Trace Elements Reconnaissance Investigations in New Mexico and Adjoining States in 1951

Trace Elements Memorandum Report 443

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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Dr. Phillip L. Merritt, Assistant Director
Division of Raw Materials
U. S. Atomic Energy Commission
P. O. Box 30, Ansonia Station
New York 23, New York

Dear Phil:

Transmitted herewith are six copies of Trace Elements Memorandum Report 443, "Trace elements reconnaissance investigations in New Mexico and adjoining states in 1951," by George O. Bachman and Charles B. Read, October 1952.

Uranium in possible commercial amounts was found at La Ventana Mesa, Sandoval County, New Mexico. These deposits and the plans for their further investigation are discussed in TEI-241, which is in preparation and should be transmitted soon.

Slightly uraniferous coal and carbonaceous shale were found near San Ysidro, Sandoval County, and Beautiful Mountain, San Juan County, New Mexico, and at Keams Canyon, Navajo County, and near Tuba City, Coconino County, Arizona. None of these occurrences appear to be of immediate economic importance, but additional reconnaissance has been under way this field season in these general areas.

Sincerely yours,

W. H. Bradley
Chief Geologist

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no. 443

Geology - Mineralogy

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plus 4 figures.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

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TRACE ELEMENTS RECONNAISSANCE INVESTIGATIONS IN NEW MEXICO AND ADJOINING STATES IN 1951*

By

George O. Bachman and Charles B. Read

October 1952

Trace Elements Memorandum Report 443

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*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission

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TRACE ELEMENTS RECONNAISSANCE INVESTIGATIONS IN NEW MEXICO AND ADJOINING STATES IN 1951

By George O. Bachman and Charles B. Read

ABSTRACT

In the summer and fall of 1951, a reconnaissance search was made in New Mexico and adjacent states for uranium in coal and carbonaceous shale, chiefly of Mesozoic age, and black marine shale of Paleozoic age. Tertiary volcanic rocks, considered to be a possible source for uranium in the coal and associated rocks, were examined where the volcanic rocks were near coal-bearing strata.

Uranium in possibly commercial amounts was found at La Ventana Mesa, Sandoval County, N. Mex. Slightly uraniferous coal and carbonaceous shale were found near San Ysidro, Sandoval County, and on Beautiful Mountain, San Juan County, all in New Mexico, and at Keams Canyon, Navajo County, and near Tuba City, Coconino County, in Arizona. Except for the La Ventana deposit, none appeared to be of economic importance at the time this report was written, but additional reconnaissance investigations have been underway this field season, in the areas where the deposits occur.

Marine black shale of Devonian age was examined in Otero and Socorro Counties, New Mexico and Gila County, Arizona. Mississippian black shale in Socorro County and Pennsylvanian black shale in Taos County, New Mexico also were tested. Equivalent uranium content of samples of these shales did not exceed 0.004 percent.

Rhyolitic tuff from the Mount Taylor region is slightly radioactive as is the Bandelier tuff in the Nacimiento region and in the Jemez Plateau. Volcanic rocks in plugs and dikes in the northern Chuska Mountains and to the north in New Mexico as well as in northeastern Arizona and southeastern Utah are slightly radioactive. Coal and carbonaceous rocks in the vicinity of these and similar intrusions are being examined.

INTRODUCTION

During 1951 the writers made a geologic reconnaissance of portions of New Mexico and adjoining states in search of uranium, primarily in black shales and carbonaceous rocks and in an effort to evaluate the potentialities of certain regions for uranium prospecting in the future. This work was done on behalf of the Atomic Energy Commission. Various reconnaissance radiometric techniques were used in the search for uranium in each region as each offered different geologic problems. Carborne radiometric equipment was used to traverse extensive areas with the objective of eliminating negative areas. Carborne equipment could not be taken into certain areas but regions which showed relatively high background gamma ray count--indicating that bodies of disseminated radioactive elements were present--were examined in more detail for possible local concentrations of minerals. Inaccessible areas were traversed as frequently as possible on foot with portable Geiger counters.

Instruments used in geologic reconnaissance consisted of a carborne gamma ray counter equipped with two 46-inch Geiger-Mueller cathode tubes, a portable gamma ray counter equipped with a 24-inch Geiger-Mueller cathode tube, portable gamma-beta counters of the Nuclear type, and a Berkeley scaler. The carborne counter and the portable 24-inch cathode tube were used to locate areas of high background gamma ray count (i.e. rock types containing minute but abnormal quantities of radioactive elements).

GENERAL CONSIDERATIONS

It is the writers' belief that, to be most effective, reconnaissance for uranium deposits must be considered in connection with the framework of the geology of the region. Areas judged most likely to contain deposits of uranium, based on the present knowledge of the geologic conditions under which uranium occurs, should be examined first and in the greatest detail. Seemingly less favorable areas then should be considered.

Particular attention has been given to the search for rock types which contain disseminated radioactive elements. This search has been stimulated by the possibility that locally, under favorable geologic conditions, radioactive minerals may be concentrated from such disseminated bodies. Thus, volcanic rocks, tuffaceous sediments, and arkose often contain small amounts of uranium which could be concentrated by geologic agents in favorable receptor rocks.

Receptor rocks include:

1. Carbon and carbonaceous materials, such as coal and carbonaceous shale, probably adsorb or otherwise concentrate the uranyl ion (Tolmachev, 1943). Hence they are suitable receptors for the concentration of uranium carried by ground water, either past or present.

2. Clay minerals of relatively large space lattice may concentrate uranium through ionic exchange or adsorption (Frederickson, 1948).

In addition to the above receptor materials limestone may be of some importance in the concentration of uranium. Notestein (1918) has stated that "calcite readily precipitates vanadium and uranium from vanadyl and uranyl sulphate solutions."

The distribution of coal and carbonaceous rocks in New Mexico is relatively well known, as are the broad outlines of the chief areas of volcanic flows, tuffs, and associated materials. Where volcanic rocks and tuffs are concerned, it is necessary also to consider the probable former extent of the potential source rocks as well as their present distribution. The places where receptor rocks and possible source rocks are associated were examined first.

REGIONS[1/] INVESTIGATED

Carbonaceous beds were examined in eight regions during the 1951 field season. Most of the regions contained extrusive igneous rocks or were adjacent to igneous activity. These include the following (figs. 1 and 2):

1. Datil Mountain region
2. Zuni-Gallup Basin region

1/In the present discussion region refers to a geographic area of rather broad extent. Area refers to a portion of a region, and locality refers to individual outcrops or lines of outcrop within an area. Areas described in this report do not necessarily fall within the confines of previous mapping projects.

3. Carthage, Sierra Blanca, and Engle regions
4. Mount Taylor region including the San Mateo area
5. San Ysidro and La Ventana areas in the Nacimiento region
6. Chuska Mountain region
7. Black Mesa region
8. Miscellaneous areas

Marine black shale bodies of various ages were examined at a number of localities and sandstone-type copper deposits were examined where present in the regions studied.

Datil Mountain region, New Mexico

The Datil Mountain region in Socorro, Catron, and Valencia Counties, New Mexico, has been mapped and described by Winchester (1921). Cretaceous coal-bearing strata of Mesaverde age are overlain locally by the Tertiary Datil formation. The Mesaverde strata consist of interbedded sandstone, shale, and subbituminous coal. The coal beds are relatively thin and lenticular. The Datil formation is composed of conglomerate, and andesitic and rhyolitic tuff. The Datil formation was checked radiometrically in the field at numerous localities but no abnormal radioactivity was observed. Coal beds were checked radiometrically throughout the stratigraphic section in Jaralosa Canyon and at positions high in the stratigraphic section in Red Canyon with negative results. As radioactivity was not noted, no samples were collected in the Datil Mountain region.

Zuni-Gallup Basin region, New Mexico

The Zuni-Gallup Basin in Valencia and southern McKinley Counties, New Mexico, has been mapped and described by Sears (1925). Interbedded sandstone, shale, and subbituminous coal of the Mesaverde formation of Upper Cretaceous age is present over most of the region. McCann (1938) has described Tertiary sediments with white tuff and bentonitic clay resting unconformably on the Mesaverde formation in the Zuni Basin. The tuffaceous material was examined by the writers at several points along New Mexico State Highway 32 between Gallup and Zuni. Coal beds a few feet stratigraphically below the erosional unconformity were also examined. Abnormal radioactivity was not found in either the tuff or the coal and no samples were collected.

Carthage, Sierra Blanca, and Engle regions, New Mexico

The Carthage, Sierra Blanca, and Engle regions in Socorro, Lincoln, and Sierra Counties, New Mexico, were examined briefly. Basic igneous intrusions of Tertiary age are in close association with carbonaceous and coal-bearing strata of Upper Cretaceous age. Abnormal radioactivity was not observed in either the igneous rocks or the carbonaceous beds. One sample (Sample 17) from a carbonaceous shale in the Upper Cretaceous about 5 miles east of Engle contained 0.002 percent equivalent uranium, which is not considered significant.

Mount Taylor region, New Mexico

A slightly radioactive tuff is widespread in the Mount Taylor region in McKinley and Valencia Counties, New Mexico. The tuff is a potential source for radioactive elements; carbonaceous beds in the Dakota sandstone and the Mesaverde formation may be important factors in the concentration of uranium derived from the tuff. The geology of the Mount Taylor region has been described by Gardner (1910) and by Hunt (1936, 1937).

Hunt (1937, p. 58) attributes the tuff to the earliest period of eruption of Mount Taylor and describes it as a rhyolitic tuff that is distinctly bedded. Other types of volcanic rocks are also present. The tuff is well exposed in the Grants Ridges about 3 miles northeast of the town of Grants where a pumice mine is now being operated. The tuff is also exposed at numerous points around La Jara Mesa in the San Mateo area and on the north end of Horace Mesa. Three samples of the tuff (Samples O, 19, 20) were collected at the mine north of Grants. The samples contained from 0.002 to 0.003 percent equivalent uranium and 0.001 percent uranium. Clayey material (Sample 21) collected from a playa in the canyon below the pumice mine contains 0.004 percent equivalent uranium and 0.002 percent uranium. These percentages are significant in that they indicate the presence of disseminated uranium in the Mount Taylor region. The tuffaceous material is porous and permeable which makes it readily susceptible to leaching by ground water solutions. Under favorable geologic conditions the disseminated uranium may be concentrated in rock units in close proximity to the present, or past, distribution of the tuff.

Cretaceous carbonaceous rocks and coal have been examined radiometrically at numerous points in the Mount Taylor region with negative results. At the places examined so far, however, the rocks between the carbonaceous material and the tuff have so little porosity and permeability that ground water could not readily carry mineral-bearing solutions into the carbonaceous material. At least 2,000 feet of argillaceous sediments is present between the tuff and the carbonaceous material. Coal (Sample 18) in Lobo Canyon, west of Mount Taylor, contained only 0.003 percent uranium in the ash of the coal. Samples 18 to 23 were collected in the Mount Taylor region.

Additional work in the Mount Taylor region will be aimed at finding carbonaceous material located favorably in relation to potential source rocks.

Nacimiento region, New Mexico

Mesaverde and Dakota sediments of Cretaceous age, containing coal and carbonaceous shale, crop out in the San Ysidro area in the southern portion of the Nacimiento region, Sandoval County, New Mexico (Hunt, 1936). The northern limits of the area are about 3 miles south of the town of San Ysidro. Pumiceous sediments of the Tertiary Santa Fe formation are exposed just east of the area and may have supplied radioactive elements which could have been concentrated in the carbonaceous Cretaceous sediments. Only minor radioactivity has been found in the San Ysidro area. A bed of coal 1.9 feet in thickness (Sample 25) in the Mesaverde formation contains 0.004 percent uranium in the ash. Samples 24-27 and 41-42 were collected in the San Ysidro area.

The La Ventana area in the southern part of the Nacimiento region is located just west of the highly folded and faulted pre-Cambrian and Paleozoic rocks in the Sierra Nacimiento. The geology of the area has been described by Renick (1931), Dane (1936), and Wood and Northrop (1946). Coal occurs in rocks of Mesaverde age in the vicinity of La Ventana. On the eastern flank of the Sierra Nacimiento the Bandelier tuff of Pleistocene (?) age caps many of the higher mesas. The Bandelier tuff is also widespread on the Jemez volcanic plateau to the east of the Sierra Nacimiento. The tuff contains as much as 0.006 percent equivalent uranium and 0.003 percent uranium (Samples 95, 96). The La Ventana area seemed favorable for the occurrence of uraniferous coal because of the possibility that the Bandelier tuff formerly lapped westward across the Sierra Nacimiento and thus supplied uranium which could be concentrated in the carbonaceous rocks of the Mesaverde formation.

Additional reconnaissance in the eastern part of the Nacimiento region will aim at finding other deposits of carbonaceous rocks favorably located in relation to the Bandelier tuff on the Jemez plateau.

Uranium was found in coal and carbonaceous shale in the Allison member of the Mesaverde formation on La Ventana Mesa in August, 1951, (Bachman and Read, 1951). Uranium was also found east of La Ventana Mesa in carbonaceous beds in the Gibson coal member of the Mesaverde formation and in the Dakota sandstone (Read, 1952). The coal on La Ventana Mesa contains as much as 0.62 percent uranium with 1.34 percent uranium in the ash. The La Ventana deposits are described in detail and with plans for further work by Vine, Bachman, Read, and Moore (1952, TEI-241, in preparation).

Chuska Mountain region, New Mexico and Arizona

Upper Cretaceous strata bearing coal and carbonaceous rocks are widespread in the Chuska Mountain region at San Juan County, New Mexico and Apache County, Arizona and the adjacent San Juan Basin in New Mexico. Volcanic rocks of Tertiary age are intimately associated with the Cretaceous strata. The volcanic rocks occur chiefly in plugs and are usually of basic composition. However, Gregory (1917, p. 81) has reported rhyolitic ash in the Chuska sandstone of Tertiary age.

The portion of the Chuska Mountain region examined is on the western flank of the San Juan structural basin. On Beautiful Mountain, (fig. 3) strata of Mesozoic age dip eastward into the basin from the northern extension of the Defiance uplift which bounds the San Juan Basin on the west. The Mesozoic rocks are truncated and overlain by the Chuska sandstone and other rocks and volcanic debris of Tertiary age.

Minor radioactivity was detected in carbonaceous sediments and coal of Upper Cretaceous age on Beautiful Mountain. The Upper Cretaceous Tocito sandstone includes a zone of carbonaceous material and coal at its top. Where the carbonaceous material is near the erosional surface upon which the Tertiary sediments were deposited, minor radioactivity was detected at many places. On Beautiful Mountain, the upper half of a bed of coal 1.3 feet thick contains 0.007 percent uranium (Sample 103). Immediately below a joint in the overlying strata the same bed contains 0.010 percent uranium with 0.021 percent uranium in the ash (Sample 102). Other carbonaceous material about 150 feet stratigraphically and topographically below the points sampled contained no abnormal radioactivity.

Slightly abnormal radioactivity was detected in many volcanic plugs and their associated dikes. Radioactivity was estimated to be 0.003 percent equivalent uranium. At several localities on Beautiful Mountain and on Lukachukai Mountain to the west, the Tertiary rocks and volcanic debris contain slight radioactivity. The Tertiary rocks and volcanic material thus seem to be potential source beds for secondary accumulation of uranium in the coal and carbonaceous rocks.

These Tertiary rocks and volcanic debris having slight radioactivity cap both Lukachukai Mountain and Cove Mesa and might be the source of the uranium in the Morrison formation at these places. This possibility probably would be of little importance in the exploration of the Morrison formation in that area but it should be considered in connection with any age determinations made on the Morrison ores of that area.

Black Mesa region, Arizona

The Black Mesa region (fig. 4) covers an area of about 3,000 square miles in Navajo, Apache, and eastern Coconino Counties, Arizona. Sedimentary rocks of Dakota (?) and Mesaverde age cap the mesa at most places. Coal and carbonaceous shale are prominent in these rocks. Hack (1942) has described the Bidahochi formation, which contains volcanic material, resting on Cretaceous and older deposits in the Black Mesa-Hopi Buttes regions. Both the Cretaceous carbonaceous sediments and the Bidahochi formation have been examined radiometrically. No abnormal radioactivity has been detected in the Bidahochi formation; however, minor radioactivity has been noted in carbonaceous material and natural coal ash on Black Mesa. At the Keams Canyon locality (Sample 111 and fig. 4) a coal bed 2.0 feet thick contains 0.004 percent equivalent uranium and 0.002 percent uranium. At the Tuba City coal mine, about 10 miles east of Tuba City, a natural ash contains 0.004 percent uranium (Sample 114 and fig. 4).

Miscellaneous areas

Other areas visited during the 1951 field season include the following:

1. Walsenburg area, Huerfano County, Colorado. Volcanic plugs intrude strata of Cretaceous and Tertiary age. Several acidic plugs in the vicinity of Walsenburg showed slightly abnormal radioactivity. R. B. Johnson collected a sample from the Pierre shale of Cretaceous age which showed slight radioactivity (Sample 105). The sample was collected in the contact zone of the Pierre shale with a dark igneous dike.
2. Pecos area, Santa Fe County, New Mexico. Coal of Pennsylvanian age in the Pecos Valley was examined but no abnormal radioactivity was detected.
3. Sage Plains, Montezuma County, Colorado, and San Juan County, Utah. Coal in the Dakota sandstone was examined at a number of localities along U. S. Highway 160 between Cortez, Colorado, and Monticello, Utah, but no abnormal radioactivity was detected.

4. Asphaltic sandstone of Triassic age (Santa Rosa sandstone) about 9 miles northeast of Santa Rosa, Guadalupe County, New Mexico, was examined radiometrically but with negative results.
5. Sandstone-type copper deposits. Numerous sandstone type copper deposits were examined. Minor radioactivity was detected in most of these deposits. The deposits are described in greater detail by Bachman and Read (1952).

MARINE BLACK SHALE

Marine black shale of Devonian, Mississippian, and Pennsylvanian age was examined at several localities in New Mexico and Arizona. Equivalent uranium content did not exceed 0.004 percent in any of the samples collected. Localities visited included black shale in the Madera formation of Pennsylvanian age near Tres Ritos, Taos County, New Mexico (Sample 1); Percha shale (fig. 1) of upper Devonian age in Otero and Socorro Counties, New Mexico (Samples 7-15); shale in the Lake Valley limestone of Mississippian age in Socorro County, New Mexico (Sample 16); and the upper shaly portion of the Martins limestone of Devonian age in Gila County, Arizona (Samples 106-109). Analyses of these samples are given in the appendix.

RADIOACTIVE VOLCANIC ROCKS

Radioactivity detected in volcanic rocks examined in this study was not restricted to a narrow range of petrologic types, but was detected more consistently in acidic volcanic rocks than in basic ones. The acidic Bandelier tuff of Pleistocene (?) age on the Jemez volcanic plateau and the rhyolitic tuff in the Mount Taylor region showed minor abnormal radioactivity at most places. However, the Abiquiu formation, an acidic volcanic tuff of early Tertiary age at the north end of the Jemez volcanic plateau, and a Tertiary acidic tuff in the Zuni basin were not radioactive.

Most dark volcanic rocks examined contained no radioactivity which was detectable in the field; however breccia and minette in volcanic plugs, such as Ship Rock, Mitten Butte, Ford Butte, and Bennett

Peak in San Juan County, New Mexico and Agathla Peak and similar bodies in Monument Valley, Arizona and Utah, (Williams, 1936) contain slightly abnormal radioactivity. The relatively high potassium content of minette does not appear to be sufficient to account for the radioactivity of the plugs as Twin Cones, near Gallup, New Mexico, contains a similar minette which shows no radioactivity. Several monchiquite volcanic plugs in the Hopi Buttes region were examined but were not radioactive.

PLANS

Areas in which abnormal radioactivity was detected during 1951 in coals and carbonaceous shales and potential source rocks in New Mexico and Arizona are being examined by the Survey in reconnaissance fashion this year. The areas in which the work is being concentrated and the occurrences there of abnormal radioactivity are summarized below.

1. The east flank of the Chuska Mountains, San Juan County, New Mexico from Chuska Valley southward to the vicinity of Washington Pass, including Beautiful Mountain where one sample from a coal bed in the Tocito sandstone contained 0.007 percent uranium. A brief airborne radiometric survey was made during September 1952 and, although the detailed results are not yet available, one anomaly of possible interest was found. Exposures of coal and carbonaceous shale are poor and the ground reconnaissance is being made with the most sensitive radiometric instruments available.

2. The Mount Taylor-Mesa Chivato region contains slightly uraniferous volcanic rocks resting on coal-bearing Cretaceous strata. The coal and carbonaceous rocks are being examined in detail. An important part of the investigation in this area is the study of the regional geology of the tuff to determine as far as possible the former extent of the tuff to focus attention on areas where carbonaceous rocks once were overlain by it.

3. Mesa Prieta, Sandoval County, New Mexico consists of Cretaceous coal-bearing strata capped by volcanic rocks. Little is known of the volcanic rocks but Mesa Prieta is about half way between the Mount Taylor-Mesa Chivato region and the Jemez volcanic plateau, where slightly radioactive volcanic rocks occur.

Exposures in the vicinity of Mesa Prieta are poor and reconnaissance radiometric examination is being made with the most sensitive instruments available. An airborne radioactivity survey will be made if feasible.

4. Chacra Mesa, McKinley County, New Mexico, consists of coal-bearing rocks that may once have been overlain by volcanic rocks. Preliminary reconnaissance is being undertaken.

5. The Black Mesa region contains coal-bearing rocks, and a natural coal ash at the Tuba City mine contains 0.004 percent uranium. Possible sources of the uranium have not been recognized. Some coal beds in the nearby areas could be mined by stripping and other strippable coal beds probably exist in the Black Mesa region. Coal beds and carbonaceous rocks are being examined wherever possible. In addition, reconnaissance is being continued in the Jemez Plateau and in the Nacimiento region.

Plans for work on La Ventana Mesa, Sandoval County are given in detail in TEI-241 (in preparation). Throughout the reconnaissance, data on volcanic rocks are being gathered. These data will contribute to knowledge of petrologic types of volcanic rocks containing disseminated uranium, the areal extent of these types, and the natural conditions under which uranium could be released from them.

REFERENCES

Bachman, G. O., and Read, C. B., 1951, Results of recent reconnaissance investigations of uranium in coal, black shale, and related deposits in Sandoval and Rio Arriba Counties, New Mexico: U. S. Geol. Survey Trace Elements Memorandum Rept. 309.

—————————— 1952, Uranium-bearing copper deposits near Guadalupita, Mora County, New Mexico: U. S. Geol. Survey Trace Elements Memorandum Rept. 435.

Dane, C. H., 1936, The La Ventana-Chacra Mesa coal field: U. S. Geol. Survey Bull. 860-c, pp. 81-166.

Denson, N. M., Bachman, G. O., and Zeller, H. D., 1950, Summary of new information on uraniferous lignites in the Dakotas: U. S. Geol. Survey Trace Elements Memorandum Rept. 175.

Frederickson, A. F., 1948, Some mechanisms for the fixation of uranium in certain sediments: Science, vol. 108, pp. 184-185.

Gardner, J. H., 1910, The coal field between San Mateo and Cuba, New Mexico: U. S. Geol. Survey Bull. 381-c, pp. 461-473.

Gregory, H. E., 1917, Geology of the Navajo Country: U. S. Geol. Survey Prof. Paper 93.

Hack, J. T., 1942, Sedimentation and volcanism in the Hopi Buttes, Arizona: Geol. Soc. Am. Bull. No. No. 2, vol. 53, pp. 335-372.

Hunt, C. B., 1936, The Mount Taylor coal field: U. S. Geol. Survey Bull. 860-b, pp. 31-80.

Hunt, C. B., 1937, Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U. S. Geol. Survey Prof. Paper 189-B.

McCann, F. T., 1938, Ancient erosion surface in the Gallup-Zuni area, New Mexico: Am. Jour. Sci., vol. 36, 5th ser. pp. 260-278.

Notestein, F. B., 1918, Some chemical experiments bearing on the origin of certain uranium-vanadium ores: Econ. Geology vol. 13, pp. 50-64.

Read, C. B., 1952, Recent discoveries of radioactive carbonaceous shale, Sandoval County, New Mexico: U. S. Geol. Survey Trace Elements Memorandum Rept. 278.

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

Sears, J. D., 1925, Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U. S. Geol. Survey Bull. 767.

Tolmachev, I. M., 1943, Adsorption of uranyl salts on solid adsorbents, USSR Acad. Sci. Bull. No. 1, pp. 28-34.

Vine, J. D., Bachman, G. O., Read, C. B., and Moore, G. W., 1952, Uranium-bearing coal and carbonaceous shale in the La Ventana Mesa area, Sandoval County, New Mexico: U. S. Geol. Survey Trace Elements Investigations Rept. 241 (In preparation).

Winchester, D. E., 1921, Geology of Alamosa Creek Valley, Socorro County, New Mexico: U. S. Geol. Survey Bull. 716-a, pp. 1-15.

Wood, G. H., Jr., and Northrop, S. A., 1946, Geology of Nacimiento Mountains, San Pedro Mountain, and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U. S. Geol. Survey Oil and Gas Prelim. Map. 57.

Williams, Howel, 1936, Pliocene volcanoes of the Navajo-Hopi country: Geol. Soc. Am. Bull., vol. 47, pp. 111-172.

APPENDIX

Samples collected for laboratory analysis, 1951

Sample Number	eU Percent	U Percent	Ash Percent	U in ash Percent	Location and Remarks
BNM-0	0.0026	0.0010			Pumice, mine ca. 5 miles north Grants, N. Mex.
1	0.002	0.001			Bituminous shale, marine Pennsylvanian (Madera fm), 1.9 miles east of Taos-Mora County line on N. Mex. State Hwy. No. 3
2	0.012	0.010			Coyote Mining Dist., Mora County, N. Mex. Carbonaceous shale associated with sandstone-type copper deposit, Sangre de Cristo fm. (Permian)
3	0.006	0.004			Tailings from prospect pit, Coyote Mining Dist.
4	0.010	0.009			Tailings from prospect pit, Coyote Mining Dist.
5	0.003	0.001			Guadalupe mine, Guadalupe Co., N. Mex. Carbonaceous shale associated with sandstone-type copper deposit. Santa Rosa sandstone, Triassic
6	0.002	0.002			Guadalupe mine, carbonaceous material in sandstone
7	Less than .001				Base of Percha shale (Devonian) Alamo Canyon, Otero Co., N. Mex.
8	.004	.002			Calcareous zone in Percha shale, ca. 15 feet above base, Alamo Canyon
9	0.004	0.002			Calcareous zone in Percha shale, ca. 22' above base, Alamo Canyon
10	0.003				Percha shale, Alamo Canyon, Basal 3' of 6' shaly unit
11	0.002				Percha shale, Alamo Canyon, Upper 3' of 6' shaly unit
12	0.001				Percha shale, Alamo Canyon, Nodular unit below contact with Lake Valley limestone (Miss.)
13	0.001				Percha shale, 20' from base, Rhodes Pass, San Andres Mts., Socorro County, N. Mex.
14	0.001				Percha shale, 20' unit above No. 13

Samples collected for laboratory analysis, 1951--Continued

Sample Number	eU Percent	U Percent	Ash Percent	U in ash Percent	Location and Remarks
BNM-15	0.001				Percha shale, 10' unit above No. 14
16	0.002				Calcareous shale, in Lake Valley limestone (Miss.) Rhodes Pass
17	0.002				Carbonaceous shale, Mesaverde fm. (Cret.) ca. 5 miles east of Engle, Sierra Co., N. Mex.
18	0.001	0.001	31.0	0.003	Coal, Mesaverde fm. (Cret.) Lobo Canyon west of Mt. Taylor, Valencia Co., N. Mex.
19	0.002	0.001			Pumice, mine ca. 5 miles north Grants, [illegible], Valencia Co., N. Mex.
20	0.003	0.001			Pumice, mine ca. 5 miles north Grants, N. Mex.
21	0.004	0.002			Clay, playa below pumice mine, 5 miles north Grants, N. Mex.
22	0.002				Carbonaceous shale parting, Dakota sandstone (Cret.), 3 miles north Prewitt, Valencia Co., N. Mex.
23	0.002				Carbonaceous shale parting, Dakota sandstone (Cret.), 5 miles north of Grants, N. Mex.
24	Less than 0.001				Santa Fe fm. (Pliocene), pumiceous, 3 miles south San Ysidro, Sandoval Co., N. Mex.
25	Less than 0.001	.001	33.2	0.004	Coal, Mesaverde fm., San Ysidro coal field, Sandoval Co., N. Mex.
26	0.001	0.001			Clay, overlying No. 25
27	0.002				Shale, overlying No. 26
28	0.004	0.005			Aggregate of rock types, Spanish Queen mine, Abo fm. (Permian), Jemez Canyon, Sandoval Co., N. Mex.
29	0.007	0.006			Carbonaceous shale, Spanish Queen mine
30	0.009	0.009			Carbonaceous shale, Spanish Queen mine
31	0.005	0.006			Sandy carbonaceous shale, Spanish Queen mine
32	0.007	0.009			Copper mineralized zone, Spanish Queen mine

Samples collected for laboratory analysis, 1951--Continued

Sample Number	eU Percent	U Percent	Ash Percent	U in ash Percent	Location and Remarks
BNM-33	0.007	0.008			Copper mineralized zone, Spanish Queen mine
34	0.004	0.003			Copper mineralized zone, Spanish Queen mine
35	0.007	0.009			Carbonaceous shale, outcrop adjacent to Spanish Queen mine
36	0.019	0.015			Pod-like mass, copper mineralized zone, Spanish Queen mine
37	0.006	0.005			Copper mineralized zone, Agua Zarca sandstone (Triassic Senorito Dist., Sandoval Co., N. Mex.
38	0.005	0.005			Copper mineralized zone, Abo fm. (Permian) Piedras Negras Canyon, Sandoval Co., N. Mex.
39	0.002	0.003			Copper mineralized zone, Poleo sandstone (Triassic) Cobre Wash, Rio Arriba Co., N. Mex.
40	0.003	0.002			Carbonaceous shale in Wanakah fm. (Jurassic), Butte 2 1/2 miles south of Coyote, Rio Arriba Co., N. Mex.
41	0.002				Carbonaceous shale in Dakota sandstone (Cret.). San Ysidro coal field, Sandoval Co., N. Mex.
42	0.001	0.001			Carbonaceous shale in Dakota sandstone. Below No. 41

Note: Samples 43-92 included in Trace Elements Investigations Report 241 (Vine, Bachman, Read, Moore)

93	0.006				Rat excreta associated with Bandelier tuff, Jemez volcanic plateau, Sandoval Co., N. Mex.
94	0.005				Tuff, same locality as No. 93
95	0.006	0.003			Bandelier tuff (Tertiary), Rio Las Vacas Canyon, Sandoval County, N. Mex.
96	0.003	0.003			Bandelier tuff, Jemez Canyon, Sandoval County, N. Mex.

Note: Samples 97-101 included in another report. (Vine, Bachman, Read, Moore).

Samples collected for laboratory analysis, 1951--Continued

Sample Number	eU Percent	U Percent	Ash Percent	U in ash Percent	Location and Remarks
BNM-102	0.010	0.010	45.5	0.021	Coal, Tocito sandstone, (Cret.), Beautiful Mountain, San Juan County, N. Mex.
103	0.006	0.007	56.1	0.013	Coal and bone, Tocito sandstone, Beautiful Mountain
104	0.002	0.002			Iron stained Tocito sandstone, Beautiful Mountain
105	0.002	0.002			Pierre shale (Cret.) associated with basaltic dike, Huerfano County, Colo.
106	0.004	Less than 0.001	93.2	Less than 0.001	Lower 5' of 20' shale in Martin limestone (Devonian) Gila County, Ariz.
107	0.004	Less than 0.001	91.0	Less than 0.001	Second 5' above 106
108	0.003		88.4		Third 5' above No. 107
109	0.004	Less than 0.001	87.8	Less than 0.001	Top 5' above No. 108
110	0.002		91.5		Carbonaceous shale, Cretaceous, Deer Creek coal field, Gila Co., Ariz.
111	0.004	0.002	79.0	0.003	Carbonaceous shale, Cretaceous, Keams Canyon, Navajo Co., Ariz.
112	0.004	0.002	91.5	0.002	Carbonaceous shale and stone above No. 111
113	0.003	0.002	97.8	0.002	Natural ash, upper 1' of 2' Tuba City coal mine, Coconino County, Ariz.
114	0.005	0.001	93.9	0.004	Natural ash, below No. 113
115	0.002	0.001	42.5	0.002	Bony coal 5.5' below No. 114