here is significant and their association with the sulfur indicators listed is suggestive of mineralized ground. It is possible that these plants which extend far down the slope below the coal outcrop may be useful in prospecting along the base of other mesas in the area.

TABLE 1.—*Chemical composition of coals, in percent, from the La Ventana area, Sandoval County, N. Mex.*

[Spectrographic analyses (Ca, Pb, Cr, Cu, Co, Mo, Ni, Ag, and Zn) by A. T. Meyers, U. S. Geological Survey. Chemical analyses (U, Se, and S) by A. M. Sherwood, E. J. Fennelly, R. F. Dufoure, Jesse Meadows, and S. P. Furman, U. S. Geological Survey]

Sample location	eU	U	Se	S	Ca	Pb	Cr	Cu	Co	Mo	Ni	Ag	Zn
Uranium-bearing coal, station 41 (fig. 62).													
8-in. sandstone	0.014	0.006	0.0063	0.35	0.X	(1)	0.000X	0.00X	0.000X	0.0X	0.000X	(1)	(1)
7-in. impure coal	.006	.04	.035	.87	.X	0.00X	.00X	.00X	.000X	.0X	.00X	(1)	(1)
5-in. carbonaceous shale	.019	.013	.007	.01	.X	(1)	.00X	.00X	.000X	.00X	.00X	(1)	(1)
Uranium-bearing coal, station 44 (fig. 62).													
5-in. carbonaceous sandstone	.039	.046	.015	.7	.X	.00X	.00X	.00X	.00X	.00X	.00X	(1)	(1)
3.5-in. impure coal	.3	.42	.06	.26	X.0	.00X	.00X	.00X	.000X	.00X	.00X	tr	0.0X
Barren coal from La Ventana mine (fig. 59) (Same horizon as stations 41 and 44).													
Coal	.0	.0006	.00001	.02	(1)	(1)	.000X	.000X	(1)	(1)	(1)	(1)	(1)

[1] Not found by analytical method used.

TABLE 2.—*Plant distribution data, La Ventana Mesa, Sandoval County, N. Mex.*

[s, selenium indicator plant; cs, calcium sulfate indicator; no, not observed; o, observed]

Plant name	Control indicated	At base of mineralized coal	On talus below mineralized coal		At base of barren coal
			South butte	North butte	
Gramineae:					
Bouteloua gracilis (HBK) Lag. (gramagrass)		no	no	no	o
rothrockii Vasey (gramagrass)		o	no	o	o
Oryzopsis hymenoides (R & S) Rick (ricegrass)	s	no	o	o	o
Elymus salina M. E. Jones (wildrye)		no	o	o	o
Pinaceae:					
Juniperus monosperma (Engelm.) Sarg. (juniper)		no	no	o	o
Pinus edulis Engelm. (pinyon)		no	no	o	o
Gnetaceae:					
Ephedra viridis Cor. (Mormon-tea)		no	no	o	no
Euphorbiaceae:					
Euphorbia fendleri Torr and Gray (sandmat)	cs	o	o	o	no
Chenopodiaceae:					
Atriplex confertifolia (T & S) S. Wats. (shadscale)		o	o	o	o
Chenopodium leptophyllum Nutt. (pigweed)		no	o	no	no
Eurotia lanata (Pursh) Moq. (winterfat)		no	o	o	no
Rosaceae:					
Cowania stansburiana Torr. (cliffrose)		no	o	o	no
Cruciferae:					
Lesquerella gordoni (A. Gray) S. Wats. (bladderpod)	cs	no	no	o	no
Stanleya pinnata Greene (princesplume)	s, cs	o	no	o	no
Dithyrea wislizeni Engelm. (spectaclepod)	cs	no	o	o	no
Capparidaceae:					
Cleome serrulata Pursh (spiderflower)		no	o	no	o
Polygonaceae:					
Eriogonum jamesi Torr. (antelope-sage)	cs	no	o	o	o
Loasaceae:					
Mentzelia sp. (stickleaf)	cs	o	o	o	no
Leguminosae:					
Astragalus greenii Gray (locoweed)	s(?)	no	o	o	no
Astragalus sp	s(?)	no	o	o	no
Compositae:					
Actinea richardsoni (Hook) Kuntze (pingwing)		no	o	no	no
Chrysothamus linifolius Greene (rabbitbrush)		no	o	o	no
Gutierrezia sp. (snakeweed)		no	o	o	no
Aster tenacetifolius HBK (aster)		o	o	no	no

ABSORPTION OF URANIUM BY TREE COVER

Trees rooted directly in barren coal were found by preliminary analyses to contain less uranium in the ash than trees growing over sandstone capping and rooted in underlying mineralized coal. The samples were collected on both buttes where uranium-bearing coals occur, and, for comparison, from nonuraniferous coal in the same bed exposed at the La Ventana coal mine several miles distant. A few preliminary samples were taken for information on variations in uranium content between livewood and deadwood of juniper (*Juniperus monosperma*), pinyon (*Pinus edulis*), and mountain mahogany

(*Cercocarpos montanus* Raf.). The results are shown in table 3. It must be remembered that the uranium content detected in the branches has been raised through 65 feet of root system and 10 feet of trunk and therefore is not large. Basic work (Cannon, 1952, p. 743) has shown that much of the uranium absorbed by the roots is precipitated within the root near the point of intake and that the uranium

TABLE 3.—*Plant absorption data, La Ventana Mesa*

[Analysts: E. J. Fennelly and Claude Huffman, U. S. Geological Survey]

Location and kind of tree	Type of branch sampled	Ash (percent)	Uranium (ppm) in ash	Uranium (ppm) in coal 65 ft. below ground surface [1]
Samples collected on South butte (fig. 62)				
Juniper, above station 44	Live	5.1	0.4	400
Pinyon, above station 44	do	2.2	.4	400
Juniper, above station 41	do	4.7	.5	4,200
Mountain mahogany, above station 41.	do	3.1	.8	4,200
Do	Dead	2.7	3.2	4,200
Traverse on North butte (figs. 60 and 61)				
1. Pinyon, above station 2	Live	2.1	.4	400
Do	Dead	4.4	.4	400
2. Mountain mahogany, 50 ft south of no. 1.	Live	1.8	.1	unknown
Do	Dead	2.5	.5	unknown
3. Pinyon, 170 ft south of no. 2.	do	2.7	.5	unknown
4. Pinyon, 200 ft south of no. 3.	Live	3.0	.2	unknown
Do	Dead	3.1	.5	unknown
5. Pinyon, 200 ft south of no. 4.	Live	2.5	.5	unknown
Do	Dead	4.4	1.6	unknown
6. Mountain mahogany, 10 ft south of no. 5.	Live	1.8	.4	unknown
Do	Dead	2.3	.8	unknown
7. Pinyon, above station 3	Live	2.6	.4	200
Do	Dead	3.1	.4	200
8. Pinyon, above station 4	Live	2.2	.8	1,500
Do	Dead	3.2	1.2	1,500
Nonuraniferous coal at La Ventana mine				
Juniper	Live	5.3	.3	6
Pinyon	do	1.8	.2	6

[1] Station numbers and coal analyses from geologic sampling described by J. D. Vine, U. S. Geological Survey.

content within the root therefore decreases with distance from the source. These variations are reduced in the parts of the tree above ground, and the comparative uranium contents of tree branches and leaves appear to reflect very closely the uranium content of the soil or rock in which the tree is rooted. The livewood of trees was found to contain from 0.2 ppm uranium in the ash when the tree was rooted in barren coal containing 0.0006 percent uranium, to 0.8 ppm uranium in the ash when the tree was rooted in mineralized coal containing 0.04 percent uranium; and the ash of deadwood ranged from 0.4 to 3.2 ppm uranium under the same respective conditions. The three species sampled show no significant difference in uranium absorption.

Closely related species that may differ markedly in percent of ash nevertheless contain closely comparable proportions of uranium in the ash. From this it follows that the uranium content of the dry weight of different species shows much more variability than does the uranium content of the ash. This is illustrated by the following summary of livewood data, taken from table 3:

Comparison of average uranium contents in juniper and pinyon branches

Tree sampled	Average percent of ash	Average uranium content—	
		In ash (ppm)	In dry weight (ppm)
Juniper	4.9	0.40	0.02
Pinyon	2.5	.45	.01

Plants of similar absorption habits may be collected, then, regardless of variations in ash content, and used interchangeably in pattern sampling. Furthermore, because uranium is measured in the laboratory in the plant ash, it is better to express it in relation to ash than to dry weight. Too, the deadwood sampled contains a larger amount of uranium in the ash than the livewood. This marked increase, shown in table 3, raises the amount to be detected chemically in a given amount of ash to a more readily determined quantity. For this reason, it was decided to use deadwood of pinyon and juniper in sampling wherever possible on the buttes of La Ventana Mesa.

The assays for each tree were plotted on maps of the buttes and the values contoured with an isogram interval of 0.5 ppm of uranium (figs. 60, 61, and 62). The resulting isograms are similar in pattern although several variations in results are apparent. First, both types of wood (live and dead) were not taken from every tree and therefore the same number of points is not available for contouring on each map. Second, the outstanding difference between maps plotted on deadwood and livewood assays is one of uranium content rather than pattern, as deadwood consistently contains more uranium in the ash. Assays of livewood samples of pinyon and juniper range from 0.1 ppm to 1.6 ppm of uranium, and deadwood samples from 0.1 to 2.3 ppm of uranium in the ash. The amount of ash in the deadwood samples averaged 4.6 percent, compared to 2.5 percent in the livewood samples. Third, a group of tree samples from the most favorable part of the buttes averaged lower in uranium content than a group of tree samples from parts of the buttes inferred to be less favorable from a study of coal analyses. The samples from the less favorable area were collected and analyzed several months later than the samples from the more favorable areas.

Although the causes of the variations mentioned have not yet been adequately investigated, it is possible to resolve the differences empirically and to compile maps to show the probable uranium-bearing parts of the buttes. It is significant that all common control points on the two maps indicate a similar isogram pattern. Therefore, in areas where there are not enough control points for close contouring on one map, isograms have been inferred from analyses of the other type of material and drawn as dashed lines (figs. 60 and 61). It can also be seen that the isogram pattern for 1 ppm of uranium in the ash of livewood coincides closely with that of 1.5 ppm of uranium in the ash of deadwood. If the outlined areas are compared, using this ratio, the areas on the east side of the butte appear to be favorable. The third variation, that in analyses, probably reflects changes in laboratory procedure. This conclusion is based on the fact that the uranium content of deadwood should not exhibit seasonal variations, and this is the only alternative explanation of the sharp change in uranium content in the adjacent areas sampled at different times. Because of these differences which resulted in an increase of about 0.5 ppm of uranium, large areas on the east end of the north butte above the cutoff values used are probably not favorable and have not been hachured (fig. 63).

Areas of plants having relatively high uranium content probably correspond with areas of relatively high uranium content in the coal. The results coincide roughly but not exactly with known areas of uraniferous coal sampled along the outcrop. The assays of uranium in coal reported by Bachman, Vine, Read, and Moore (in preparation) are shown on figures 60, 61, and 62. A final compilation of favorable areas has been made in figure 63. The tree assays indicate that the areas of uraniferous coal may be fracture controlled and of relatively small magnitude.

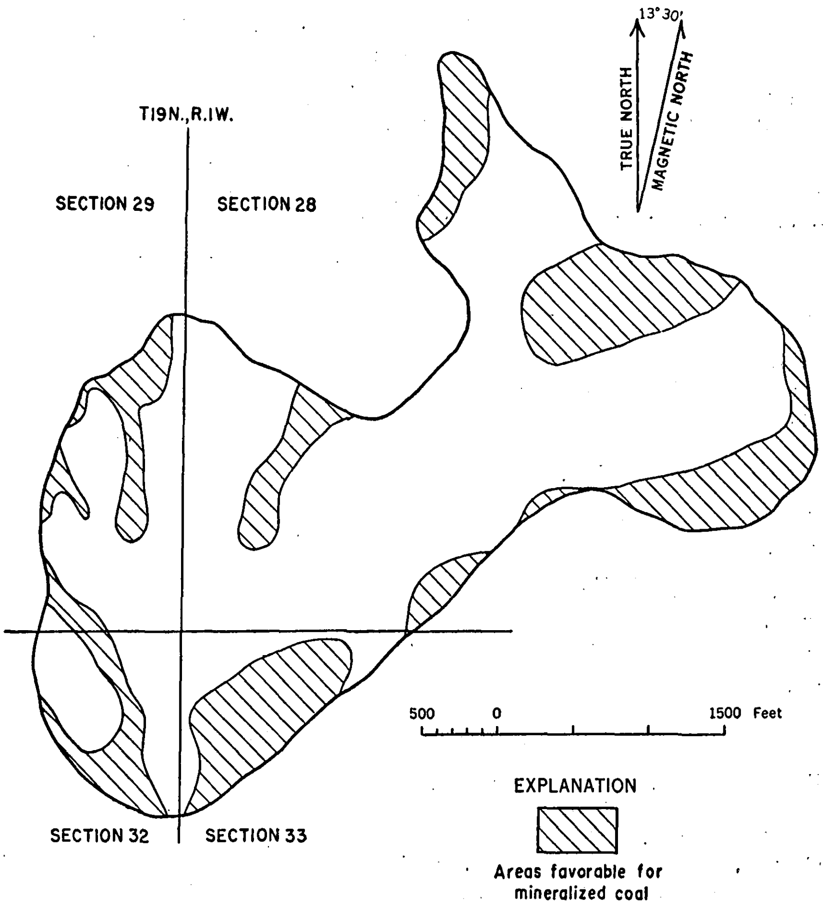

FIGURE 63.—Probable areas of uranium-bearing coal, as interpreted from analyses of livewood and deadwood samples of pinyon and juniper branches from the north butte of La Ventana Mesa.

SUMMARY AND CONCLUSIONS

A preliminary study was made of the metal content of the uraniferous coal that crops out on La Ventana Mesa and the effect of the sulfur and selenium on the vegetation of the mesa slopes. In addition, about two hundred tree branch samples were collected in an area of one-half square mile of mesa and analyzed for uranium as a guide to exploration in outlining uraniferous portions of the coal.

Minor amounts of sulfur, selenium, chromium, copper, lead, cobalt, molybdenum, and nickel were found to be concentrated in uranium-bearing parts of the coal. A selenium content of 600 ppm was reported in one sample. The selenium-indicator plants *Stanleya* and two species of *Astragalus* were noted on the slopes below the coal outcrop. These were associated with sulfur-absorbing Crucifers and *Eriogonum*.

Pinyon and juniper trees growing on the sandstone which caps the mesa absorb uranium from the underlying coal. The assays ranged from 0.1 ppm of uranium in ash of pinyon and juniper trees rooted in barren ground to 2.3 ppm of uranium in the ash of these trees rooted in mineralized coal. The uranium content of dead branches was found to exceed that of live branches in the majority of trees. Areas presumed to be favorable for drilling were outlined on maps of the mesa. Botanical anomalies coincide fairly well with the known areas of uraniferous coal sampled previously along the outcrop.

Several conclusions may be drawn from the studies made in connection with the botanical sampling program. The association of metals in the uranium-bearing coal suggests enrichment from an unusual source, possibly the Pliocene(?) Bandelier tuff of Smith (1937). The distribution of metals within the coal is limited to isolated patches and presumably resulted from ground-water solution and deposition. Weathering of the mineralized coal has affected the vegetation of the slopes. It is possible that sulfur and selenium plants which grow down slope from the deposits may be useful in prospecting.

The assays indicate that the areas of mineralized coal may be fracture controlled and relatively small. This botanical survey suggests that uraniferous areas of coal may be present in the eastern part of the north butte where the coal in the rim is largely under cover.

LITERATURE CITED

Bachman, G. O., Vine. J. D., Read, C. B., Moore, G. W., 1956 Uranium bearing coal and carboniferous shale in the La Ventana Mesa area, Sandoval County, N. Mex.: U. S. Geol. Survey Bull. [in preparation].

Cannon, H. L., 1952, The effect of uranium-vanadium deposits on the vegetation of the Colorado Plateau: Am. Jour. Science, v. 250, p. 735–770.

Darton, N. H., 1929, "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794.

Meinzer, O. E., 1923, The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489, p. 95.

Renick, B. C., 1931, Geology and ground-water resources of western Sandoval County, New Mexico: U. S. Geol. Survey Water-Supply Paper 620, p. 6–8.

Smith, H. T. U., 1937, Tertiary and Quaternary geology of the Abiquiu Quadrangle, N. Mex. [Abstract] Geol. Soc. Amer. Proc. 1936, p. 103.

INDEX

U. S. GOVERNMENT PRINTING OFFICE: 1956