Selected Annotated Bibliography of the Geology of Uranium-bearing Coal and Carbonaceous Shale in the United States

GEOLOGICAL SURVEY BULLETIN 1059-A

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By THOMAS M. KEHN

SELECTED BIBLIOGRAPHIES OF URANIUM GEOLOGY

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SELECTED ANNOTATED BIBLIOGRAPHY OF THE GEOLOGY OF URANIUM-BEARING COAL AND CARBONACEOUS SHALE IN THE UNITED STATES

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INTRODUCTION

This annotated bibliography of literature and open-file reports dealing with uranium in coal and associated carbonaceous shale in the United States includes nearly all pertinent reports published or in preparation as of June 1955. In addition, several foreign references are listed which have contributed to the study of the origin and distribution of uranium in coal and lignite.

Most of the coal beds and associated carbonaceous shales in the United States are practically nonradioactive, but many have been found during the past few years that assay from 0.005 to about 0.10 percent uranium; the concentration is greater in the ash. Investigations suggest that coal of lignite rank contains the most uranium; that coals of subbituminous B and C ranks contain the next largest concentration; and that only rarely do the higher rank coals contain more than 0.001 percent uranium. Lignite containing more than 0.10 percent uranium recently has been found in the northern Great Plains. Economic utilization of the large low-grade reserves of uranium in coal is partly dependent upon the use of the coal as fuel and the recovery of uranium from the ash as a byproduct.

The stratigraphic nomenclature in this report is that used by the various authors and does not necessarily conform to the nomenclature of the U. S. Geological Survey.

EXPLANATION OF INDEX MAP

The index map (fig. 1) shows localities underlain by uranium-bearing coal beds and carbonaceous shale. Places where the concentration of uranium is 0.005 percent or more are shown on the map, but those that contain less than 0.005 percent uranium are not, although they are included in the bibliography. The locality numbers shown on the index map correspond to the numbered entries in the bibliography.

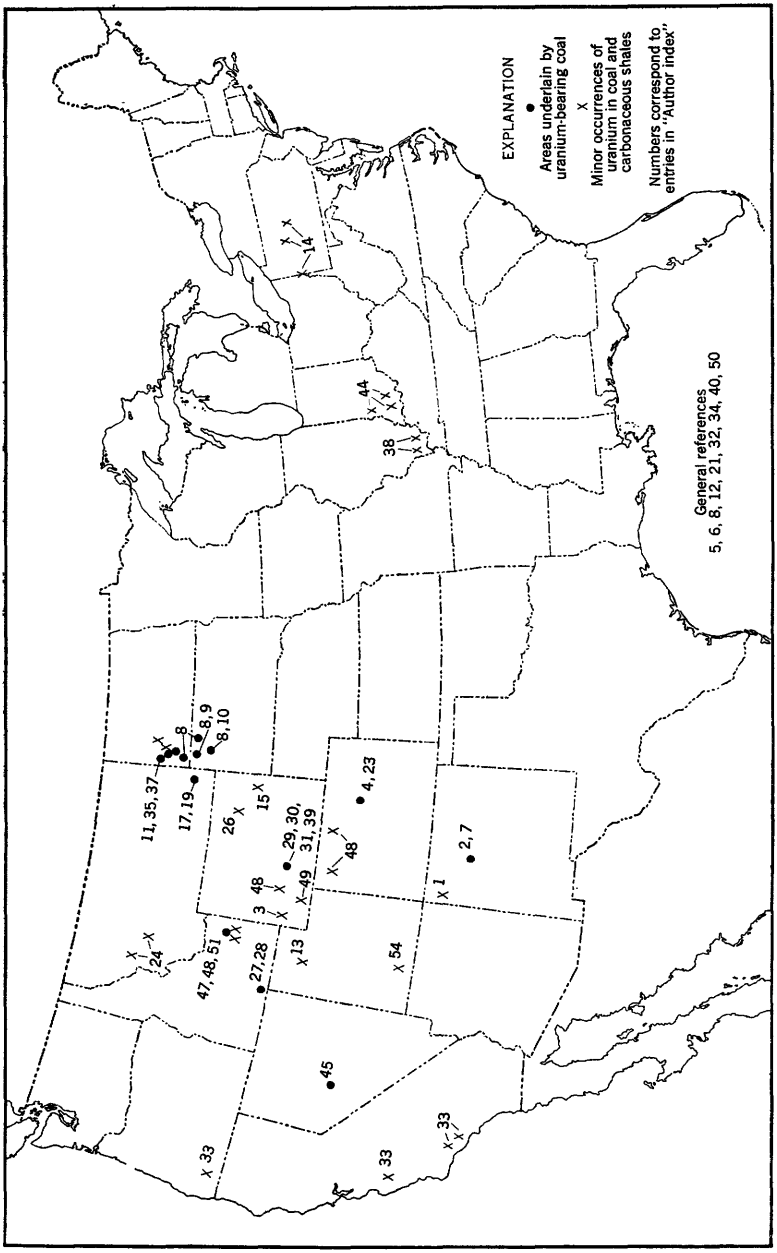

FIGURE 1.—Index map of uranium-bearing coal and carbonaceous shale in the United States.

ANNOTATED BIBLIOGRAPHY

1 Bachman, G. O., and Read, C. B., 1952, Trace elements reconnaissance investigations in New Mexico and adjoining States in 1951: U. S. Geol. Survey TEM–443–A, 22 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A reconnaissance was made of uranium-bearing coals and carbonaceous shale, chiefly of Mesozoic age, in Arizona and New Mexico. Coal in the Allison member of the Mesaverde formation on La Ventana Mesa, Sandoval County, N. Mex., has a maximum uranium content of 0.62 percent, and 1.34 percent in the ash. Slightly uraniferous coal was found near San Ysidro, Sandoval County; on Beautiful Mountain, San Juan County, N. Mex.; and near Tuba City, Coconino County, Ariz. Also examined was the black shale of Devonian age in Otero and Socorro Counties, N. Mex., and Gila County, Ariz.; and the black shale of Mississippian age in Socorro County and the black shale of Pennsylvanian age in Taos County, N. Mex. The equivalent uranium content of these shales did not exceed 0.004 percent. Cenozoic volcanic rocks may be the source of the uranium in the coal and carbonaceous rocks. Volcanic rocks of Pleistocene(?) age are mildly radioactive at most places, but the Tertiary volcanic rocks are not radioactive.

2 Bachman, G. O., Vine, J. D., Read, C. B., and Moore, G. W., 1957, Uranium-bearing coal and carbonaceous shale in the La Ventana Mesa area, Sandoval County, N. Mex.: U. S. Geol. Survey Bull. 1055–J (in preparation).

Uranium-bearing coal, carbonaceous shale, and carbonaceous sandstone occur in the Mesaverde formation and Dakota sandstone of Cretaceous age on and adjacent to La Ventana Mesa. Analyses indicate that the coal contains from 0.001 to 0.62 percent uranium and as much as 1.34 percent uranium in the ash. Structural control of uranium concentration is indicated by the proximity of major deposits to the axis of the La Ventana syncline and by individual uranium concentrations in and near tent-shaped structures, minor synclines, and joints. All important concentrations of uranium are closely related to carbonaceous sediments and porous sandstone beds. This close association of porous sandstone beds to uranium deposits suggests that the sandstone beds served as aquifers through which uranium-bearing solutions migrated. The uranium in the La Ventana area probably is of epigenetic origin and derived from the Bandelier tuff of Pliocene(?) age. The Bandelier tuff probably once covered the area but the nearest existing remnants are several miles away. Data on reserves of coal and uranium, geologic maps, and analyses of samples are presented.

3 Beroni, E. P., and McKeown, F. A., 1952, Reconnaissance for uraniferous rocks in northwestern Colorado, southwestern Wyoming, and northwestern Utah: U. S. Geol. Survey TEI–308–A, 41 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Coal-bearing rocks within the Bridger, Great Divide, and Washakie Basins of southwestern Wyoming are of Cretaceous and Tertiary age.

Two coal beds, which are about 4 feet thick, near Sage, Lincoln County, Wyo., contain from 0.004 to 0.013 percent uranium in the ash. These coal beds are in the Bear River formation, which probably is a time equivalent of the Dakota sandstone. Other types of uranium occurrences also are discussed.

4 Berthoud, E. L., 1875, On the occurrence of uranium, silver, iron, etc., in the Tertiary formation of Colorado Territory: Acad. Nat. Sci. Phila. Proc., v. 27, p. 363–365.

Uranium, iron, and silver were discovered in a mineralized bed of coal at the Leyden coal mine northwest of Denver, in Jefferson County, Colo. The mineralized portion of the coal is described as an intruded "dike" (presumably of igneous origin) consisting of hard black mineral matter containing geodes of brilliant quartz crystals, small veins of pyrite, chalcedony, orange crystals, and concretions.

5 Breger, I. A., Deul, Maurice, and Rubinstein, Samuel, 1955, Geochemistry and mineralogy of a uraniferous lignite: Econ. Geology, v. 50, p. 206–226.

Detailed studies have been carried out on a uraniferous lignite from the Mendenhall strip mine, Harding County, S. Dak. By means of heavy liquid separations a mineral-free concentrate of the lignite was obtained that contained 13.8 percent ash and 0.31 percent uranium in the ash. The minerals (gypsum 69 percent, jarosite 10 percent, quartz 2 percent, kaolinite and clay minerals 19 percent, and calcite trace) contain only 7 percent of the uranium in the original coal, indicating an association of the uranium with the organic components of the lignite.

Batch extractions show that 88.5 percent of the uranium can be extracted from the lignite by two consecutive treatments with boiling 1N hydrochloric acid. Continuous extraction with hot 6N hydrochloric acid removes 98.6 percent of the uranium.

Columns of coal were treated with water, 1N hydrochloric acid, 6N hydrochloric acid, and a solution of lanthanum nitrate. The experiment with lanthanum nitrate indicated that only 1.2 percent of the uranium in the coal is held by ion exchange. The elutriation experiments showed that the uranium is held in the coal as an organo-uranium compound or complex that is soluble at a pH of less than 2.18.

A geochemical mechanism by which the uranium may have been introduced into and retained by the lignite is discussed.—*Authors' abstract*

6 Davidson, C. F., and Ponsford, D. R. A., 1954, On the occurrence of uranium in coals: Mining Mag. (London), v. 91, Nov. 1954, p. 265–273. Reprinted in South African Min. and Eng. Jour., Johannesburg, v. 65, pt. 2, p. 721, 723, 725–727.

Coals generally are considered to be very low in uranium content, but there are notable exceptions. Attention is directed to a number of coals in which there is an anomalous concentration of uranium. This report is limited to groups of coals in Europe and America that have a uranium content three times higher than is usual for such strata.

A uranium-bearing coal bed was discovered during gamma-ray logging in the Warwickshire coalfield near Coventry, England. This coal, probably less than 1 foot thick, is a few hundred feet above the productive coal measures and is believed to be a part of the Halesowen Sandstone Group. Lateral extent of the uraniferous enrichment is unknown; a bore-hole 200 yards to the west does not show radioactivity on the gamma-ray log; a sandstone of Triassic age that contains scattered, highly uraniferous black nodules is believed to truncate the coal to the east of the radioactive bore-hole. This suggests that the uranium in the coal was derived from downward-moving water from the sandstone. The coal contains 0.008 percent uranium and the ash contains 0.08 percent uranium. Uranium minerals have not been identified in microscopic examinations of polished sections of coal from this locality.

The Freital coal, near Dresden, Germany, has been exploited as a source of uranium. This coal, which is Lower Rotliegende in age (base of Permian system), contains some coaly shale. Information is not available on the extent and uniformity of the uranium content, but it is probable that the uranium is confined to one or more beds at the top of the coal, as it is in similar coals in other countries. Coal ash from the most radioactive specimens contains 0.18 to 1.00 percent uranium. The granites of the Erzegebirge and Lausitzergebirge to the southwest and southeast probably are the source of the uranium.

Recent studies of the Hungarian coalfields have shown that in some localities thin layers of coal and coaly shale of Liassic age contain a maximum of 0.01 percent equivalent uranium. In general the highest concentrations of uranium are in the thinner coal seams near mountain massifs of radioactive granite or interbedded with radioactive sills and other intruded bodies. On the basis of experimental data it is suggested that the uranium fixation is contemporaneous with deposition of the organic matter.

Studies of coal and lignite deposits in the western United States have shown that most of the uranium-bearing coal is associated with contemporaneous or younger sequences of acidic lavas and tuffs. In the South Dakota lignites only the top lignite bed, just below the volcanic rock, possesses any significant amount of uranium. In Idaho the carbonaceous beds near the top of any sequence are the most uraniferous; 1 foot below the top of the carbonaceous bed the uranium content diminishes abruptly—a fact suggesting downward-moving water as the transporting medium for the uranium. Most of these western coal deposits contain only 0.005–0.02 percent uranium, but some small deposits have a maximum of 0.1 percent uranium.

7 Denson, N. M., and others, 1952, Summary of uranium-bearing coal, lignite, and carbonaceous shale investigations in the Rocky Mountain region during 1951; with descriptions of deposits by G. O. Bachman and others: U. S. Geol. Survey TEM–341, 44 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

This paper reports the results of investigations by the Geological Survey of uranium-bearing lignite deposits of South Dakota; coal deposits of the Red Desert, Great Divide Basin, Wyo.; deposits at Pumpkin Buttes, Wyo.; coal deposits of Fall Creek and Goose Creek, Idaho; and desposits at La Ventana, N. Mex. The investigations were conducted to estimate the potential uranium resources and to study the mode of occurrence of uranium. The potential resources range from 350 million tons of coal containing 20,000 tons of uranium in the Red Desert area of Wyoming, to 100,000 tons of lignite containing 20 tons of uranium in the Lodgepole area of South Dakota. The proposed epigenetic hypothesis of origin for the deposits is based on field and laboratory data. It is suggested that the uranium in the deposits in the carbonaceous rocks was leached by ground water from the overlying tuffaceous rocks.

8 Denson, N. M., Bachman, G. O., and Zeller, H. D., 1957, Uranium-bearing lignite and its relation to the White River and Arikaree formations in northwestern South Dakota and adjacent States: U. S. Geol. Survey Bull. 1055–B (in preparation).

In northwestern South Dakota and adjacent States uranium-bearing lignite beds occur in the Hell Creek formation of Late Cretaceous age and the overlying Ludlow, Tongue River, and Sentinel Butte members of the Fort Union formation of Paleocene age. Analyses indicate that many of the lignite beds contain 0.005 to 0.02 percent uranium and 0.05 to 0.10 percent uranium in the ash.

Stratigraphic units containing the uraniferous lignite beds are unconformably overlain by tuffaceous sandstone and bentonitic claystone of the White River and Arikaree formations of Oligocene and Miocene age. The lignite bed directly below this unconformity in the local sequence has the greatest concentration of uranium. Lignite beds lower in the section are nonuraniferous except where intersected by faults or joints. This distribution indicates that the uranium is independent of the age of the lignite, that the uranium has been transported downward by descending and laterally moving ground water, and that the uranium probably was leached from the overlying mildly radioactive tuffaceous rocks.

The most significant conditions controlling the concentration of uranium are explained and illustrated in the text. Maps show the extent, thickness, and variations in mineral content of deposits in the Table Mountain, Cave Hills, Slim Buttes, Lodgepole, and Medicine Pole areas.

9 Denson, N. M., Bachman, G. O., and Zeller, H. D. 1955, Geologic map of Cave Hills and Table Mountain area, Harding County, South Dakota: U. S. Geol. Survey Coal Inv. Map C 34, scale 1:63,360.

The geologic map of the Cave Hills and Table Mountain area shows the areal distribution of lignite and the amount of uranium in lignite at sampled localities. Rocks exposed in this area are Late Cretaceous to Oligocene in age.

10 Denson, N. M., Bachman, G. O., and Zeller, H. D., 1955, Geologic map of Slim Buttes area, Harding County, South Dakota: U. S. Geol. Survey Coal Inv. Map C 35, scale 1:63,360.

The map shows the geology of the northern and central parts of the Slim Buttes area, Harding County, S. Dak., and indicates lignite outcrops and the amount of uranium in the lignite at sampled localities. The rocks are Late Cretaceous to Recent in age.

11 Denson, N. M., Bachman, G. O., Zeller, H. D., Gill, J. R., Moore, G. W., and Melin, R. E., 1955, Uraniferous coal beds in parts of North Dakota, South Dakota, and Montana: U. S. Geol. Survey Coal Inv. Map C 33.

This map is composed of a series of geologic and block diagrams of the Sentinel Buttes area, Golden Valley County, N. Dak.; Bullion Butte area, Billings and Golden Valley Counties, N. Dak.; Medicine Pole area, Bowman County, N. Dak.; Ekalaka Hills area, Carter County, Mont.; and the Lodgepole area, Perkins County, S. Dak. Two block diagrams show the relation of radioactive lignite deposits to the regional geologic setting and to the base of the White River group in these areas. The geologic maps show the position and correlation of the lignite outcrops; the maps of the Lodgepole and Medicine Pole areas also show the uranium content of the lignite at sampled localities.

12 Denson, N. M., and Gill, J. R., 1955, Uranium-bearing lignite and its relation to volcanic tuffs in eastern Montana and the Dakotas; Contr. to the Internat. Conf. on peaceful uses of atomic energy, Geneva, Switzerland, August 1955: U. S. Geol. Survey Paper, United Nations No. P/57.

The uranium-bearing lignite deposits in western North and South Dakota and southeastern Montana occur near the north-central part of the Great Plains province about 100 miles north of the Black Hills. The region is a rolling prairie, broken by small areas of badlands or by buttes and ridges which are rugged and precipitous. The important uranium-bearing lignite deposits underlie the more prominent buttes. The mineralized lignite beds occur throughout 2,200 feet of fluviatile deposits of early Tertiary and Late Cretaceous age. In general the strike of the rocks is northwest and the regional dip is about 10 to 40 feet per mile northeast into the Williston Basin. Overlapping the lignite-bearing sequence with marked regional unconformity are 300 feet or more of ash-gray mildly radioactive tuffs and bentonitic clays of Oligocene and Miocene age. Field evidence indicates that the uranium was leached from the tuffs and concentrated in the underlying lignite. Lignites in the paths of these uranium-bearing waters are believed to have acted as receptors that extracted the uranium to form organo-uranium complexes or ionic organic-uranium compounds. Chemical analyses of water from the tuff show significant concentrations of uranium in association with arsenic, copper, phosphorus, vanadium, and molybdenum. An epigenetic theory of origin explaining the presence of uranium in the lignite is supported by the facts that the mineralized beds, irrespective of their ages, closely underlie the unconformity at the base of the Oligocene and that greater concentrations of uranium occur in the upper parts of the stratigraphically highest lignites.

Much of the uranium-bearing lignite in the region is adapted to strip mining and is in beds four feet in thickness. Analyses of approximately 500 surface and 1,000 core samples indicate that the mineralized lignites contain 0.005 to 0.02 percent uranium with concentrations of 0.05 to 0.1 percent uranium in the lignite ash. Molybdenum is also closely associated with uranium in the lignite in concentrations ranging from 0.01 to 1.0 percent in the lignite ash. In general, the grade of the uranium-bearing lignite deposits is low; but, since the tonnages of lignite containing an average of 0.008 percent uranium are great, these deposits form a resource of possible future value particularly if industry should use the lignite as fuel and recover the uranium and other metals as byproducts from the ash. It is quite possible that with the development of new metallurgical techniques and recovery processes many of these deposits will eventually be exploited. The discovery of significant tonnages of autunite and zeunerite-bearing lignite, containing as much as 2 to 5 percent uranium in beds 18 to 30 inches thick in the Cave Hills area of northwestern South Dakota, adds greater interest to lignite as an economic source for uranium and indicates that other deposits of uranium-bearing lignite of comparable grade will be discovered.—*Authors' abstract*

13 Duncan, D. C., 1953, Results of reconnaissance for uranium in nonmarine carbonaceous rocks in parts of California, Idaho, Nevada, Oregon, Utah, and Washington during 1951 and 1952: U. S. Geol. Survey TEM-444-A, 26 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Nonmarine carbonaceous rocks, including lignitic shales, coals, and peat, were tested at about 30 localities in California, Idaho, Nevada, Oregon, Utah, and Washington. Rocks ranging in age from Carboniferous to Quaternary were examined, although the principal attention was given middle and late Tertiary lignites of the northern part of the Great Basin. Most carbonaceous rocks examined contained essentially no uranium; but lignitic shales in the Goose Creek district, Idaho, a thin carbonaceous shale near Hagerman, Idaho, and a small peat deposit in Davis County, Utah, contained more than 0.003 percent uranium.—*Author's abstract*

14 Ferm, J. C., 1955, Radioactivity of coals and associated rocks in Beaver, Clearfield, and Jefferson Counties, Pa.: U. S. Geol. Survey TEI-468, 52 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Radioactivity investigations were made of the coal beds and associated rocks of the Pottsville, Allegheny, and Conemaugh formations in Beaver, Clearfield, and Jefferson Counties, Pa. Most of the coals and shales collected were nonradioactive or only slightly radioactive. At two localities near Darlington, Beaver County, the Lower Freeport underclay contains up to 0.014 percent equivalent uranium, 0.016 percent uranium and 0.026 percent uranium in ash. The bottom six inches of coal contains about 0.007 percent equivalent uranium, 0.010 percent uranium, and 0.060 percent uranium in the ash. Near Dora, Jefferson County, the Lower Freeport Rider coal contains a maximum of 0.006 percent and an average of 0.003 to 0.004 percent equivalent uranium. The underclays consistently show the greatest radioactivity of the rock types tested. Structure and weathering apparently had little effect on the distribution and concentration of uranium in the coal and shale.

15 Gill, J. R., 1953, Parts of Colorado, Wyoming and Montana; *in* Search for and geology of radioactive deposits, Semiannual progress report, December 1, 1952 to May 31, 1953: U. S. Geol. Survey TEI-330, p. 118, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The South Park, Crested Butte, Paonia, Trinidad, Colorado Springs, and Canon City coalfields in Colorado, coal-bearing rocks near Mancos and Durango, and coal in the Denver basin were examined for uranium-bearing coal and carbonaceous rocks. Only two samples contained more than 0.002 percent uranium in the ash. Ash of impure coal in the Cambria coalfield, Weston County, Wyo., contained 0.0085 percent uranium. This is believed to be stratigraphically the highest coal bed in the Lakota sandstone. Commercially mined coal beds are practically nonradioactive. In Ekalaka lignite field, Carter County, Mont., there are several uraniferous lignite beds; the ash of most lignite samples contained 0.005 percent or more uranium. Samples from a 1.5-foot lignite bed averaged about 34 percent ash and 0.057 percent uranium.

16 Gill, J. R., 1954, Northwestern South Dakota, southwestern North Dakota, and eastern Montana, *in* Geologic investigations of radioactive de-

posits, Semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI-490, p. 149-155, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Occurrences of uranium-bearing lignite, carbonaceous shale, and sandstone estimated to contain 0.10 percent or more uranium were discovered in six widely separated areas in northwestern South Dakota, southwestern North Dakota, and eastern Montana. In the North Cave Hills, Harding County, S. Dak., strippable deposits of lignite an average of 1.4 feet thick in an area of 1500 acres contain 0.20 percent uranium and the mineral meta-autunite. In the Tepee Butte area, Harding County, a carbonaceous shale and sandstone underlying about 4 acres contains about 0.40 percent equivalent uranium. In the Slim Buttes area, Harding County, lignite and carbonaceous sandstone containing 0.10 percent or more uranium was found at widely separated localities in the Ludlow member of the Fort Union formation.

The most important discovery is the Reva Gap or Thybo deposit where metatyuyamunite occurs in sandstone that averages about 0.68 percent uranium. Other deposits are: lenses of fresh-water limestone and siltstone in the West Short Pine Hills, Harding County, from 0.01 to 0.1 percent uranium; in the Long Pine Hills area, Carter County, Mont., lignite, siliceous shale, and sandstone from 0.01 to 0.2 percent uranium; in the Rhame area, Bowman County, N. Dak., a carbonaceous shale bed in the Tongue River member of the Fort Union formation, from 0.1 to 0.2 percent equivalent uranium; in the Whetstone Butte area, Adams County, N. Dak., a sandstone in the Tongue River member of the Fort Union formation, from 0.01 to 0.2 percent uranium; and in the Killdeer Mountain area, McKenzie County, N. Dak., a lignitic shale, 0.1 percent equivalent uranium. Other areas having anomalous radioactivity also are mentioned.

17 Gill, J. R., 1954, Ekalaka lignite field, Carter County, Montana, *in* Geologic investigations of radioactive deposits, Semiannual progress report, December 1, 1953 to May 31, 1954: U. S. Geol. Survey TEI-440, p. 109-112, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

In the southern Ekalaka Hills approximately 16.5 million tons of lignite contains 745 tons of uranium. The uranium-bearing lignite is in three beds and has an average uranium content of 0.004 percent. In the northern part of the Ekalaka Hills the lignite beds are overlain by impervious shale and are nonradioactive. Gill believes that the uranium in the lignite is epigenetic and was leached from radioactive tuffaceous rocks and transported by ground water. Maps are included which show the area underlain by uranium-bearing lignite, the concentration and distribution of uranium in the lignite beds, and stratigraphic sections.

18 Gill, J. R., 1954, Mendenhall area, Slim Buttes, Harding County, South Dakota, *in* Geologic investigations of radioactive deposits, Semiannual progress report, December 1, 1953, to May 31, 1954: U. S. Geol. Survey TEI-440, p. 113-117, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Core drilling in the Mendenhall area, Slim Buttes, Harding County, S. Dak., indicates that about 30 million tons of lignite is radioactive and contains about 0.008 percent uranium. The Mendenhall rider, the Mendenhall, and the Olesrud beds contain uranium but only where each bed is highest in the stratigraphic section below the pre-Oligocene unconformity. Maps showing the geology, grade and distribution of uranium, and a table of inferred reserves of lignite and uranium are presented in the text.

19 Gill, J. R., 1957, Reconnaissance for uranium-bearing lignite in the Ekalaka lignite field, Carter County, Montana: U. S. Geol. Survey Bull. 1055–F (in preparation).

Uraniferous lignite beds of the southern Ekalaka Hills are in the lower part of the Fort Union formation of Paleocene age and are directly overlain by the Arikaree formation of Miocene age. Lignite beds that are radioactive in the southern part of the area are nonradioactive elsewhere in the Ekalaka Hills area, where the Arikaree formation unconformably overlies impervious younger rocks of the Fort Union formation. The lignite contains from 0.001 to 0.034 percent uranium; there is a greater concentration in the ash. Analyses of spring water from the Arikaree formation indicate that uranium is being leached now from that formation. The uranium content of representative samples of spring waters is given. It is estimated that about 16 million tons of lignite contain 700 tons of uranium.

20 Gill, J. R., and Zeller, H. D., 1957, Results of core drilling for uranium-bearing lignite, Mendenhall area, Harding County, South Dakota: U. S. Geol. Survey Bull. 1055–D (in preparation).

Core drill data on the Mendenhall area near the center of Slim Buttes indicate that the lignite is about 5 feet thick and contains about 0.005 percent or more uranium. The uranium-bearing lignite is in the Ludlow member of the Fort Union formation of Paleocene age. The geological factors that may have controlled the placement of the uranium are discussed. The distribution of uranium in the lignite indicates that the uranium is of epigenetic origin and derived from the Chadron and Arikaree formations of Oligocene and Miocene age. Data on overburden thickness, fuel analysis, and lignite and uranium reserves are given in the text.

21 Gott, G. B., Wyant, D. G., and Beroni, E. P., 1952, Uranium in black shales, lignites, and limestones in the United States: U. S. Geol. Survey Circ. 220, p. 31–35.

The complete text of the part of this report pertaining to lignite is as follows:

Uraniferous coals of Paleozoic, Mesozoic, and Tertiary ages are known in the United States. The greatest concentrations of uranium occur in Paleocene and Eocene lignites in the Dakotas, Montana, and Wyoming and in a high-ash lignite in Nevada. A few bituminous Pennsylvanian coals in the midcontinent region and sub-bituminous Cretaceous coal in southwestern Wyoming contain as much as 0.004 percent uranium, but hundreds of others have been tested radiometrically and chemically with negative results.

In the Dakotas, Montana, and part of Wyoming, the greatest concentrations of uranium occur in the first group of lignite beds below the Paleocene-Eocene unconformity. The uranium content of the lignite beds is variable, but some contain slightly more than 0.01 percent. The apparent relationship between these lignites and the unconformity between the Paleocene and the Eocene rocks suggest that the uranium may have been leached from volcanic ash in the White River formation and introduced into the lignite by surface waters during post-Paleocene time. The even distribution, however, of the uranium in the lignites, as indicated by an autoradiograph of one sample from North Dakota, and the absence of any apparent concentration of uranium on fracture planes in this area, suggest that the uranium was present before coalification.

In the Red Desert area of Wyoming uraniferous lignites in the Wasatch formation of Eocene age contain from about 0.002 to 0.007 percent uranium. The presence of about 60 percent more radium than that required for equilibrium with uranium indicates that uranium in the exposed lignite has recently been leached and suggests that fresh lignite contains more uranium.

A high-ash lignite of Tertiary age in Churchill County, Nev., contains as much as 0.05 percent uranium. The extremely high ash content of this lignite, however, seems to preclude a significant concentration of uranium by burning such as can be effected with the other lignites mentioned.

22 Gott, G. B., and Hill, J. W., 1953, Radioactivity in some oil fields of southeastern Kansas: U. S. Geol. Survey Bull. 988–E, p. 69–120.

Coal samples from drill cuttings were not available for radiometric analyses; so a few of the Pennsylvanian coals were sampled at outcrops in Bourbon, Cherokee, Crawford, Franklin, Montgomery, and Osage Counties, Kans. Radiometric analyses of the coal samples indicate that the uranium content is uniformly low. The Mulky coal of the Cherokee formation in Bourbon County was the most radioactive sample collected; it contains 0.004 percent equivalent uranium oxide. Uranium in other types of rock also is discussed in the report.

23 Gude, A. J., 3d, and McKeown, F. A., 1953, Results of exploration at the Old Leyden coal mine, Jefferson County, Colorado: U. S. Geol. Survey TEM–292, 14 p. (open-file report).

Six diamond-core holes were drilled at the Old Leyden coal mine to explore the lateral and downward extent of a uranium-bearing coal and the associated carnotite deposits in the adjacent sandstone. The coal bed, in the Laramie formation of Late Cretaceous age, is exposed on the monoclinal fold on the west flank of the Denver Basin. The uranium is restricted to areas where the coal bed is in or adjacent to shear zones associated with faulting. Small lenticular bodies of material occurring at intervals in the coal and silicified coal contain 0.10 to 0.50 percent uranium. Data obtained from the drill samples indicate a discontinuous radioactive zone between these higher grade ore bodies; assays show a range of from 0.001 to 0.10 percent uranium in the samples. Material that contains 0.10 or more percent uranium was found in only one core. The rocks penetrated in the other holes were of lower grade.

24 Hail, W. J., Jr., and Gill, J. R., 1953, Results of reconnaissance for uraniferous coal, lignite, and carbonaceous shale in western Montana: U. S. Geol. Survey Circ. 251, 9 p.

A reconnaissance for uraniferous lignite and carbonaceous shale associated with volcanic rocks was made during the summer of 1951 in 22 areas in western Montana and one adjacent area in Idaho. The coal in 5 of the areas is of Late Cretaceous age; the coal and carbonaceous shale in 18 areas are in Tertiary "lake bed" deposits of Oligocene and Miocene age. Both the Cretaceous and Tertiary coal and carbonaceous shale are associated with volcanic rock, which is thought to be the source of uranium in many areas. The field examination of the coal did not reveal appreciable radioactivity. A sample of carbonaceous shale from Prickly Pear Valley northeast of Helena contained 0.013 percent uranium, and a sample of carbonaceous shale from Flint Creek Valley southwest of Drummond, Mont., contained 0.006 percent uranium. The carbonaceous shale of the Prickly Pear Valley district is overlain by bentonitic ash which contains 0.003 percent equivalent uranium. A table of sample data and a map showing districts and outcrop localities are presented in the text.

25 Lloyd, S. J., and Cunningham, J., 1913, The radium content of some Alabama coals: Am. Chem. Jour., v. 50, p. 47–51.

Coal samples taken from the major coalfields of Alabama were analyzed for their radium content, as the first in a series of examinations of rocks, minerals, and waters of the State. Results of the tests are presented in a table which lists the mine and field from which the samples were taken as well as other data. Coal from the Pratt No. 5 mine in the Warrior coalfield had the highest concentration of radium in the ash. The ash of the richest sample contained 7.05×10^{-12} gram of radium per gram of ash and the poorest sample contained 0.51×10^{-12} gram of radium per gram of ash; the average was 2.15×10^{-12} gram of radium per gram of ash for the coals tested. It is assumed that a gram of uranium is in equilibrium with 3.4×10^{-7} gram of radium in these tests.

26 Love, J. D., 1952, Preliminary report on uranium deposits in the Pumpkin Buttes area, Powder River Basin, Wyoming: U. S. Geol. Survey Circ. 176, 37 p.

Uranium-bearing coal and carbonaceous rocks associated with uranium deposits in sandstone were examined in the Wasatch formation of Eocene age in the Pumpkin Buttes area. Most of the coal beds are about 1 foot thick, but some of the combined coal and associated carbonaceous shale beds are a maximum of 4 feet thick. The uranium content of the coal samples ranges from 0.004 to 0.10 percent. Most of this report is concerned with uranium deposits in sandstone.

27 Mapel, W. J., and Hail, W. J., Jr., 1953, Goose Creek district, Cassia County, Idaho, *in* Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to Nov. 30, 1953: U. S. Geol. Survey TEI–390, p. 135, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Analysis of cores showed that the Barrett zone of carbonaceous shale may contain 0.02 percent uranium and the carbonaceous shale of Zone B in the lower part of the Salt Lake formation may contain 0.01 percent uranium. The core samples were obtained in the central part of the Goose Creek district, Cassia County, Idaho. A geologic map and thickness and radioactivity diagrams accompany the report.

28 Mapel, W. J., and Hail, W. J., Jr., 1957, Tertiary geology of the Goose Creek district, Cassia County, Idaho; Box Elder County, Utah; and Elko County, Nevada: U. S. Geol. Survey Bull. 1055–H. (in preparation).

The Goose Creek district is part of an intermontane basin in Cassia County, Idaho, Box Elder County, Utah, and Elko County, Nev. Rocks of the Payette formation of late Miocene(?) age and of the Salt Lake formation of early Pliocene age contain abundant volcanic material. Uranium is concentrated in the carbonaceous shale and lignite beds in the middle part of the Salt Lake formation. Most of the rocks contain 0.001 to 0.003 percent equivalent uranium, but some carbonaceous shale beds contain 0.01 percent or more uranium. The richest deposit is the top foot of an 8-foot bed of carbonaceous shale that contains 0.12 percent uranium; the bed averages 0.042 percent uranium. The uranium is believed to have been leached from volcanic ash by ground water. The principal mineralized area is on the flanks and in the trough of a syncline where the richest uranium-bearing carbonaceous shale is directly overlain by a thick bentonite. Reserves are estimated to be 900 tons of uranium in beds 2 or more feet thick which average 0.005 percent or more uranium, and 115 tons of uranium in beds 1 foot or more thick which average 0.01 percent or more uranium.

29 Masursky, Harold, 1953, Eastern Red Desert area, Sweetwater County, Wyoming; *in* Geologic investigations of radioactive deposits, Semi-annual progress report, June 1 to November 30, 1953: U. S. Geol. Survey TEI–390, p. 139, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The eastern part of the Red Desert area, Sweetwater County, Wyo., was explored for uranium-bearing coal by drilling 60 core holes. The average uranium content of the coal, estimated from radiometric determinations, is about 0.003 percent. Some of the coal contains 0.007 percent uranium and 0.05 percent uranium in the ash. Data from this drilling program affirm earlier conclusions that the uranium content is greater to the east where the enclosing rocks are more coarse-grained and permeable, and greatest at the bottom of a coal bed where there is a permeable sandstone below and a clay shale above.

30 Masursky, Harold, 1955, Trace elements in coal in the Red Desert, Wyoming; Contr. to the Internat. Conf. on peaceful uses of atomic energy, Geneva, Switzerland, August 1955: U. S. Geol. Survey Paper, United Nations No. P/56.

Uranium-bearing coal underlies approximately 300 square miles of the Red Desert, near the central part of the Great Divide Basin, a large topographic basin of interior drainage along the Continental Divide in south-central Wyoming.

The coal-bearing rocks were cyclically deposited in swamps marginal to the lakes formed in Green River time and are interbedded with coarse-grained fluviatile arkose of the Wasatch formation, to the northeast, and organic lacustrine shale of the Green River formation, to the southwest. The sequence is about 1,200 feet thick and is of early Eocene age. The axis of maximum coal deposition trends northwest; the coal beds are lenticular in cross section and grade into shale to the east and west.

The strata are inclined at angles of one to two degrees so that the coal beds, which are as much as 40 feet thick, are potentially strippable over large areas. The coal is subbituminous B in rank.

The highest concentrations of uranium are localized in the carbonaceous rocks unconformably overlain by gravels of possible Miocene age, as at Creston Ridge where the uppermost coal contains as much as 0.051 percent uranium near the top of the bed, whereas a coal 20 feet lower contains less than 0.001 percent uranium.

Lower widespread concentrations of uranium in the coal, averaging about 0.003 percent, are apparently related to the permeability of the rocks enclosing the coal beds. The uranium content of the coal beds increases toward the northeast as the lithofacies change and become coarser-grained and more permeable. In the cyclically deposited sequence several coal beds in vertical succession are enriched in uranium adjacent to the intercalated beds of coarse-grained sandstone which generally underlie the coals. The close relationship between the uranium content of the coal and the permeability of the surrounding rocks indicates that the uranium was probably epigenetically emplaced.

Gallium, germanium, iron, molybdenum, lead, vanadium, and the rare earths have parallel distribution in the carbonaceous rocks as does uranium, according to semiquantitative spectrographic analyses, and may have been similarly emplaced.

Three possible sources for the uranium and other trace elements partially supported by available evidence are: 1) hydrothermal solutions rising along faults; 2) leaching from the granite during its weathering and erosion; 3) leaching from the overlying tuffaceous rocks.

Laboratory experiments on the solubility of uranium demonstrate the effectiveness of the Red Desert coal as an adsorbent of uranium from natural waters. Investigation of the sedimentary rocks included studies of mineralogic composition, grain size and shape, and porosity and permeability.

Results of the investigation indicate that the large reserves of coal in the Red Desert are of interest primarily as a fuel resource and that uranium probably can only be produced as a by-product. However, thin carbonaceous shale in the coarse-grained clastic facies to the northeast of the principal coal area may be the site of localization of higher-grade uranium deposits.—*Author's abstract*

31 Masursky, Harold, and Pipiringos, G. N., 1957, Preliminary report on uranium-bearing coal in the Red Desert, Great Divide Basin, Sweetwater County, Wyoming: U. S. Geol. Survey Bull. 1055–G (in preparation).

Uranium-bearing coal in the northeastern part of Sweetwater County, Wyo., is in the flat-lying beds of the Wasatch formation of early Eocene age which interfinger with the Green River formation. The Red Desert area, part of a structural and topographic basin between the Rawlins uplift on the east and the Rock Springs uplift on the west, is flanked on the north by the Green Mountains.

The uranium content of the coal beds is greatest in the northeast part of the basin where the coal is interbedded with greater amounts of coarse sediments. The coal highest in the stratigraphic section commonly has the greatest uranium content if impermeable units are not present higher in the section. If the highest coal is associated with impermeable shales and a lower coal is associated with a permeable sandstone, the coal associated with the shale will have a low uranium content and the coal associated with the sandstone will have a high uranium content. The relationship of coal with relatively high uranium content to topographic and stratigraphic highs and to permeable zones suggests a downward and lateral movement of uranium from an overlying source. The uranium content ranges from 0.001 to 0.047 percent in the coal and from 0.005 to 0.19 percent in the ash. Inferred reserves of coal are 162.5 million tons that contain 6,100 tons of uranium; in the Luman coal zone 800 tons of uranium is estimated to be contained in the 21 million tons of coal.

32 Miller, R. L., and Gill, J. R., 1954, Uranium from coal: Sci. Am., v. 191, p. 36–39.

North of the Black Hills in the Dakotas and eastern Montana, lignites and coals in the Fort Union formation of Paleocene age, overlain by the Arikaree and White River formations, contain much low-grade uranium. The uranium-bearing coal has the same appearance as ordinary coal unless, rarely, associated minerals have discolored the coal surfaces. Prospecting is done by scanning a lignite bed with a Geiger counter, or similar device, and having analyses made of any radioactive samples to determine the presence and percentage of uranium. It is thought that the uranium in these lignites is derived from water that leached volcanic ash and sand deposits of the overlying White River and Arikaree formations; the uranium was taken into solution and redeposited in the lignite. Most of these lignites are of very low grade in comparison with other uranium sources that are being mined.

33 Moore, G. W., and Stephens, J. G., 1953, Reconnaissance for uranium-bearing carbonaceous rocks in California and adjacent parts of Oregon and Nevada: U. S. Geol. Survey Circ. 313, 8 p.

A reconnaissance was conducted in California and parts of Oregon and Nevada to find uranium-bearing carbonaceous rocks. Coal, lignite, and shale that are or were overlain by rocks of volcanic origin and rhyolitic composition received special attention. Coal beds were investigated in 21 counties in California. They range from Paleocene to Pliocene in age, and from high-volatile bituminous coal to partly coalified wood. Most of the deposits are of lignite or subbituminous coal. The highest concentration of uranium was found in the Newhall prospect, Los Angeles County, where a 6-inch bed contains 0.020 percent uranium; the ash contains 0.054 percent uranium. Other deposits having relatively high uranium contents are at the: Fire Flex mine, San Benito County, 0.005 percent; American Lignite mine, Amador County, 0.004 percent; and Tesla prospect, Alameda County, 0.003 percent. Coal of Eocene age in Coos, Douglas, and Jackson Counties of southwestern Oregon was sampled and tested for uranium. Examination at many localities of these coal beds revealed a lack of significant radioactivity and the absence of uranium in the ash. At Esmeralda County in western Nevada a coal in contact with a tuff contains 0.003 percent equivalent uranium. Lignite from Lyon and Washoe Counties, Nev., has less than 0.001 percent equivalent uranium.

34 Moore, G. W., 1954, Extraction of uranium from aqueous solution by coal and some other materials: Econ. Geology, v. 49, p. 652–658.

Uranium in nature is commonly associated with carbonaceous material. Laboratory studies were therefore conducted to determine the relative ability of various types of carbonaceous material and some other substances to remove uranium from solution. The results of these experiments indicate that the low-rank coals are more effective in extracting uranium than any of the other materials used. A chemical determination shows that nearly 100 percent of the available uranium in solution is removed by subbituminous coal. The uranium is apparently retained in the coal by an irreversible process. The notable affinity of uranium for coalified plant remains suggests that some uranium deposits may have been formed over a long period of time by the extraction of uranium from dilute ground water solutions. A possible application of the results of this work may be the extraction of uranium by coal from natural water or from waste solutions from uranium processing industrial plants.—*Author's abstract*

35 Moore, G. W., 1954, North Dakota, *in* Geologic investigations of radioactive deposits, Semiannual progress report, December 1, 1953 to May 31, 1954: U. S. Geol. Survey TEI–440, p. 102–109, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Geologic mapping and sampling in the HT Butte, Chalky Butte, Bullion Butte, and Sentinel Butte areas of southwestern North Dakota indicate that the four areas contain inferred reserves of 43,380,000 tons of lignite averaging 0.013 percent uranium and 0.040 percent in the ash. Lignite from the Slide Butte in the HT Butte area, Slope County, N. Dak., has the greatest uranium content, averaging 0.024 percent uranium and 0.12 percent in the ash. A summary of the inferred reserves of lignite and uranium in these five buttes are presented in table form. From the data presented it is concluded that the uranium in the lignite was deposited by ground water that leached uranium from the overlying White River group. Maps showing areas underlain by uranium-bearing lignite and the thickness and percent uranium in the lignite at sample localities are presented in the text.

36 Moore, G. W., and Gill, J. R., 1955, Geologic map of the southern part of the Slim Buttes area, Harding County, South Dakota: U. S. Geol. Survey Coal Inv. Map C 36, scale 1:31,680.

The geologic map of the southern part of the Slim Buttes area, Harding County, S. Dak., indicates the lignite-sampling localities, the calculated uranium content, and the location of springs from which samples of water were taken. Rocks exposed in this area are Late Cretaceous to Recent in age.

37 Moore, G. W., Melin, R. E., and Kepferle, R. C., 1957, Uranium-bearing lignite in southwestern North Dakota: U. S. Geol. Survey Bull. 1055–E (in preparation).

Uraniferous lignite occurs in the Sentinel Butte member of the Fort Union formation of Paleocene age in the Bullion Butte, Sentinel Butte, HT Butte, and Chalky Butte areas. The uranium content of the lignite beds apparently is controlled primarily by their stratigraphic position below the overlying White River formation of Oligocene age. Lignite beds enclosed by permeable rocks are more uraniferous than lignite beds enclosed by impermeable rocks. Thin beds of lignite have a higher uranium content than thick beds. The stratigraphy and structure of the areas are discussed and a diagram showing the relation of the radioactive lignite beds to the base of the White River formation in North and South Dakota is shown. The uranium probably was leached by ground water from the White River and Arikaree formations and deposited in the lignite. Reserves of lignite and uranium are given for each of the areas.

38 Patterson, E. D., 1954, Radioactivity of some coals and shales in southern Illinois: U. S. Geol. Survey TEI–466, 23 p, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Commercially important coal beds and associated shales in the Caseyville, Tradewater, Carbondale, and McLeansboro formations of Pennsylvanian age in southern and central Illinois were examined to determine the amount and distribution of uranium. The coals generally contain less than 0.001 percent uranium but the Herrin No. 6 coal near Harrisburg, Ill., contains 0.008 percent uranium and 0.125 percent uranium in the ash. The black shales overlying the coals generally contain from 0.003 to 0.017 percent uranium. The most widespread uraniferous black shale is above the Harrisburg No. 5 coal in Saline, Gallatin, and Williamson Counties. Basic igneous dikes that intruded the coal-bearing formations are in effect non-radioactive.

39 Pipiringos, G. N., 1955, Uranium-bearing coal in the central part of the Great Divide Basin, Sweetwater County, Wyoming; Contr. to the Internat. Conf. on peaceful uses of atomic energy, Geneva, Switzerland, August 1955: U. S. Geol. Survey Paper, United Nations No. P/287.

Uranium-bearing coal of early Eocene age underlies about 750 square miles of the Great Divide Basin, Sweetwater County, Wyo. More than half of this area lies within the central part of the Basin. Caliche-like schroeckingerite deposits occur near the northern edge of the coal field. The shroeckingerite occurs in alluvium and in the upper few feet of the underlying claystone and arkosic sandstone beds of early and middle(?) Eocene age.

Most of the coal contains less than 0.003 percent uranium, but locally parts of some coal beds contain as much as 0.016 percent uranium. The uranium content of the ash of these coal beds ranges from 0.003 to 0.023 percent.

In the central part of the Great Divide Basin, the thickest coal beds underlie a relatively narrow belt in the trough and on the west flank of the northwest-trending Red Desert syncline; those containing the most uranium are on the east flank and are thinner. The Red Desert syncline also coincides with a zone of intertonguing of the highly permeable coarse-grained arkosic sandstone beds of the Battle Spring formation on the northeast and the less permeable, and locally impermeable, clay shale, siltstone, fine-grained sandstone and low grade oil shale beds of the Wasatch and Green River formations on the southeast. These formations of early and middle Eocene age rest unconformably on the Fort Union formation of late Paleocene age and are overlain, in ascending order, by the Bridger and Browns Park formations of middle Eocene and Miocene age respectively.

A broad gentle arch, trending about N. 70° E., separates the Washakie Basin on the southeast from the Red Desert syncline, which plunges gently northwestward into the nearly circular structural Niland Basin. The south flank of the arch dips southeast at an average rate of about 230 feet per mile; the north flank dips northeast about 140 feet per mile. The dominant structural feature of the area north of the Niland Basin is a graben which trends about N. 70° W. This graben is about 3 miles wide and is bounded on the north by a normal fault of about 3,000 feet vertical displacement. This fault extends for several miles northwest beyond the northern boundary of the Great Divide Basin and for an undetermined distance southeast across the northeastern part of the Great Divide Basin. The fault on the south side of the graben has a vertical displacement of a few hundred feet in the vicinity of the schroeckingerite deposits; it appears to pass northwestward within a few miles into an anticline or a monoclinal flexure and extends for an undetermined distance southeast of the schroeckingerite deposits into the northeastern part of the Great Divide Basin.

The schroeckingerite deposits in the north-central part of the Great Divide Basin occur within and along the southern edge of the graben. Weakly uraniferous tuffaceous sandstone beds of the Browns Park formation that once probably blanketed the entire Great Divide Basin are preserved today as erosional remnants less than two miles north and northwest of the schroeckingerite deposits.

The source of uranium in the coal and in the schroeckingerite deposits is probably the tuffaceous beds in the Browns Park formation localized in its present sites by ground-water circulation guided by structure and the inter-fingering of sedimentary facies.—*Author's abstract*

40 Schopf, J. M., and Gray, R. J., 1954, Microscopic studies of uraniferous coal deposits: U. S. Geol. Survey Circ. 343, 10 p.

Quantitative petrographic studies were made of the uranium-bearing lignite deposits of the Slim Buttes area, Harding County, S. Dak. These lignites are in the Ludlow member of the Fort Union formation of Paleocene age. The Slim Buttes coal appears to have a wide range of petrographic constituents in the different beds. This study does not support a direct correlation of uranium content with the amount of any single microscopic component of coal. The richest uranium-bearing samples of the Slim Buttes lignites also contained the greatest amount of humic matter. This extensively weathered plant material might be most favorable to uranium emplacement, but weathered coal of low radioactivity indicates that extensive decay only predisposes the coal to uranium emplacement.

41 Schopf, J. M., Gray, R. J., and Felix, C. J., 1954, Coal petrology, *in* Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI–490, p. 175–177, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Petrologic studies indicate that uranium-bearing coal from the Dakotas differs slightly from that of the Red Desert in Wyoming and the Goose Creek district in Idaho. These petrologic differences are (1) the Dakota coal contains less transported organic matter, (2) there is less waxy matter in the most uraniferous layers, and (3) there is a top-preferential pattern of uranium enrichment. The average petrologic composition of coal beds in the Slim Buttes area, Harding County, S. Dak., are presented in the text.

42 Snider, J. L., 1953, Reconnaissance for uranium in coal and shale in southern West Virginia and southwestern Virginia: U. S. Geol. Survey TEI–409, 28 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A reconnaissance of uranium-bearing coal, shale, and clay of Devonian, Mississippian, and Pennsylvanian age was conducted in parts of West Virginia and Virginia. All samples of bituminous coal collected contain less than 0.001 percent equivalent uranium. A semi-anthracite coal of Mississippian age, from Montgomery County, Va., contains a maximum of 0.001 percent equivalent uranium. Shales and sandstones associated with the coal beds contain from 0.001 to 0.003 percent equivalent uranium.

A black shale of Late Devonian age near Ben Hur, Lee County, Va., contains from 0.003 to 0.004 percent equivalent uranium.

43 Snider, J. L., 1953, Radioactivity of some coal and shale of Pennsylvanian age in Ohio: U. S. Geol. Survey TEI–404, 22 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The commercially important coal beds and associated rocks in the Pottsville, Allegheny, and Monongahela formations of Pennsylvanian age in eastern Ohio were examined for radioactive content. Most of the coal contains less than 0.001 percent equivalent uranium, but there is a maximum of 0.003 percent equivalent uranium in the Pittsburgh No. 8 coal at Crescent, Ohio. Associated carbonaceous shales generally contain less than 0.001 percent equivalent uranium but have a maximum of 0.003 percent equivalent uranium.

44 Snider, J. L., 1954, Reconnaissance for uranium in the Indiana coalfield: U. S. Geol. Survey TEM–784, 26 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The coalfield in the southwestern part of Indiana is a part of the Eastern interior coal province. Most of the coal beds contain less than 0.001 percent equivalent uranium, but 5 of the coal beds (Upper Block, Minshall, Gentryville, Coal V, and Coal VII) contain 0.001 or more percent equivalent uranium in some places. The radioactive zones are not widespread and are limited to the top of the bed in thick coals. Black carbonaceous shales above Coal V and the Minshall coal contain about 0.006 and 0.003 percent equivalent, respectively; the shale above Coal V is widespread; the radioactivity apparently is proportional to the amount of organic matter in the shale.

45 Staatz, M. H., and Bauer, H. L., Jr., 1954, Gamma Group, *in* Radioactive deposits of Nevada, by T. G. Lovering: U. S. Geol. Survey Bull. 1009–C, p. 76–77.

Uraniferous, impure lignite is found at the Gamma property, Churchill County, Nev., in a sequence of sandstone and clay beds of Tertiary age overlain by dark-red volcanic rock. Five beds of impure lignite from less than 1 foot to 3.5 feet thick are exposed continuously for 1,285 feet. These beds contain a maximum of 0.059 percent uranium and 75 percent ash.

46 Szalay, S., 1954, The enrichment of uranium in some brown coals in Hungary: Magyar Tudom. Akad. Acta Geol., v. 2, p. 299–310.

Most of the important coal beds of the larger producing mines in Hungary were sampled to determine the distribution of radioactive coals. The samples were in effect essentially nonradioactive—most registered even less radioactivity than the average for the earth's crust—except for samples from mines close to granitic terranes, the Mecsek and Velence Mountains of Hungary, which had radioactive intensities of 5 to 6 times the background rate. It was observed that radioactive and nonradioactive coal beds and associated shales exist in the same mine. Chemical analyses indicate that the radioactive coal contains about 0.006 percent uranium and 0.01 percent in the ash. A geochemical enrichment at the time of coal deposition is proposed. It is suggested that the uranium was derived from the decomposition of granite and carried by water to the areas where coal was being formed.

Experiments were conducted to determine the capacity of plant debris, peat, and lignite to adsorb uranium from a uranylnitrate solution and the rate at which adsorption takes place. Different volumes (1 to 5 cc) of a 1 percent solution of uranylnitrate were poured over gram samples of the adsorbing material. A test of the filtrate indicated that all uranium was adsorbed from the solution within 1 to 2 minutes; this time may be shortened by agitation. Peat becomes saturated with uranium in the range of 50 to 250 milligrams of uranylnitrate per gram of peat; the adsorption capacity of lignite is approximately the lower limit cited for peat. Other tests indicate that humic acids are largely responsible for the adsorption of the uranium by a cation-exchange process.

47 Vine, J. D., and Moore, G. W., 1952, Uranium-bearing coal and carbonaceous rocks in the Fall Creek area, Bonneville County, Idaho: U. S. Geol. Survey Circ. 212, 10 p.

Uranium-bearing coal, carbonaceous shale, and carbonaceous limestone in the Bear River formation of Cretaceous age were examined in the Fall Creek area, Bonneville County, Idaho. The area is in the Caribou Mountains which are part of the system of parallel ranges that form an arcuate belt along the Idaho-Wyoming border. Thrust sheets and tight folds, commonly overturned, characterize the complex structure of these mountains.

Exposed sedimentary strata include the Stump formation of Late Jurassic age and the Gannett group and Bear River formation of Early Cretaceous age; these are overlain unconformably by silicic volcanic rocks which are probably of Miocene age.

Analyses of samples collected from an abandoned inclined shaft, known as the Fall Creek coal prospect, indicate that there is a maximum of 0.13 percent uranium in the top foot of impure coal and 0.3 percent uranium in the ash. The average uranium content in impure coal, carboneacous shale, and limestone is about 0.02 percent. Uranium minerals were not identified in the carbonaceous rocks—a fact which suggests that the carbonaceous matter fixes uranium by ionic adsorption. An epigenetic origin by leaching from overlying volcanic rocks is proposed for the uranium.

48 Vine, J. D., and Moore, G. W., 1952, Reconnaissance for uranium-bearing carbonaceous rocks in northwestern Colorado, southwestern Wyoming, and adjacent parts of Utah and Idaho: U. S. Geol. Survey TEI–281, 25 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The reconnaissance of carbonaceous rocks in parts of Colorado, Wyoming, Utah, and Idaho revealed one possible commercial deposit of uranium-bearing coal. The Fall Creek deposit in the Bear River formation of Cretaceous age, Bonneville County, Idaho, contains a maximum of 0.13 percent uranium in the coal and 0.31 percent in the ash. Three localities in which coal beds contain more than 0.010 percent uranium in the ash are near Lay and Walden, Colo., and the Leucite Hills, Wyo. Gilsonite of Tertiary age south of Rand, Colo., contains 0.0013 percent uranium and 0.016 percent uranium in the ash. Bitumen from a bituminous sandstone quarry west of Vernal, Utah, contains 0.003 percent uranium and 0.028 percent in the ash.

49 Vine, J. D., 1953, Parts of Colorado, Utah, Idaho and Wyoming; *in* Search for and geology of radiaoctive deposits, Semiannual progress report, December 1, 1952 to May 31, 1953: U. S. Geol. Survey TEI–330,

p. 117, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Small quantities of uranium were found in carbonaceous rocks in Colorado, Idaho, Utah, and Wyoming. The ash of coal of the Bear River formation of Early Cretaceous age contains a maximum of 0.03 percent uranium in samples from the Caribou Mountains, Bonneville County, Idaho, and a maximum of 0.009 percent uranium in samples from near Driggs, Teton County, Idaho. Coaly shale in the Bridger formation of Eocene age in southwestern Sweetwater County, Wyo., contains up to 0.012 percent uranium in the ash.

50 Vine, J. D., 1955, Uranium-bearing coal in the United States; Contr. to the Internat. Conf. on peaceful uses of atomic energy, Geneva, Switzerland, August 1955: U. S. Geol. Survey Paper, United Nations No. P/55.

Large reserves of uranium are contained in coal and lignite, particularly in Cretaceous and Tertiary sediments in some parts of the Rocky Mountains and northern Great Plains regions of the United States. The concentration of uranium in the ash of coal provides a possibility for recovering uranium as a byproduct. Ore-grade uranium in lignite is present locally in the northern Great Plains. Uranium-bearing lignite occurs in the Fort Union formation of Paleocene age in the northern Great Plains, in the Salt Lake formation of Pliocene age in southern Idaho, and in Tertiary sediments in Nevada and southern California. Uranium-bearing coal is present in the Wasatch formation of Eocene age in Wyoming, in the Laramie formation of Cretaceous age in Colorado, in the Mesaverde formation of Cretaceous age in New Mexico, and in the Bear River formation of Cretaceous age in southeastern Idaho. Bituminous coal and anthracite of Paleozoic age in the central and eastern United States contain only very small quantities of uranium.

The distribution of uranium in coal is erratic. In many areas uranium is preferentially concentrated in the stratigraphically highest coal bed and at the top of the beds. In the Red Desert area of Wyoming uranium is concentrated in coal beds adjacent to permeable units of the enclosing strata.

Uranium is thought to be held in coal as a fixed adventitious constituent of epigenetic origin. When more uranium is available to the coal than can be chemically combined with the organic matter, uranium minerals including carnotite, autunite, torbernite, zeunerite and coffinite may form. Uranium is thought to be introduced into coal in the northern Great Plains by ground water that leaches uranium from unconformably overlying volcanic sediments.—*Author's abstract*

51 Vine, J. D., 1957, Geology and uranium deposits in carbonaceous rocks of the Fall Creek area, Bonneville County, Idaho: U. S. Geol. Survey Bull. 1055–I (in preparation).

Impure coal in the Bear River formation of Early Cretaceous age at the Fall Creek prospect contains an average of about 0.02 percent uranium; there is a maximum of 0.1 percent uranium and 0.3 percent in the ash. Rock units that contain the most carbonaceous matter generally contain more uranium, though the distribution is not uniform within a unit. These rocks include coal, coaly shale, carbonaceous shale, and black carbonaceous limestone. The uranium-bearing strata are widespread and are repeated several times by folding and faulting.

Data from spectrographic analyses indicate a correlation of molybdenum and germanium with uranium and suggest a geochemical relationship and a common origin for the three metals. Four general hypotheses are discussed for the origin of uranium in carbonaceous rocks. Reserves for a 400-acre area are estimated at 6.5 million tons of carbonaceous rock that contains about 1,300 tons of uranium.

52 Welch, S. W., 1953, Radioactivity of coal and associated rock in the coalfields of eastern Kentucky and southern West Virginia: U. S. Geol. Survey TEI–347–A, 38 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A reconnaissance of coal and associated rocks was made in the Lee and Breathitt formations in the coalfields of eastern Kentucky, and Logan and Mingo Counties, W. Va. Radioactivity determinations showed that the coal contains 0.000–0.001 percent equivalent uranium. Shales and clays are slightly more radioactive; they contain about 0.002 percent equivalent uranium.

53 Welch, S. W., 1953, Radioactivity of coal and associated rocks in the anthracite fields of eastern Pennsylvania: U. S. Geol. Survey TEI–348, 31 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The coal-bearing rocks in the anthracite fields are the Pottsville, Allegheny, and Conemaugh formations of Pennsylvanian age. Reconnaissance of the four principal fields—the Southern, the Western Middle, the Eastern Middle, and the Northern—showed 0.001 or less percent equivalent uranium in the coal, and 0.001 to 0.003 percent equivalent uranium in the shale.

54 Zeller, H. D., 1955, Reconnaissance for uranium-bearing carbonaceous materials in southern Utah: U. S. Geol. Survey Circ. 349, 9 p.

A reconnaissance was made in parts of southern Utah to locate and evaluate uranium-bearing carbonaceous rocks. Coal and carbonaceous shale of Cretaceous age were systematically sampled in three major areas: Kaiparowits Plateau, Henry Mountains, and Kolob Terrace. Carbonaceous shales, 1 to 2 feet thick, at two localities in the Kaiparowits Plateau contain 0.006 and 0.007 percent uranium. Other carbonaceous sediments examined contain 0.002 percent or less uranium.

55 Zeller, H. D., 1957, Results of exploratory drilling for uranium-bearing lignite deposits in Harding and Perkins Counties, South Dakota, and Bowman County, North Dakota: U. S. Geol. Survey Bull. 1055–C (in preparation).

Data obtained from most of the cores show that the uranium content is greatest in the stratigraphically highest lignite beneath the White River and Arikaree formations. In the Medicine Pole Hills the uranium is concentrated at the base of the lignite in a number of cores. Mineralized ground water, moving laterally along fractured lignite that overlies impervious underclays apparently controlled the uranium distribution in these beds. Spectrographic studies indicate that the molybdenum content correlates with the uranium content. Distribution and concentration of uranium, reserves of uranium and lignite, quality of lignite, lithologic description of the cores, and general description of areas are presented.

56 Zeller, H. D., 1955, Preliminary geologic map of the Bar H area, Slim Buttes, Harding County, South Dakota: U. S. Geol. Survey Coal Inv. Map C 37, scale 1:20,000.

This map shows the geology of the Bar H area in the northern part of Slim Buttes, Harding County, S. Dak. The radioactive lignite and clinker beds in the Ludlow member of the Fort Union formation are shown on the map. The rocks exposed in this area are Paleocene to Recent in age.

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GEOGRAPHIC AREAS

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