Geology and Mineralogy

This document consists of 91 pages.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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

By

Thomas M. Kehn

June 1955

Trace Elements Investigations Report 533

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

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

GEOLOGY AND MINERALOGY

Distribution (Series A)	No. of copies
Atomic Energy Commission, Washington	2
Division of Raw Materials, Albuquerque	1
Division of Raw Materials, Austin	1
Division of Raw Materials, Butte	1
Division of Raw Materials, Casper	1
Division of Raw Materials, Denver	1
Division of Raw Materials, Ishpeming	1
Division of Raw Materials, Phoenix	1
Division of Raw Materials, Rapid City	1
Division of Raw Materials, St. George	1
Division of Raw Materials, Salt Lake City	1
Division of Raw Materials, Washington	3
Exploration Division, Grand Junction Operations Office	1
Grand Junction Operations Office	1
Pennsylvania State University (Spackman)	1
Technical Information Extension, Oak Ridge	6
U. S. Geological Survey:	
Fuels Branch, Washington	17
Geochemistry and Petrology Branch, Washington	1
Geophysics Branch, Washington	1
Mineral Deposits Branch, Washington	1
P. C. Bateman, Menlo Park	1
A. L. Brokaw, Grand Junction	1
N. M. Denson, Denver	1
V. L. Freeman, College	1
R. L. Griggs, Albuquerque	1
J. W. Huddle, Lexington	1
M. R. Klepper, Spokane	1
A. H. Koschmann, Denver	1
R. A. Laurence, Knoxville	1
J. D. Love, Laramie	1
L. R. Page, Washington	1
J. F. Pepper, New Philadelphia	1
J. M. Schopf, Columbus	1
Q. D. Singewald, Beltsville	1
A. E. Weissenborn, Spokane	1
TEPCO, Denver	5
TEPCO, RPS, Washington, (including master)	3
	67

CONTENTS

ILLUSTRATION

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

By Thomas M. Kehn

INTRODUCTION

The following annotated bibliography consists of references to published literature and open-file reports dealing with uranium in coal and associated carbonaceous shales in the United States; the listings include nearly all the pertinent reports available as of June 1955 and also include some reports in preparation. Several foreign references are included because of their contribution to the study of the origin and distribution of uranium in coal and lignite.

Most of the coal beds _/ and associated carbonaceous shales in

_/Judging from investigation to date, coal beds of lignite rank contain the most uranium. Coal beds of subbituminous B and C rank contain the next largest concentration of uranium. Higher-rank coal beds rarely contain more than 0.001 percent uranium.

the United States are essentially non-radioactive. However, many have been found in the last few years that contain 0.005 to about 0.10 percent uranium with a greater concentration in their ash. 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 partially dependent upon the use of the coal as fuel and the recovery of uranium as a byproduct from the ash.

Explanation of the index map

The index map (fig. 1) shows localities underlain by uranium-bearing coal beds and carbonaceous shale. Minor occurrences of uranium in coal and carbonaceous shales are shown where the concentration of uranium is 0.005 percent or more. Areas, investigated and included in the bibliography but found to contain less than 0.005 percent uranium, are not shown on the index map. The numbers that correspond to localities shown on the index map refer to the numbered entries in the bibliography.

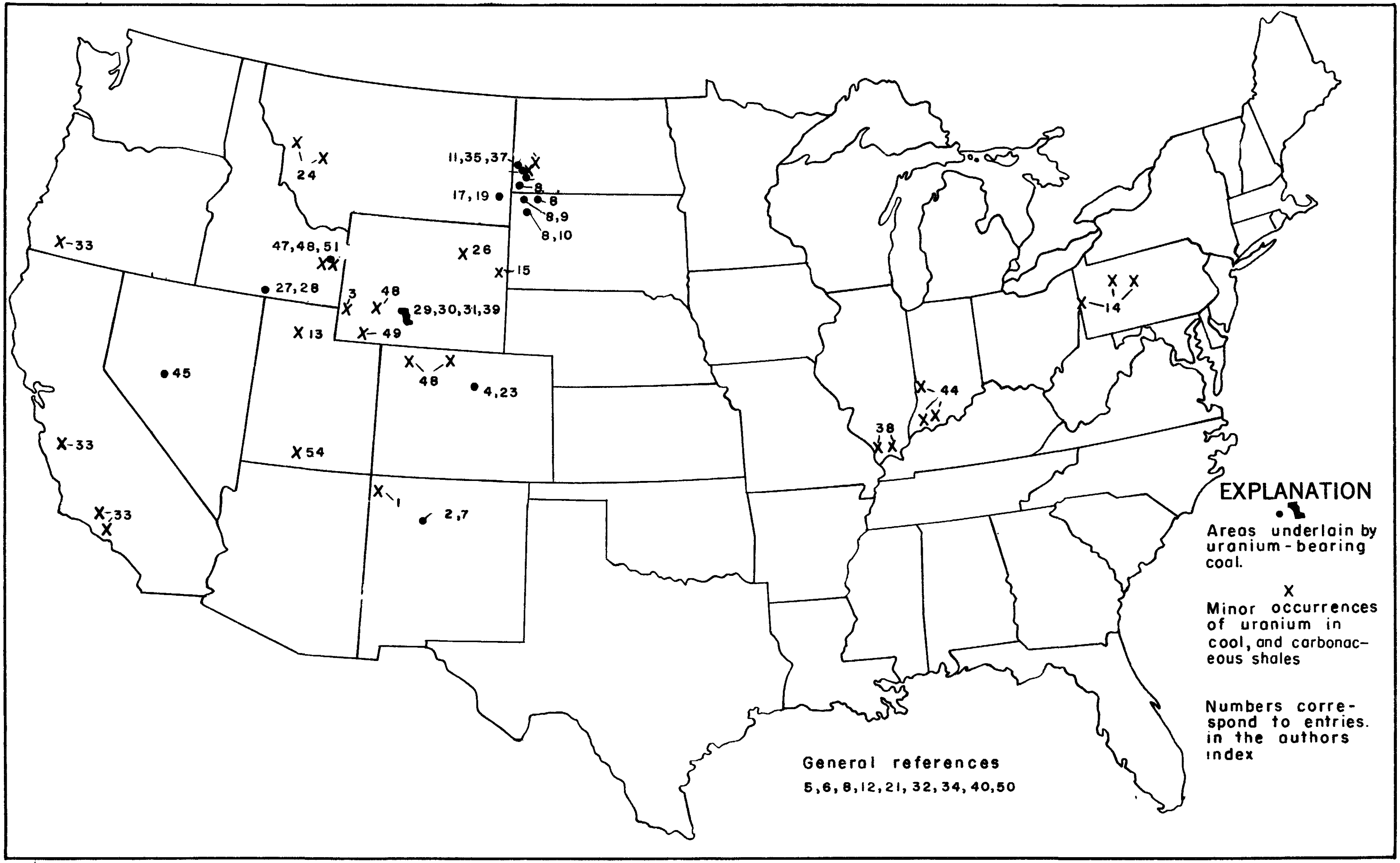

FIGURE 1 — —. INDEX MAP OF URANIUM-BEARING COAL AND CARBONACEOUS SHALE IN THE UNITED STATES

99763

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.

A reconnaissance search was made for uranium-bearing coals and carbonaceous shale, chiefly of Mesozoic age, in Arizona and New Mexico. The coal in the Allison member of the Mesaverde formation on La Ventana Mesa, Sandoval County, N. Mex., contains as much as 0.62 percent uranium, with 1.34 percent uranium in the ash. Slightly uraniferous coal was found near San Ysidro, Sandoval County, and 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., 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, whereas the Tertiary volcanic rocks that were examined are not radioactive.

2. Bachman, G. O., Vine, J. D., Read, C. B., and Moore, G. W., 1956, Uranium-bearing coal and carbonaceous shale in the La Ventana Mesa area, Sandoval County, New Mexico: 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 of the major 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 is thought to be of epigenetic origin and possibly was derived from the Bandelier tuff of Pliocene(?) age. The Bandelier tuff probably once covered the area although existing remnants are several miles from the area. Reserves of coal and uranium, geologic maps, and analytical data for the 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.

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 that probably is a time equivalent of the Dakota sandstone. Other types of uranium occurrences also are discussed in the report.

4. Berthoud, E. L., 1875, On the occurrence of uranium, silver, iron, etc., in the Tertiary formation of Colorado Territory: Acad. Nat. Sci. Philadelphia 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 igenous origin) consisting of hard black mineral matter containing geodes of brilliant quartz crystals, small veins of pyrite, chalcedony, orange-colored crystals, and concretions.

5. Breger, I. A., Duel, 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, South Dakota. 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 1 N hydrochloric acid. Continuous extraction with hot 6 N hydrochloric acid removes 98.6 percent of the uranium.

"Columns of coal were treated with water, 1 N hydrochloric acid, 6 N 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: The Mining Magazine (London) v. XCI, Nov. 1954, p. 265-273. (Reprinted in the South African Mining and Engineering Jour., (Johannesburg), v. 65, pt. 2, p. 721, 723, 725-727.

Coals generally are considered to be very low in uranium, but 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 by means of a gamma-ray logging operation in the Warwickshire coal field near Coventry, England. This coal, which probably is less than a foot thick, occurs 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, but a bore-hole 200 yards to the west shows no radioactivity on the gamma-ray log. To the east of the radioactive bore-hole the coal is believed to be truncated by a sandstone of Triassic age that contains scattered, highly uraniferous black nodules. 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. No uranium minerals have 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), consists of coal and coaly shale. Information is not available on the extent and uniformity of the uranium content, but from the knowledge of such coals in other countries it is probable that the uranium is confined to one or more beds at the top of the coal horizon. Coal ash from the most radioactive specimens contains 0.18 to 1.00 percent uranium. It is believed that the granites of the Erzegebirge and Lausitzergebirge to the southwest and southeast are the source of the uranium.

Recent studies of the Hungarian coal fields have shown that in various localities thin layers of coal and coaly shale of Liassic age contain up to 0.01 percent equivalent uranium. In general the highest concentrations of uranium are found in the thinner coal seams that are located near mountain massifs of radioactive granite or are interbedded with radioactive sills and intrusions. On the basis of experimental evidence it is suggested that the uranium fixation is contemporaneous with the 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, immediately below the volcanic rock, possesses any significant uranium content. In Idaho the carbonaceous beds near the top of any sequence are the most uraniferous and below the top one foot of the carbonaceous bed the uranium content diminishes abruptly downward, which suggests downward moving water as the transporting medium for the uranium. Most of these western coal deposits contain only 0.005 percent to 0.02 percent uranium, but as much as 0.1 percent uranium occurs in small areas.

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, J. R. Gill, W. J. Hail, Jr., J. D. Love, Harold Masursky, N. M. Denson, G. W. Moore, G. N. Pipiringos, J. D. Vine, and H. D. Zeller: U. S. Geol. Survey TEM-341, 44 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge.

This paper reports the results of investigations by the Geological Survey of uranium-bearing coal, lignite, and carbonaceous shale in the following areas: the lignite deposits of South Dakota; the coal deposits of the Red Desert, Great Divide Basin, Wyo.; the deposits at Pumpkin Buttes, Wyo.; the coal deposits of Fall Creek and Goose Creek, Idaho; and the deposits at La Ventana, N. Mex. These investigations were conducted to outline the potential uranium resources and mode of occurrence of uranium in the above-mentioned areas. The potential resources range from 350,000,000 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. An epigenetic hypothesis of origin for the deposits is proposed, based on field and laboratory data. It is suggested that the uranium in the deposits was leached by groundwater from the overlying tuffaceous rocks and redeposited in the underlying carbonaceous rocks.

8. Denson, N. M., Bachman, G. O., and Zeller, H. D., 1956, 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 non-uraniferous except where intersected by faults or joints. This distribution indicates 1) that the uranium is independent of the age of the lignite, 2) that the uranium has been transported downward by descending and laterally moving ground water, and 3) 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 are included showing the extent, thickness, and variations in mineral content of the 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 range from 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. Lignite outcrops are shown and the amount of uranium in the lignite at sampled localities are presented. The rocks range from 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 relationship 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, and 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; Contribution to the International Conference on peaceful uses of atomic energy, Geneva, Switzerland, August 1955, U. S. Geological 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 900 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.

"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, Pennsylvania: U. S. Geol. Survey TEI-468, 52 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge.

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 non-radioactive 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 appear to have had little effect on the distribution and concentration of the 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.

The South Park, Crested Butte, Paonia, Trinidad, Colorado Springs, and Canon City coal fields in Colorado were examined for uranium-bearing coal and carbonaceous rocks; also examined were coal-bearing rocks in the vicinity of Mancos and Durango, as well as coal in the Denver Basin. Only two samples contained more than 0.002 percent uranium in the ash. Impure coal in the Cambria coal field, Weston County, Wyo. contained 0.0085 percent uranium in the ash. This is believed to be the stratigraphically highest coal bed in the Lakota sandstone. Commercially mined coal beds are essentially non-radioactive. In the Ekalaka lignite field, Carter County, Mont., several uraniferous lignite beds were found. Most of the lignite samples collected contained 0.005 percent or more uranium in the ash. A 1.5 foot lignite bed contains an average of 0.057 percent uranium and about 34 percent ash.

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

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 that average 1.4 feet thick and contain 0.20 percent uranium, containing the mineral meta-autunite, are indicated in an area of 1500 acres. In the Tepee Butte area, Harding County, a carbonaceous shale and sandstone is estimated to underlie about 4 acres and to contain 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 occurrence where metatyuyamunite occurs in sandstone and averages about 0.68 percent uranium. Lenses of fresh water limestone and siltstone in the West Short Pine Hills, Harding County, are estimated to contain from 0.01 to 0.1 percent uranium. In the Long Pine Hills area, Carter County, Mont., uranium-bearing lignite, siliceous shale, and sandstone are estimated to contain 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 is estimated to contain between 0.1 and 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 is estimated to contain between 0.01 and 0.2 percent uranium. In the Killdeer Mountain area, McKenzie County, N. Dak., a lignitic shale is estimated to contain 0.1 percent equivalent uranium. Other areas having anomalous radioactivity also are mentioned in the report.

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. 107-112, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge.

In the southern Ekalaka Hills approximately 16,500,000 tons of lignite contain 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 non-radioactive. The uranium in the lignite is believed to be epigenetic and to have been leached and transported by ground water from radioactive tuffaceous rocks. Maps are included that 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.

Core drilling in the Mendenhall area, Slim Buttes, Harding County, S. Dak., indicates that about 30,000,000 tons of lignite is radioactive and contains about 0.008 percent uranium. The Mendenhall rider, the Mendenhall, and the Olesrud beds contain uranium locally 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., 1956, 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 occur in the southern part of the Ekalaka Hills in the lower part of the Fort Union formation of Paleocene age where the lignite is directly overlain by the Arikaree formation of Miocene age. Lignite beds that are radioactive in the southern part of the area are non-radioactive 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 and greater concentrations in the ash. Analyses of spring water from the Arikaree formation indicate that uranium is being leached from that formation at the present time. The uranium contents of representative samples of spring waters for the area are given in the text. It is estimated that about 16,000,000 tons of lignite contain 700 tons of uranium.

and Zeller, H. D.,
20. Gill, J. R., 1956, Results of core drilling for uranium-bearing lignite, Mendenhall area, Harding County, South Dakota: U. S. Geol. Survey Bull. 1055-D (in preparation).

Core drilling of the Mendenhall area, which is near the center of Slim Buttes, indicates that the uranium-bearing lignite is about 5 feet thick and contains about 0.005 percent or more uranium. The uranium-bearing lignite occurs 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 indicates that uranium in the lignite is of epigenetic origin and is derived from the Chadron and Arikaree formations of Oligocene and Miocene age. Data on overburden thickness, fuel analysis, 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, containing 0.004 percent equivalent uranium oxide. Uranium occurrences in other types of rocks are discussed in the report.

23. Gude, A. J., III, 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).

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 is in the Laramie formation of Late Cretaceous age exposed on the monoclinal fold on the west flank of the Denver Basin. The uranium is localized where the coal bed is in or adjacent to shear zones associated with faulting. Small lenticular bodies of uraniferous material occur at intervals in the coal and silicified coal and contain 0.10 to 0.50 percent uranium. Data obtained from the drilling indicate a discontinuous radioactive zone between these higher grade ore bodies; assays of the samples range from 0.001 to 0.10 percent uranium. Material with a content of 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 search for uraniferous lignite and carbonaceous shale associated with volcanic rocks was made during the summer of 1951. Twenty-two areas in western Montana and one adjacent area in Idaho were examined. The coal in five of these areas is of Late Cretaceous age, and the coal and carbonaceous shale in eighteen areas occur in Tertiary "lake bed" deposits of Oligocene and Miocene age. Both the Cretaceous and Tertiary coal and carbonaceous shale are associated with volcanic rock, thought to be the source for uranium in other areas. The field examination of the coal showed no appreciable radioactivity. A sample of carbonaceous shale from the Prickly Pear Valley northeast of Helena contained 0.013 percent uranium, and a sample of carbonaceous shale from the Flint Creek Valley southwest of Drummond, Mont., contained 0.006 percent uranium. The carbonaceous shale sample from the Prickly Pear Valley district is associated with an overlying bentonitic ash containing 0.003 percent equivalent uranium. A map showing districts and outcrop localities and a table of sample data 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 coal fields of Alabama were analyzed, as the first in a series of examinations of the rocks, minerals, and waters of the state, for their radium content. Results of these tests are presented in table form, listing 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 coal field had the highest concentration of radium in the ash. The ash of the richest sample contained 7.05×10^{-12} grams radium per gram ash and the poorest sample contained 0.51×10^{-12} grams radium per gram ash, the average being 2.15×10^{-12} grams radium per gram ash for the coals tested. It is assumed that a gram of uranium is in equilibrium with 3.4×10^{-7} grams 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 one foot thick, but some of the combined coal and associated carbonaceous shale beds are as much as four feet thick. The uranium content of the coal samples ranges from 0.009 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 November 30, 1953: U. S. Geol. Survey TEI-390, p. 135, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge.

The Barrett carbonaceous shale zone and the carbonaceous shale Zone B in the lower part of the Salt Lake formation were tested by core holes in the central part of the Goose Creek district, Cassia County, Idaho. Carbonaceous shale in the Barrett zone may contain as much as 0.02 percent uranium. The most radioactive bed found may contain as much as 0.1 percent uranium and is in Zone B. At two localities, carbonaceous shale is known to contain about 0.1 percent uranium. A geologic map and thickness and radioactivity diagrams accompany the report.

28. Mapel, W. J., and Hail, W. J., Jr., 1956, 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 comprises 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 the Salt Lake formation of early Pliocene age, both containing abundant volcanic material, comprise most of the rocks exposed in the district. 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; however, some carbonaceous shale beds contain 0.01 percent or more uranium. The richest occurrence is the top foot of an 8-foot bed of carbonaceous shale that contains 0.12 percent uranium and averages 0.042 percent uranium for the bed. The uranium is believed to be derived from volcanic ash that has been leached by ground water. The principal mineralized area is on the flanks and in the trough of a syncline, and the richest uranium bearing carbonaceous shale is directly overlain by a thick bentonite. Reserves are estimated to be 900 tons of uranium in beds two or more feet thick and averaging 0.005 percent or more uranium, and 115 tons of uranium in beds one foot or more thick and containing 0.01 percent or more uranium.

29. Masursky, Harold, 1953, Eastern Red Desert area, Sweetwater County, Wyoming; in Geologic investigations of radioactive deposits, Semiannual 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.

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

30. Masursky, Harold, 1955, Trace elements in coal in the Red Desert, Wyoming; Contribution to the International Conference on peaceful uses of atomic energy, Geneva, Switzerland, August 1955, U. S. Geological 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., 1956, 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 occurs in the Wasatch formation in the northeastern part of Sweetwater County, Wyo. The Wasatch formation of early Eocene age inter-fingers with the Green River formation and the beds are essentially flat lying. The Red Desert area is in a structural and topographic basin between the Rawlins uplift on the east and the Rock Springs uplift on the west and 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 increasing amounts of coarse sediments. In a given area, the coal highest in the stratigraphic section has the greatest uranium content. However, this is true only where 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 total 162,500,000 tons that contain 6,100 tons of uranium; in the Luman coal zone 21,000,000 tons of coal are inferred to contain 800 tons of uranium.

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, are now known to contain a large potential source of low-grade uranium. The uranium-bearing coal has the same appearance as ordinary coal except in rare instances when associated minerals discolor the coal surfaces. Prospecting is conducted by scanning a lignite bed with a Geiger counter or similar device and having analyses made of any radioactive samples in order to determine the presence and percentage of uranium. Uranium in these lignites is thought to be derived from water passing through the coal from volcanic ash and sand deposits of the overlying White River and Arikaree formations, taking uranium into solution and redepositing it in the lignite. When compared with other sources of uranium that are being mined or developed, most of these lignites are very low-grade.

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 survey was conducted in California and parts of Oregon and Nevada in search for 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 in age from Paleocene to Pliocene, and in rank from high-volatile bituminous coal to partly coalified wood. Most of the deposits are of lignite or sub-bituminous 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 and 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 in Coos, Douglas, and Jackson Counties of southwestern Oregon was sampled and tested for uranium. Examination at many localities of these coal beds, which are of Eocene age, revealed no significant radioactivity and no uranium in the ash. At Esmeralda County, in western Nev., 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 sub-bituminous 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.

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 uranium in the lignite 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 is secondary and was introduced by ground-water which had leached uranium from the overlying White River group. Maps showing areas underlain by uranium-bearing lignite, 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 map shows the geology of the southern part of the Slim Buttes area, Harding County, S. Dak. Lignite sample localities are shown and the uranium content and location of spring waters sampled are presented. Rocks exposed in this area range from Late Cretaceous to Recent in age.

37. Moore, G. W., Melin, R. E., and Kepferle, R. C., 1956, Uranium-bearing lignite in southwestern North Dakota: U. S. Geol. Survey Bull. 1055-E (in preparation).

Uraniferous lignite occurs in the Bullion Butte, Sentinel Butte, HT Butte and Chalky Butte areas in the Sentinel Butte member of the Fort Union formation of Paleocene age. The uranium content of the lignite beds seems to be 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 relationship of the radioactive lignite beds to the base of the White River formation in North and South Dakota is shown. The uranium in the lignite is thought to have been leached from the White River and Arikaree formations by ground water and introduced into the lignite. Reserves of lignite and uranium for each of the areas studied are presented.

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.

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 they contain. 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 occurs above the Harrisburg No. 5 coal in Saline, Gallatin, and Williamson Counties. Basic igneous dikes that have intruded into the coal bearing formations were found to be essentially non-radioactive.

39. Pipiringos, G. N., 1955, Uranium-bearing coal in the central part of the Great Divide Basin, Sweetwater County, Wyoming; Contribution to the International Conference 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 schroeckingerite 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 groundwater 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 have been made of the uranium-bearing lignite deposits in the Slim Buttes area of Harding County, S. Dak. These uranium-bearing 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. Data obtained in this study cast doubt on 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 amounts of humic matter. Humic matter is primarily the product of extensive weathering of plant materials and might be most favorable to uranium emplacement. However, weathered coal of low radioactivity indicates that extensive decay can only predispose 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.

Petrologic studies indicate that uranium-bearing coal from the Dakotas differ 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.

A reconnaissance for 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 as much as 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 upper Devonian age, near Ben Hur, Lee County, Va., contains 0.003-0.004 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.

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, with a maximum of 0.003 percent equivalent uranium from the Pittsburgh No. 8 coal at Crescent, Ohio. Associated carbonaceous shales generally contain less than 0.001 percent equivalent uranium with a maximum of 0.003 percent equivalent uranium.

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

The Indiana coal field is located in the southwestern part of the state and is a part of the Eastern Interior coal province. Most of the coal beds contain less than 0.001 percent equivalent uranium; however, five of the coal beds (Upper Block, Minshall, Gentryville, Coal V, and Coal VII) locally contain 0.001 or more percent equivalent uranium. The radioactive zones do not persist over wide lateral areas and are limited to the top of the bed in thick coals. Black carbonaceous shales above Coal V and Minshall coal contain about 0.006 and 0.003 percent equivalent uranium respectively, and the radioactivity appears to increase as the amount of organic matter increases in the shale. Reserves of the black shale above Coal V are large as it is present over most of the coal.

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, Nevada. The lignite occurs in a sequence of sandstone and clay beds of Tertiary age that are overlain by dark-red volcanic rock. Five beds of impure lignite ranging in thickness from less than 1 foot to 3.5 feet are exposed continuously for 1,285 feet. These beds contain as much as 0.059 percent uranium and up to 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 significant coal beds of the major producing mines in Hungary were sampled to determine the distribution of radioactive coals. A majority of the samples were found to be essentially non-radioactive, generally below the average for the earth's crust. The remaining samples had radioactive intensities of 5-6 times the background rate and are from mines that are close to granitic terranes, the Mecsek and Velence Mountains, of Hungary. It was observed that in the same mine some coal beds and associated shales were radioactive and other coals and shales were non-radioactive. Chemical analyses indicate that the radioactive coal contains about 0.006 percent uranium with 0.01 percent uranium in the ash. A geochemical enrichment at the time of deposition is proposed for this uraniferous coal. It is suggested that the uranium was derived from the decomposition of the granite and carried by water to the areas where coal was being formed. Experiments were conducted to determine the rate and capacity of plant debris, peat and lignite to adsorb uranium from a uranylnitrate solution. Different volumes (1-5 c.c.) of a 1 percent solution of uranylnitrate solution were poured over gram samples of the adsorbing material. A test of the filtrate indicated that all of the uranium had been adsorbed from the solution. The adsorption process is completed within 1-2 minutes and this time may be shortened by agitation. Peat becomes saturated with uranium in the range of 50-250 milligrams of uranylnitrate per gram of peat, and the adsorption capacity of lignite is approximately the lower limit cited above. Other tests indicate that humic acids are largely responsible for the adsorption of the uranium and that it is 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 of southeastern Idaho. The Caribou Mountains comprise a part of the system of parallel mountain ranges which form an arcuate belt along the Idaho-Wyoming border. Tight folds, commonly overturned, and thrust sheets characterize the complex structure of these mountains.

Sedimentary strata that are exposed 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 of probable Miocene age.

Analyses of samples collected from an abandoned inclined shaft, known as the Fall Creek coal prospect, indicate that the coal contains as much as 0.13 percent uranium in the top foot of impure coal and 0.3 percent uranium in the ash. The average uranium content, however, in impure coal, carbonaceous shale, and limestone is about 0.02 percent. No uranium minerals were identified in the carbonaceous rocks and it is suggested that the carbonaceous matter fixes uranium by ionic adsorption. An epigenetic origin is proposed with the uranium being introduced by meteoric water that leached uranium from overlying volcanic rocks.

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.

The reconnaissance for uranium-bearing 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 as much as 0.13 percent uranium in the coal and as much as 0.31 percent uranium in the ash. Three localities were found in which coal beds contain more than 0.010 percent uranium in the ash. They are located near Lay and Walden, Colo., and the Leucite Hills, Wyo. Gilsonite of Tertiary age south of Rand, Colo., contains 0.0013 percent uranium with 0.016 percent uranium in the ash. Bitumen from a bituminous sandstone quarry, west of Vernal, Utah, contains 0.003 percent uranium with 0.028 percent uranium in the ash.

49. Vine, J. D., 1953, Parts of Colorado, Utah, Idaho and Wyoming; 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. 117, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge.

Small quantities of uranium were found in a number of areas that were examined for uranium-bearing carbonaceous rocks in Colorado, Idaho, Utah and Wyoming. Coal in the Bear River formation, of Early Cretaceous age contains as much as 0.03 percent uranium in the ash from localities in the Caribou Mountains, Bonneville County, Idaho and 0.009 percent uranium in the ash from localities 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; Contribution to the International Conference on peaceful uses of atomic energy, Geneva, Switzerland, August 1955: U. S. Geological 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., 1956, 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 was found to contain an average of about 0.02 percent uranium with as much as 0.1 percent uranium and 0.3 percent uranium 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 indicated to be widespread and are repeated several times by folding and faulting in the complex structural belt in the area. Data from spectrographic analyses indicate a correlation of molybdenum and germanium with uranium and suggest a geochemical relationship and a common origin for these metals. Four general hypotheses are discussed for the origin of uranium in carbonaceous rocks. Reserves for a 400 acre area are estimated to be about 6,500,000 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 coal fields 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.

A reconnaissance for uranium-bearing coal and associated rocks was made in the Lee and Breathitt formations in the coal fields of eastern Kentucky and Logan and Mingo Counties, W. Va. Radioactivity determinations showed that the coal contained from 0.000-0.001 percent equivalent uranium. Shales and clays that were sampled are slightly more radioactive, containing 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.

The coal-bearing rocks in the anthracite fields are the Pottsville, Allegheny, and Conemaugh formations of Pennsylvanian age. Reconnaissance in the four major fields--the Southern field, the Western Middle field, the Eastern Middle field, and the Northern field--showed that the radioactivity of the coal was 0.001 or less percent equivalent uranium and from 0.001-0.003 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 investigation was made in parts of southern Utah for 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, 1-2 feet thick, at two localities in the Kaiparowits Plateau contain 0.006 and 0.007 percent uranium. Other carbonaceous sediments that were examined contain 0.002 percent or less uranium.

55. Zeller, H. D., 1956, 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-Arikaree formations. In the Medicine Pole Hills the uranium is concentrated at the base of the lignite in a number of cores. Laterally moving mineralized groundwater, along fractured lignite that overlies impervious underclays, appears to have controlled the uranium distribution in these beds. Spectrographic studies indicate that molybdenum has positive correlation with 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, which occur in the Ludlow member of the Fort Union formation are shown on the map. The rocks exposed in this area range in age from Paleocene to Recent.

INDEXES

Part I - Author index

(Numbers correspond to the reference number, not to page number.)

Part II - Geographic index

(Numbers correspond to the reference number, not to page number.)

Part III - Stratigraphic unit index

(Numbers correspond to the reference number, not to page number.)

Part IV - Subject index

(Numbers correspond to reference number, not to page number.)