Uranium in Coal in the Western United States

GEOLOGICAL SURVEY BULLETIN 1055

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Based on the joint and individual work of Norman M. Denson, George O. Bachman, James R. Gill, William J. Hail, Jr., Roy C. Kepferle, William J. Mapel, Harold Masursky, Robert E. Melin, George W. Moore, George N. Pipiringos, Charles B. Read, James M. Schopf, James D. Vine, and Howard D. Zeller

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[The letters in parentheses preceding the titles designate individual chapters]

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By NORMAN M. DENSON

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URANIUM IN COAL IN THE WESTERN UNITED STATES

INTRODUCTION

By Norman M. Denson

GENERAL STATEMENT

During the 5-year period 1950–1954, the United States Geological Survey made extensive investigations of the occurrence and distribution of uranium in coal and related carbonaceous materials throughout large areas in the western United States. By use of portable geiger and scintillation counters and carborne scintillation equipment, hundreds of exposures of coal were tested for radioactivity, and samples were collected for chemical and spectrographic analyses. Subsequently, exploratory core-drilling was carried out in several coal-bearing areas in North Dakota, South Dakota, Wyoming, and Idaho, by the United States Bureau of Mines and the United States Geological Survey, to determine the uranium content of coal beds below the surface. These investigations have shown that several large coal deposits in the Tertiary basins of the Rocky Mountain and the Great Plains regions contain very low grade concentrations of uranium. The uranium content of the coal in these deposits is not uniform but ranges from about 0.005 to 0.02 percent. Within the low-grade uranium-bearing coal deposits, smaller irregular masses of coal containing 0.1 percent or more uranium have been found in places. A number of uranium minerals including autunite, zeunerite, torbernite, carnotite, becquerelite, and coffinite have been identified in the higher grade uraniferous coals, but much of the uranium is inconspicuously disseminated in the carbonaceous material. In the larger and lower grade deposits individual uranium minerals have not been identified. The uranium is disseminated in the carbonaceous material.

This chapter presents an outline of the history and extent of the Survey's investigations of uraniferous coal in the Western States and a short discussion of the origin of the uranium in the coal; subsequent chapters in this report deal with the geology and economic potentialities of those areas where uranium was found in sufficient amount in coal to be of possible future value. Briefly mentioned are other areas not examined in detail where the geologic setting is favorable for the occurrence of similar deposits.

This report is based on work undertaken as part of a program of exploration for radioactive materials for the U. S. Atomic Energy Commission and is published with the permission of the Commission.

HISTORICAL BACKGROUND

Although the association of uranium with carbonaceous material has been recognized for many years (Berthoud, 1875; Boutwell, 1905; Unkovskaya, 1940; Davidson and Bowie, 1951; and Gruner, 1954), it has long been known that most coal beds are some of the least radioactive of the common sedimentary strata for the uranium content of coal is generally very low (Russell, 1945; Newmarch, 1950; Couret, 1952; and Davidson and Ponsford, 1954). Little attention was given to the possibility that significant quantities of uranium occur in coal beds in the western United States until 1945, when Slaughter and Nelson of the Geological Survey discovered extensive low-grade deposits of uranium-bearing coal in the Great Divide Basin of south-central Wyoming (Slaughter and Nelson, written communication, 1946). In 1948 and 1949 beds of coal in the Williston basin area of North and South Dakota were found to be uranium-bearing by Wyant and Beroni (written communication, 1949) and by Beroni and Bauer (written communication, 1952). In 1950 Denson, Bachman, and Zeller continued studies of uranium-bearing coals in the southern part of the basin to evaluate their economic possibilities and to determine the geologic factors controlling the accumulation of the uranium. Emphasis was placed on finding coal in beds of minable thickness and grade that could be used as fuel and from which uranium could be extracted from the ash as a by-product. From 1951 through 1954 the Geological Survey conducted extensive investigations for uranium-bearing coal and carbonaceous shale in many other areas in the Western States. These studies included brief examinations of several of the better known deposits of Cretaceous and Tertiary coal in the Rocky Mountain province from southern Montana to New Mexico, the Colorado Plateau, the Great Basin, and the Pacific Coast region. Results of some of these investigations, most of which were negative, have been briefly described in reports by Bachman and Read (1952); Beroni and McKeown (1952); Gude and McKeown [1]; Love (1952); Vine

[1] Gude, A. J., 3rd, and McKeown, F. A., 1952, Results of exploration at the Old Leyden coal mine, Jefferson County, Colorado: U. S. Geol. Survey open-file report.

and Moore (1952); Bachman, Baltz, and O'Sullivan (written communication, 1953); Duncan (1953a); Hail and Gill (1953); Troyer and others (1953); Vine and Flege (1953); Griggs (1954); Moore and Stephens (1954); Staatz and Bauer (1954); Baltz (written communication, 1955); Zeller (1955); and Wyant, Sharp, and Sheridan (1956).

SOURCE AND ACCUMULATION OF URANIUM

Three hypotheses of source and accumulation have been advanced by geologists to explain the occurrence of uranium in coal of the Western States. They are:

1. Syngenetic.—Uranium was deposited from surface waters by living plants or in dead organic matter in swamps prior to coalification.
2. Diagenetic.—Uranium was introduced into the coal during coalification by waters bringing the uranium from areas marginal to the coal deposits or from the consolidating enclosing sediments.
3. Epigenetic.—Uranium was introduced in the coal after coalification and after consolidation of the enclosing sediments by ground water deriving uranium from hydrothermal sources or from unconformably overlying volcanic rocks.

The source and manner of accumulation of uranium in coal are briefly discussed here, because a systematic search for additional deposits will be successful chiefly to the extent that it is guided by valid concepts of origin. The epigenetic hypothesis favored by the author and presented in greater detail in chapter B is but one of the possible processes, as indicated above, by which uranium may be concentrated in coal. The author wishes, however, to emphasize that the accumulation of uranium in coal may vary markedly from place to place and that each newly discovered deposit should be objectively considered and interpreted in relation to the geologic history of the region in which each deposit occurs.

As a result of the investigation of uraniferous lignite in the Dakotas in 1948 and 1949, Gott, Wyant, and Beroni (1952) concluded that the uranium was probably of syngenetic origin, having been initially concentrated from swamp waters by the vegetation from which the coal was formed. Beroni and Bauer (written communication, 1952) recognized, however, that the lignite is interbedded with strata in the Dakotas that contain minerals of volcanic origin and suggested that the uranium might be of diagenetic origin, having been redistributed from volcanic materials during or shortly after the deposition of the lignite. Systematic sampling and regional studies of beds of radioactive lignite in the Dakotas and eastern Montana by Denson, Bachman, and Zeller in 1950 (see chapter B of this bulletin) led them to propose the theory that the uranium in these deposits is of epigenetic origin, secondarily derived by leaching of the volcanic materials in the Oligocene and Miocene rocks that at one time covered most of the region. They thought that the uranium was a primary constituent of volcanic ash and that the uranium was leached from it by ground water during weathering and devitrification. This concept was based largely on the fact that beds of uranium-bearing lignite, irrespective of age, closely underlie the unconformity at the base of tuffaceous rocks of the White River group, and that the greater concentrations of uranium occur in the upper parts of the stratigraphically highest lignite beds.

Application of this theory to the search for other deposits during 1950 led to the discovery of uranium-bearing coal in the Lost Creek coal field in the southern part of the Powder River Basin of eastern Wyoming (Love, 1952), and to similar discoveries in 1951 in the Ekalaka Hills area of Montana, the Fall Creek and Goose Creek areas of Idaho, and the La Ventana Mesa area of New Mexico, described in chapters F, I, H, and J, respectively, and shown on figure 1. In general, the uranium-bearing coal in each of these areas forms the topmost seam of a sequence overlain unconformably by layers of silicic volcanic materials or other strata from which uranium may have been leached by ground waters.

The fact that the most highly mineralized beds of coal are those adjacent to beds of coarse-grained permeable sandstone suggests that the latter acted as a conduit for the mineralizing solutions, which in some areas may have carried uranium great distances under hydrostatic head (Masursky and Pipiringos *in* Denson and others, 1952). The average range in uranium content of water from seeps and springs issuing from these volcanic rocks is about 10–100 times greater than that of normal ground water, which generally contains less than 3 parts per billion (Aberdeen, E. J., and others, written communication, 1952; Gill and Moore, 1955; Denson, Zeller, and Stephens, 1955; Fix, 1955). The uranium content of these ground waters and also the occurrence of carnotite, autunite, metatyuyamunite, and uranocircite in these volcanic rocks at several widely separated localities in the Rocky Mountain and Great Plains regions (Staatz and Bauer, 1951; Duncan, 1953b; Gill and Moore, 1955; and Moore and Levish, 1955) suggest that the volcanic rocks may be source beds of uranium. The uranium could have been leached out of these or similar source rocks and transported considerable distances downward and laterally by ground water, being deposited in favorable host materials in the underlying strata.

POSSIBLE ECONOMIC VALUE OF URANIUM-BEARING COAL

Large quantities of uranium are contained in the low-rank coal of Cretaceous and Tertiary age in the basin areas of Wyoming, Idaho, and New Mexico, and the northern Great Plains region of eastern Montana and the Dakotas (fig. 1). In comparison with current sources of uranium, most of the uranium-bearing deposits herein described are very low grade. Detracting from their value as a possible source of uranium is the fact that, in general, the more highly uraniferous coals have greater ash and much lower heating value than nonuraniferous coals. Considered on this basis, utilization of the coals and the recovery of the uranium as a byproduct from the ash would depend upon the coals' suitability for use as fuel in competition with other coals. No efficient or inexpensive means of extracting small amounts of uranium from coal has yet been found, but the possible development of new metallurgical techniques and recovery processes may eventually lead to the utilization of some of the larger uraniferous coal deposits, many of which are suited to strip-mining methods.

Some of the uranium-bearing coal described in subsequent chapters have been found to contain small irregular occurrences of material containing 0.1 or more percent uranium, as for example those beds in the La Ventana (chapter J), Goose Creek (chapter H), and Fall Creek (chapter I) areas. In these areas a closer search might disclose some uranium-bearing coal that can be mined under present economic conditions.

Adding interest to coal as an important future source of uranium is the recent discovery of large tonnages of coal containing as much as 6 percent and averaging 0.7 percent uranium in beds as much as 24 inches thick on the southern flank of the Williston basin in the Cave Hills area of northwestern South Dakota (Gill, 1954). This discovery indicates that uranium-bearing coal of comparable grade may occur at other localities in the Western States.

GUIDES IN EVALUATING EVIDENCE FOR URANIUM-BEARING COAL IN UNEXPLORED AREAS

During the investigations of the occurrence and distribution of uranium in coal and related carbonaceous materials in the Western States, several thousand water samples, mostly of ground water sources from seeps, springs, and wells, were analyzed for uranium. These analyses served not only to delimit areas where the abnormally high uranium content of water reflects present leaching of ore deposits but also helped to evaluate the relative possibilities of widespread vol-

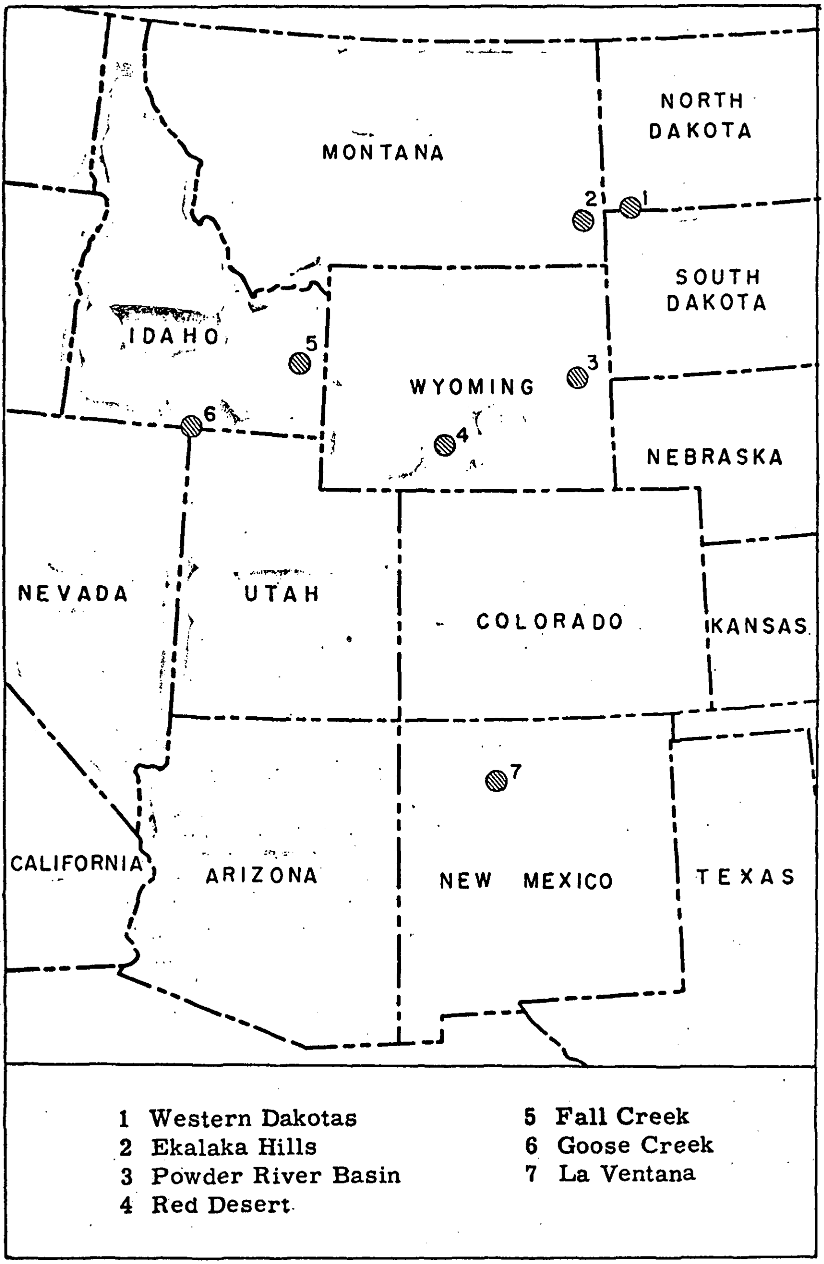

FIGURE 1.—Index map showing areas of uranium-bearing coal and carbonaceous shale in the western United States.

canic-rock units which may have been an important primary source of uranium now present in deposits in the underlying sedimentary rocks. Although many volcanic rocks of Tertiary age contain small amounts of uranium, not all furnish uranium to the ground-water system in equal amounts. Analyses have been made of water samples from volcanic rocks ranging in age from Late Cretaceous to Pliocene throughout the Rocky Mountain and Great Plains regions. Ground water issuing from rock units of Oligocene and Miocene age, irrespective of geographic location, is notable for its relatively great uranium content.

Although the factors controlling the solubility of uranium are imperfectly understood, it is probable that those causing the variations in physical, chemical, and climatic environments to which normal ground water is subjected affect its acidity, chemical composition, and colloidal content. These factors may be significant in controlling the solubility of uranium by natural solutions. The average range in uranium content of ground water from the areas studied showed the following variation. The highest concentrations of uranium in ground water are found in areas of known deposits (about 70–300 parts per billion) and in ground water from silicic tuffs and tuffaceous rocks of Oligocene and Miocene age (about 20–45 parts per billion). The most highly mineralized water from tuffaceous terranes has an alkaline pH range of 7.5–9.5. In general, the greater the alkalinity of the waters from these rocks, the more uranium the waters contain. Analyses showing greater contents of uranium also show proportionately greater contents of sodium and calcium, the water from Oligocene rocks being more sodic and the water from the Miocene rocks being more calcic. The trace-metal content of these waters has not been related to their uranium content. Chemical and spectrographic analyses of residues obtained by evaporation of large samples of water from these units show that they contain more than normal amounts of molybdenum, vanadium, copper, phosphorus, zinc, and arsenic. There may be a genetic relationship between these rocks and those of the ore minerals (autunite, carnotite, torbernite, and zeunerite) associated with coal at some localities in the western interior.

In evaluating uranium possibilities of unexplored areas, ground-water sampling may be a useful means of prospecting, particularly in areas where thick overburden makes geiger and scintillation counters ineffective.

AREAS THAT MAY CONTAIN URANIUM-BEARING COAL

In comparison with the areas known to contain uranium-bearing coal, there are several other areas, not described in the following chapters and perhaps not adequately examined for radioactive materials, where the geologic setting seems favorable for the occurrence of uranium deposits. These areas (fig. 2) contain coal-bearing rocks

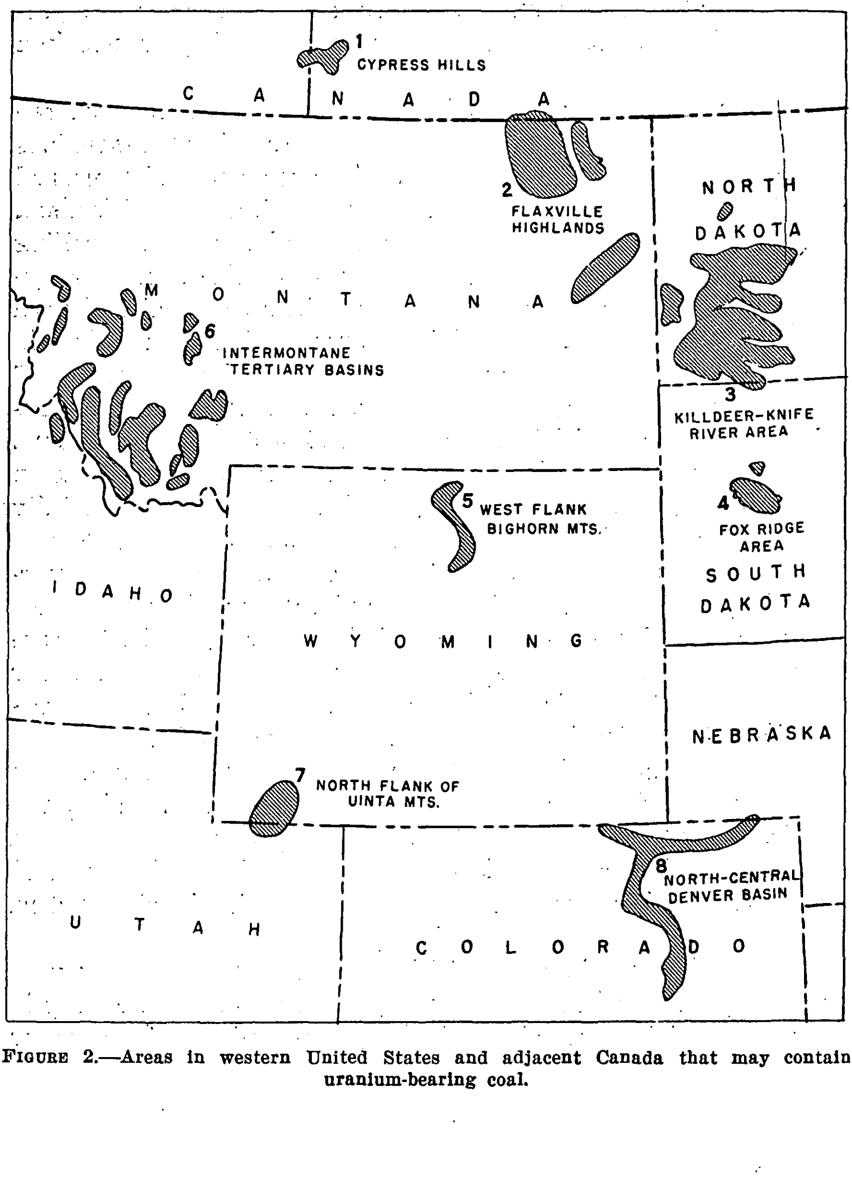

FIGURE 2.—Areas in western United States and adjacent Canada that may contain uranium-bearing coal.

that are today or were once closely overlain by slightly uraniferous volcanic rock and may have significant deposits of uranium-bearing coal. They are the following:

No. on fig. 2	*Area*
1	Cypress Hills in Canada (Saskatchewan and Alberta)
2	Flaxville Highlands in Montana
3	Killdeer-Knife River area in North Dakota
4	Fox Ridge area in South Dakota
5	West flank of the Bighorn Mountains in Wyoming
6	Intermontane basins of Tertiary age in Montana
7	North flank of Uinta Mountains in Wyoming
8	North-central part of the Denver basin in Colorado

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Uranium-Bearing Lignite in Northwestern South Dakota and Adjacent States

By NORMAN M. DENSON, GEORGE O. BACHMAN, *and* HOWARD D. ZELLER

URANIUM IN COAL IN THE WESTERN UNITED STATES

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ILLUSTRATIONS

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TABLES

URANIUM IN COAL IN THE WESTERN UNITED STATES

URANIUM-BEARING LIGNITE IN NORTHWESTERN SOUTH DAKOTA AND ADJACENT STATES

By NORMAN M. DENSON, GEORGE O. BACHMAN, and HOWARD D. ZELLER

ABSTRACT

In northwestern South Dakota and adjacent areas, uranium-bearing lignite beds occur at many horizons in the Hell Creek formation of Late Cretaceous age and in the overlying Ludlow, Tongue River, and Sentinel Butte members of the Fort Union formation of Paleocene age. Analyses for uranium of 275 samples of lignite taken from outcrops or obtained by auger-drilling and of about 1,000 core samples of lignite show that many of the lignite beds contain 0.005–0.02 percent uranium, and their ash contains 0.05–0.10 percent. Analytical data also indicate that the region contains an aggregate of at least 47,500,000 tons of lignite having an average uranium content of slightly more than 0.008 percent. Almost a fifth of the lignite occurs in beds suitable for strip mining and averaging about 4 feet in thickness. Recent discoveries of ore-grade deposits of autunite-bearing lignite and of secondary minerals of uranium in carbonaceous sandstone at Cave Hills and Slim Buttes indicate that northwestern South Dakota and adjacent areas may contain important deposits of uranium minerals.

The stratigraphic units containing the uraniferous lignite beds have a combined thickness of about 1,500 feet and are unconformably overlain by a sequence of 300 feet or more of tuffaceous sandstone and bentonitic claystone of the White River group of Oligocene age and the Arikaree formation of Miocene age. The stratigraphically highest lignite beds in the area have the greatest content of uranium, and the concentration of uranium is greatest at the top of thick lignite beds, diminishing progressively downward to a vanishing point in their lower parts. Variations in permeability of the rocks overlying the mineralized lignite beds seem to be related to the concentration of uranium. Most of the known beds of uranium-bearing lignite in the region are closely overlain by rocks of the White River group and the Arikaree formation, which have about 12 times more uranium than the average sedimentary rock. Furthermore, the uranium content of spring water from these formations is 30 or more times that of normal ground water. The presence of uranium in the lignite is independent of the age of the formation in which the lignite occurs. Field relations thus suggest that the uranium is of secondary origin and has been introduced after the accumulation and marked regional uplift and warping of the lignite beds and associated rocks.

The uranium is believed to have been a finely disseminated constituent of the overlying mildly radioactive volcanic ash and was released or displaced during weathering, and carried—probably in the ionic form—by downward and laterally moving ground waters. Carbonaceous material—lignite or carbonaceous shale—is believed to have taken the uranium from solution by ion exchange or by the formation of organo-metallic compounds.

Geologic factors that seem most significant in controlling the distribution and concentration of uranium in these beds of lignite are the following: (1) Stratigraphic proximity of the lignite to the base of the White River group, (2) permeability of the rocks overlying the lignites, (3) adsorptive properties and porosities of the constituents of lignite, (4) present and past position of the ground-water table; and (5) the amount of uranium in the original White River and Arikaree sediments.

INTRODUCTION

The study of uranium-bearing lignite in northwestern South Dakota and adjacent areas was undertaken to evaluate its economic possibilities and to determine the geologic factors controlling the accumulation of uranium in lignite. Field work began in June 1950 and was completed in October 1950. Geiger-Mueller counters and a portable scaler were used in the field work as guides in the sampling program. A jeep-powered auger was employed to obtain samples of unweathered uranium-bearing lignite. During the field investigations, 275 other samples were collected for laboratory analysis. Radiometric and chemical analyses for uranium, and chemical and semiquantitative spectrographic analyses for other minor elements in these samples were made by the Geological Survey.

The validity of the theory herein presented on the origin and accumulation of the uranium in the lignite was tested during the latter part of the summer of 1950 in the Powder River Basin in eastern Wyoming and in other areas in the Rocky Mountain region during the summer of 1951; here its application led to the discovery of other concentrations of uranium-bearing carbonaceous materials.

GEOGRAPHY

The lignite field of northwestern South Dakota and adjacent areas of Montana and North Dakota includes about 5,000 square miles near the eastern margin of the Great Plains province and north of the Black Hills (fig. 3) in a region of rolling prairie, interrupted by small areas of badlands, or by rugged and precipitous buttes and ridges. The more prominent buttes are the Cave Hills and the Slim Buttes near the center of the area, and the Short Pine Hills (S. Dak.) and Long Pine Hills (Mont.) near the southwest corner of the area. These buttes stand 300–500 feet above the surrounding country and support a growth of yellow pine. Strata are well exposed in the cliffs rimming the buttes. The eastward-flowing Grand River and the northward-flowing Little Missouri River and their tributaries drain most of the region. Low sandy hills and broad sandy flats border the rivers, but the divides in many places are capped by small rock buttes or by red baked rock and clinker resulting from the burning of the lignite beds.

The altitude of the lignite field ranges from 2,100 feet above sea level, along the east border, to 4,019 feet, on the Short Pine Hills, giving a maximum relief of about 1,900 feet. Buffalo (population 400), the county seat of Harding County, is the largest town within the area in South Dakota. Many county roads and prairie trails, supplementing State and Federal highways, make most places fairly accessible. Bowman, N. Dak. (population 1,400), 50 miles north of Buffalo, is the nearest railroad shipping point.

The prominent topographic features in the region and their relationship to the general geologic setting are shown on plate 1.

ACKNOWLEDGMENTS

Several members of the Geological Survey contributed information and advice that greatly aided this investigation. C. H. Dane, W. G. Pierce, and V. E. McKelvey made helpful suggestions in the field. D. G. Wyant and E. P. Beroni supplied analytical data and information on the uranium-bearing lignites in North Dakota and eastern Montana. W. E. Benson permitted the authors to use his then unpublished map showing the areal distribution of upper Tertiary formations in western North Dakota (Benson, 1951). R. W. Brown gave valuable assistance in the field, identifying plant collections and establishing the age relationships of the rock units mapped. W. E. Benson and D. G. Wyant also assisted during the early stages of the field work, and Howard A. Powers studied and interpreted thin sections of volcanic rocks.

STRATIGRAPHY

The stratigraphic section exposed in northwestern South Dakota and adjacent areas includes rocks of Cretaceous, Tertiary, and Quaternary age. Figure 4 is a generalized columnar section adapted from Winchester and others (1916) and Hares (1928), showing the average thicknesses, characteristics, and relations of the various formations and the stratigraphic position of the principal coal beds.

Beds of uranium-bearing lignite occur sporadically throughout the region at many horizons in the Ludlow, Tongue River, and Sentinel Butte members of the Fort Union formation of Paleocene age and in the underlying Hell Creek formation of Late Cretaceous age. The sequence of lignite-bearing stratigraphic units has a thickness of 1,500 feet or more and consists predominantly of fluviatile deposits of somber-colored, soft, sandy, clay shale and massive, thick-bedded,

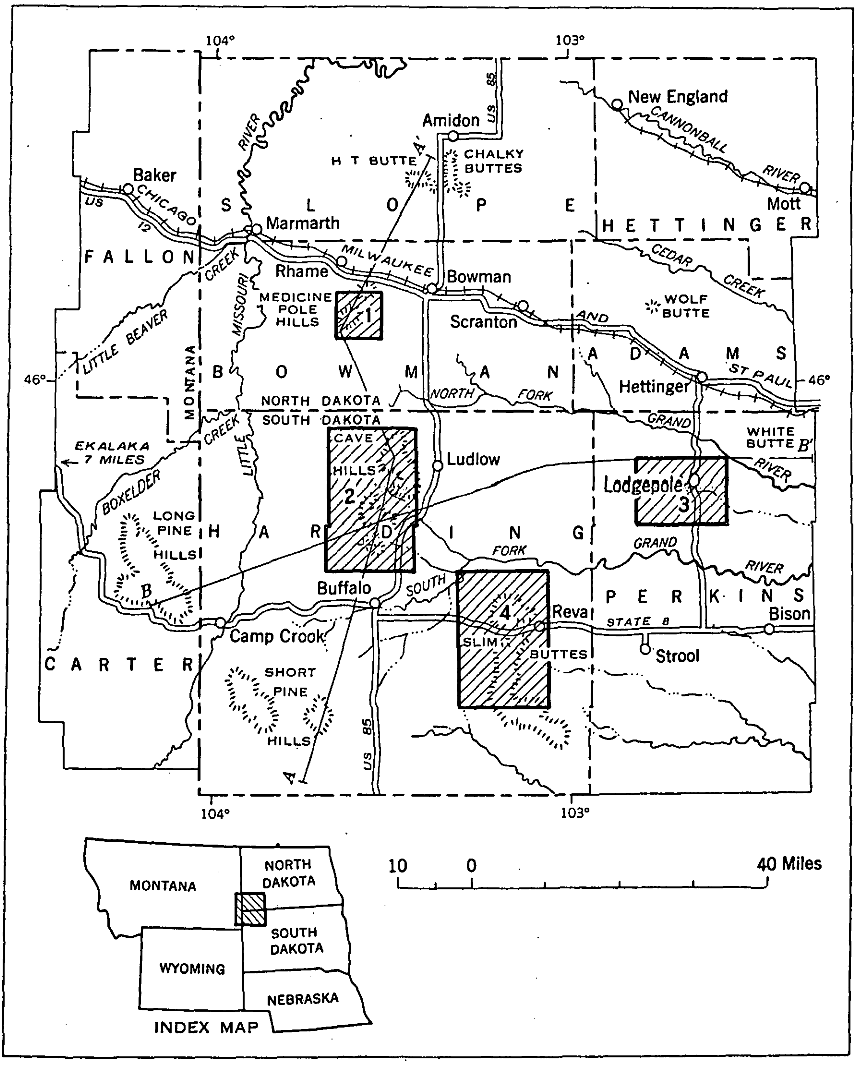


FIGURE 3.—Index map showing areas of uranium-bearing lignite deposits described in this report.

tan, and buff-gray sandstone. A marked regional unconformity separates them from 300 feet or more of ash-gray, mildly radioactive tuffaceous sandstone and bentonitic clay of the overlying White River group of Oligocene age and the Arikaree formation of Miocene age. Remnants of the latter two units, which cap many of the high buttes and escarpments, indicate that they once covered most if not all the lignite-bearing rocks in western South Dakota and adjacent parts of North Dakota and Montana (pl. 1).

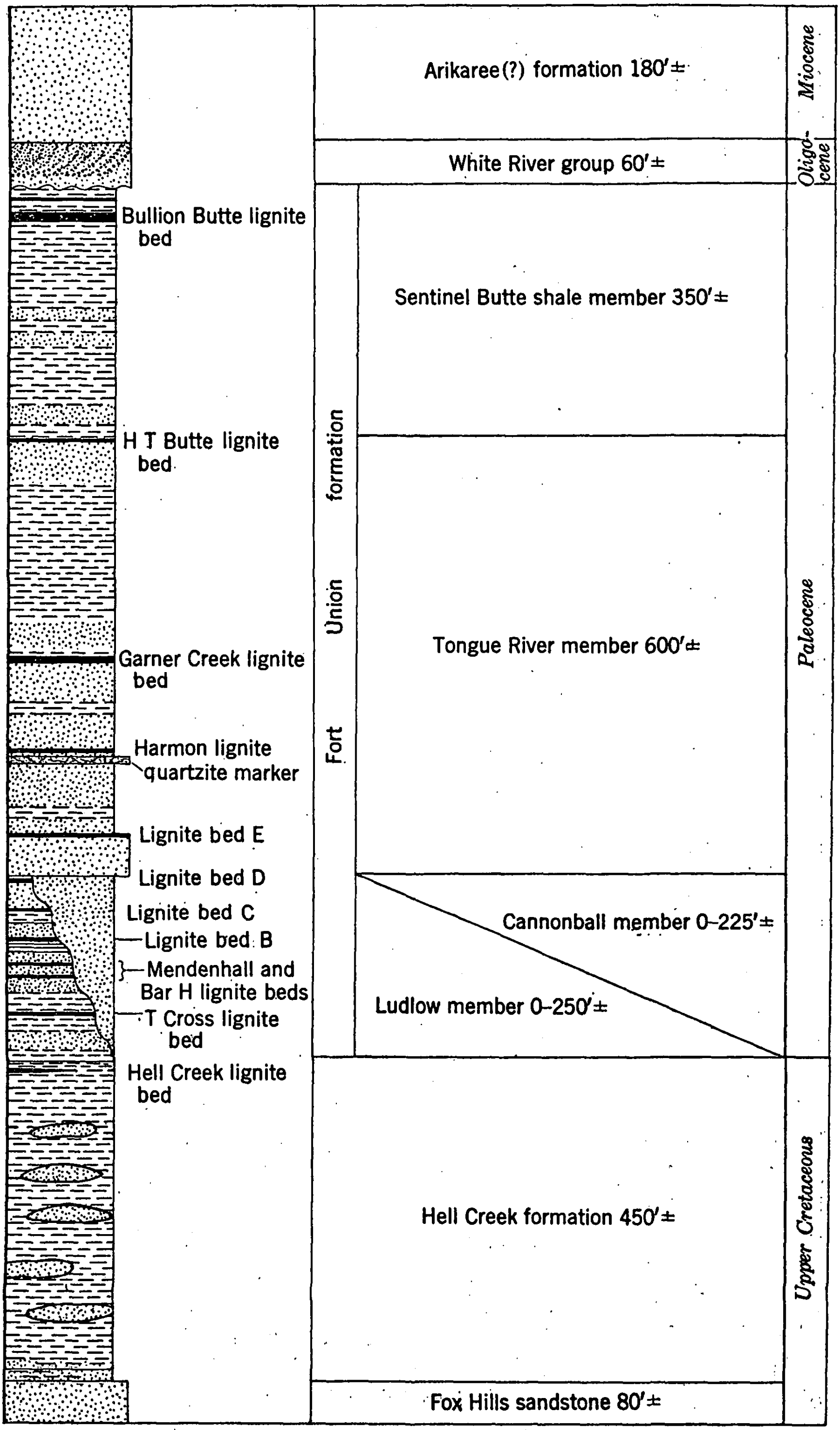


FIGURE 4.—Generalized columnar section showing stratigraphic position of principal lignite beds in northwestern South Dakota and adjacent areas.

The geology of the region has been described in detail in reports by Winchester and others (1916), Bauer (1924), Hares (1928), and Baker (1952), and therefore no attempt is made in this report to treat the geology in detail. The stratigraphy and general geology of the various areas underlain by significant deposits of uranium-bearing lignite are summarized.

CRETACEOUS SYSTEM, HELL CREEK FORMATION

The Hell Creek formation is the oldest stratigraphic unit of the thick sequence of lignite-bearing continental sediments exposed in Harding and Perkins Counties, S. Dak., and in the adjoining areas in Bowman County, N. Dak., and southeastern Montana. The formation overlies the Fox Hills sandstone, of marine origin, and crops out extensively in South Dakota south and west of Slim Buttes, Cave Hills, and Table Mountain, and in North Dakota along the east flank of the Cedar Creek anticline in southwest Bowman County.

The Hell Creek formation ranges from 300 to 575 feet in thickness and consists of fresh- and possibly some brackish-water deposits of sandstone, bentonitic claystone, and thin beds of lignite. In places the strata contain ellipsoidal, buff, or dirty-brown, iron-cemented sandstone concretions which range from an inch or less to 5–6 feet in diameter. Thin layers of bog iron and ferruginous masses formed by the weathering of iron carbonate are also present. The Hell Creek strata are heterogeneous and crossbedded. As a rule, single beds are not traceable more than a few miles, even where exposures are good. Although weakly cemented, the rocks are resistant to erosion, weathering into rounded and fluted surfaces having a rough, coarse, irregular appearance. They commonly produce a characteristic varied badland topography interspersed with broad flat areas. The uniformly dark, somber hues of gray, buff, olive green, and chocolate distinguish them at a distance from the overlying prevailing yellow sandy strata of the Ludlow member of the Fort Union formation. They are sparingly fossiliferous and have yielded species of turtles, dinosaurs, and poorly preserved plants of Late Cretaceous age.

The Hell Creek formation as a whole is barren of valuable lignite beds. Such lignite as occurs is usually in lenticular beds of small areal extent in the uppermost 100 feet of the formation. Uranium-bearing lignite was found at only two places in the formation in northwestern South Dakota: (1) in the E ½ sec. 13, T. 17 N., R. 3 E.; and (2) near the center of the south line of sec. 17, T. 19 N., R. 3 E. There the beds are thin, and the occurrence of uranium in them is only of academic interest. According to R. W. Brown (1952) the lignite beds here mapped as in the upper part of the Hell Creek should be placed in the lower part of the overlying Ludlow formation. Because there is no distinct lithologic difference between these rocks and the lower part of the Hell Creek they are here assigned to the Hell Creek formation.

TERTIARY SYSTEM

FORT UNION FORMATION (PALEOCENE)

In northwestern South Dakota and in the adjoining area to the north in North Dakota, the Fort Union formation, of Paleocene age, consists of 1,200 feet or more of lignite-bearing sandstone, shale, and claystone. The continental strata of the lower 300 feet of the formation are assigned to the Ludlow member, and intertongue to the east with marine strata not containing lignite and assigned to the Cannonball member of the formation. Overlying the Ludlow and Cannonball members with apparent conformity is the Tongue River member, in turn overlain by the Sentinel Butte member. The significant lithologic characteristics and stratigraphic relationships of each of the four members are described below.

Ludlow member.—The Ludlow member of the Fort Union formation, named from the town of Ludlow in Harding County, S. Dak., is well exposed at its type locality along the south face of the North Cave Hills (Winchester and others, 1916, p. 20). Rocks assigned to the member occur throughout much of the region as a thin cover on divides, particularly along the south fork of the Grand River north and east of Slim Buttes, and as belts around the higher buttes and mesas, as in the South Cave Hills, Table Mountain, and Long Pine Hills areas. Most of the rocks are loosely consolidated and easily disintegrated.

At its type locality the member consists of 300–350 feet of interbedded sandstone, shale, and lignite, most of which is believed to be of fresh-water origin. The most prominent feature of typical Ludlow is the predominance of light-yellow sandstone. The Ludlow member is very similar to the overlying Tongue River member, but it is separated from that member throughout the eastern part of the area by the marine Cannonball member with which it intertongues (fig. 5). Although dinosaur remains are absent in the Ludlow and are commonly present in the underlying Hell Creek formation on which the Ludlow rests conformably, the differentiation of these stratigraphic units at many places is difficult because of the local similarity of the lithologic and color criteria by which the formations are distinguished. At most places, however, the lower limit of the Ludlow is placed where predominantly somber-colored shale of the Hell Creek is overlain by prominent yellow sandy strata characteristic of the Ludlow member of the Fort Union formation, and is marked in many places by a bed of lignite.

Most of the lignite beds which occur throughout the Ludlow member are lenticular, and persist for only a few miles along their outcrop. Locally, the beds are thick, and have been mined to supply fuel for local use. Deposits of uranium-bearing lignite occur in the Ludlow member in the Bar H and Mendenhall areas, along the west-central and northeastern parts of Slim Buttes (pl. 11), and in the North and South Cave Hills and Table Mountain areas, Harding County, S. Dak. Slightly radioactive lignite also occurs in the Ludlow in the Long Pine Hills, Carter County, Mont.

Cannonball member.—The Cannonball member of the Fort Union formation is named for exposures along the Cannonball River in Grant County, N. Dak. (Tps. 132 and 133 N., R. 88 W.), about 50 miles northeast of the area of this report. It consists of sediments of a sea which extended from the east into northern Perkins and northeastern Harding Counties, S. Dak., and southern Adams and southwestern Bowman Counties, N. Dak. The Cannonball member is reported to be about 300 feet thick along the Cannonball River (Lloyd, 1914, p. 248–249), but thins as it interfingers to the west with the Ludlow. It has not been recognized west of R. 8 E. in the vicinity of Anarchist (Mud) Butte, northeastern Harding County, S. Dak. The Cannonball is composed largely of thick-bedded gray to buff, calcareous or ferruginous sandstone, and alternating beds of yellow to buff clay, and silty limestone. Concretions ranging in diameter from 6 inches to 10 feet are commonly present. Because the Cannonball member does not contain lignite beds, it was not studied in detail.

Tongue River member.—The Tongue River member of the Fort Union formation has been eroded from most of northwestern South Dakota and the adjacent areas in North Dakota and Montana. Where the rocks of this unit are present, they conformably overlie the Ludlow member or its marine equivalent, the Cannonball member. The Tongue River member caps Table Mountain, North and South Cave Hills, and forms the bedrock near Anarchist Butte and Lodgepole Buttes in northeastern Harding and northern Perkins Counties, S. Dak., and near the Medicine Pole Hills in Bowman County, N. Dak. At most places the Tongue River weathers to a gently rolling upland and to a fertile sandy loam.

An estimate of the original thickness of the Tongue River in South Dakota cannot be made because its upper part has been eroded. A maximum thickness of about 300 feet was measured by Winchester and others (1916, p. 27) near Anarchist Butte in the southeastern part of T. 22 N., R. 8 E., in Harding County, S. Dak. Hares (1928, p. 47–48) describes a total of 600 feet of Tongue River strata to the north, in the Marmarth field where these rocks are overlain by the Sentinel Butte member. The rocks are light gray, tan, buff, and white and are predominantly sandstone, for the most part, fine grained and evenly thin bedded, though quite massive in places. The sandstone commonly resists erosion and forms vertical walls, to which is due the mesalike character of the Cave Hills and Table Mountain. The rocks of the Tongue River are lighter in color, contain a larger percentage of sandstone, and have thicker and more persistent beds of lignite than those of the underlying Ludlow member. The individual strata are also more persistent and regular.

On the southwest side of the North Cave Hills and stratigraphically about 170 feet above the base of the Tongue River, a 2-foot bed of quartzite, the lowest of such beds in the Fort Union formation, forms the top of the massive sandstone caprock. The quartzite is gray, very fine grained, and contains impressions of plant roots. Boulders of quartzite containing impressions of stems and roots and derived from this bed and from beds higher in the section are scattered over the surface of much of the area. Quartzite similar to that of the North Cave Hills has been described by Hares (1928, p. 34–36) and Brown (1948, p. 1268–1269) in adjacent areas of North Dakota. In Harding and Perkins Counties, S. Dak., the lowest quartzite bed persists for about 30 miles from the North Cave Hills eastward to the vicinity of Lodgepole Post Office. The bed forms the caprock on the prominent buttes east of the North Cave Hills. It is present in the Tepee Buttes, Anarchist Butte, and on the Johnson outlier in the Lodgepole area. (See pls. 1 and 10.) It normally occurs 10–20 feet below a widespread and persistent bed of lignite, referred to in this report as the Harmon lignite bed. In western Perkins County the quartzite may be within 100 feet of the base of the Tongue River member; however, the Tongue River rests on the Cannonball member and the stratigraphic position of the quartzite is difficult to determine because of poor exposures and the gradational boundary between the Cannonball and Tongue River members.

Plants of Paleocene age from the Tongue River member collected from beds above the Harmon lignite bed at Anarchist Butte in SW¼ sec. 27, T. 22 N., R. 9 E., Harding County, S. Dak., were identified by R. W. Brown of the U. S. Geological Survey as follows:

Sparganium antiquum (Newberry) Berry
Glysptostrobus dakotensis Brown
Metasequoia occidentalis (Newberry) Chaney
Platanus raynoldsi Newberry
Cercidiphyllum arcticum (Heer) Brown
Unidentified seeds

Deposits of uranium-bearing lignite occur in the Tongue River member of the Fort Union formation in three areas: (1) the Medicine Pole Hills area, Bowman County, N. Dak.; (2) the Lodgepole area of Perkins County, S. Dak.; and (3) Cave Hills area, Harding County, S. Dak.

Sentinel Butte member.—The Sentinel Butte is the uppermost member of the Fort Union formation. It has been removed by erosion from all parts of northwestern South Dakota and is preserved only in the higher buttes in the adjoining area of North Dakota. There, it is unconformably overlain by claystone of probable Oligocene age. The Sentinel Butte member is about 350 feet thick and in lithology is similar to the Hell Creek formation of Late Cretaceous age. The member is composed chiefly of siltstone, clay shale, and thin beds of lignite. Somber shades of gray and brown predominate, but the upper part of the unit, directly underlying the White River group, is characteristically oxidized to a yellow or light tan.

Uranium-bearing lignite beds occur in the Sentinel Butte member at HT Butte near the central part of Slope County (fig. 5), but the beds of lignite are thin.

WHITE RIVER GROUP (OLIGOCENE)

The White River group crops out prominently in the Slim Buttes and Short Pine Hills in Harding County, S. Dak., and in the adjoining area to the west in the Long Pine Hills, Carter County, Mont. Many isolated hills in Perkins and Bowman Counties have thin remnants of the White River group capping them. The group lies unconformably on the Hell Creek formation in the Short Pine Hills, on the Ludlow member in the Slim Buttes and Long Pine Hills, on the Tongue River member in Cave Hills and Medicine Pole Hills, and on the Sentinel Butte member on HT Butte. At least 1,200 feet of older rocks were removed in the Short Pine Hills before the deposition of the White River (fig. 5).

The White River group is 40–200 feet thick. It commonly consists of a basal clastic unit of coarse-grained, tuffaceous sandstone and conglomerate succeeded by light-colored bentonitic clay, thin limestone lenses, and white calcareous grit. Locally these rocks exhibit slump structures (see Gill, Zeller, and Schopf, chapter D, this bulletin) and are commonly overlain by massive, nearly horizontal, cliff-forming sandstone of the Arikaree formation (pl. 14). The lower 25 feet or more of the White River group at many places consists of very fine-grained sandstone and silty carbonaceous shale eroded from the weathered pre-Oligocene formations. Where present, these rocks are characteristically stained yellow or rusty tan. Volcanic material in the White River group consists of pebbles of pink porphyry in the basal clastic phases of the formation; glass shards are common in the succeeding finer-grained clastics. A persistent 10–40-foot bed of dark-gray bentonitic clay occurs in the upper part of the sequence. Its

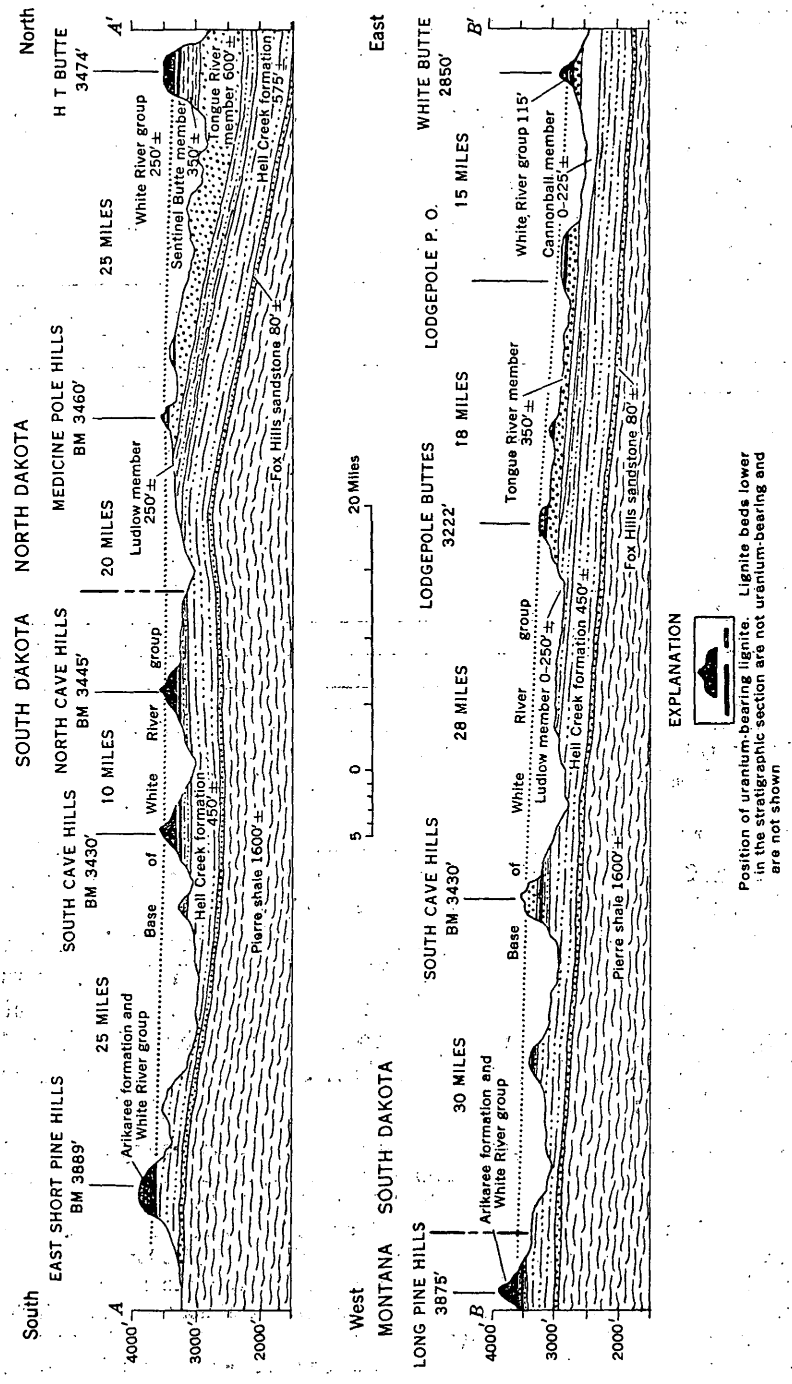


FIGURE 5.—Cross sections, *A–A′*, from Short Pine Hills, Harding County, S. Dak., to HT Butte, Slope County, N. Dak., and *B–B′*, from Long Pine Hills, Carter County, Mont., to White Butte, Perkins County, S. Dak., showing interrelation of uranium-bearing lignite beds to the base of the White River group. Line of sections is shown on figure 3.

presence, particularly in Slim Buttes, controls the position of a perched water table marked by springs and seeps on the flanks of the buttes.

Analyses, in parts per million, of two water samples from the White River group taken at springs on the west flank of Slim Buttes, Harding County, S. Dak., in the Custer National Forest, made by the U. S. Geological Survey, are given below. Uranium analyses, in parts per million are included for comparison.

	Colonel Spring [1] [Mendenhall area]	West Spring [2] [Bar H area]
Silica (SiO_2)	29	24
Iron (Fe)	.03	.03
Calcium (Ca)	4.3	1.0
Magnesium (Mg)	1.2	.4
Sodium (Na)	144	279
Potassium (K)	4.5	2.8
Carbonate (CO_3)	9	87
Bicarbonate (HCO_3)	367	544
Sulfate (SO_4)	8.0	16
Chloride (Cl)	2.5	3.0
Fluoride (F)	.6	.6
Nitrate (NO_3)	1.3	2.2
Dissolved solids	398	698
Total hardness, as $CaCO_3$	16	4
Specific conductance (micromhos at 25° C)	591	1,100
pH	8.4	9.3
Uranium (parts per million)	[3] 0.030–[4] 0.036	[3] 0.030–[4] 0.045

[1] Colonel Spring is in SE¼ sec. 1, T. 17 N., R. 7 E., Harding County, S. Dak.
[2] West Spring is in NE¼ sec. 26, T. 19 N., R. 7 E., Harding County, S. Dak.
[3] Uranium determinations made by the U. S. Geological Survey.
[4] Uranium determinations made by Oak Ridge National Laboratory, Oak Ridge, Tenn.

Gill and Moore (1955) report that the average uranium content of water from 26 springs in the White River group and Arikaree formation in the Slim Buttes area is 41 parts per billion.

Volcanic material forms an appreciable part of the White River group in other areas (Wanless, 1922; Wood, 1949). Various workers have noted that volcanic material in the White River may be absent or range in quantity from very little to the bulk of the unit. Wood (1949, p. 88) summarized the volcanic nature of the White River group as follows:

> . . . The ash falls became steadily heavier during the Oligocene and extended progressively east and north during this epoch. Thus, in eastern and northern White River deposits (Nebraska, South Dakota, North Dakota, and Montana) the Chadron is a true sedimentary rock with clays, silts, and sandstones. The Brule, in these same areas, is of composite origin; the Orella, its lower member, is still largely a sediment, with minor amounts of volcanic material; the *Leptauchenia* clays of the upper, Whitney member are almost a tuff. Much, but not quite all, of the ash was apparently reworked and deposited by water rather than as direct ash falls. To the west, in Colorado and eastern Wyoming, the ash content rises markedly in both Chadron and Brule, so that these units become progressively more difficult to distinguish from each other by color,

erosional habit, or lithology. Still farther west, in central Wyoming, the whole White River is one nearly uniform, predominantly volcanic, tuff facies, which may locally be treated as a formation . . .

The writers made no attempt to subdivide the Oligocene rocks in northwestern South Dakota into the Chadron and Brule formations as recognized in the Big Badlands of South Dakota (Bump, 1951).

Fossils of early Oligocene age (Chadronian) from the sandstone in the White River capping Medicine Pole Hills in secs. 1, 2, and 12, T. 130 N., R. 104 W., Bowman County, N. Dak. (pl. 9), were identified by C. L. Gazin of the U. S. National Museum as follows:

Hyaenodon sp.	*Hyracodon* sp.
Dinictis sp.	*Proebrotherium* sp.
Titanothere teeth	*Leptomeryx* sp.

Winchester and others (1916, p. 33) report Oligocene fossils from the White River at many localities in the Slim Buttes and Short Pine Hills in northwestern South Dakota.

ARIKAREE FORMATION (MIOCENE)

The rocks referred to the Arikaree formation in northwest South Dakota and adjacent areas to the west in Carter County, Mont., are so assigned because of their stratigraphic position and lithologic similarity to the middle Miocene Arikaree formation in the Big Badlands of southern South Dakota. On the basis of age determination of a beaver fossil collected in Carter County, Mont., Wood (1945, p. 5) interpreted the rocks assigned to the Arikaree in this area to be of upper rather than of middle Miocene age. The rocks, however, are lithologically more closely related to the Arikaree formation than to the Ogallala formation of the Great Plains. As the available evidence does not seem to justify renaming of the unit for purposes of this report, the writers follow Darton (1909, p. 31), Winchester and others (1916, p. 34), and Bauer (1924, p. 245) in assigning them to the Arikaree. The age and stratigraphic relationships of the Arikaree and Ogallala formations in northwestern South Dakota and adjacent areas are discussed by Wood and others (1941) and Wood (1945).

The Arikaree formation in northwestern South Dakota and adjacent areas is predominantly a cliff-forming formation, about 200 feet thick, consisting almost wholly of chalky to greenish-gray sandy and quartzitic tuffaceous beds (pl. 13). A distinctive zone, 20–30 feet thick, composed largely of concretions with concentric and columnar structure occurs at many places within 25 feet of the base of the formation. The zone is typically developed along the west face of Slim Buttes in the vicinity of the Mendenhall mine, sec. 1, T. 17 N., R. 7 E. (pl. 15). The Arikaree rests disconformably on the White River group in the

Slim Buttes and the Short Pine Hills in Harding County, S. Dak., and the Long Pine Hills in Carter County, Mont. A bed of conglomerate 2–3 feet thick, composed of very fine grained tuffaceous sandstone pebbles as much as 3 inches in diameter, occurs at many places directly above the basal contact. In parts of the Long Pine Hills, the White River is absent and the Arikaree rests on the Ludlow member of the Fort Union formation. Volcanic material is abundant throughout the formation. Typical specimens contain angular feldspar, biotite, quartz, epidote, augite, hornblende, and fragments of glass, together with chloritic material. These rocks have been termed rhyolitic tuff by E. S. Larsen, Jr. (Winchester and others, 1916, p. 34–35). The Arikaree formation and the White River group are remarkably uniform in lithologic characteristics over large areas in western North and South Dakota, Nebraska, and eastern Wyoming. Their general areal distribution is shown on figure 6.

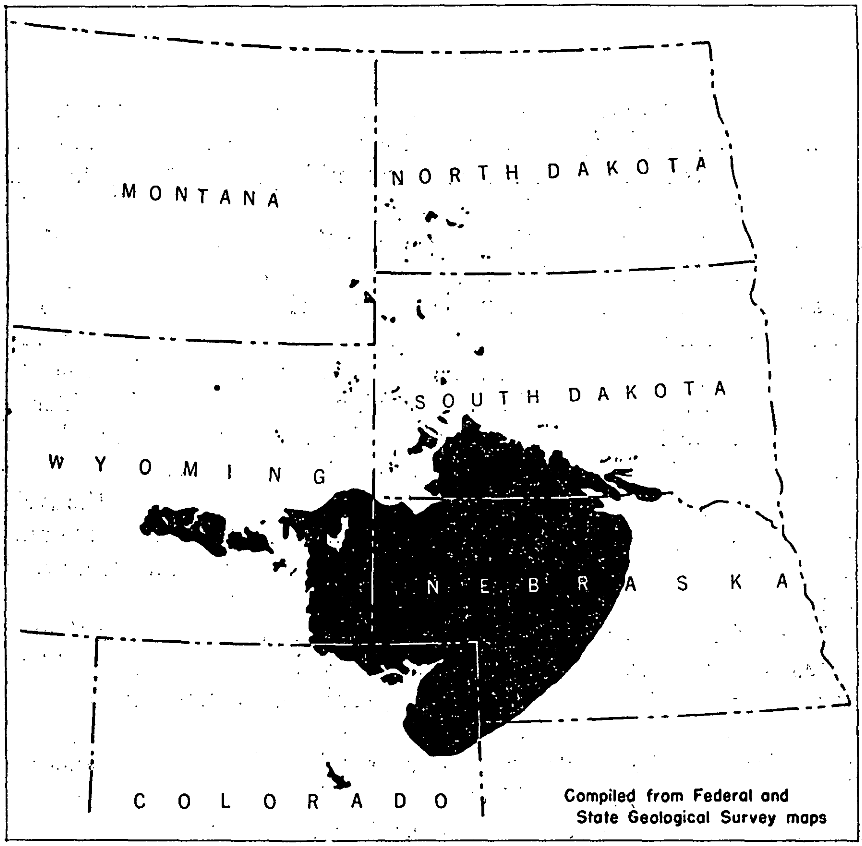


FIGURE 6.—Generalized map showing areal distribution (black areas) of the White River group of Oligocene age, and the Arikaree formation of Miocene age.

Three hand specimens from the tuffaceous Arikaree formation in the Slim Buttes area (ZD–33, –40, and –41) and thin sections of two of these (ZD–33 and –40) were studied by Howard A. Powers. Field data on these specimens are:

Specimen	*Source in Arikaree formation*
ZD–33	Concretionary zone near base of formation, SE¼ sec. 36, T. 18 N., R. 7 E.
ZD–40	At depth of 120 feet in core hole 16A, near base of formation, NE¼ sec. 12, T. 17 N., R. 7 E. (from same horizon as ZD–33).
ZD–41	At depth of 53 feet in core hole 17, near top of formation, SW¼ sec. 6, T. 17 N., R. 8 E. (Gill, Zeller, and Schopf, chapter D, this bulletin, pl. 26).

Mr. Powers reports the following data (written communication, July 1, 1952):

Hand specimen notes: All three are sandstones containing well rounded to subangular mineral and rock fragments in matrix material. Samples ZD–33 and –40 are compacted but not in the least indurated; ZD–41 is moderately indurated; ZD–33 is a concentrically banded nodule, 2 inches in diameter. ZD–40 contains about 5 percent of fragments as much as 1 mm. in diameter, about 35 percent fragments between 0.05 and 0.15 mm., and 60 percent matrix; the other two samples contain about 60 percent of fragments ranging in diameter from 0.02 to 0.25 mm. with the greatest number between 0.05 and 0.15 mm. Sample ZD–41 owes its induration to opal in the matrix.

Microscopic determinations: All three rocks have essentially the same general composition, except for the larger fragments in sample ZD–40 and the opal in the matrix of sample ZD–41 mentioned above. The mineral and rock fragments range from well rounded to subangular in form, and are present in about the following relative proportions:

clear crystalline quartz	about half of the fragments
cloudy, yellowish to greenish, cryptocrystalline fragments of fine-grained altered material, perhaps altered mudstone.	about a third of the fragments
clear, twinned, zoned plagioclase, composition about andesine.	about an eighth of the fragments
clear, twinned microcline	numerous
green hornblende crystals	numerous
biotite	common
brown hornblende crystals	common
zircon crystals and rounded grains	common
apatite crystals and rounded grains	common
iron oxide grains	common
black tourmaline, augite, and rounded grains of garnet.	rare

From 5 to 10 percent of shard-shaped bodies should also be listed with the fragments and not with the matrix material. These shapes are outlined in thin section by a thin film of a high-birefringent flakey mineral, which also mantles all of the mineral and rock fragments. The material composing the shard-shaped bodies is colorless, clear to cloudy, isotropic, soft material with index of refraction lower than balsam. It cannot be isolated and separated on a freshly broken rock surface, so that the material examined in index oils cannot with confidence be assigned to the shard-shapes rather than to some similar materials appearing in the matrix.

The matrix, except for the opal in ZD–41, is an incoherent mass of at least three sorts of material; a clear, birefringent mineral which occurs in sheaves of fibers, a cloudy cryptocrystalline birefringent low index clay mineral (or minerals), and some clear isotropic interstitial material. The fibrous sheaf mineral has the habit of a zeolite, but its index of refraction, 1.464±.003 is low for most of the fibrous zeolites. Two hydrous aluminum sulphate minerals have an index in this range, i. e. mendozite, and aluminite, but both are described as uncommon, and I hesitate to suggest either one without much more determinative work. The clay minerals have an index of refraction that would permit them to be in the montmorillonite group. Some of the clear isotropic material has an index slightly below 1.480 (which I presume is that from the shard-shaped bodies) and some of it has an index about 1.562.

Thoughts on the origin of the rock: In the nodule (ZD–33) nothing was discovered either in texture or in the observed mineral composition which apparently could account for the suggested concentric layering. The rock as a whole must be a mixture of materials from two different sources, and with two different erosion histories. Several different considerations force this conclusion. The presence of rounded microcline and rounded tourmaline grains requires a source of crystalline rock, and a history of strong mechanical erosion. The presence of rounded fragments of cryptocrystalline aggregate, probably chlorite, serpentine and chalcedony requires a source of metamorphosed fine sediments and some mechanical erosion. The presence of zoned and twinned plagioclase, in fragments subrounded to subangular, requires a source of extrusive volcanic rock, with not too strong mechanical erosion. The presence of many needle-shaped crystals of green hornblende indicates very moderate mechanical erosion, and suggests a source in volcanic tuff or lava which was easily broken up. The

TABLE 2.—*Analyses of core samples of the White River*

[Analyst, Paul

Semiquantitative spectrographic analyses: range in percent: A, more for but not found: P, Ag, As, Au, Bi, Cd, Ce, Ge, In, Ir, Hf, Hg, Li,

Core hole	Sample						Semiquantitative spectrographic analyses (see key)							
	Field No.	Laboratory No.	Thickness (inches)	Depth in hole (feet)	Geologic unit	Rock type	Si	Al	Fe	Mg	Ca	Na	K	Ba
17 [a]	ZD-41	62912	8	53	Arikaree formation.	Quartzitic siltstone.	A	B	B	C	B	B	B	D
16A [a]	-40	62911	7	120	do	Siltstone	A	B	B	C	B	B	B	C
16A [a]	-39	62910	6	137	White River group.	Bentonitic clay.	A	B	B	B	C	C	B	D
16A [a]	-37	62908	8	173	do	Calcareous grit.	A	B	B	C	C	B	B	D
16 [a]	-38	62909	9	242	do	Pink clay	A	B	B	B	C	C	B	D
19 [b]	-36	62907	8	240	do	Green clay	A	B	B	B	C	B	C	D

[a] From Gill, Zeller, and Schopf, chapter D, this bulletin, pl. 22.
[b] From Zeller and Schopf, chapter C, this bulletin, pl. 17.

shard-shaped fragments most logically could be assumed to have been shards of volcanic glass which had undergone very little transportation and mechanical erosion. Probably the simplest proposed origin which can account for the observed mineralogy and petrography is that the rock is fluviatile or lacustrine sandstone derived from a crystalline and metamorphic country rock at some distance, mixed with crystal-vitric ash from a nearby source.

A photomicrograph of a thin section of a sandstone concretion (ZD-33) from the zone near the base of the Arikaree formation is shown in pl. 2. Semiquantitative spectrographic and chemical determinations on core samples of the White River group and Arikaree formation in the Slim Buttes area, Harding County, South Dakota, are listed in table 2. The minimum amounts of elements detectable with semiquantitative spectrographic methods are indicated in table 1.

TABLE 1.—*Minimum amounts of elements detectable with semiquantitative spectrographic methods*

[Revised May 22, 1952]

Element	*Percent*	*Element*	*Percent*	*Element*	*Percent*	*Element*	*Percent*
Ag	0.0001	Fe	0.001	Nb	0.005	Si	0.001
Al	.001	Ga	.001	Nd	.01	Sm	.01
As	.1	Gd	.05	Ni	.0005	Sn	.001
Au	.005	Ge	.0005	Os	.005	Sr	.0005
B	.005	Hf	.1	P	.5	Ta	.05
Ba	.0001	Hg	1.0	Pb	.001	Te	.5
Be	.0001	In	.001	Pd	.0005	Th	.05
Bi	.001	Ir	.005	Pr	.005	Ti	.001
Ca	.001	K	[a] 1.0 (0.005)	Pt	.005	Tl	.05
Cd	.005	La	.005	Rb	[a] (0.01)	U	.05
Ce	.05	Li	[a] .01 (0.0001)	Re	.005	V	.001
Co	.0005	Mg	.005	Rh	.005	W	.01
Cr	.0005	Mo	.001	Ru	.005	Y	.001
Cs	[a] 1.0 (0.05)	Mn	.0005	Sb	.05	Zn	.05
Cu	.0001	Na	[a] .05 (0.001)	Sc	.001	Zr	.001

[a] A second exposure is required for the high sensitivity listed.

group and Arikaree formation, the Slim Buttes, S. Dak.

R. Barnett]

than 10; B, 1-10; C, 0.1-1; D, 0.01-0.1; E, 0.001-0.01; F, 0.0001-0.001; looked Nb, Nd, Os, Pd, Pt, Re, Rh, Ru, Sb, Sm, Ta, Te, Th, Tl, U, W, Zn

Semiquantitative spectrographic analyses (see key)—Continued																		Analyses, in percent		
																		Radiometric	Chemical	
Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Be	La	Equivalent uranium	Uranium	Fluorine
D	D	C	---	E	----	E	E	E	F	F	F	D	F	E	----	----	----	0.002	0.001	0.008
D	D	C	E	E	----	E	E	F	F	F	F	D	F	E	----	----	E	.002	.001	.005
D	D	C	E	E	F	E	E	E	F	F	E	E	F	---	F	----	----	.001	.001	.002
D	D	C	---	E	E	E	E	E	F	----	----	E	F	E	----	----	E	.001	.001	.008
D	D	C	E	E	----	D	E	E	E	F	E	E	F	E	E	F	E	.003	.001	.008
D	D	C	E	E	----	E	E	E	E	F	F	D	F	E	----	----	----	.001	.001	.009

QUATERNARY SYSTEM

Thin terrace deposits are distributed along the principal streams of the region here described. The material in these deposits ranges in size from sand grains to cobbles 3–5 inches in diameter, and is composed principally of quartzite, sandstone, limestone, and fossil wood. Sand dunes cover large areas along the Grand and Little Missouri Rivers, but since neither the dunes nor the terrace deposits seem to be related to the occurrence of uranium-bearing lignites, they were not studied in detail.

STRUCTURE

The lignite-bearing formations occupy the west limb of a very shallow structural trough, the Lemmon syncline, the axis of which trends approximately north and lies well to the eastern edge of the area (fig. 3). In general, the strike of the rocks is northwest and the regional dip is 10–40 feet per mile to the northeast. The dominant structural feature effecting the regional dip is the plunging north end of the Black Hills uplift, the axis of which trends north-northwest and is just to the west of the Short Pine Hills in western Harding County, S. Dak., and the Long Pine Hills in eastern Carter County, Mont. All of the lignite-bearing formations are slightly deformed to an equal degree. The younger White River group, Arikaree formation and Quaternary terrace gravel lie almost horizontally on the truncated edges of the older formations. A few faults with stratigraphic displacement of less than 150 feet were observed at the north end of the Slim Buttes. At many places, however, landslides of Recent and of Miocene(?) age have produced effects similar to faulting and folding.

URANIUM-BEARING LIGNITE

MODE OF OCCURRENCE OF THE URANIUM

Uranium minerals of megascopic size recently discovered in lignite and carbonaceous sandstones in the Cave Hills and Slim Buttes areas of northwestern South Dakota (J. R. Gill, written communication, 1954) are autunite, zeunerite, torbernite, and metatyuyamunite. These impregnate fractures and joints in thin impure lignite beds and in the enclosing sandstone.

Uranium minerals have not been found in the radioactive lignite deposits in the other Dakota areas. Detailed microscopic and analytical studies have not been completed on samples from the deposits herein described and the exact nature of the occurrence of uranium is not known. However, the common concept is that the uranium occurs as a disseminated constituent of carbonaceous material. Petrographic and mineralogic studies by the Battelle Memorial Institute (R. A. Ewing, written communication, 1950), the U. S. Geological Survey (Schopf and Gray, 1954; I. A. Breger and M. Deul, written communication, 1952) and Pennsylvania State University (T. F. Bates and others, written communication, 1952) of lignite from North and South Dakota demonstrate that the uranium, although not present as a distinct mineral, is closely associated with the organic carbonaceous material. Gypsum, analcite, jarosite, limonite, quartz, and other minerals were identified in decreasing order of abundance but had no observed relationship to the amount of uranium in the lignite. Semiquantitative spectrographic analyses of the ash from uranium-bearing lignite cores from South Dakota (see chapter C, this bulletin, table 4) show that most chemical elements are uniformly distributed through a vertical section of lignite. Uranium and molybdenum are among those which show a marked decrease downward from the top of the bed. The presence of small amounts of nickel, lead, vanadium, and arsenic is suggested by spectrographic data but the association and the distribution of these elements with uranium is less consistent.

Lignite from South Dakota has been shown to be a good extractor of uranium from solution (Moore, 1954). Nonradioactive lignite from the Slim Buttes, S. Dak., was immersed in a solution of uranyl sulfate containing 200 parts per million uranium. After 19 days the lignite contained 0.19 percent uranium and the solution contained 2.0 parts per million uranium. This confirms, in a striking manner, the affinities of carbonaceous material for uranium pointed out by Tolmachev (1943) and Szalay (1954). Similar adsorptive relationships have been postulated by McKelvey and Nelson (1950, p. 46) for the origin of uranium in marine black shale, and Frederickson (1948) has discussed the relation between uranium and other types of carbon.

THEORIES OF ORIGIN AND ACCUMULATION

The origin of uranium in the lignites in South Dakota cannot be conclusively demonstrated, although the writers believe an abundance of field evidence favors the epigenetic hypothesis, the third of three opposing concepts, numbered here as the (1) diagenetic, (2) syngenetic, and (3) epigenetic hypotheses of origin.

As the result of work in 1948 and 1949, D. G. Wyant and E. P. Beroni (written communication, 1950) proposed the following two hypotheses of origin:

1. That uranium was deposited with other detrital minerals in sediments overlying or marginal to the lignite and subsequently leached from them, carried downward, or laterally, and fixed by the carbon of the lignite; or,

2. That uranium was deposited from surface waters by the action of living organisms or dead organic matter at the same time as the carbonaceous debris from which the lignite formed.

E. P. Beroni and H. L. Bauer, Jr. (written communication, 1952), as the result of more detailed work in 1949, reiterated these two hypotheses, and stated: "Both of these hypotheses require that there was uraniferous source material being eroded and leached either at the time of deposition of the organic material of the lignite or shortly thereafter." They concluded as did Gott, Wyant, and Beroni (1952, p. 34) and L. R. Page (written communication, 1953) that the second, "syngenetic", origin was more probable.

The results of our work in 1950 led us to propose the third hypothesis: 3. the uranium is epigenetic in origin, being derived from unconformably overlying tuffaceous source rocks and carried by ground water percolating downward or moving laterally along aquifers near the lignite beds and extracted by the lignite after coalification. The uranium ion is believed to have been held as a finely disseminated constituent in volcanic ash and other glassy extrusive rocks. Subsequent release or displacement of the uranium may have been accomplished by weathering and ultimate devitrification of the volcanic materials. Whatever the reason for the displacement, carbonaceous materials are believed to have acted as filters to concentrate and cause fixation of the uranium as a result of ion exchange or by the formation of organo-metallic compounds (I. A. Breger and M. Deul, written communication, 1952).

Subsequent field work, including extensive core drilling in the Dakotas, has provided data and confirmed this hypothesis, now termed the "ash-leach" or volcanic-ash theory (Thomas, 1954; Hager, 1954; and Miller and Gill, 1954). The concept has been applied in other areas, both as a guide in exploration and as an explanation of the distribution of known deposits. Love (1952) has attributed the origin of certain sandstone-type uranium deposits in Wyoming to the ash-leach process as has R. L. Griggs (1954) in New Mexico and J. W. Gruner (1954) in the Colorado Plateau and other areas. Koeberlin (1938) suggested that volcanic ash may have been the source of various metals in some deposits in southwestern United States where evidence of hydrothermal activity is obscure or lacking. The recent discoveries of ore-grade deposits of autunite-bearing lignite and of metatyuyamunite in carbonaceous sandstones closely underlying tuffaceous rocks in the Slim Buttes and North Cave Hills areas (J. R. Gill and G. W. Moore, written communication, 1954) offer additional confirmatory evidence for the theory. The origin of the uranium seems important because search for other deposits will be successful chiefly to the extent that it is guided by application of valid concepts of origin.

EVIDENCE IN SUPPORT OF A SYNEGETIC THEORY OF ORIGIN

The following observations were summarized by E. P. Beroni and H. L. Bauer (written communication, 1952):

1. Uranium-bearing lignites are confined to a limited stratigraphic zone and uranium content is due to a process which operated only during the time of deposition of sediments of that zone.
2. Uranium content of individual lignite beds is remarkably uniform over wide areas indicating an environmental control.
3. Uranium is closely associated with analcite-bearing rocks. Both analcite and uranium are deemed to be syngenetically derived from the breakdown of volcanic material deposited in the coal swamps.
4. An autoradiograph suggests a homogeneous distribution of uranium in lignite, which in turn suggests introduction of the uranium before coalification.
5. In some areas, as at Sentinel Butte, N. Dak., the lignite nearest the unconformity at the base of the White River does not have the highest uranium content as it should if the uranium were coming from downward moving solutions.
6. There is little evidence of radioactive materials in the overlying White River group which could make it a source bed for the radioactive materials in the lignite.

EVIDENCE IN SUPPORT OF AN EPIGENETIC THEORY OF ORIGIN

There is much field evidence which supports the theory that the uranium in the Dakota lignites was secondarily derived by ground-water leaching of the volcanic materials in the White River group and Arikaree formation, of which the following relationships are believed to be of particular significance:

1. All uranium-bearing lignite deposits reported from eastern Montana and the Dakotas are stratigraphically near the unconformity at the base of the Oligocene and bear no apparent relationship to the age of the formation in which they occur:

Areal relationships of the uranium-bearing lignite beds in wide areas in the Dakotas, eastern Montana, and Wyoming indicate that the uranium in the lignite is independent of the age of the formation in which the lignite occurs but is very closely related to the topographic position of the widespread unconformity at the base of a thick sequence of tuffaceous rocks which at one time covered most of the region (pl. 1). Because lignite beds of successively younger age are uranium-bearing adjacent to the unconformity it seems logical to assume that uranium-mineralization occurred after the tilting and truncation of the lignite-bearing rocks.

A summary of the uranium-bearing lignite deposits in the Dakotas and eastern Montana, all in the Fort Union formation of Paleocene age, are listed below by formation and stratigraphic proximity to the base of the White River group (or Arikaree formation)

Location	Unit of the Fort Union formation in which deposit occurs	Stratigraphic proximity of deposits to base of White River group or Arikaree formation
Slim Buttes, S. Dak	Ludlow member	5-40 feet.
South Cave Hills, S. Dak	do	75-160 feet.
North Cave Hills, S. Dak	Ludlow and Tongue River members	135-150 feet.
Table Mtn., S. Dak	Ludlow member	150-160 feet.[a]
Long Pine Hills, Mont	do	75-150 feet.
Ekalaka Hills, Mont	do	10-85 feet.
Lodgepole area, S. Dak	Tongue River member	25-75 feet.[a]
Medicine Pole Hills, S. Dak	do	25-60 feet.
HT Butte, N. Dak	Sentinel Butte member	160-180 feet.
Chalky Buttes, N. Dak	do	10-80 feet.
Bullion Butte, N. Dak	do	160-180 feet.
Sentinel Butte, N. Dak	do	80-100 feet.

[a] Indicated projected position of base of the White River group in areas where White River has been removed by erosion.

In addition to the Paleocene units listed above, thin beds of uranium-bearing lignite are found in the Hell Creek formation of Late Cretaceous age near the East Short Pine Hills, Harding County, S. Dak., and in the Golden Valley formation of Eocene age in the Little Badlands, Stark County, N. Dak. At both localities, the beds are within 10-20 feet of the base of the White River group.

If the uranium in the lignite is syngenetic, it is difficult to explain why uranium-bearing lignite occurs only on the flanks of the highest buttes capped with volcanic materials. Many lignite beds are exposed along the low plains and stream valleys throughout the Dakotas and eastern Montana and many have been sampled or tested for radioactivity. However, none are uranium bearing. Much of the information gathered during the course of the investigation is not presented in this report. Such data, however, are pertinent and were critically evaluated in developing working hypotheses to explain the origin of the uranium and to determine the factors controlling its accumulation.

2. Most of the lignite beds having the most uranium are highest in the stratigraphic section:

Within a series of nearly flat-lying carbonaceous beds the stratigraphically and topographically higher beds, in general, have more uranium. The uranium content of succeeding lower beds decreases to the vanishing point. This suggests that the uranium probably was derived from an overlying source. This relationship is noted at a majority of the localities where a sufficient number of samples has been collected from each stratigraphic section. Locality 84 (pls. 11, 12, and 16) at the Mendenhall mine in the Slim Buttes is an excellent example. There the highest bed of lignite in the stratigraphic section contains 0.030 percent uranium. The second highest bed of lignite contains 0.010 percent uranium, while the third highest bed contains 0.005 percent uranium in the upper half and only 0.002 percent uranium in the lower half. The fourth highest bed of lignite sampled at this locality contains only 0.002 percent uranium. Beds lower in the stratigraphic section in this area were tested for radioactivity but did not show appreciable amounts. Many localities which show this relationship may be cited: for example, localities 82, 88, 92, 96, and 97 (pl. 12) in the Slim Buttes; locality 9 (pl. 7), at Table Mountain; localities 36, 38, 39, 40, 44, 45, and 46 (pl. 7), in the North Cave Hills; and localities 66 and 68 (pl. 5) in the South Cave Hills. Anomalies may be explained by the presence and the position of the permeable zones which, in some places, may have carried ground water laterally for a considerable distance under hydrostatic head. For example, at locality 7 (pl. 7) at Table Mountain the stratigraphically highest bed of lignite contains only 0.003 percent uranium; whereas the second highest contains 0.036 percent uranium. The highest bed of lignite in this stratigraphic section is a thin lens enveloped in shale. The relatively impermeable shale would prevent access of the uranium-bearing solutions to the lignite. The second highest bed of lignite in this section is somewhat more continuous and is overlain by a relatively thick, poorly cemented, coarse-grained sandstone. This sandstone may have served as an aquifer for the lateral movement of uranium-bearing solutions. Other notable exceptions to the relationship also occur at localities 52 and 63 (pl. 5) in the South Cave Hills.

3. Uranium concentrations are highest at the top of thick lignite beds, diminishing progressively downward to a vanishing point in their lower parts:

In general the uranium content within a uranium-bearing lignite bed 3 feet or more thick is greater at the top and diminishes progressively downward. This suggests that the uranium was derived from an overlying source. The analyses in table 3 (p. 34) show the progressive decrease downward in distribution of uranium, characteristic of thick beds of radioactive lignite in the Dakotas.

At those places where the stratigraphically highest lignite is less than 3 feet thick, the uranium in general is concentrated in the lower part of the bed. Examples of this "inverted" pattern were noted by Zeller and Schopf (chapter C, this bulletin, p. 68), who concluded that the higher concentration in the lower rather than the upper parts of these beds might be explained by the lateral movement of uranium-bearing ground water along the base of these generally incompetent and highly fractured beds which normally overlie thick, impervious underclays. Analyses showing the "inverted" pattern are listed below:

Lignite bed in Fort Union formation	Interval	Analyses, in percent			
		Ash	Uranium		Equivalent uranium
			In ash	In sample	
A: lignite bed, 12 inches thick, near top of Sentinel Butte member, north side of Sentinel Butte, SE¼, sec. 6, T. 39 N., R. 104 W., Golden Valley County, N. Dak.	Uppermost 6 inches	50.5	0.002	0.001	0.001
	Lowest 6 inches	41.7	.030	.012	.009
B: lignite bed, 19 inches thick, near top of Ludlow member, east side of Table Mountain, SE¼, sec. 5, T. 22 N., R. 4 E., Harding County, S. Dak. (locality 9, pl. 4).	Uppermost 1 inch	38.1	.004	.001	.003
	Next 9 inches	22.8	.035	.008	.008
	Lowest 9 inches	28.6	.078	.022	.017

TABLE 3.—*Analyses of uranium, in percent, showing vertical distribution of uranium in three lignite beds, in the Dakotas*

[Analysts: M. Delevaux, S. Furman, S. Lundine, W. Tucker, and J. Wilson]

Harmon(?) bed in Perkins County, S. Dak. Core hole 14 [1] (Pl. 20)	Mendenhall bed in Harding County, S. Dak. Auger hole 86 [2] (Pl. 12)	Slide Butte bed in Slope County, N. Dak. Surface section 30 [3] (Fig. 27)
Sampled-interval, thickness, 6 inches	For sampled-interval thickness, see footnotes	Sampled-interval, thickness, 12 inches
(*Top of bed*)	(*Top of bed*)	(*Top of bed*)
0.036	[4] 0.010	0.022
.028	[5] .006	.013
.021	[6] .003	.010
.013	[7] .002	.006
.008	(*Base of bed*)	.004
.002		.001
.001		.005
-----------		(*Base of bed*)

(*Base of bed*)		

[1] After Zeller and Schopf, chapter C, this bulletin.
[2] Contamination makes analyses of cuttings 25–45 percent less than their true values.
[3] After Moore, Melin, and Kepferle, chapter E, this bulletin.
[4] Uppermost 2 feet.
[5] Two to 4 feet below top of bed.
[6] Four to 9 feet below top of bed.
[7] Nine to 11 feet below top of bed.

The order of magnitude and normal pattern of distribution of uranium in the Dakota lignites are shown on figure 7. Due to contamination of lignite cuttings by the wall rock, the uranium analyses shown for the lignite from auger holes in figure 7 are approximately 25–45 percent below their true values.

4. Variations in the permeability of the rock overlying the mineralized bed are reflected in the intensity of uranium mineralization.

Where a uranium-bearing lignite bed is directly overlain by permeable sandstone, the lignite is more highly mineralized than where it is overlain by clay or shale. An excellent example of the effect of the permeability of the roof rock on the distribution of uranium in a lignite bed is shown by the data from localities 111 and 112 (pl. 12) in the northeast corner of Slim Buttes. At locality 111, the Bar H lignite bed is directly overlain by at least 30 feet of coarse-grained permeable sandstone, which grades laterally within half a mile into a thick impervious clay shale at locality 112. At locality 111, where the sandstone rests directly on the lignite, the upper bench of the Bar H lignite bed is about 5 feet thick and contains at least 0.011 percent uranium; the lower bench is about 7 feet thick and contains 0.007

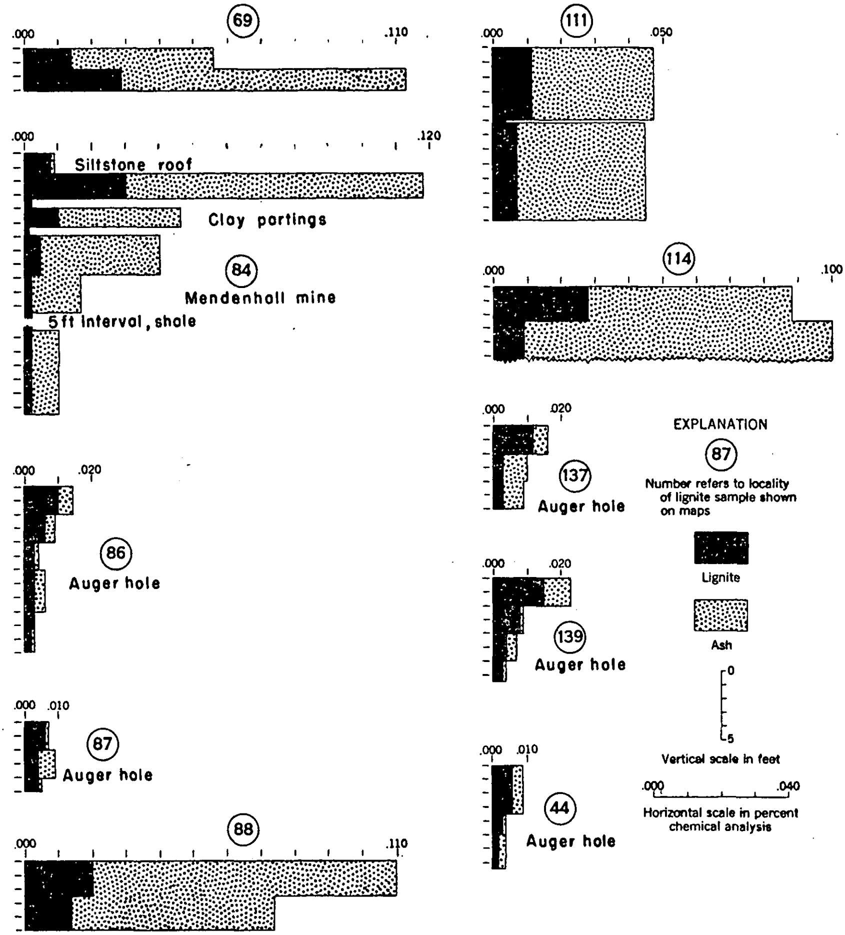


FIGURE 7.—Diagram showing pattern of distribution and order of magnitude of uranium concentrations in lignite and lignite ash, Harding and Perkins Counties, S. Dak. (Note.—Locality 44 should be No. 49)

percent uranium. At the Bar H mine (locality 112) the same lignite bed is directly overlain by 25 feet or more of impervious clay shale, and the uranium content of the upper bench is only 0.001 percent; the lower bench is not uranium bearing.

5. Volcanic materials in the White River group and Arikaree formation show appreciable radioactivity and at some localities are associated with uranium minerals:

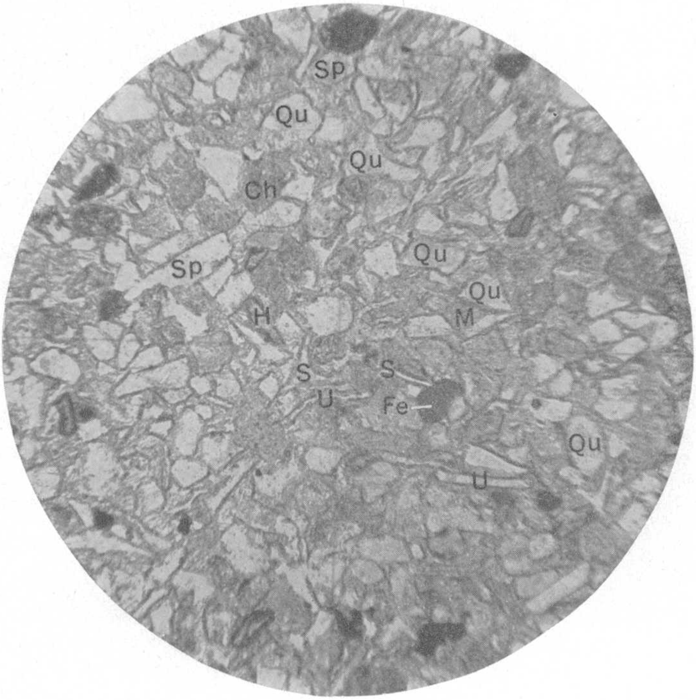
The radioactivity of the source beds in the White River and Arikaree unconformably overlying the uranium-bearing lignites on Slim Buttes was measured in four core holes with a scaler equipped with a Geiger-Mueller-counter tube and a 400-foot coaxial cable (Gill, Zeller, and Schopf, chapter D, this bulletin, p. 115). Logs obtained by this method show radioactivity greater than background throughout most of the rocks entered by the holes.

Chemical analyses of representative samples from the White River group and Arikaree formation show a maximum content of 0.0030 percent and an average of about 0.0015 percent uranium, indicating a uranium content of about 12 times that of the average sedimentary rock (Evans and Goodman, 1941). Analyses of these rocks also show concentrations of about 0.04 percent vanadium (Davidson, 1953). These analyses and the occurrence of carnotite, a potassium uranyl vanadate; metatyuyamunite(?), a calcium uranyl vanadate; and uranocircite, a barium uranyl phosphate; in the White River group at several widely separated localities in South Dakota (Gill and Moore, 1955; and Moore and Levish, 1955) suggest that these volcanic materials may be source beds of uranium.

6. Water analyses show large uranium content for spring water now issuing from the White River group and Arikaree formation indicating that uranium as well as other elements are being leached today from these volcanic materials:

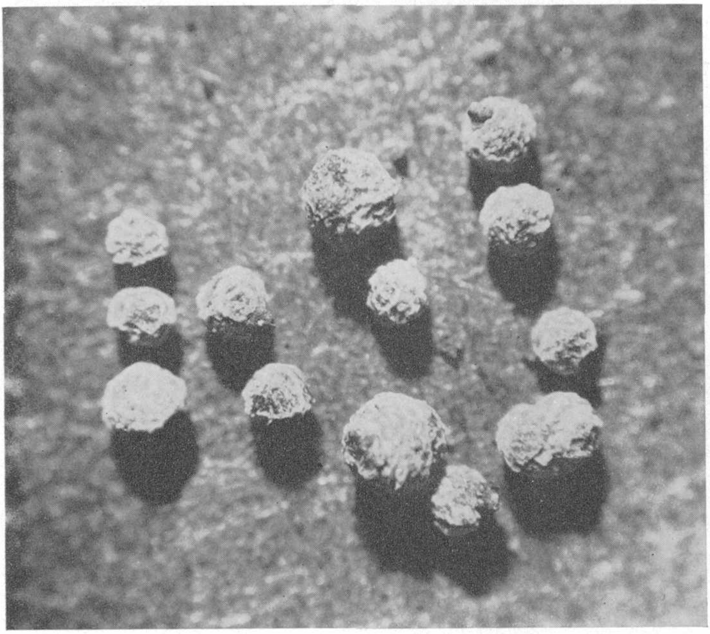
Gill and Moore (1955) have shown that spring water issuing from the White River and Arikaree in the Slim Buttes area of Harding County, S. Dak., contains 10–30 times more uranium than water from the Fort Union and Hell Creek formations. Chemical analyses show that the water from the White River group also contains significant concentrations of vanadium. The average uranium content of water from 26 springs in the White River and Arikaree is 41 parts per billion, whereas water from 8 springs in the underlying formations averages 4 parts per billion. The uranium content of the water from the Fort Union and Hell Creek formations is even smaller in areas distant from known sources of uranium. The average uranium content of the ocean is about 1.5 parts per billion (Rankama and Sahama, 1950).

Concerning the role of volcanism in the geochemistry of uranium Farrington Daniels (written communication, 1953) concludes:



PHOTOMICROGRAPH OF A THIN SECTION OF SANDSTONE FROM THE ARIKAREE FORMATION

U, High-index (greater than 1.60), isotropic, somewhat brownish, scaly-shaped, secondary mineral; *M*, matrix of isotropic, low index (less than 1.48) secondary material, clear in transmitted and white in reflected light; *Qu*, quartz; *Sp*, andesine; *Ch*, chalcedony; *H*, brown or green hornblende; *Fe*, opaque iron oxide; *S*, shard. A common fibrous, low-index (less than 1.48) secondary mineral of low birefringence and rounded grains of microcline can not be seen in the photograph (× 60). Identifications by Howard A. Powers.



PHOTOMICROGRAPH OF A GROUP OF ANALCITE ($NaAlSi_2O_6 \cdot H_2O$) ROSETTES ISOLATED FROM URANIUM-BEARING LIGNITE, SOUTH CAVE HILLS, HARDING COUNTY, S. DAK. (× 13).

We believe that the distribution of uranium in volcanic dust and ashes is an important factor in providing the preliminary source of uranium for later concentration into secondary deposits in sedimentary rocks. The volcanic ash has a very large surface area and uranium can be leached out rather quickly by water passing through porous material of this type.

If uranium can be leached by ordinary ground water today, it is logical to assume that ground water in the past could have leached the uranium out of these or similar rocks, transported it along aquifers in the underlying strata, and deposited it in favorable host materials. Favorable host material, in addition to the lignite underlying the White River group and Arikaree formation, would include carbonaceous sandstone which E. P. Beroni and H. L. Bauer (written communication, 1952) predicted would be favorable for the localization of secondary uranium minerals if the tuffaceous rocks in the White River were a significant source of uranium. A recent discovery of a bed of such carbonaceous sandstone, 3.2 feet thick and containing as much as 3.9 percent and averaging 0.68 percent uranium, in the Ludlow member of the Fort Union formation underlying the pre-Oligocene unconformity at Reva Gap in the Slim Buttes (J. R. Gill and G. W. Moore, written communications, 1954), seems to substantiate Beroni and Bauer's prediction and adds supporting evidence to the theory that the uranium may have been derived from the overlying volcanic materials.

At many places in some of the most highly radioactive lignite, analcite ($NaAlSi_2O_6H_2O$) is a common impurity (R. A. Ewing, written communication, 1950; E. P. Beroni and H. L. Bauer, written communication, 1952; Gill, chapter F, this bulletin). The mineral occurs as finely disseminated minute white particles or rosettes 0.5–1 mm in diameter (pl. 3) or as minute trapezohedral crystals and generally in such abundance as to give the lignite a characteristic "salt and pepper" appearance. As analcite occurs only rarely in sedimentary mineral deposits (Ross, 1928; Bradley, 1930), and has been reported in few coal deposits (Foster and Feicht, 1946, p. 359; Tourtelot, 1946), its occurrence in the lignite deposits of South Dakota is worthy of some discussion.

Foster and Feicht (1946) point out that analcite must form in alkaline water, although coal accumulates in acidic water. It therefore is improbable that the analcite is syngenetic in origin or that it could have been formed in the acidic waters characteristic of the deposition of coal. As both clastic and hydrothermal hypotheses for its origin are inadequate to explain its occurrence and the spring waters issuing from the White River group and Arikaree formation are soda rich and alkaline in character (pH of 8.5–9.5), it is possible that the analcite was derived from the overlying volcanic materials and introduced into the lignite by ground water after coalification.

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In a report on the occurrence of uranium in coal Davidson and Ponsford (1954) conclude:

> A syngenetic origin for the mineralization fails, however, to explain why it is that in the uraniferous coal deposits which have been studied in some detail, high values are commonly restricted to a single seam, usually the highest in the local sequence. Further, the geological evidence tends to suggest that uranium-rich coals are only found where there is direct access to overlying sedimentary, volcanic or pyroclastic rocks likely to form sources for uraniferous ground-water solutions. The close relation between uranium-bearing coals and ancient surfaces truncating them, and the manner in which a higher coal protects an underlying coal from becoming mineralized, can best be explained by the *epigenetic* introduction of the mineralization by means of descending meteoric water.

From the foregoing statements and the detailed description of the deposits which follow, it is reasonable to conclude that most of the uranium in the lignite is of secondary origin, being derived from tuffaceous materials of Oligocene and Miocene age in which lignite is absent.

FACTORS CONTROLLING CONCENTRATION OF URANIUM

The distribution of uranium in the lignite in the area is controlled by a combination of factors, none of which has absolute control but all of which are potentially complementary. The factors listed below are believed to be of primary importance (letters *A–H* referred to below are shown on fig. 8).

1. Stratigraphic proximity of lignite to base of the White River group of Oligocene age (*A*), or to the projected position of its base in areas where the White River has been removed by erosion (*B*):

Lignite 200 feet or more below this base is not uranium bearing. This observation is in general accordance with the work of D. G. Wyant and E. P. Beroni (written communication, 1950) who report that radioactive lignite in North Dakota appears to be limited to a zone 40–140 feet below the White River group.

2. Permeability of the rocks overlying the lignite, whether the permeability is inherent as in sandstone (*C*) or induced by jointing (*D*), fracturing or faulting (*E*):

Greatest concentrations of uranium are present in a lignite bed where directly overlain by sandstone. The same bed where overlain by beds of shale or clay contains little or no uranium. Lignite adjacent to joints, in general, shows greater concentrations of uranium than that farther from joints.

3. Adsorptive properties and porosities of the organic lignitic constituents.

The writers believe that soft porous lignite is a much better host material for the adsorption and fixation of uranium than is dense,

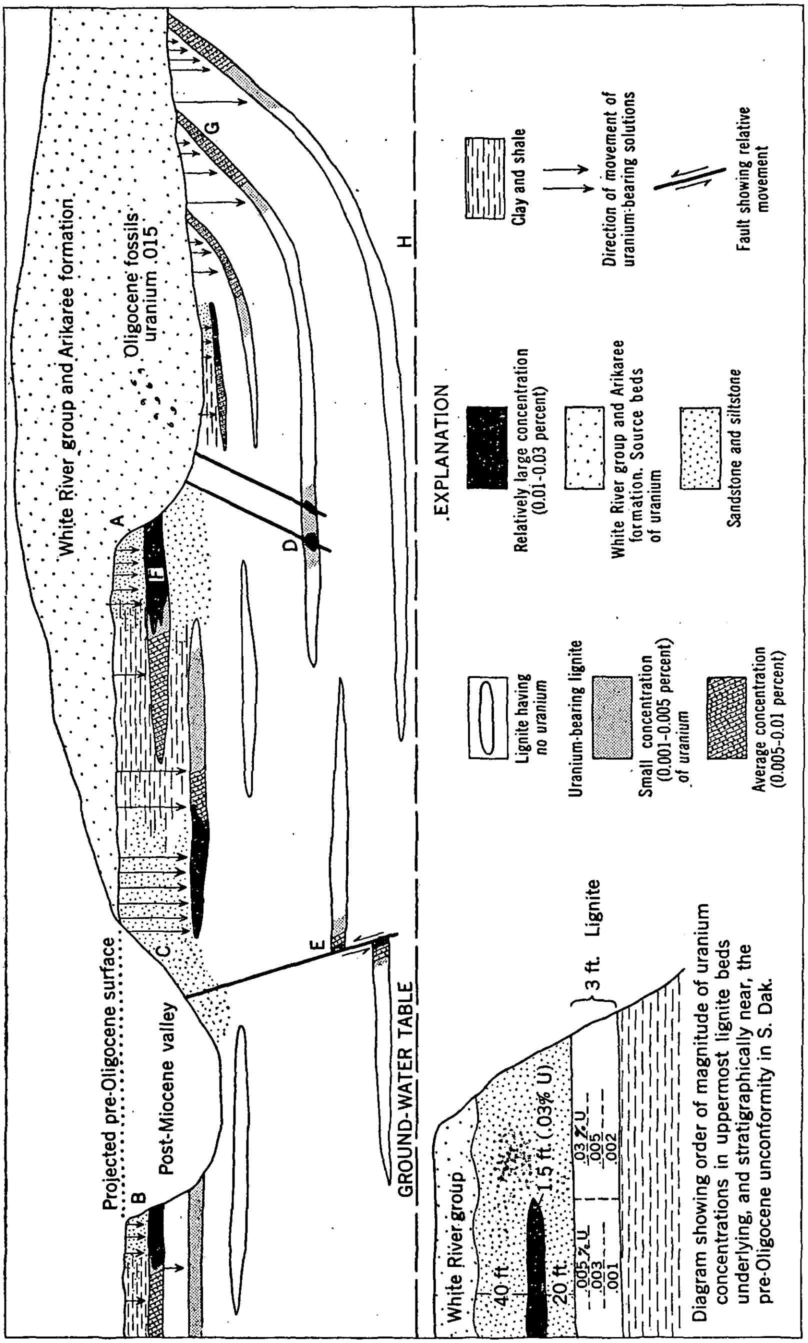


FIGURE 8.—Diagram illustrating an interpretation of factors that control the uranium content of lignite.

hard, impervious, semibituminous coal and anthracite, and that the amount of uranium extracted from solution may be directly proportional to the presence of certain specific lignitic constituents.

4. Attitude of the beds:

Horizontal or very gently dipping lignite beds (*F*) are more radioactive than beds having greater dips (*G*).

5. The position both present and past of the water table in relation to lignite and its effects on active ground-water circulation (*H*).

6. Amount of uranium originally present in the White River and Arikaree and the nature and degree of its dissemination and distribution:

Studies of drill cores by Farrington Daniels of the University of Wisconsin (oral communication, 1952) indicate that the uranium content is fairly uniform throughout most of the White River and Arikaree. Whether the uranium content of these rocks was uniform over wide areas is not known, but if a considerable variation did occur, it seems reasonable to conclude, other conditions being equal, that this variation would be reflected in the degree of mineralization in the underlying lignite.

AREAS OF URANIUM-BEARING LIGNITE

SOUTH CAVE HILLS

The South Cave Hills is a conspicuous mesa that occupies about 9 square miles in parts of Tps. 20 and 21 N., Rs. 4 and 5 E., 12 miles north of Buffalo in Harding County, S. Dak. (pl. 4). The mesa rises several hundred feet above the surrounding country in almost impassable cliffs. Several flat-topped ridges separated by deep box canyons extend outward from the main area of the mesa. Below the massive-sandstone cap rock a steep talus slope of large blocks of slumped sandstone makes the top of the mesa almost inaccessible but it can be reached by way of a few cattle trails and by narrow secondary Forest Service roads. Directly to the south, across the valley of Jones Creek, are many small buttes, the largest being McKensie Butte. Some of the buttes are capped with clinker resulting from the burning of lignite. Their brick-red colors are very distinctive and they are visible many miles.

The lower part of the South Cave Hills mesa and the surrounding country consists of soft sandstone and shale of the Ludlow member of the Fort Union formation, but the cap rock of the prominent McKensie and Rattlesnake Buttes and of the main area of the South Cave Hills mesa is a massive well-indurated sandstone 125 feet thick, in the lower part of the Tongue River member of the Fort Union formation. A remnant of the White River group, 50 feet or less in thickness, caps the mesa over an area of about 160 acres in parts of sec. 31 and 32, T.

21 N., R. 5 E. The pre-Oligocene surface in the Cave Hills area was apparently close to the present mesa top. At most places, beds of the Fort Union dip uniformly about 40 feet per mile to the northeast.

Because of the heavy cover of talus and scarcity of lignite outcrops, most of the correlations between lignite beds in the Cave Hills and Table Mountain areas are at best tentative.

The lignite bed having the greatest uranium content in the South Cave Hills is not more than 50 feet below the top of the Ludlow member of the Fort Union formation and is referred to in this report as Bed *D* (pls. 5 and 6). The bed has a maximum measured thickness of 4.2 feet at locations 55 and 60, and an average thickness, based on 17 measured sections, of about 2.5 feet. A thin bed of lignite or a carbonaceous zone, tentatively referred to as Bed *E*, occurs 30 to 40 feet above the base of the Tongue River member, but its lenticular character and poor quality make it only of local importance. Because the autunite occurs in lignite in bed *E* in the North Cave Hills (J. R. Gill, written communication, 1954) and the bed is near the base of the overlying White River group, significant deposits of secondary minerals of uranium may be found in this bed in the South Cave Hills. The thickest and most persistent beds of lignite in the South Cave Hills are in the middle and lower parts of the Ludlow member. These beds are not radioactive and were not mapped or studied in detail.

The three areas in the South Cave Hills underlain by significant deposits of uranium-bearing lignite, at least 3 feet thick, are listed here in order of their apparent importance: (1) SW¼ sec. 28 and NW¼ sec. 33, T. 21 N., R. 5 E., locations 57–61; (2) NE¼ sec. 5, T. 20 N., R. 5 E., location 63; and (3) S½ sec. 13, T. 21 N., R. 4 E., and SW¼ sec. 18 and SW¼ sec. 16, T. 21 N., R. 5 E., locations 55 and 56. These areas, with a combined total of about 600 acres, are estimated to contain 3.15 million tons of uranium-bearing lignite (table 4).

A small area of about 50 acres at McKensie Butte in SE¼ sec. 20, T. 20 N., R. 5 E., may also contain an additional 262,000 tons of uranium-bearing lignite (pl. 5, location 69 and table 4). Although bed *D* is persistent and may contain significant tonnages of uranium-bearing lignite in other areas in the South Cave Hills than those listed, the poor exposures and wide spacing of localities sampled make a closer estimate of the potentialities of the area impossible without trenching or coring.

There is no strippable uranium-bearing lignite in the South Cave Hills. There, because of the thickness and character of the overburden, all the lignite will require underground-mining methods. Bowman, N. Dak., the nearest railroad shipping point, is 25–30 miles to the north along U. S. Highway 85.

TABLE 4.—*Tonnage of uranium-bearing lignite in the North Cave Hills, South Cave Hills, McKensie Butte, and Table Mountain areas, Harding County, S. Dak.*

Area	Extent (acres)	Average thickness (feet)	Uranium content (percent)	Tonnage of lignite [1] (short tons)
In beds suitable for strip-mining methods				
North Cave Hills,[2] center of sec. 19, T. 22 N., R. 5 E., Harding County	20	5.0	0.005	175,000
Total				175,000
In beds accessible by underground-mining methods				
South Cave Hills, in SW¼ sec. 28 and NW¼ sec. 33, T. 21 N., R. 5 E., NE¼ sec. 5, T. 20 N., R. 5 E., S½ sec. 13, T. 21 N., R. 4 E., Harding County	600	3.0	0.009	3,150,000
McKensie Butte, in SE¼ sec. 20, T. 20 N., R. 5 E., Harding County	50	3.0	.01	262,000
Table Mt., in parts of secs. 5, 6, 7 and 8, T. 22 N., R. 4 E., Harding County	500	2.0	.008	1,750,000
Total				5,162,000
Grand total				5,337,000

[1] Tonnage estimates based on 1,750 tons of lignite per acre foot, net result rounded to nearest 1,000 tons.
[2] Tonnage data for the mineralized bed *E* in parts of secs. 22, 26, and 27, T. 22 N., R. 5 E., in the North Cave Hills are not included.

NORTH CAVE HILLS

The North Cave Hills occupy about 15 square miles in Tps. 21 and 22 N., R. 5 E., in north-central Harding County, S. Dak. (pls. 1 and 4). Topographically and structurally they resemble the South Cave Hills and are separated from that mesa by about 4 miles of low rolling country and the valley of Bull Creek. From a distance the North Cave Hills appear to be a single mesa rising 300–400 feet above the surrounding country, but in reality they are a series of narrow flat-topped ridges separated by narrow canyonlike gullies. They are capped by about 200 feet of thick-bedded sandstone which in most places forms sheer cliffs, and the Tongue River-Ludlow contact is placed at the base of this sandstone. Two small remnants of conglomerate from the White River group overlie the Tongue River in secs. 21 and 28, T. 22 N., R. 5 E., but throughout the rest of the area the White River has been removed by erosion. In some parts of the North Cave Hills two distinct cliffs are formed by two sandstone units of the Tongue River member (Winchester and others, 1916, p. 27), separated by 40–125 feet of light-gray friable sandstone and whitish-gray clay. A thin bed of carbonaceous shale or clayey lignite rests on the lower unit of sandstone. This bed, which is also present at some places in the sandstone cap rock in the South Cave Hills, is referred to as bed *E* (pl. 6). The lower sandstone unit in the North Cave Hills is 75–100 feet thick and is gray to buff. The upper sandstone unit is commonly pink, crossbedded and at some places contains clay pellets and rounded pebbles of sandstone. A two-foot bed of quartzite, described on page 19, occurs on top of the massive sandstone cap rock (pl. 6, locations 33, 34, and 40). At many places wind action along joints and on the unequally indurated sandstone has developed characteristically pitted and cavernous surfaces in the cliff faces. The beds in the North Cave Hills, in general, dip about 25 feet per mile to the northeast (Winchester and others, 1916, p. 73).

Only two lignite beds of minable thickness, beds *B* and *C*, are mildly radioactive in the North Cave Hills area (pl. 7). These beds occur in the upper 100 feet of the Ludlow member of the Fort Union formation. Lack of exposures and marked variability in thickness and quality make an exact correlation of the beds in many places doubtful. The samples, taken from 36 localities, indicate there are few, if any, places where the uranium content of these beds is sufficient to warrant underground mining. An area of about 15 acres near the center of sec. 19, T. 22 N., R. 5 E., may be favorable for strip mining. Here, bed *B* is 5–10 feet thick and is overlain by about 35 feet of soft sandstone. Analyses of 14 samples of contaminated auger cuttings from 3 auger holes indicate that the area may contain 175,000 tons of uranium-bearing lignite (pl. 4, locations 47, 48, and 49, and table 4). Bed *E*, absent in most of the North Cave Hills, is present in parts of secs. 22, 26, and 27, T. 22 N., R. 5 E., where it ranges from 6 inches to 2 feet in thickness and locally contains as much as 5 percent uranium. Where the bed is most highly radioactive, visible uranium minerals, autunite and torbernite, occur (J. R. Gill, written communication, 1954). The reason for the small uranium content of lignite in other parts of the North Cave Hills is not known but probably is due to the presence of 40–75 feet of impervious shale directly above the stratigraphically highest beds of lignite (beds *B* and *C*). The shale may have prevented downward-moving uranium-bearing ground water from reaching the lignite.

TABLE MOUNTAIN

Table Mountain is a high butte with steep and rocky slopes which occupies about 500 acres in northwestern Harding County, S. Dak. (pl. 4). The butte is capped by about 125 feet of tan and buff massive sandstone of the Tongue River member of the Fort Union formation and underlain by 250 feet or more of poorly indurated yellowish- and light-gray sandstone and shale of the Ludlow member. At the south end of the butte, thin lenses of fine-grained, chalky, gray tuffaceous sandstone containing shards are present within the cap rock. These lenses are rarely more than a foot thick, but are quite conspicuous by their color and by the indentation which they form in the cliff. The regional eastward dip at Table Mountain and vicinity is about 50 feet to the mile.

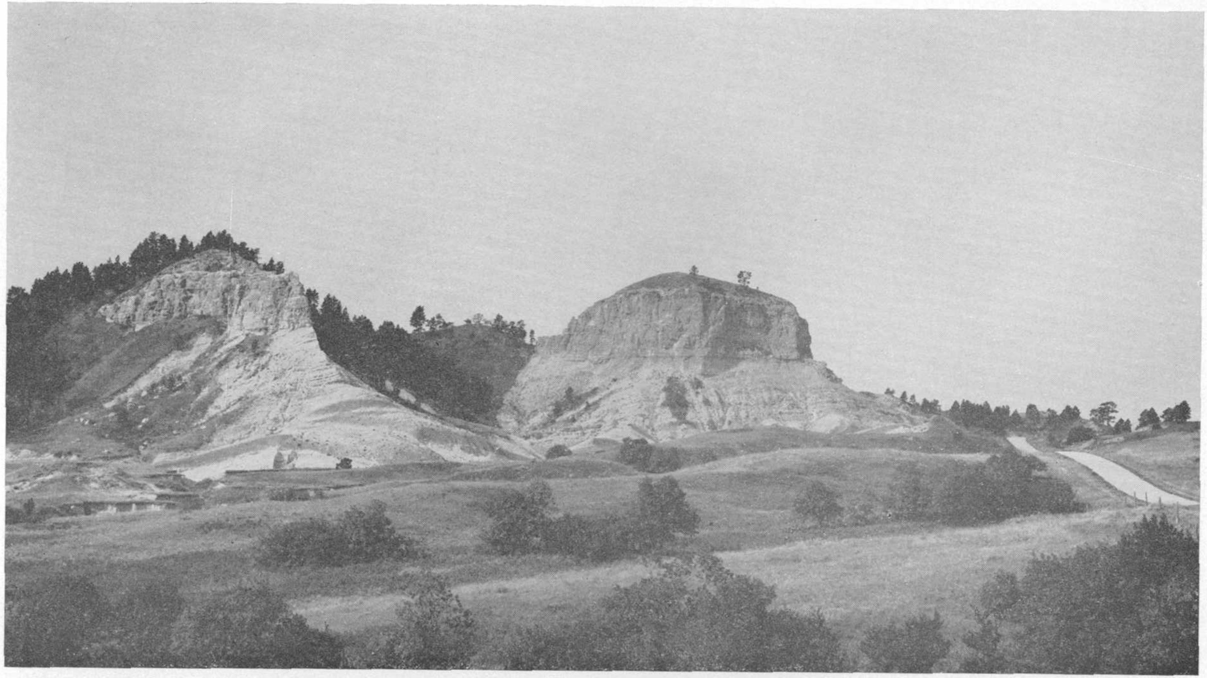
The uranium-bearing lignite at Table Mountain occurs in the uppermost 40 feet of the Ludlow member. It is found in two beds referred to as beds *D* and *C*, which average about 2 and 2.5 feet in thickness, respectively (pls. 6 and 7). The lack of exposures and the prevalence of slumping along the steep sides of the butte make their indentification and correlation at many places very difficult. The uranium-bearing lignite of bed *C* is thicker and less variable in thickness than that of bed *D*. The average uranim content of bed *C*, however, is not as great as that of bed *D*. This is probably due to the fact that bed *C* is overlain at most places by bed *D* and also by relatively impervious shale. The lignite beds stratigraphically below bed *C* show little or no radioactivity (pl. 7). From 17 measured sections and as many analyses at least 1.75 million tons of uranium-bearing lignite (table 4) in beds averaging about 30 inches thick are estimated to underlie about 500 acres on Table Mountain (secs. 5, 6, 7, and 8, T. 22 N., R. 4 E.). The character and thickness of the overburden will require that the lignite be recovered by underground mining.

MEDICINE POLE HILLS

The Medicine Pole Hills, mapped and described in detail by Hares (1928, p. 95, 98), are part of a hilly divide separating the Little Missouri and Grand River drainage basins in the southwestern part of the Marmarth lignite field, Bowman County, N. Dak. (pl. 1). The general geology and a brief description of the stratigraphy in the Medicine Pole Hills area are given by Zeller and Schopf in chapter C of this bulletin. Data obtained from 6 auger holes and 4 surface sections indicate that there are about 360 acres underlain by approximately 3 million tons of uranium-bearing lignite in beds 3–4.5 feet thick (pls. 8 and 9).

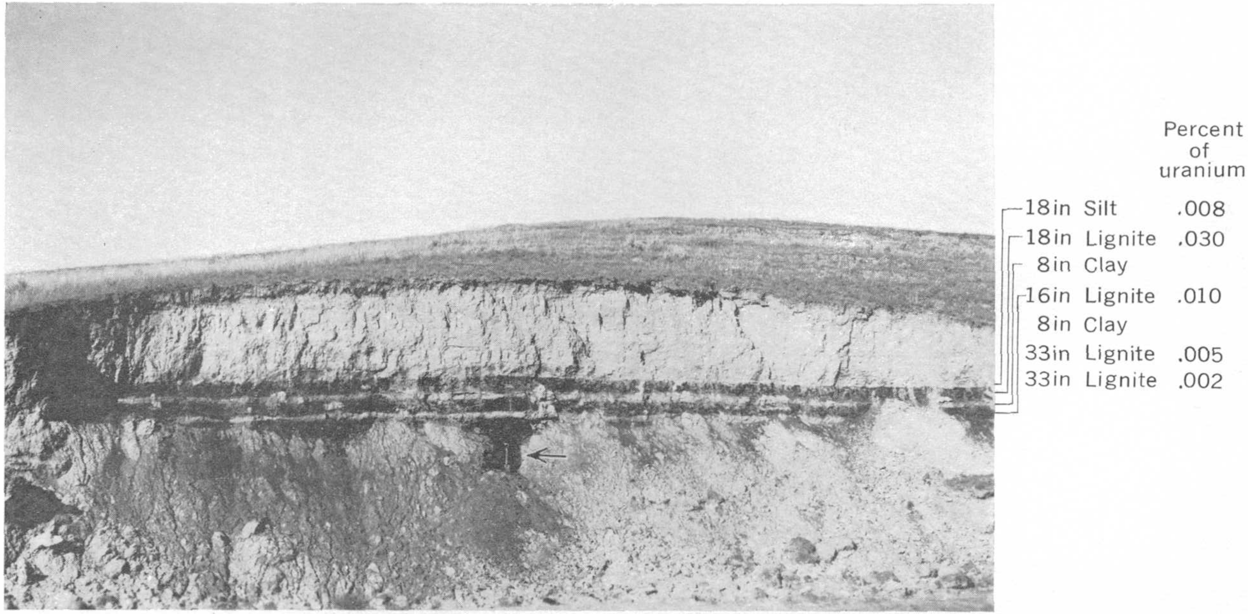
Hares (1928, p. 97) estimates that there are 4.48 million tons of lignite in the Harmon lignite bed, which underlies the low hills three miles to the northeast of Medicine Pole Butte, but significant amounts of uranium were not found in samples of lignite taken at surface exposures or from auger holes (pls. 8 and 9). In this area the Harmon bed is at least 20 feet thick and throughout most of the area is overlain by less than 75 feet of soft sandstone and shale. Although uranium in the Harmon lignite bed at the four localities (nos. 129–132) sampled is not of commercial significance, there is a good possibility that there are other places in the area where conditions for mineralization were much more favorable. The inadequacy of the exposures

West face of the Slim Buttes in T. 16 N., R. 7 E., showing badland topography formed by landslides and slumping in the White River group and the Arikaree formation.



Cliff-forming tuffaceous sandstone of the Arikaree formation unconformably overlying bentonitic clay and siltstone of the White River group at Reva Gap, SW¼ sec. 8, T. 18 N., R. 8 E., Harding County, S. Dak.

Uranium-bearing lignite in the Fort Union formation unconformably overlain by source beds of uranium in the White River group and Arikaree formation in T. 17 N., R. 7 E., Harding County, S. Dak. Mendenhall strip mine (see plate 16) is in the left foreground.



MENDENHALL STRIP MINE, NW¼SE¼ SEC. 1, T. 17 N., R. 7 E., HARDING COUNTY, S. DAK.

The 3-foot shovel in center foreground (arrow) rests on base of lignite bed which has an average thickness of 8 feet. Analyses listed on right margin show uranium content of lignite and of siltstone roof.

make necessary additional trenching and drilling before the area's potentialities can be fully appraised.

LODGEPOLE AREA

The Lodgepole area is part of an upland surface between the North and South Forks of the Grand River in T. 21 N., Rs. 11 and 12 E., northwestern Perkins County, S. Dak. (fig. 3 and pl. 10). A brief description of the stratigraphy and general geology of the area underlain by uranium-bearing lignite is presented in chapter C. Data from 5 auger and 8 surface sections indicate that there are at least 120 acres underlain by approximately 680,000 tons of strippable uranium-bearing lignite in beds 3–6 feet thick (pl. 9).

A mile northeast of the Lodgepole Post Office the Harmon lignite bed averages 6 feet in thickness and underlies approximately 1,000 acres (Winchester, 1916, pl. 10). In this area the lignite is directly overlain by thick impervious clay and at the two localities sampled contains only a trace of uranium in its upper 2 feet (locations 142 and 143, pl. 10). It is possible, however, that secondary uranium minerals may be localized in the massive coarse-grained sandstone capping the buttes.

SLIM BUTTES

Slim Buttes is a timber-covered steep sided mesa ½–7 miles wide and 20 miles long in southeastern Harding County, S. Dak. (fig. 3, and pls. 11 and 12). The mesa is composed chiefly of massive, chalky gray, tuffaceous sandstone of the Arikaree formation, which in places forms sheer cliffs 200 feet or more high. Slumped rocks that Recent erosion has dissected into nearly impassable badlands are present at many places around the mesa (pl. 13). Slumping and landslides have so greatly disturbed and covered the zones in which lignite beds crop out along the edges of the mesa that at many places it is very difficult to correlate beds or correctly interpret geologic structure. Many good springs issue from rocks along the edge of the mesa, but the surface in their vicinity is so rugged that few stock ranches can be located to take advantage of the excellent water. The top of the mesa, at a mean elevation of about 3,600 feet, is 400 to 600 feet above the general level of the surrounding plains and is gently rolling. A few pine trees grow about its margin. The central part of Slim Buttes is most easily accessible along the top of the buttes by a U. S. Forest Service road that extends north from J–B Pass road half a mile east of the divide. The northern part is most easily accessible from the top of the buttes by 6 miles of Forest Service road extending northeastward from State Route 8 at a point 2 miles west of Reva.

The oldest rocks in the Slim Buttes area are exposed at its southern margin, where the White River group and Arikaree formation unconformably overlie the Hell Creek formation of Late Cretaceous age. To the north the pre-Oligocene unconformity bevels progressively younger beds, and in the central and northern parts of Slim Buttes the Oligocene rocks rest on the lignite-bearing Ludlow member of the Fort Union formation of Paleocene age (pl. 11), which dips northeastward at about 20 feet or less per mile.

The lignite beds and associated strata are relatively undisturbed except at the north end of the buttes, where the rocks are broken by a pre-White River fault (pl. 11) and pre-Arikaree landsliding. The fault trends N. 75° W. for an inferred distance of about a mile in sec. 28, T. 19 N., R. 8 E., and has a maximum stratigraphic displacement of about 150 feet. The only other place examined in the Slim Buttes area where pre-White River faulting may have occurred is in the vicinity of Reva Gap, sec. 8, T. 18 N., R. 8 E. There, however, the exposures are so poor and Recent slumping so prevalent that the pre-White River faults and pre-Arikaree landslides were not differentiated.

The two areas in the Slim Buttes where core and surface samples are adequate for estimation of resources are along the west-central part of the buttes in the vicinity of the Mendenhall mine, locations 83–96 (pls. 11, 15, and 16) and in the Bar H area at the northeast tip of the buttes, locations 110 to 118. The uranium-bearing beds in these areas average 6–12 feet in thickness (pl. 12) and are of excellent quality lignite. The content of uranium is not uniform and appears to be most closely controlled by the nearness of the lignite bed to the base of the White River group and to the permeability of the rocks directly overlying the bed.

Uranium-bearing lignite at widely separated localities (79, 81, 101, 107, and 108, pl. 11) indicate that beds of such lignite 5 feet or more in thickness probably underlie most of the 60 square miles of White River and Arikaree strata that cap the Slim Buttes. Surface and core data were considered adequate for estimating tonnage of lignite for only 7 square miles. On the basis of the surface and core hole data, it is estimated that there are at least 5.25 million tons of strippable lignite in beds 5 feet or more in thickness in the Mendenhall area and a combined total of 33.25 million tons of lignite in the Mendenhall and the Bar H areas which will require underground mining. The potential resources of uranium-bearing lignite underlying all of Slim Buttes are estimated to be 340 million tons.

LONG PINE HILLS

The Long Pine Hills are a high mesa, 2–5 miles wide and 14 miles long from north to south, in the eastern part of Carter County, Mont.

Throughout the length of the mesa, chalky-gray sandstone and bentonitic clay of the White River group and Arikaree formation unconformably overlie the lignite-bearing Ludlow member of the Fort Union formation (pl. 1). These stratigraphic units make up the main body of the mesa, which rises 500 feet or more above the general level of the surrounding plains. Beds of lignite 30 inches or more thick occur at few places around the mesa and are generally overlain by 100 feet or more of impervious shale. Reconnaissance examination of most of the lignites exposed along the flanks of the mesa did not find significant deposits of radioactive carbonaceous materials. At the abandoned Chuning mine at the southern tip of the mesa, in the NE¼ sec. 21, T. 3 S., R. 62 E., a lignite bed 5 feet thick occurs 150 feet below the base of the White River (Bauer, 1924, pl. 23, locality 287). The impure character of the bed and its small uranium content (pl. 9, locality 121) makes the occurrence of academic interest only. The lignite at the Chuning mine thins to the west and in the NW¼ sec. 19, T. 3 S., R. 62 E. (locality 291 of Bauer) ranges from 6 inches to 2 feet in thickness. The lignite is only mildly radioactive (pl. 9, locality 120). At the northern tip of the mesa in the NE¼ sec. 20, T. 1 S., R. 61 E. (pl. 9, locality 122) the same bed, or one at about the same stratigraphic horizon contains a significant amount of uranium but is 1 foot or less in thickness at most places.

The massive coarse-grained sandstone of the Ludlow member directly beneath the base of the Oligocene rocks in the Long Pine Hills, however, may at some places act as a favorable host rock for the concentration of secondary minerals of uranium. The discovery of such minerals in sandstone underlying the White River group at Reva Gap in Slim Buttes is evidence that they may be found in the Long Pine Hills.

POTENTIAL RESOURCES OF URANIUM-BEARING LIGNITE

Available data from northwestern South Dakota and the adjacent areas indicate that the region as a whole contains an aggregate of at least 47.5 million tons of uranium-bearing lignite. Almost a fifth of this lignite is strippable and in beds averaging 4 feet in thickness. Analyses of about 275 channel and auger samples (table 5) and 1,000 samples from drill cores indicate that the lignite contains an average of slightly more than 0.008 percent uranium. In some areas the uranium content ranges from 0.015 to 0.03 percent. The ash content of the lignites ranges from 10 percent or less to about 20 percent; the uranium content of the ash thus is at least 5 times and generally 7–10 times that of the lignite. Proximate and ultimate analyses of the lignite cores by the U. S. Bureau of Mines are tabulated in chapters C and D of this bulletin.

The uranium-bearing lignite deposits in the Slim Buttes are of Harding County, S. Dak., are perhaps the most promising of those examined in the Dakotas. The lignite beds underlying the Slim Buttes average ten feet or more in thickness and closely underlie the base of the White River group, thus being in a favorable position for widespread mineralization by ground water.

Approximately 880 feet of core-drilling in 8 shallow holes along the northeast side of Slim Buttes was completed late in July 1952 (see chapter C, this bulletin). The core-drilling, however, is not adequate to appraise the area's potential resources of uranium-bearing lignite. The incomplete data at hand indicate the Slim Buttes may be underlain by 340 million tons of uranium-bearing lignite in beds averaging 5 feet or more in thickness. A total of 15–20 core holes, each 375–400 feet deep, would provide a more complete and accurate appraisal of the area's potentialities. At most places in the Slim Buttes area, below the uppermost bed of uranium-bearing lignite are large deposits of nonuraniferous lignite that require underground mining methods. Additional large deposits of such lignite, some of which are strippable, are present 7–9 miles north of the Slim Buttes along the South Fork of the Grand River in the vicinity of the Shirley mine (sec. 35, T. 21 N., R. 8 E.). The Slim Buttes area, therefore, seems particularly well adapted for providing large tonnages of lignite for lignite-consuming industrial installations.

In Harding County, S. Dak., estimates of uranium-bearing lignite for the Mendenhall area of the Slim Buttes total 5.25 million tons in strippable beds and 28 million tons in beds requiring underground mining; in the Bar H area there are 5.25 million tons in beds that require underground mining (see chapter C).

In Perkins County, S. Dak., 682,000 tons of strippable uranium-bearing lignite are reported in the Lodgepole and Johnson outlier areas, and in Bowman County, N. Dak., 3.045 million tons of strippable uranium-bearing lignite are estimated in the Medicine Pole Hills area (see chapter C, this bulletin).

In addition to the estimates of uranium-bearing lignite listed herein for northwestern South Dakota and adjacent areas, other resources in beds averaging 2.5–4.5 feet in thickness at Bullion Butte, Billings County, and at Sentinel Butte, Golden Valley County, in the southwest corner of North Dakota and 38 and 52 miles north of the Medicine Pole Hills respectively, are reported by Moore, Melin, and Kepferle (see chapter E, this bulletin). They report about 5 million tons of uranium-bearing lignite with an average grade of 0.007 percent of uranium underlying an area of about 1,200 acres at Sentinel Butte and about 4.2 million tons of the same grade underlying 500 acres at Bullion Butte. The thickness and the character of the White River group which caps these buttes makes underground mining necessary.

They estimate that in the vicinity of the Chalky Buttes, in Slope County, N. Dak., about 5 miles north of Bowman, a total of about 18 million tons of uranium-bearing lignite underlie about 5,200 acres. The grade is estimated to be about 0.017 percent, but the beds average 2.5 feet or less in thickness and most will require underground mining methods. Approximately 600 acres are beds of lignite averaging 0.016 percent uranium and at least 2 feet thick and beneath no more than 30 feet of overburden which can be worked by strip mining.

In the Ekalaka Hills, Carter County, Mont., Gill (chapter F, this bulletin) estimates that 16.5 million tons of lignite having a moderate content of uranium (average grade 0.005 percent) underlies about 2,000 acres. The beds average about 5 feet in thickness and at most places are overlain by 200 feet or more of massive-bedded sandstone.

TABLE 5.—*Analyses of surface samples and auger cuttings of uranium-bearing lignite from northwestern South Dakota and adjacent areas in North Dakota and Montana*

[Chemical analyses by F. Cuttitta, A. Dufour, E. Mallory, J. J. McGee, W. P. Tucker, Jr., and H. W. Worthing; radioactivity analyses by C. Cox, B. A. McCall, J. N. Rosholt, and J. J. Warr, Jr., U. S. Geological Survey]

Locality[1]		Sample		Analyses, in percent			
No.	Location in township and section	Laboratory No.	Thickness (ft)	Equivalent uranium	Uranium: In sample	Uranium: In ash	Ash
	TABLE MOUNTAIN AND ADJACENT OUTLIERS, HARDING COUNTY, S. DAK. (LOCALITIES 1–15, PL. 7)						
	T. 22 N., R. 4 E.						
1	NW¼NW¼ sec. 7	42469	2.3	0.004	0.005	0.028	23.6
2	do	42458	2.6	.006	.005	.017	34.6
	do	42461	3.8	.000	.000	.002	16.1
3	do	42459	2.6	.016	.020	.090	26.4
4	NW¼SE¼ sec. 7	42460	2.9	.014	.012	.026	57.3
7	NE¼SE¼ sec. 7	42465	1.3	.002	.003	.006	45.0
	do	42467	.3	.021	.036	.067	63.2
	do	42468	2.1	.002	.003	.012	28.7
	do	42462	4.8	.001	.002	.005	33.5
8	NE¼NE¼ sec. 8	42466	1.6	.004	.005	.010	45.4
	do	42933	3.0	.005	.005	--------	26.8
9	NW¼SE¼ sec. 5	42455	1.7	.014	.013	.046	30.9
	do	42457	2.8	.008	.009	.062	17.0
	do	42463	3.0	.000	.001	.001	44.1
	do	42470	2.3	.000	.001	.003	29.7
10	do	42454	1.7	.012	.015	.038	32.4
11	do	43901	2.2	.004	.004	--------	--------
13	NW¼SE¼ sec. 6	42936	5.0	.001	.000	--------	22.1
14	Center of south line, sec. 17	42934	2.2	.001	.001	--------	29.1
	do	42935	.7	.002	.001	--------	59.6
15	SE¼SW¼ sec. 9	42937	.5	.004	.003	--------	53.5

[1] At localities 5, 6, and 12, lignite is not radioactive and was not sampled.

TABLE 5.—*Analyses of surface samples and auger cuttings of uranium-bearing lignite from northwestern South Dakota and adjacent areas in North Dakota and Montana*—Continued

Locality [1]		Sample		Analyses, in percent			
No.	Location in township and section	Laboratory No.	Thickness (ft)	Equivalent uranium	Uranium: In sample	Uranium: In ash	Ash
	NORTH CAVE HILLS, HARDING COUNTY, S. DAK. (LOCALITIES 16–51, PL. 7)						
	T. 21 N., R. 5 E.						
33	SW¼SE¼ sec. 12	43900	2.2	0.001	0.001		
	do	43899	5.8	.000	.001		
34	NE¼NW¼ sec. 13	45110	4.8	.000	.001		
35	SW¼SE¼ sec. 11	46222	1.3	.002	.003		
	do	46221	5.0	.001	.002		
36	SW¼NW¼ sec. 10	43654	2.1	.007	.006	0.018	42.23
	SW¼NE¼ sec. 10	43653	4.6	.002	.003		
	T. 22 N., R. 4 E.						
43	NW¼NE¼ sec. 25	44267	1.2	0.005	0.003		
44	SE¼NE¼ sec. 24	43649	3.6	.003	.005	0.028	19.96
	do	43650	1.1	.014	.010	.043	27.13
	T. 22 N., R. 5 E.						
16	Center of east line, SE¼ sec. 4	43148	3.2	0.004	0.003	0.012	25.77
17	Center of west line, NE¼ sec. 9	43150	3.9	.001	.001	.003	27.16
19	SW¼NW¼ sec. 10	43151	.5	.007	.003	.003	95.63
21	SW¼SE¼ sec. 10	43153	.5	.006	.011	.016	95.40
	do	43152	4.8	.001	.001	.005	29.49
[2] 22	do	45024	2.0	.002	.002	.002	76.9
	do	45025	2.0	.002	.002	.002	65.66
23	SW¼SW¼ sec. 11	43154	5.2	.001	.001	.002	22.14
24	SW¼NW¼ sec. 11	43155	5.0	.000	.001	.005	42.27
25	NW¼SE¼ sec. 2	44254	1.9	.005	.005		
26	NW¼SW¼ sec. 14	43659	4.5	.000	.001		
	do	43660	4.0	.004	.006	.015	42.65
[2] 27	do	45023	3.0	.006	.005	.008	69.54
28	SE¼NW¼ sec. 26	43658	1.8	.006	.007	.025	35.49
[2] 29	do	45022	1.0	.004	.002	.002	82.08
30	Center of east line, SE¼ sec. 27	47864	2.0	.003	.003	.011	27.42
31	SW¼SW¼ sec. 35	43898	1.6	.004	.004		
[2] 32	SE¼SE¼ sec. 36	43903	10.0	.001	.001	.001	53.43
37	SE¼NW¼ sec. 34	43657	1.1	.004	.004	.025	38.82
38	NE¼SE¼ sec. 33	43656	.8	.006	.006	.019	37.21
	do	43655	3.6	.001	.001		
39	Center of east line SW¼NW¼ sec. 33	43652	1.7	.006	.008	.023	42.71
	do	43651	3.3	.002	.003		
40	SE¼SE¼ sec. 29	44264	.5	.007	.006		
	do	44263	.3	.004	.005		
	do	44262	2.0	.003	.002		
	do	44261	1.9	.001	.001		
41	NE¼SW¼ sec. 29	44260	1.8	.002	.002		
42	SW¼NE¼ sec. 30	44258	1.6	.000	.000		
	do	44259	5.4	.000	.000		
45	NW¼SW¼ sec. 19	44269	1.0	.021	.018		
	do	44268	4.3	.002	.002		
[2] 46	do	45026	1.25	.004	.006	.008	73.94
	do	45027	1.25	.007	.005	.007	62.84
	do	45028	2.25	.003	.003	.003	61.2
	do	45029	2.25	.004	.003	.003	65.28
[2] 47	NW¼SE¼ sec. 19	45039	1.0	.005	.004	.006	69.14
	do	45040	5.0	.004	.003	.005	46.26
[2] 48	NW¼SE¼ sec. 19	45396	1.0	.004	.002		71.86
	do	45030	1.0	.003	.003	.005	52.81
	do	45031	1.0	.002	.003	.006	54.33
	do	45032	1.0	.002	.003	.004	54.59
	do	45033	1.0	.002	.003	.007	52.68

[1] At localities 5, 6, and 12, lignite is not radioactive and was not sampled.

[2] Auger hole. Owing to contamination of wall rock with lignite cuttings, uranium analyses are 25 to 45 percent less than their true values.

TABLE 5.—*Analyses of surface samples and auger cuttings of uranium-bearing lignite from northwestern South Dakota and adjacent areas in North Dakota and Montana*—Continued

Locality [1]		Sample		Analyses, in percent			
No.	Location in township and section	Laboratory No.	Thickness (ft)	Equivalent uranium	Uranium: In sample	Uranium: In ash	Ash
NORTH CAVE HILLS, HARDING COUNTY, S. DAK. (LOCALITIES 16–51, PL. 7)—continued							
T. 22 N., R. 5 E.—Continued							
[2] 48	NW¼SE¼ sec. 19	45034	1.0	0.003	0.003	0.005	54.94
	do	45035	1.0	.002	.003	.004	58.42
	do	45036	1.0	.002	.002	.004	42.61
	do	45037	1.0	.003	.003	.005	45.0
	do	45038	1.0	.002	.003	.006	55.73
[2] 49	SW¼NE¼ sec. 19	45397	2.5	.006	.005	--------	40.80
	do	45041	4.0	.001	.003	.006	32.85
	do	45042	1.5	.003	.003	.003	70.63
50	SW¼SW¼ sec. 9	44256	2.0	.004	.004	--------	--------
51	SE¼SE¼ sec. 8	44255	4.5	.001	.002	--------	--------
SOUTH CAVE HILLS AND ADJACENT OUTLIERS, HARDING COUNTY, S. DAK. (LOCALITIES 52–75, PL. 5)							
T. 20 N., R. 4 E.							
72	SE¼SW¼ sec. 13	47926	2.3	0.003	0.005	--------	--------
73	NE¼NE¼ sec. 21	47930	.5	.017	.018	0.019	94.93
74	Center of south line, sec. 21	47931	1.5	.018	.025	.046	54.93
75	NE¼NE¼ sec. 28	47928	1.6	.003	.002	--------	--------
	do	47929	1.6	.001	.003	--------	--------
[2] 76	SE¼SW¼ sec. 23	--------	5.5	--------	.002	--------	--------
T. 20 N., R. 5 E.							
62	SE¼NW¼ sec. 9	43889	1.0	0.011	0.014	0.039	39.59
63	SW¼NE¼ sec. 5	43888	2.0	.006	.007	.013	49.8
	do	43887	3.3	.008	.013	.031	40.42
64	NE¼NE¼ sec. 6	43890	3.0	.006	.006	.014	38.8
	do	43891	1.0	.003	.007	.021	30.15
65	NE¼SE¼ sec. 6	44715	3.0	.001	.001	--------	42.13
66	NW¼SE¼ sec. 6	43893	1.7	.011	.006	.011	60.01
	do	43892	6.0	.001	.001	--------	--------
69	NE¼SW¼ sec. 20	47934	1.75	.015	.014	.056	25.17
	do	47933	1.75	.016	.029	.116	25.07
	do	47932	3.0	.003	.002	--------	--------
70	NE¼NE¼ sec. 19	47937	.7	.023	.018	.020	83.61
	do	47936	.7	.038	.028	.035	94.87
	do	47935	.8	.020	.024	.031	87.62
71	SW¼SE¼ sec. 30	47925	.5	.14	.19	.22	85.74
	do	47927	.8	.018	.020	.022	88.94
T. 21 N., R. 4 E.							
52	SW¼NE¼ sec. 23	43668	0.8	0.006	0.009	0.025	34.22
	do	43667	.8	.041	.555	.084	68.29
	do	43666	.5	.025	.034	.093	36.63
	do	43669	2.7	.000	.001	--------	--------
53	SE¼SW¼ sec. 23	43664	2.2	.028	.007	.013	48.5
[2] 54	do	43663	.8	.017	.012	.020	69.39
	do	45097	2.0	.005	.004	.004	93.88
55	SW¼SW¼ sec. 13	43894	4.2	.003	.003	--------	--------
67	Center of NE¼ sec. 36	43673	2.5	.003	.004	--------	--------
68	SE¼NE¼ sec. 35	43671	1.2	.004	.004	--------	--------
	do	43672	3.0	.000	.001	--------	--------

[1] At localities 5, 6, and 12, lignite is not radioactive and was not sampled.
[2] Auger hole. Owing to contamination of wall rock with lignite cuttings, uranium analyses are 25 to 45 percent less than their true values.

TABLE 5.—*Analyses of surface samples and auger cuttings of uranium-bearing lignite from northwestern South Dakota and adjacent areas in North Dakota and Montana*—Continued

Locality[1]		Sample		Analyses, in percent			
No.	Location in township and section	Laboratory No.	Thickness (ft)	Equivalent uranium	Uranium: In sample	Uranium: In ash	Ash
SOUTH CAVE HILLS AND ADJACENT OUTLIERS, HARDING COUNTY, S. DAK. (LOCALITIES 52–75, PL. 5)—continued							
T. 21 N., R. 5 E.							
56	Center of SW¼ sec. 18	44716	3.5	0.007	0.009	--------	21.93
57	NW¼SW¼ sec. 28	44717	1.0	.042	.045	--------	82.20
58	NW¼NW¼ sec. 33	47866	2.5	.020	.024	0.108	22.12
59	Center of south line, sec. 28	44719	1.5	.029	.030	--------	70.13
60	Center of south line, sec. 28	44718	4.2	.014	.015	--------	29.33
61	do	43670	1.1	.006	.013	.021	51.18
SLIM BUTTES, HARDING COUNTY, S. DAK. (LOCALITIES 77–119, PL. 12)							
T. 16 N., R. 7 E.							
77	SW¼NW¼ sec. 1	45052	0.3	0.000	0.002	--------	--------
T. 17 N., R. 7 E.							
78	NE¼NW¼ sec. 35	45050	4.0	0.005	0.002	--------	--------
79	NE¼SW¼ sec. 35	45051	.6	.002	.001	--------	--------
[2] 83	SE¼SW¼ sec. 1	45064	1.5	.010	.010	0.011	76.19
	do	45065	2.0	.009	.008	.009	82.5
	do	45066	2.0	.008	.010	.010	80.3
	do	45067	3.0	.003	.002	.003	69.74
	do	45069	1.0	.001	.002	.003	33.21
	do	45070	1.0	.003	.002	.003	48.07
84	NW¼SE¼ sec. 1	45368	1.5	.010	.008	--------	86.53
	do	45367	1.75	.031	.030	--------	25.53
	do	45366	.7	.003	.002	--------	85.80
	do	45365	1.3	.008	.010	--------	21.93
	do	45364	.7	.002	.001	--------	82.0
	do	45362	2.75	.004	.005	--------	12.20
	do	45055	2.75	.002	.002	--------	--------
	do	45054	3.0	.001	.002	--------	--------
	do	45053	3.0	.002	.002	--------	--------
[2] 85	NE¼SW¼ sec. 1	45063	4.0	.005	.008	.011	64.56
	do	45049	4.0	.002	.001	.002	40.84
[2] 86	SW¼NE¼ sec. 1	45061	2.0	.010	.010	.014	78.15
	do	45062	2.0	.006	.006	.009	63.61
	do	45044	5.0	.004	.003	.006	56.94
	do	45045	3.0	.001	.002	.003	50.60
T. 17 N., R. 8 E.							
80	NW¼SE¼ sec. 8	47851	1.0	0.003	0.002	--------	43.79
81	SW¼SE¼ sec. 8	47852	4.9	.009	.007	0.039	17.85
82	SE¼NE¼ sec. 5	47853	2.1	.009	.010	.029	34.30
	do	47854	2.7	.005	.005	.017	29.47
T. 18 N., R. 7 E.							
[2] 87	SW¼SE¼ sec. 36	45072	2.0	0.005	0.006	0.007	55.51
	do	45073	3.0	.003	.004	.009	38.45
	do	45076	8.0	.000	.001	.002	22.18
88	NW¼SE¼ sec. 36	45104	2.5	.012	.020	.011	20.39
	do	45103	2.5	.009	.014	.074	20.26
	do	45102	2.0	.002	.002	--------	--------
	do	45101	2.75	.001	.002	--------	--------
	do	45100	2.75	.003	.004	--------	--------
89	do	45206	2.2	.004	.006	.017	34.84
	do	46205	2.0	.001	.001	--------	--------

[1] At localities 5, 6, and 12, lignite is not radioactive and was not sampled.
[2] Auger hole. Owing to contamination of wall rock with lignite cuttings uranium analyses are 25 to 45 percent less than their true values.

TABLE 5.—*Analyses of surface samples and auger cuttings of uranium-bearing lignite from northwestern South Dakota and adjacent areas in North Dakota and Montana*—Continued

Locality[1]		Sample		Analyses, in percent			
No.	Location in township and section	Laboratory No.	Thickness (ft)	Equivalent uranium	Uranium In sample	Uranium In ash	Ash
SLIM BUTTES, HARDING COUNTY, S. DAK. (LOCALITIES 77–119, PL. 12)—continued							
T. 18 N., R. 7 E.—Continued							
90	NW¼SE¼ sec. 36	46204	2.9	0.012	0.014	0.042	40.34
91	SW¼NE¼ sec. 36	46207	2.2	.017	.025	.075	37.15
92	do	45106	3.0	.015	.019	.058	33.09
	do	45105	5.5	.004	.003		
[2] 93	do	45080	7.0	.005	.007	.009	58.5
94	SW¼SE¼ sec. 25	47843	3.1	.017	.016	.075	22.67
95	NW¼SW¼ sec. 25	47844	3.5	.010	.008	.039	25.63
96	do	46212	.8	.007	.010	.043	27.13
	do	46210	.5	.005	.004		
	do	46209	1.2	.002	.003		
	do	46208	4.5	.003	.003		
97	do	46213	2.7	.026	.032	.110	33.99
98	do	46211	4.4	.002	.004		
99	NE¼SE¼ sec. 24	47848	.2	.009	.010	.121	8.24
	do	47847	1.8	.014	.014	.053	26.20
106	NE¼SE¼ sec. 1	43895	3.5	.003	.002		
107	do	43896	5.0	.003	.004		
	do	43897	3.0	.001	.001		
T. 18 N., R. 8 E.							
100	SE¼SW¼ sec. 20	47849	3.0	0.009	0.010	0.050	19.87
	do	47850	2.5	.006	.006	.034	17.61
101	NW¼SW¼ sec. 28	47855	3.7	.005	.008	.020	25.05
102	SW¼SW¼ sec. 29	47856	3.5	.007	.009	.025	35.80
103	SE¼SE¼ sec. 8	47857	4.2	.002	.002	.011	17.93
104	NE¼NE¼ sec. 17	47859	1.7	.004	.004	.014	28.07
	do	47858	3.1	.003	.002		12.55
105	do	47860	.4	.012	.011	.014	80.13
[2] 108	SE¼SE¼ sec. 8	47943	1.0	.002	.005		
	do	47944	2.0	.002	.003		
	do	47945	2.0	.001	.002		
	do	47946	2.0	.002	.003		
	do	47947	2.0	.001	.002		
	do	47948	2.0	.001	.003		
[2] 109	SE¼NW¼ sec. 8	47949	8.0	.002	.003		
	do	47953	2.0	.003	.004		
	do	47954	4.0	.002	.003		
	do	47956	1.5	.002	.004		
T. 19 N., R. 8 E.							
110	NW¼NE¼ sec. 33	42930	0.8	0.019	0.019		93.3
	do	42931	.7	.013	.012		29.1
111	do	42729	5.0	.011	.011	0.059	23.7
	do	42730	.25	.003	.003	.002	94.5
	do	42731	7.0	.019	.007	.064	15.7
112	NW¼SW¼ sec. 27	42928	4.2	.000	.001		17.0
	do	42927	1.5	.002	.001		92.9
	do	42926	8.0	.000	.000		14.6
113	Center of south line, sec. 28	42929	3.5	.007	.009		36.1
114	Center E½ sec. 28	46196	2.5	.013	.028	.088	28.32
	do	46195	2.5	.007	.009	.010	9.89
115	Center of E½ sec. 28	46198	.5	.019	.014	.012	97.80
	do	46197	.7	.011	.010	.010	97.07
116	SW¼NE¼ sec. 28	46199	2.0	.007	.006	.038	22.54
117	SW¼SE¼ sec. 20	46200	5.5	.011	.015	.085	19.70
118	SE¼SE¼ sec. 20	46201	2.0	.007	.009	.053	18.12

[1] At localities 5, 6, and 12, lignite is not radioactive and was not sampled.
[2] Auger hole. Owing to contamination of wall rock with lignite cutting, uranium analyses are 25 to 45 percent less than their true values.

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TABLE 5.—*Analyses of surface samples and auger cuttings of uranium-bearing lignite from northwestern South Dakota and adjacent areas in North Dakota and Montana*—Continued

Locality[1]		Sample		Analyses, in percent			
No.	Location in township and section	Laboratory No.	Thickness (ft)	Equivalent uranium	Uranium		Ash
					In sample	In ash	
SLIM BUTTES, HARDING COUNTY, S. DAK. (LOCALITIES 77–119, PL. 12)—continued							
T. 21 N., R. 8 E.							
119	SW¼ sec. 20	42923	0.7	0.005	0.003	--------	36.5
	do	42924	3.2	.001	.001	--------	19.4
	do	42925	2.2	.001	.001	--------	18.0
LONG PINE HILLS, CARTER COUNTY, MONT. (LOCALITIES 120–123, PL. 9)							
T. 1 N., R. 48 E.							
123	SW¼SW¼ sec. 13	46217	0.8	0.002	0.003	--------	--------
T. 1 S., R. 61 E.							
122	NE¼NE¼ sec. 20	46216	0.8	0.008	0.014	0.043	33.62
T. 3 S., R. 62 E.							
120	NW¼NW¼ sec. 19	42472	2.0	0.004	0.004	0.006	70.6
121	SW¼NE¼ sec. 21	46215	2.5	.005	.004	--------	--------
	do	46214	2.5	.005	.003	--------	--------
MEDICINE POLE HILLS, BOWMAN COUNTY, N. DAK. (LOCALITIES 125–132, 147–148, PL. 9)							
T. 130 N., R. 104 W.							
125	NE¼NW¼ sec. 12	42474	4.0	0.005	0.005	0.015	45.1
[2] 147	NE¼SE¼ sec. 2	45391	3.5	.019	.019	--------	58.40
[2] 148	SW¼NW¼ sec. 1	45392	5.0	.003	.003	--------	60.66
T. 131 N., R. 103 E.							
129	NW¼NW¼ sec. 29	45056	2.0	0.001	0.001	--------	--------
[2] 130	SW¼SW¼ sec. 20	45394	8.0	.002	.001	--------	55.46
131	NE¼NE¼ sec. 21	45369	2.0	.008	.010	--------	34.26
[2] 132	do	45395	5.0	.002	.001	--------	59.60
	do	45060	5.0	.003	.002	0.002	54.20
T. 131 N., R. 104 W.							
[2] 126	SE¼SW¼ sec. 35	45390	5.0	0.005	0.004	--------	61.33
[2] 127	NW¼SE¼ sec. 35	45393	4.5	.008	.010	--------	64.0
128	do	45398	5.5	.007	.009	--------	17.33
LODGEPOLE AREA, PERKINS COUNTY, S. DAK. (LOCALITIES 133–145, PL. 90)							
T. 21 N., R. 11 E.							
[2] 144	Center of east line, SE¼SE¼ sec. 9	45093	3.5	0.006	0.006	0.009	64.75
	do	45094	1.5	.003	.003	.004	53.05
	do	45095	2.5	.002	.002	.004	52.53
145	NE¼SW¼ sec. 9	44272	5.5	.003	.004	--------	--------

[1] At localities 5, 6, and 12, lignite is not radioactive and was not sampled.
[2] Auger hole. Owing to contamination of wall rock with lignite cutting, uranium analyses are 25 to 45 percent less than their true values.

TABLE 5.—*Analyses of surface samples and auger cuttings of uranium-bearing lignite from northwestern South Dakota and adjacent areas in North Dakota and Montana*—Continued

Locality[1]		Sample		Analyses, in percent			
No.	Location in township and section	Laboratory No.	Thickness (ft)	Equivalent uranium	Uranium In sample	Uranium In ash	Ash
LODGEPOLE AREA, PERKINS COUNTY, S. DAK. (LOCALITIES 133–145, PL. 9)—continued							
T. 21 N., R. 12 E.							
133	SW¼SW¼ sec. 20	42473	6.0	0.000	0.000	0.001	21.3
134	South line of SE¼SW¼ sec. 20	45091	2.0	.004	.004	.005	76.94
	do	45092	6.0	.000	.001	.001	38.48
135	do	45109	2.1	.007	.009	.035	29.95
136	do	43902	2.0	.004	.005	.016	29.12
	NW¼NE¼ sec. 30	43156	4.0	.001	.002	.008	19.89
[2] 137	SW¼NW¼ sec. 19	45081	2.0	.008	.012	.016	64.17
	do	45082	2.0	.002	.003	.005	57.13
	do	45083	2.0	.001	.003	.004	40.43
138	do	45107	2.0	.010	.015	.028	54.28
[2] 139	do	45084	2.0	.015	.015	.023	61.99
	do	45085	2.0	.006	.008	.009	66.20
	do	45086	2.0	.002	.004	.007	47.31
	do	45087	1.5	.002	.003	.004	48.10
[2] 140	NW¼NE¼ sec. 19	45088	2.0	.002	.003	.004	56.53
	do	45089	2.0	.001	.002	.003	21.9
	do	45090	1.5	.002	.002	.002	54.41
141	NE¼NW¼ sec. 19	45108	2.6	.003	.004	--------	--------
142	SW¼SW¼ sec. 2	47958	2.0	--------	.001	--------	--------
T. 22 N., R. 12 E.							
143	NW¼SW¼ sec. 33	43157	3.0	0.001	0.001	0.003	23.41

[1] At localities 5, 6, and 12, lignite is not radioactive and was not sampled.
[2] Auger hole. Owing to contamination of wall rock with lignite cutting, uranium analyses are 25 to 45 percent less than their true values.

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Core Drilling for Uranium-Bearing Lignite in Harding and Perkins Counties, South Dakota and Bowman County North Dakota

By HOWARD D. ZELLER *and* JAMES M. SCHOPF

URANIUM IN COAL IN THE WESTERN UNITED STATES

GEOLOGICAL SURVEY BULLETIN 1055-C

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CORE DRILLING FOR URANIUM-BEARING LIGNITE IN HARDING AND PERKINS COUNTIES, SOUTH DAKOTA, AND BOWMAN COUNTY, NORTH DAKOTA

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ABSTRACT

Twenty core holes having a total footage of 1,907 feet were drilled and from them 94 feet of lignite were taken for analyses for uranium during part of the summers of 1951 and 1952 in northwestern South Dakota and southwestern North Dakota.

About 9 million tons of lignite averaging 0.01 percent uranium are estimated to be present in the areas covered by this report. The results of 191 chemical determinations for uranium show that generally the greatest concentrations of uranium are in the upper parts of uranium-bearing lignite beds 3 feet or more in thickness and that the uranium content decreases downward to near the vanishing point in succeeding lower beds. The results of 191 semiquantitative spectrographic analyses of the ash from the lignite cores reveal that molybdenum closely parallels uranium in distribution and concentration and may possibly be significant as an indicator element in prospecting for uranium.

INTRODUCTION

The main objective of the core-drilling program in the Dakotas was to determine the quality of unweathered uranium-bearing lignite, particularly from those areas where surface sampling had indicated that significant concentrations of uranium might be present. A secondary objective was to collect unweathered samples from, and to measure the radioactivity of, the White River group of Oligocene age and the Arikaree formation of Miocene age that overlie the lignite. The uranium in the lignite is believed to have been derived from these formations.

Core holes were drilled by a private contractor, for the U. S. Geological Survey, in four major areas: the Mendenhall and Bar H areas of the Slim Buttes, Harding County, S. Dak.; the Lodgepole area and Johnson outlier, Perkins County, S. Dak.; and the Medicine Pole

Hills area, Bowman County, N. Dak. The locations of these areas are shown on figure 9, and the data on core holes are given in table 1, except for the Mendenhall area, the data for which are presented in chapter D.

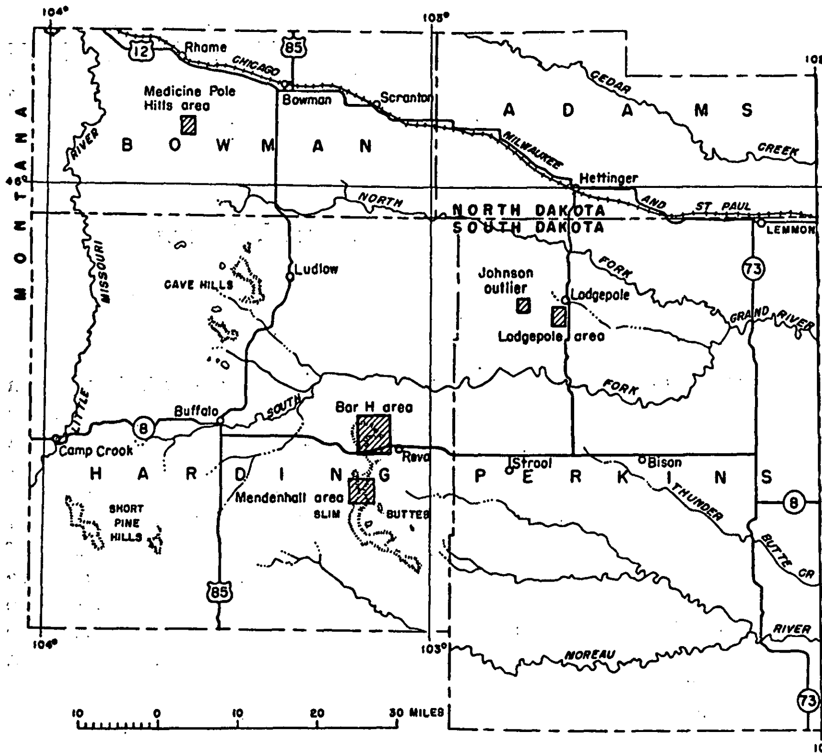

FIGURE 9.—Index map, showing the areas of core drilling for uranium-bearing lignite described in this report.

The detailed description of lignite cores (table 6) and the selection of samples for uranium and semiquantitative spectrographic analyses (TE) (table 4) and for fuel analyses (table 5) were made at the Geological Survey laboratory at Columbus, Ohio, under the direction of James M. Schopf. Chemical determination of percent uranium and semiquantitative spectrographic analyses for other elements in the lignite (table 4) were made by the U. S. Geological Survey and the proximate and ultimate fuel analyses (table 5) by the U. S. Bureau of Mines at Pittsburgh, Pa.

TE samples were sawed to include about one-fourth the volume of the core. A similar quadrant of the coal in the core constituted the Bureau of Mines analytic sample of the lignite. The remainder of the core was reserved for the preparation of thin sections and for more

TABLE 1.—*Summary of core holes drilled in North and South Dakota*

Core hole	Location	Elevation (feet above sea level)	Depth to lignite		Thickness of lignite		Depth of hole (ft)
			Ft	In	Ft	In	
	Bar H area, Harding County, S. Dak.						
19	NE¼NE¼ sec. 32, T. 19 N., R. 8 E	3503	379	4½	6	½	412
20	SW¼ sec. 8, T. 18 N., R. 8 E	3320	------	------	------	------	146
21	SW¼ sec. 8, T. 18 N., R. 8 E	3285	10	0	20	4	100
22	SE¼NW¼ sec. 8, T. 18 N., R. 8 E	3260	28	6	4	10	105
23	SW¼SE¼ sec. 8, T. 18 N., R. 8 E	3216	21	10	8	0	100
24	NE¼ sec. 5, T. 18 N., R. 8 E	3270	105	8	9	0	190
25	NE¼NE¼ sec. 3, T. 18 N., R. 8 E	3177	27	10	9	4	100
26	NW¼ sec. 35, T. 19 N., R. 8 E	3100	30	5	10	0	75
27	NW¼NE¼ sec. 35, T. 19 N., R. 8 E	3085	10	0	3	0	69
	Lodgepole area and Johnson outlier, Perkins County, S. Dak.						
10	SE¼SE¼ sec. 18, T. 21 N., R. 12 E	2970	------	------	------	------	100
11	SE¼NE¼ sec. 19, T. 21 N., R. 12 E	2959	41	7	8	5½	67
12	NW¼SE¼ sec. 19, T. 21 N., R. 12 E	2961	53	11½	7	7½	65
13	NW¼NE¼ sec. 19, T. 21 N., R. 12 E	2949	33	4½	4	2	42
14	SE¼SE¼ sec. 9, T. 21 N., R. 11 E	3015	14	8	7	9	25
15	SE¼SW¼ sec. 9, T. 21 N., R. 11 E	3017	18	2	5	10½	30
	Medicine Pole Hills area, Bowman County, N. Dak.						
5	SW¼SE¼ sec. 35, T. 131 N., R. 104 W	3427	68	9½	4	½	73
6	SE¼NE¼ sec. 2, T. 130 N., R. 104 W	3427	58	5	5	8½	66
7	NE¼SE¼ sec. 2, T. 130 N., R. 104 W	3417	20	0	------	2	45
8	NW¼SW¼ sec. 1, T. 130 N., R. 104 W	3414	29	6	2	6	36
9	NW¼NE¼ sec. 2, T. 130 N., R. 104 W	3422	53	0	5	½	61
	Total	----------	------	------	121	10½	1,907

detailed study of radioactive-material distribution in lignite constituents.

GEOLOGY

No attempt is made in this report to describe the geology in detail; only a brief account of the geology of each area is given. A detailed description of the regional geology may be found in Winchester and others (1916), and Hares (1928). Darton (1909), Toepelman (1923), and Wood (1942) have also briefly described the geology of small areas within Harding and Perkins Counties. Uranium-bearing lignite in this region was reported by D. G. Wyant and E. P. Beroni (written communication, 1950).

Details on the geology and origin of the uranium-bearing lignite in the areas are given by Denson, Bachman, and Zeller in chapter B. In most respects the data obtained by core drilling in the Dakotas substantiate the theory presented in that report. Generally the analyses of the lignite cores show greater concentrations of uranium in the upper parts of uranium-bearing beds 3 feet or more thick, the uranium content decreasing progressively downward to near the vanishing point in the lower parts and in the succeeding lower beds (pls. 19, 20, and 21).

Gamma counts recorded with a portable scaler equipped with a geiger tube and a 400-foot coaxial cable showed marked radioactivity in the source beds of the White River group and the Arikaree formation, which unconformably overlie the uranium-bearing lignite beds at the Slim Buttes.

BAR H AREA

The Bar H area is at the northeast tip of the Slim Buttes in east-central Harding County, S. Dak. (fig. 9). The outcrops are accessible only from the top of the buttes by 6 miles of the U. S. Forest Service dirt road that joins State Route 8 at a point 2 miles west of Reva. The bedrock in the area is divided into 3 geologic units. The oldest, the lignite-bearing Ludlow member of the Fort Union formation of Paleocene age, crops out along the base of the buttes and consists predominantly of soft, light-buff and tannish-gray sandstone, gray shale, and lignite. It is unconformably overlain by 150 feet or more of tuffaceous sandstone and bentonitic clay of the White River group of Oligocene age. The youngest unit, the Arikaree formation of Miocene age, consists of greenish-gray, chalky, tuffaceous sandstone, and forms imposing cliffs 200 feet high along the margins of the Slim Buttes that rise 300–400 feet above the surrounding country. The geologic map (pl. 17) shows the locations of the core holes and the areal distribution of the rock units described above.

The Bar H lignite bed is believed to be the stratigraphically highest persistant lignite in most of the area, although in some places a thin lignite bed, the Bar H rider bed, lies 60 feet or more above it. The Bar H bed has an average thickness of about 12 feet and is exposed at many places along the north base of the Slim Buttes. Erosion before deposition of the White River group removed the Bar H lignite in much of the southern part of the area. In this area, only beds stratigraphically below the Bar H bed were drilled; a possible exception is the upper lignite in hole 21 (pl. 18), which may be a correlative of the Bar H bed.

Structure.—High-angle normal faults cut the lignite beds in several places along the east margin of the buttes and trend N. 60–80° W. The more prominent ones are shown on the geologic map (pl. 17). Between core holes 20 and 21, in Reva Gap, there is a fault with a displacement of about 55 feet (pls. 17 and 18). Strata of the Ludlow member dip steeply where adjacent to faults, because of drag along the faults. Large-scale slumping in Recent time, especially along the north face of the Slim Buttes, complicates the mapping of individual lignite beds. The rocks in the greater part of the area are almost horizontal but the regional dip appears to be northeast.

Distribution and concentration of uranium.—As shown by samples from core hole 19 (pl. 19), the uranium is distributed in the Bar H rider lignite bed in the pattern observed in most of the other lignite beds, with the greatest amount in the upper part—here the uppermost of three seams—and decreasing amounts in the lower two seams. This upper seam, 2 feet 10 inches thick, averages 0.02 percent uranium and 0.10 percent uranium in its ash; this is the greatest concentration of uranium found in the Bar H area during drilling.

The lignite cores from holes 21, 22, 26, and 27 contain only a small amount of uranium, although the uppermost foot of the highest bed of lignite cored in hole 22 contains 0.001 percent uranium and almost 0.01 percent in the ash. Upper lignite seams, ranging from 6 to 18 inches in thickness, in holes 23, 24, and 25 contain from 0.005 to 0.01 percent uranium. The two uppermost seams in hole 25, aggregating 2 feet 8 inches in thickness, contain 0.005–0.008 percent uranium, with 0.03–0.066 percent in the ash (pl. 19). In most of the more highly uraniferous beds, the uranium content is greatest at the top of the bed, and the lignite beds in the upper part of the stratigraphic section contain more uranium than beds in the lower part.

The upper lignite bed reached by core hole 21 is 10 feet thick, but no core was recovered. However, it is estimated the uppermost three feet of the bed contains about 0.01 percent uranium, a figure based on comparison of the gamma-ray log of the hole with those from other core holes in the Slim Buttes area from which the uranium content has been determined by chemical analysis.

Quality of the lignite.—Fuel analyses by the U. S. Bureau of Mines show that the lignite of cores from the Bar H area contain an average of 24.7 percent fixed carbon, 12 percent ash, and 1.3 percent sulfur, and has an average heating value of 5,470 Btu. These figures represent analyses of lignite in the "as received" condition. Analyses of individual beds are given in table 5.

LODGEPOLE AREA AND JOHNSON OUTLIER

The Lodgepole area and the Johnson outlier are in northwestern Perkins County, S. Dak. The areas are readily accessible by 17 miles of graveled road extending north from State Route 8 about 9 miles west of Bison, S. Dak. Hettinger, N. Dak., the nearest shipping point, is 17 miles to the north (fig. 9). A low grassy butte a mile south of Lodgepole Post Office is the main topographic feature in the Lodgepole area. A smaller butte, referred to in this report as the Johnson outlier, is 3 miles to the west. The lignite beds in both areas were mapped and described by Winchester (1916, p. 138, 142). A map compiled from aerial photographs at a scale of 1:20,000 (fig. 10) shows the areal distribution of the beds and the location of the core holes in the Lodgepole area.

The beds of uranium-bearing lignite in these areas occur about 150 feet above the base of the Tongue River member of the Fort Union formation of Paleocene age, which has a regional dip of about 24 feet

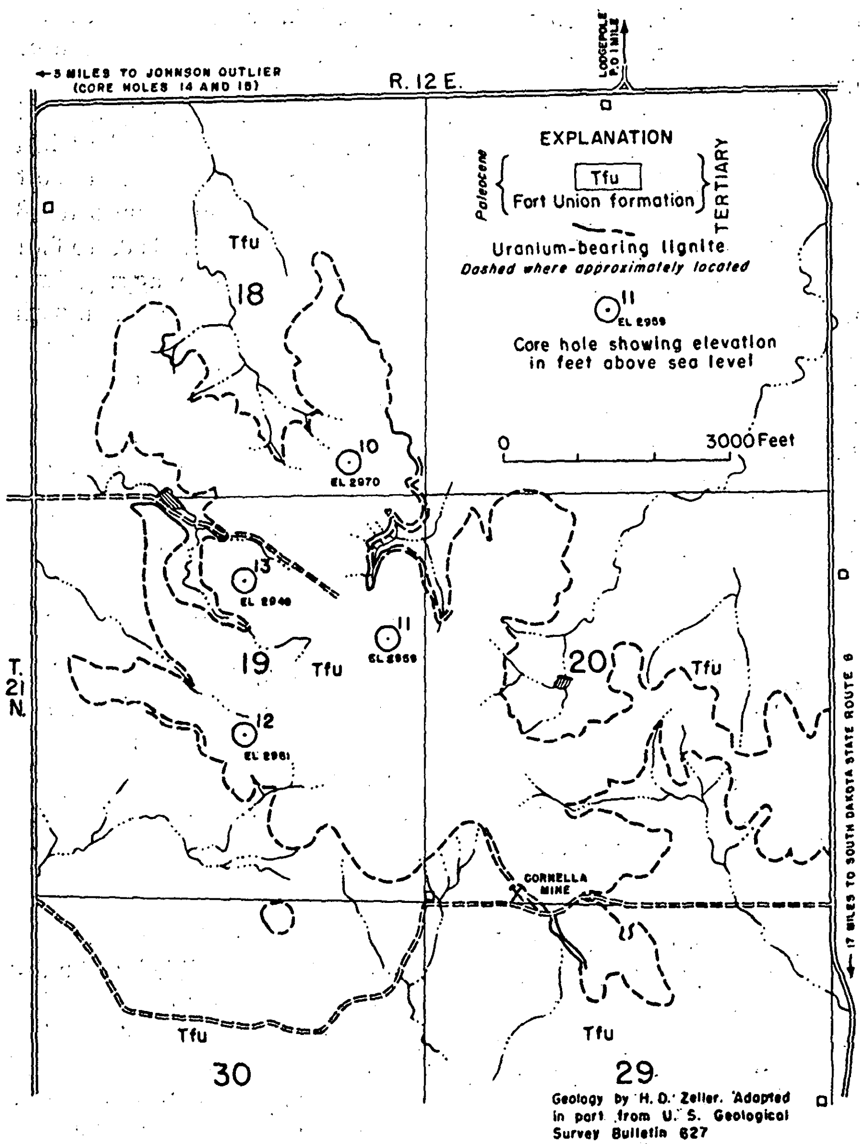

FIGURE 10.—Geologic map of the Lodgepole area, Perkins County, S. Dak., showing locations of core holes.

per mile to the northeast. The Tongue River member consists of pink sandstone and siltstone, with interbedded gray shale and lignite. The main lignite bed averages 6 feet or more in thickness and is believed to be the Harmon lignite bed (fig. 11). With it is commonly associated the Harmon rider lignite bed, 10–15 feet stratigraphically higher, which ranges from a few inches to 6 feet in thickness in short distances along the outcrop. The only bed exposed in the Johnson outlier may be either of these beds.

Distribution and concentration of uranium.—The lignite cored in holes 11, 12, and 13 in the Lodgepole area contains only a small percentage of uranium. Only the uppermost 1–2 feet of the Harmon rider lignite bed contains more than 0.001 percent uranium and the underlying Harmon lignite bed was not uranium-bearing. The only lignite bed exposed in the Johnson outlier, however, contains larger amounts of uranium (pl. 20). The analyses of the lignite cores from hole 14 demonstrate ideally the pattern of distribution and concentration in most of the uranium-bearing parts of lignite beds sampled in 1950 (see chapter B, table 3). Uranium decreased in concentration downward within a 3½-foot interval from 0.036 percent at the top of the bed to 0.001 percent at the base of the interval.

The lignite in the Harmon lignite bed of the Lodgepole area, as shown by fuel analyses of samples in the "as received" condition, averages 28 percent fixed carbon, 11 percent ash, and 1.5 percent sulfur, and has an average heating value of 6,940 Btu. This is the best grade of lignite found in drilling (table 5). On the Johnson outlier the lignite is of a poorer quality; it averages 16 percent fixed carbon, 12.4 percent ash, and 1.5 percent sulfur, and has a heating value of 4,160 Btu ("as received" condition).

MEDICINE POLE HILLS AREA

The Medicine Pole Hills, in Bowman County, N. Dak., are on a hilly divide separating the Little Missouri River and Grand River drainage basins. The Tongue River member of the Fort Union formation of Paleocene age, which includes ledge-forming beds of hard sandstone and quartzite, underlies the main part of the hills (fig. 12). The hills are capped by a thin veneer of the White River group of Oligocene (Chadronian) age (C. L. Gazin, written communication, 1950) which unconformably overlies the Tongue River member. The hills are nearly flat topped and are easily accessible by a dirt road that leaves the main graveled road 8 miles south of Rhame, N. Dak., the nearest rail shipping point. The Medicine Pole Hills are in the southwestern part of the Marmarth lignite field, which was mapped and described in detail by Hares (1928, p. 95, 98).

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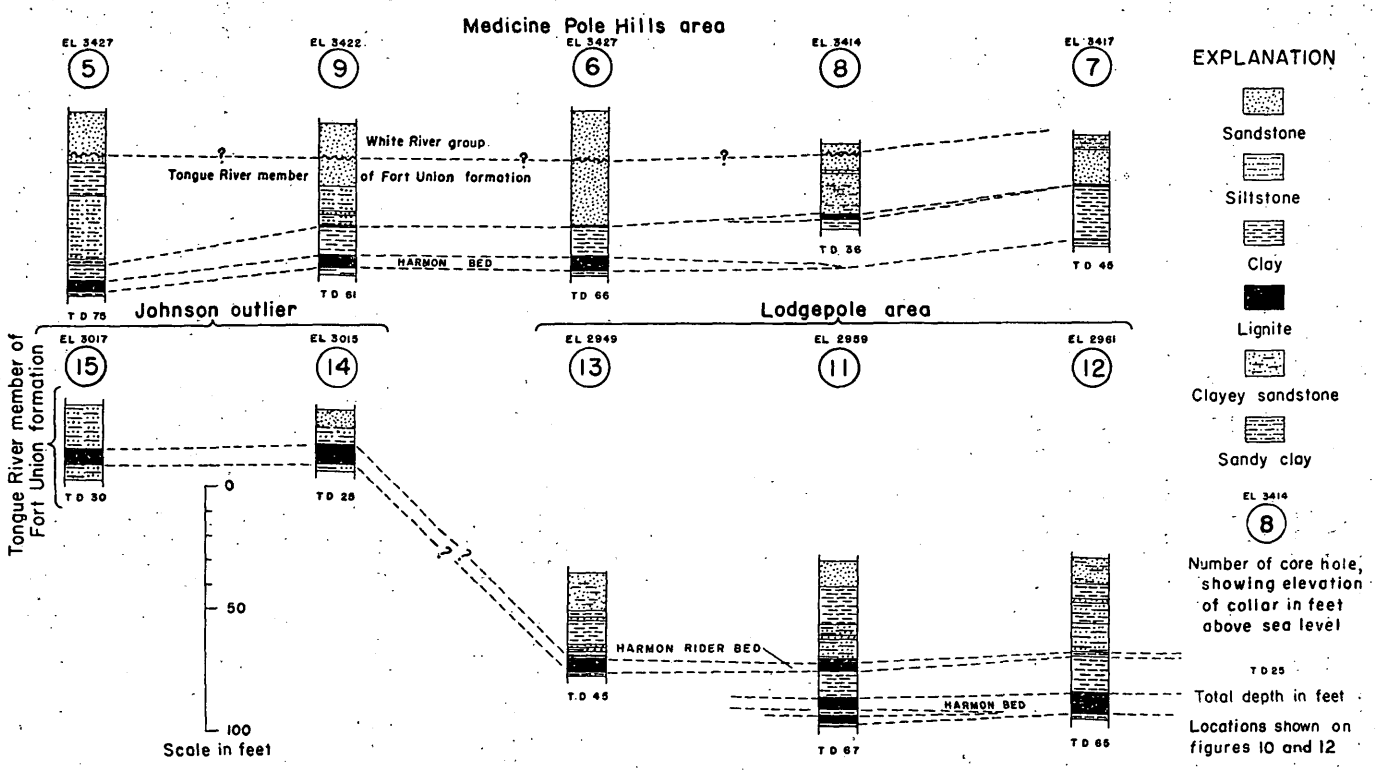

FIGURE 11.—Stratigraphic chart showing correlation of uranium-bearing lignite beds in core holes, Medicine Pole Hills area, Bowman County, N. Dak., and Lodgepole area and Johnson outlier, Perkins County, S. Dak.

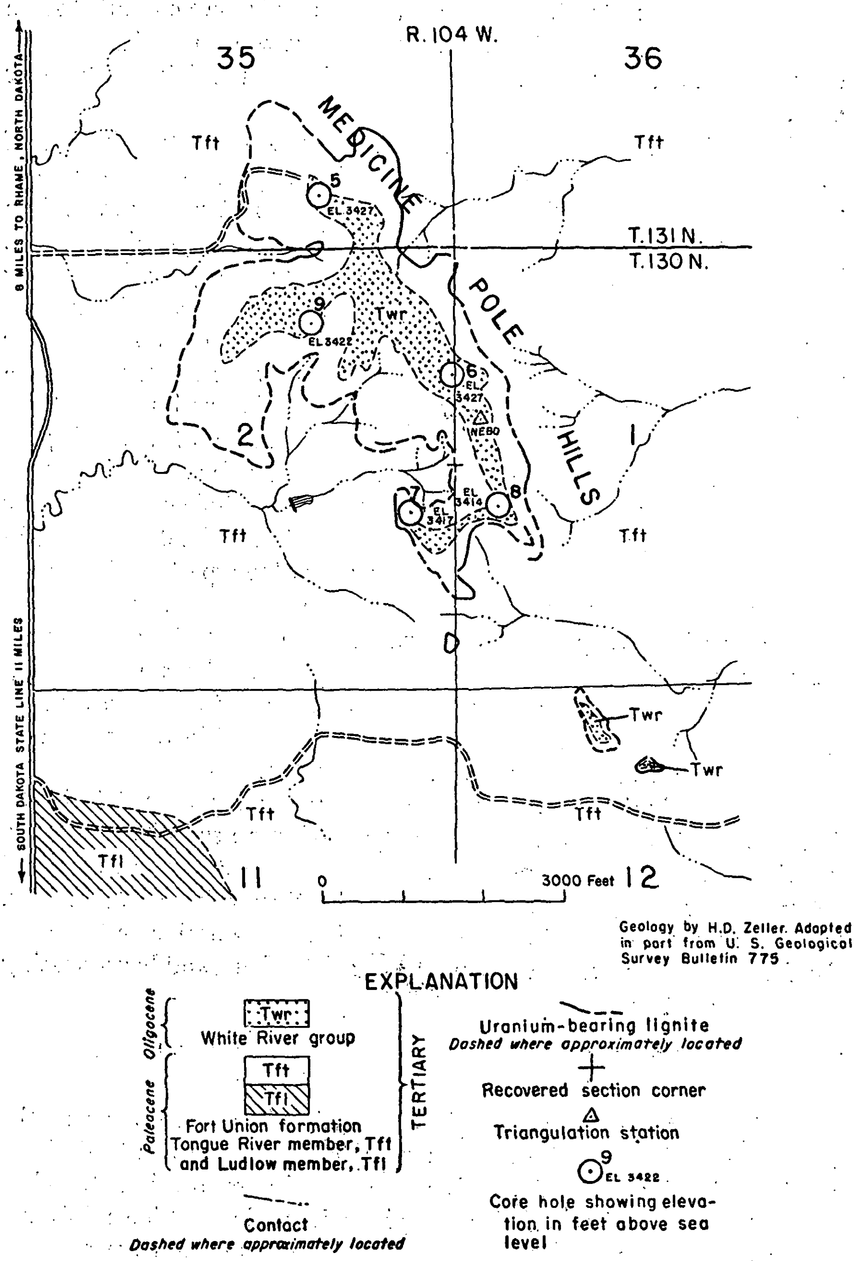

FIGURE 12.—Geologic map of the Medicine Pole Hills area, Bowman County, N. Dak., showing locations of core holes.

A widespread persistent lignite bed, the Harmon lignite bed, underlies most of the area (fig. 11). This bed and the associated Harmon rider lignite bed were mapped on aerial photographs at a scale of approximately 1:20,000. Figure 12, the geologic map compiled from the photographs, shows the locations of the core holes which reached the uranium-bearing Harmon lignite bed in the Medicine Pole Hills area.

Distribution and concentration of uranium.—The distribution of uranium in the lignite cored at hole 5 (pl. 21) follows the general pattern of uranium distribution in which the concentration of uranium decreases progressively downward from the top of the lignite bed. The concentration and distribution of uranium in lignite from other core holes in the Medicine Pole Hills, however, differ from the pattern observed in other areas. In the lignite from core holes 6 and 9, for example, the uranium is fairly uniformly distributed throughout the bed, with perhaps a slightly greater concentration at its base. This distribution pattern has not been observed in uranium-bearing lignite elsewhere in the Dakotas, either in cores or in surface samples. The Harmon rider lignite bed is 30 inches thick at core hole 8 and contains 0.005 percent uranium in the uppermost 6 inches and 0.016 percent in the basal 12 inches of the bed. This "inverted" pattern is a very common feature of uranium-bearing lignite beds not more than 2½ feet thick where they have been examined in the Dakotas. A possible explanation for the greater concentrations of uranium in the lower rather than the upper parts of these beds is that uranium-bearing ground water moved laterally along the base of thin and fractured beds which normally overlie impervious underclays.

Quality of lignite.—The lignite in the Harmon lignite bed (table 5) in core holes 5, 6, and 9, based on analyses of samples in "as received" condition, averages 21.2 percent fixed carbon, 10.3 percent ash, and 1.4 percent sulfur, and has an average heating value of 5,400 Btu. The Harmon rider lignite bed at hole 8 (fig. 11) contains 15.1 percent fixed carbon, 16.5 percent ash, and 0.3 percent sulfur, and has a heating value of 3,730 Btu.

RELATIONSHIP BETWEEN URANIUM AND OTHER TRACE ELEMENTS IN LIGNITE IN THE DAKOTAS

Semiquantitative spectrographic determinations were made of the ash of most of the lignite core samples from the Dakotas to find the vertical distribution and possible relationship of uranium to other trace elements. These results are given in table 4. The minimum amounts of elements detectable with the semiquantitative spectrographic methods used are indicated in table 3.

Preliminary work on the occurrence and distribution of the various elements as determined by spectrographic analyses indicates that only one element, molybdenum, shows a consistent relationship to uranium. In the upper parts of the beds, where the uranium content commonly is greater, the molybdenum content is also greater, and conversely, in the lower parts of the beds, where the uranium content is small, the molybdenum content is also small. The notable correlation between the amounts of uranium and molybdenum in various parts of uranium-bearing lignite beds is believed to be due to the close chemical similarity of these elements (Clarke, 1924, p. 722).

There is no apparent correlation between the distribution of uranium and vanadium in lignite of the Dakotas, although these elements commonly occur together in the deposits of the Colorado Plateau. Their chemical characteristics, however, do not seem to indicate that the two should necessarily occur together.

The net result of the preliminary spectrographic studies of uranium-bearing lignite to date seems to indicate that greater importance and attention should be given to the presence of molybdenum as a possible geologic indicator for the presence of uranium. Considerably more data and work are necessary to establish its validity, but it seems possible that the association of molybdenum and uranium may prove valuable in the search for uranium.

TONNAGE AND GRADE OF URANIUM-BEARING LIGNITE

On the basis of the drilling done at the time of the investigation of the areas in northwestern South Dakota and southwestern North Dakota described in this report, it is estimated that there were about 9 million tons of lignite (table 2). Approximately half the lignite is at

TABLE 2.—*Estimated tonnage of uranium-bearing lignite, Harding and Perkins Counties, S. Dak., and Bowman County, N. Dak.*

Area	Location in area	Extent (acres)	Thickness (feet)	Uranium (percent)	Resources [1] (short tons)	Number of core holes
Strippable lignite						
Lodgepole area, Perkins County.	SW¼ sec. 19, T. 21 N., R. 12 E.	30	4.0	0.010	210,000	4
Johnson outlier, Perkins County.	S½ sec. 9, and SW¼SW¼ sec. 10, T. 21 N., R. 11 E.	90	[2] 3.0	.010	472,000	2
Medicine Pole Hills, Bowman County.	In parts of secs. 1 and 2, T. 130 N., R. 104 W., and SE¼ sec. 35, T. 131 N., R. 104 W.	360 40	4.5 3.0	.006 .013	2,835,000 210,000	5 --------
Total					3,727,000	
Lignite requiring underground mining						
Bar H area, Harding County.	In parts of secs. 20, 21, 28, 29, and 33, T. 19 N., R. 8 E.	600		0.010	5,250,000	8
Grand total					8,977,000	

[1] Tonnage estimates based on 1,750 tons of lignite per acre foot.
[2] Uppermost 3 feet of 6-foot bed of lignite.

depths shallow enough for strip mining and in beds averaging more than 4 feet thick. Analyses of 200 samples from cores, in addition to analyses of 175 samples obtained during the previous season's fieldwork, indicate that the uranium content of the lignite averages about 0.01 percent, although the content is highly variable. The average grade of the uranium in small parts of the areas may be as much as 0.03 percent. The ash content of the lignite ranges from 10 percent or less to about 20 percent, which indicates that after ignition of the lignite the uranium content of the ash is at least 5 times and generally 7–10 times the uranium content of the lignite. Proximate and ultimate analyses (table 5) show a sulfur content of 2 percent or less and the heating value of samples in the "as received" condition ranges from 4,200 to 6,900 Btu.

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TABLE 3.—*Threshold values of elements included in the semiquantitative spectrographic method (revised June 4, 1951).*

Element	*Percent*	*Element*	*Percent*	*Element*	*Percent*
Ag	0.001	Gd	0.01	Sb	0.001
Al	.0001	Ge	.001	Sc	.1
As	.1	Hf	.1	Si	.0001
Au	.01	Hg	.1	Sm	.1
B	.001	Ho	.01	Sn	.01
Ba	.0001	In	.001	Sr	.01
Be	.0001	[2] K	.01 (1.0)	Ta	.1
Bi	.001	La	.01	Tb	.1
Ca	.001	[2] Li	.0001 (0.1)	Te	.1
Cb	.01	Lu	.01	Th	.1
Cd	.01	Mg	.0001	Ti	.001
Ce	.1	Mo	.001	Tl	.1
Co	.01	Mn	.001	Tm	.01
Cr	.001	[2] Na	.001 (0.1)	U	.1
Cs	1.0	Nd	.01	V	.01
Cu	.0001	Ni	.001	W	.1
Dy	.01	P	.1	Y	.001
Eu	.01	Pb	.01	Yb	.0001
Er	.01	Pr	.01	Zn	.01
F	[1] .1	Pt	.01	Zr	.001
Fe	.001	Rb	10.0		
Ga	.01	Re	.1		

[1] A third exposure is required for the fluorine estimation.
[2] A second exposure is required for the high sensitivity listed.

TABLE 4.—*Semiquantitative spectrographic and chemical analyses on ash from Dakota lignite cores*

[Spectrographic analyses: C. Annell, K. Valentine, C. L. Waring, and H. Worthing; chemical analyses: M. Delevaux, E. Farley, C. R. Hoy, H. Levine, S. Lundine, and I. May, U. S. Geological Survey.]

Length of core section: entries in italics show part of interval not sampled; semiquantitative spectrographic analyses: range in percent represented by letter symbols: A, more than 10 percent; B, 1-10 percent; C, 0.1-1 percent; D, 0.01-0.1 percent; E, 0.001-0.01 percent; F, 0.0001-0.001 percent.

Sample			Chemical analyses (percent)		Semiquantitative spectrographic analyses (elements in lignite ash)																																		
Core hole TE No.	Laboratory No.	Length of core section (inches)	Ash in sample	Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.																																							
Core hole 19 (NE¼NE¼ sec 32, T. 19 N., R. 8 E.) elev 3,503 ft																																							
[Sampled interval, 340 ft 8 in–392 ft 8½ in]																																							
1	72413A	17	91.5	0.002	A	A	B	B	C	B	C	D	D	C	D	E	----	E	D	D	D	D	E	D	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
2	72414A	2½	93.5	.001	A	A	B	B	C	B	C	D	D	D	D	----	----	E	D	E	D	E	F	---	E	---	---	F	F	---	---	E	---	---	---	---	---	E	---
3	72415A	2½	65.5	.001	A	A	A	C	C	B	C	D	D	C	D	----	D	E	D	D	D	D	E	D	E	E	---	F	F	---	---	E	---	---	C	---	---	D	---
4	72416A	3	68.7	.002	A	A	B	C	C	B	C	D	D	C	D	E	D	D	D	D	D	D	E	D	E	E	---	F	F	---	E	E	---	---	---	---	---	---	---
		[a] *435*																																					
5	72417A	4½	36.7	.017	C	C	A	C	C	B	C	D	D	C	D	----	C	D	D	D	D	E	E	D	E	E	---	F	F	---	D	---	---	---	C	---	---	---	---
6	72418A	8	14.0	.120	B	A	B	B	B	A	C	C	D	C	C	E	C	E	D	E	E	---	E	D	E	E	---	F	F	---	E	---	---	---	---	---	---	---	---
7	72419A	11¼	20.9	.180	A	A	B	B	B	B	C	D	D	D	C	E	C	E	E	E	---	---	F	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
8	72420A	5¾	41.4	.036	A	A	B	C	C	B	C	D	D	D	C	E	C	E	D	D	D	E	E	D	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
9	72421A	4¼	55.2	.021	A	A	B	C	C	B	C	D	D	C	D	E	D	E	D	E	D	E	E	D	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
		[b] *42¾*																																					
10	72422A	10	24.2	.036	A	A	B	B	B	B	C	D	D	D	C	E	C	E	D	E	D	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
11	72423A	11	18.8	.010	A	A	B	B	B	B	C	D	D	D	C	E	D	E	E	E	E	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
12	72424A	6	19.9	.019	A	A	B	B	B	B	C	D	D	D	C	E	D	E	D	D	E	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		[a] *38½*																																					
13	72425A	2	46.7	.008	A	A	B	B	C	B	C	D	D	D	D	E	D	E	D	D	D	D	E	D	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
14	72426A	10	26.7	.008	A	A	B	B	B	B	C	D	D	D	C	E	D	E	E	E	D	E	E	D	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
15	72427A	9½	20.7	.025	A	A	B	C	B	B	C	D	D	D	C	E	D	E	D	E	E	E	E	D	E	E	---	F	F	---	E	---	D	---	---	---	---	---	---

See footnotes on p. 79.

TABLE 4.—*Semiquantitative spectrographic and chemical analyses on ash from Dakota lignite cores*—Continued

BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—continued

Core hole 21 (SW¼ sec 8, T. 18 N., R. 8E.) elev 3,285 ft

[Sampled interval, 31 ft 4 in–74 ft 8¼ in]

Sample: Core hole TE No.	Sample: Laboratory No.	Sample: Length of core section (inches)	Chemical analyses (percent): Ash in sample	Chemical analyses (percent): Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
[c] 1	82968	5	21.8	0.001	A	A	B	B	B	B	D	D	C	C	C	D	---	D	D	E	D	D	E	D	E	E	---	E	F	F	---	---	---	---	---	---	---	---	---
[c] 2	82969	6¼	8.8	.001	A	B	C	B	A	B	C	D	C	D	C	D	E	D	D	E	E	D	E	D	E	E	E	E	F	F	D	E	D	---	---	---	---	---	---
3	82970	7⅛	10.7	.002	B	A	B	B	B	B	C	D	C	D	C	D	---	E	E	E	E	D	E	D	E	D	E	E	F	F	---	---	D	---	---	---	---	---	---
4	82971	10⅝	13.4	.001	B	A	B	B	B	B	C	D	C	D	C	D	E	D	E	E	D	D	E	D	E	D	E	E	F	F	---	---	---	---	---	---	---	---	---
		[d] 8¼																																					
[e] 5	82972	1⅛	20.4	.001	A	A	C	B	B	B	C	D	C	C	C	D	---	D	D	E	D	D	E	D	E	D	E	E	F	F	---	---	D	B	---	---	---	---	---
		[f] 7⅜																																					
6	82973	8⅛	19.3	.001	A	A	B	B	B	B	C	D	C	D	C	D	---	D	D	E	D	D	E	D	E	E	E	E	F	F	---	---	---	B	---	---	---	E	---
7	82974	9⅛	17.7	.001	A	A	C	B	B	B	C	D	C	C	C	D	---	E	D	E	D	---	E	D	E	E	E	E	F	F	---	---	D	B	---	---	---	---	---
8	82975	9	22.2	.001	A	A	C	B	B	B	C	D	C	D	C	D	---	E	D	E	D	---	E	D	E	E	E	E	F	F	---	---	D	B	---	---	---	---	---
		[g] 29 2¾																																					
9	82976	2½	18.2	.003	A	A	C	B	B	B	C	D	C	D	C	D	E	D	D	E	D	D	E	D	E	E	E	E	F	F	D	---	D	B	---	---	---	D	---
		[f] 2½																																					
[e] 10	82977	2	21.2	.004	A	A	C	B	B	B	C	D	C	D	C	D	E	D	D	E	D	D	E	D	E	D	E	E	F	F	D	---	D	B	---	---	---	---	---
		[f] 9¼																																					
11	82978	9½	27.1	.003	A	A	B	B	B	B	C	D	C	D	C	D	---	D	E	E	D	D	E	D	E	E	E	E	F	---	---	---	---	---	---	---	---	E	---
12	82979	9⅛	14.6	.003	B	A	C	B	B	B	C	D	C	D	C	D	---	E	E	---	D	D	E	D	E	D	E	E	F	E	---	---	D	---	---	---	---	---	---
[h] 13	82980	7¾	10.2	.007	A	B	C	B	B	B	C	C	C	D	C	D	E	E	E	---	D	D	E	D	E	C	---	E	F	F	D	C	D	---	---	---	D	---	C
14	82981	7⅝	29.7	.001	B	B	A	C	B	B	C	D	C	D	C	D	---	E	E	---	E	---	---	D	E	E	---	E	F	---	---	---	---	---	---	---	---	---	---
15	82982	10⅛	11.1	.006	A	B	C	B	B	B	C	C	C	D	C	D	E	E	E	---	D	D	---	D	E	E	---	E	F	F	---	D	D	B	---	---	---	---	C
16	82983	6⅞	9.5	.004	A	B	C	B	B	B	C	C	C	D	C	D	E	E	E	E	E	D	E	D	E	D	E	E	F	F	---	D	D	B	---	---	---	---	D
17	82984	8¼	17.8	.006	A	A	C	B	B	B	C	C	C	D	C	D	E	D	D	E	E	D	E	D	E	E	E	E	F	F	---	E	D	B	---	---	---	---	---

Core hole 22 (SE¼NW¼ sec. 8, T. 18 N., R. 8 E.) elev 3,260 ft

[Sampled interval, 28 ft 6 in–86 ft 8½ in]

1	85589	5½	10.3	0.009	A	A	B	B	B	B	C	C	C	C	C	D	D	E	E	E	E	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
2	85590	4¼	9.4	.010	A	A	B	B	B	B	C	C	C	C	C	D	D	E	D	E	D	E	E	D	D	E	---	F	---	---	E	---	---	---	---	---	---	---	---
3	85591	9	19.9	.005	A	A	B	B	B	B	C	D	D	C	C	D	D	D	D	D	D	D	E	D	E	E	---	F	F	---	E	---	---	---	---	---	---	---	---
		[g] 367⅛																																					
4	85592	4⅛	13.7	.007	A	A	B	B	B	A	C	D	D	D	C	D	D	E	E	E	---	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
5	85593	5¾	7.0	.007	A	B	B	B	B	B	C	C	D	D	C	D	D	E	E	E	---	E	E	D	E	E	---	F	F	F	---	---	D	---	---	---	---	---	---
6	85594	6	12.6	.007	A	B	B	B	B	B	D	C	D	D	C	D	D	E	E	D	---	D	E	D	E	E	---	F	F	F	---	---	D	---	---	---	---	---	---
7	85595	5¼	29.1	.006	A	A	B	B	B	B	D	D	D	C	C	E	D	E	D	D	D	D	E	D	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
		[g] 272½																																					
8	85596	5¾	17.5	.004	A	A	B	B	B	B	C	D	D	C	C	D	D	E	E	E	E	E	E	E	E	E	---	F	F	---	D	---	---	---	---	---	---	---	---
9	85597	6	8.8	.011	A	A	B	B	B	B	C	C	D	D	C	D	E	E	D	E	E	E	E	E	D	E	---	F	F	F	E	---	D	---	---	---	---	---	---
10	85598	5¼	29.5	.003	A	A	B	B	B	B	C	D	D	C	C	D	D	E	D	E	E	E	E	E	E	E	---	F	F	---	E	---	---	---	---	---	---	---	---

Core hole 23 (SW¼SE¼ sec. 8, T. 18 N., R. 8 E.) elev 3,216 ft

[Sampled interval, 21 ft 9¾ in–90 ft 1 in]

1	85554	4⅜	37.4	0.027	B	A	A	B	B	C	C	C	D	C	D	D	D	D	D	D	D	D	E	D	E	D	---	E	F	F	E	E	---	---	D	---	---	D	---
2	85555	2⅛	44.6	.013	B	A	B	C	B	C	C	C	D	C	D	D	D	E	D	D	D	D	E	D	E	E	---	F	F	F	E	E	---	---	---	---	---	---	---
3	85556	2	32.3	.009	B	A	A	B	B	B	C	C	D	D	D	E	D	E	E	D	E	D	F	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
4	85557	2	43.0	.006	A	A	B	B	B	C	C	C	D	C	D	E	D	E	D	D	E	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
5	85558	2	45.7	.007	A	A	B	B	B	C	C	C	D	C	D	E	D	E	D	D	E	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
6	85559	1¾	47.4	.013	A	A	B	B	B	C	C	C	D	C	D	E	D	E	D	D	E	D	E	D	E	E	---	F	F	---	E	---	---	---	---	---	---	---	---
7	85560	1¼	52.4	.015	A	A	B	B	B	C	C	C	D	C	D	E	D	E	D	D	E	D	E	D	E	E	---	F	F	---	E	E	---	---	---	---	---	---	---
		[d] 192																																					
8	85561	6	20.9	.005	B	A	A	B	B	B	C	C	D	C	C	E	E	E	D	E	E	E	F	D	E	E	---	F	F	---	E	---	---	---	---	---	---	---	---
9	85562	3¾	13.3	.008	B	B	A	B	B	B	C	C	D	D	C	E	D	E	E	D	E	E	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		[f] 33																																					
10	85563	7⅛	6.2	.008	B	B	B	A	A	B	C	C	C	C	C	D	D	D	D	E	D	D	E	D	D	E	E	F	F	F	E	---	D	---	---	---	---	---	---
11	85564	3⅞	42.3	.001	B	A	B	B	B	C	C	D	D	C	C	D	E	E	D	E	D	---	E	D	E	E	E	F	F	---	---	---	---	---	---	---	---	---	---
12	85565	5½	19.0	.004	A	A	B	B	B	B	C	C	D	C	C	D	E	E	D	E	D	E	E	D	D	E	E	F	F	F	D	---	D	---	---	---	---	---	---
		[g] 294½																																					
13	85566	3	12.3	.004	A	A	B	B	B	B	C	C	D	C	C	D	D	E	D	E	E	D	E	D	D	E	---	F	F	F	D	---	---	---	---	---	---	---	---
		[f] 10																																					
14	85567	7½	24.6	.002	A	A	B	B	B	B	C	C	D	D	C	D	E	E	E	E	D	E	E	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
15	85568	4¼	16.9	.002	A	A	B	B	B	B	C	C	D	D	C	D	E	E	E	E	E	E	F	E	E	E	E	F	F	F	---	---	---	---	---	---	---	---	---
16	85569	8½	9.1	.006	A	A	B	B	B	B	C	C	D	D	C	D	E	E	E	E	E	E	E	D	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
18	85571	10½	17.5	.004	A	A	B	B	B	B	C	D	D	D	C	D	E	E	D	D	E	D	F	E	E	---	E	F	F	F	E	---	---	---	---	---	---	---	---
		[f] 42½																																					
19	85572	6	38.0	.003	B	A	A	C	C	B	C	D	D	D	C	E	E	E	D	D	E	D	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
20	85573	2¼	26.6	.006	A	A	B	B	B	B	C	D	D	C	C	D	D	D	D	D	D	D	E	D	D	E	---	F	F	---	E	---	---	---	---	---	---	---	---
		[d] 151																																					
21	85574	6½	17.6	.002	A	A	B	B	B	B	C	C	D	C	C	---	E	E	D	E	D	E	E	D	D	E	---	F	E	---	D	---	---	---	---	---	---	---	---

See footnotes on p. 79.

TABLE 4.—*Semiquantitative spectrographic and chemical analyses on ash from Dakota lignite cores*—Continued

Sample			Chemical analyses (percent)		Semiquantitative spectrographic analyses (elements in lignite ash)																																
Core hole TE No.	Laboratory No.	Length of core section (inches)	Ash in sample	Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—Continued																																					
Core hole 24 (NE¼ sec. 5, T. 18 N., R. 8 E.) elev 3,270 ft																																					
[Sampled interval 105 ft 8 in–177 ft ½ in]																																					
1	85740	2¼	26.8	0.034	A	A	B	B	B	B	C	C	C	C	C	D	D	E	E	D	D	E	E	E	E	E	---	E	E	F	E	---	---	---	---	---	---	D	---
2	85741	3	59.6	.016	A	A	B	B	C	C	D	D	D	C	D	E	D	E	D	D	E	D	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	E	---
		t 16¾																																					
3	85742	2	48.1	.007	A	A	B	C	C	B	D	D	D	C	C	D	D	E	D	D	D	D	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		g 100																																					
4	85743	5	8.25	.020	A	B	B	B	A	A	C	C	C	C	C	D	D	D	D	E	E	D	E	E	D	E	---	F	F	---	E	---	---	---	---	---	---	---	---
5	85744	6¾	11.0	.013	A	B	B	B	A	A	C	C	C	C	C	D	D	E	E	E	---	E	E	E	E	E	E	F	F	F	---	---	D	---	---	---	---	---	---
6	85745	7½	21.8	.005	A	A	B	B	B	B	C	D	C	C	C	D	E	E	E	E	D	---	E	E	E	E	E	F	F	---	---	---	D	---	---	---	---	---	---
7	85746	4¾	19.2	.005	A	A	B	B	B	B	C	C	C	C	C	D	D	E	D	E	D	---	E	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
		d 270½																																					
8	85747	6½	19.9	.002	A	B	B	B	B	B	C	D	C	D	C	D	D	E	E	D	E	E	E	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
9	85748	5¾	15.3	.001	A	A	B	B	B	B	C	C	C	C	C	D	D	E	E	E	E	E	E	E	E	E	E	F	F	---	---	---	D	---	---	---	---	---	---
10	85749	9¼	47.1	.001	A	A	B	B	C	B	D	D	D	C	C	E	D	E	D	D	E	E	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		t 14																																					
11	85750	7½	45.7	.001	A	A	B	B	C	C	D	D	D	C	C	D	E	E	D	D	E	D	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	D	---
		t 4¼																																					
12	85751	7¾	37.6	.001	A	A	B	B	B	B	D	D	D	C	C	E	E	E	E	E	D	E	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
13	85752	8½	23.6	.001	A	A	B	B	B	B	D	D	D	C	C	E	E	E	E	E	D	E	F	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
14	85753	7¼	14.4	.002	A	A	B	B	B	B	C	D	C	C	C	D	E	E	E	E	E	E	E	E	E	E	E	F	F	F	E	---	D	---	---	---	---	---	---
		d 341¾																																					
15	85754	9½	18.7	.001	A	A	B	B	B	B	D	D	C	D	C	D	E	E	E	E	E	E	F	E	E	E	---	F	F	F	---	---	---	---	---	---	---	E	---
16	85755	7¾	22.6	.001	A	A	B	B	B	B	D	D	D	C	C	D	E	E	D	D	E	E	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	E	---
		t 1¼																																					
17	85756	3	33.3	.001	A	A	B	B	B	B	D	D	C	D	C	D	D	E	D	E	E	E	E	E	E	E	---	F	F	---	D	---	---	---	---	---	---	---	---
		t 1¾																																					
18	85757	2¼	21.8	.005	A	A	B	B	B	B	D	D	C	D	C	D	D	E	D	E	E	E	E	E	E	E	---	F	F	---	D	---	---	---	---	---	---	---	---

Core hole 25 (NE¼NE¼ sec. 3, T. 18 N., R. 8 E.) elev 3,177 ft

[Sampled interval 27 ft 9½ in–91 ft 8¾ in]

1	87658	7¼	26.7	0.031	B	A	B	B	B	C	C	C	D	C	C	E	C	E	E	E	---	---	F	D	E	E	---	F	F	---	E	---	---	---	D	---	---	---	C
2	87659	10¼	8.1	.066	A	B	B	B	B	B	C	C	D	D	C	D	C	E	E	D	E	E	E	D	E	E	---	F	F	F	E	---	---	---	D	---	---	---	---
		f 8																																					
3	87660	8¾	18.8	.040	A	A	C	B	B	B	C	C	D	D	C	D	D	E	E	E	---	E	E	E	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
4	87661	4¾	8.4	.056	A	B	C	B	B	B	C	C	C	D	C	D	D	E	D	D	E	D	E	D	E	D	---	F	F	F	E	D	---	---	---	D	D	---	C
		d 36																																					
5	87662	7⅜	15.2	.011	B	B	A	B	B	C	D	D	D	D	C	D	E	E	E	D	---	E	F	E	E	---	---	F	F	---	---	---	---	---	D	---	---	---	---
6	87663	8⅝	8.7	.013	A	A	C	B	B	B	C	C	C	C	C	D	E	E	E	E	E	---	---	E	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---
7	87664	7½	7.4	.016	A	A	C	A	B	B	C	C	C	C	C	D	E	E	E	E	E	E	F	E	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---
8	87665	9¾	5.2	.024	A	B	C	A	B	B	C	C	C	D	C	D	E	E	E	E	E	E	F	E	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---
9	87666	8¾	14.3	.007	B	B	A	B	B	C	C	D	D	D	C	D	E	E	E	E	---	---	---	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---	---
10	87667	8	10.6	.012	A	A	C	B	B	B	C	C	D	D	C	D	E	E	E	E	E	E	E	D	E	E	---	F	---	---	E	---	---	---	---	---	---	---	---
		s 265¼																																					
11	87668	8¾	19.7	.002	A	A	A	B	B	B	D	C	D	C	C	D	E	E	E	D	---	E	E	D	E	E	---	F	E	---	E	---	---	---	---	---	---	---	---
		d 112½																																					
12	87669	6½	14.4	.002	A	A	C	B	B	B	D	C	D	D	C	D	E	E	E	E	E	---	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		d 239¼																																					
13	87670	4½	34.1	<.001	B	A	C	B	B	B	D	C	D	C	C	E	E	E	E	E	---	E	E	---	E	E	---	F	E	---	E	---	---	---	---	---	---	---	---

Core hole 26 (NW¼ sec 35, T. 19 N., R. 8 E.) elev 3,100 ft

[Sampled interval, 30 ft 4⅝ in–64 ft 2 in]

1	87671	8⅜	18.3	0.005	A	B	A	B	B	C	D	D	D	D	C	E	D	---	E	E	E	---	E	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
2	87672	8	9.8	.007	A	B	B	A	B	B	C	C	C	D	C	D	D	---	E	E	E	---	F	E	E	E	---	F	---	---	---	D	---	---	---	---	---	---	---
3	87673	9	13.1	.001	B	B	A	B	B	B	C	C	C	D	C	D	E	---	E	E	E	---	---	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
4	87674	4½	16.2	<.001	B	C	A	B	B	B	C	D	D	D	C	D	E	---	E	---	---	---	---	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
5	87675	6¾	15.2	.001	A	A	B	B	B	B	C	D	D	C	C	D	D	E	D	E	E	E	E	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	---
6	87676	3¾	14.5	.002	B	A	B	B	B	B	C	D	C	D	C	D	E	E	E	E	E	---	F	E	E	---	---	F	---	---	---	---	---	---	---	---	---	---	---
7	87677	6¾	17.3	.002	A	A	B	B	B	B	C	C	C	C	C	E	D	---	E	E	D	E	E	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	---
8	87678	6¾	7.7	.001	A	B	B	A	A	B	C	C	C	C	C	D	D	---	E	E	E	E	F	E	E	E	---	F	---	F	---	---	D	---	---	---	---	---	---
9	87679	6½	7.4	.001	A	B	B	A	A	B	C	C	C	D	C	D	E	---	E	E	---	E	---	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	---
10	87680	6	6.6	.001	B	C	A	B	B	B	C	C	C	D	C	D	E	---	E	E	E	E	---	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
11	87681	7½	8.9	<.001	A	C	B	A	A	B	C	C	D	E	C	D	E	---	E	E	---	D	F	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	---
12	87682	8½	4.5	.001	B	B	A	B	B	B	C	C	D	D	C	D	E	---	E	E	E	E	E	E	E	E	E	F	---	---	---	---	D	---	---	---	---	---	---
13	87683	6½	8.9	.002	A	B	B	B	B	B	C	D	D	D	C	D	E	---	E	E	E	---	F	E	E	E	---	F	---	---	E	---	---	---	---	---	---	---	---
14	87684	6½	15.0	.002	B	B	A	B	B	B	C	D	D	D	C	D	E	---	E	D	E	E	E	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
		d 285½																																					
15	87685	8¼	20.6	<.001	B	B	A	B	B	B	C	D	D	E	C	D	E	---	E	D	E	E	---	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
16	87686	8¾	10.8	.001	A	B	B	B	B	B	C	C	D	D	C	D	---	---	E	E	E	---	F	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	---
17	87687	3¾	9.8	.003	B	B	A	B	B	B	C	C	D	D	C	D	E	---	E	E	E	E	E	E	E	E	---	F	---	---	E	---	---	---	---	---	---	---	---

See footnotes on p. 79.

TABLE 4.—*Semiquantitative spectrographic and chemical analyses on ash from Dakota lignite cores*—Continued

Sample			Chemical analyses (percent)		Semiquantitative spectrographic analyses (elements in lignite ash)																																	
Core hole TE No.	Laboratory No.	Length of core section (inches)	Ash in sample	Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—Continued																																							
Core hole 27 (NW¼NE¼ sec 35, T. 19 N., R. 8 E.) elev 3,085 ft																																							
[Sampled interval, 10 ft–48 ft]																																							
1	87654	2¾	35.1	0.002	B	A	A	B	B	B	C	D	D	D	D	D	D	E	D	E	E	E	F	E	E	E	---	F	F	---	E	---	---	---	---	---	---	---	---
		[d] *424½*																																					
2	87655	13½	13.2	<.001	B	A	B	B	B	B	C	C	D	D	C	D	E	E	E	E	E	E	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
3	87656	9	14.5	.001	B	B	A	B	A	B	C	C	D	D	C	D	E	E	D	E	E	E	---	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
4	87657	8	42.3	<.001	B	A	A	B	C	B	C	D	D	D	D	D	E	E	D	E	E	---	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
LODGEPOLE AREA AND JOHNSON OUTLIER, PERKINS COUNTY, S. DAK.																																							
Core hole 11 (SE¼NE¼ sec 19, T. 21 N., R. 12 E.) elev 2,959 ft																																							
[Sampled interval, 41 ft 7 in–63 ft 8½ in]																																							
1	63677	7½	41.2	0.006	A	A	B	C	C	C	D	D	E	C	D	D	E	E	D	D	D	D	E	D	E	E	---	F	F	---	E	D	---	---	---	---	---	D	---
		[t] *1½*																																					
2	63678	10¾	23.2	.006	B	A	A	C	B	C	E	C	D	C	C	E	E	E	E	D	D	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	D	---
3	63679	12¾	30.1	.004	A	A	A	C	B	C	C	D	D	C	C	E	D	E	D	D	D	D	E	E	E	E	---	F	E	---	---	---	---	---	---	---	---	E	---
		[t] *128*																																					
4	63680	9¼	11.0	.003	A	B	B	C	B	B	E	C	D	D	C	E	E	E	D	D	D	E	E	E	D	E	---	F	E	---	D	---	---	---	---	---	---	---	---
5	63681	11¾	9.8	.001	A	B	B	B	B	B	E	C	D	D	C	D	E	E	E	E	D	E	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
6	63682	11	7.6	<.001	A	B	B	B	B	B	D	C	D	D	C	D	E	E	E	E	D	E	F	E	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
7	63683	8	18.4	.001	A	A	B	B	B	C	D	C	D	C	C	E	E	E	D	E	D	---	E	C	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		[a] *1½*																																					
8	63684	7½	15.9	.001	A	A	B	B	B	C	D	C	D	D	C	E	---	E	E	E	D	---	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
9	63685	9½	11.5	.001	A	A	B	B	B	C	E	C	D	C	C	D	E	E	D	E	D	E	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
		[t] *34*																																					
10	63686	12½	16.7	.001	A	A	B	B	B	C	D	C	D	C	C	E	E	E	D	E	D	E	E	D	D	E	---	F	F	---	E	---	---	---	---	---	---	---	---

Core hole 12 (NW¼SE¼ sec 19, T. 21 N., R. 12 E.) elev 2,961 ft

[Sampled interval, 37 ft 4 in–63 ft 2 in]

1	63688	2¾	94.1	<0.001	A	A	B	C	C	C	C	D	E	C	D	E	---	D	D	E	D	E	E	D	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
2	63689	7¼	84.1	.001	A	A	B	C	C	C	D	C	E	C	D	E	E	D	D	E	C	E	E	D	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
3	63690	12	92.0	<.001	A	A	B	C	C	C	D	D	E	C	D	E	---	E	D	E	D	E	E	E	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
		[t] 177½																																					
4	63691	14¼	15.8	.002	A	A	B	C	B	C	D	C	D	C	C	E	D	E	D	E	D	D	E	D	E	E	---	F	E	---	---	---	---	---	---	---	---	---	---
5	63692	13	12.8	<.001	A	A	B	B	B	C	D	C	D	D	C	E	E	D	E	E	E	---	F	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
6A	63693	19½	11.5	<.001	A	A	B	B	B	C	C	C	D	D	C	D	E	E	E	E	---	---	F	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
7A	63694	13½	13.7	<.001	A	A	B	B	B	C	C	C	D	C	C	E	E	E	E	E	D	---	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
8A	63695	18¼	15.3	<.001	A	A	B	B	B	C	D	C	D	C	C	E	E	E	D	E	D	---	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
9	63696	13	17.7	<.001	A	A	B	B	B	C	D	C	D	C	C	E	E	E	D	E	D	---	E	D	D	E	---	F	F	---	---	E	---	---	---	---	---	---	---
10	63697	18	84.8	<.001	B	A	B	C	C	D	D	D	E	C	D	E	---	E	D	---	D	---	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---

Core hole 13 (NW¼NE¼ sec 19, T. 21 N., R. 12 E.) elev 2,949 ft

[Sampled interval, 33 ft 4½ in–38 ft]

1	63838	1¼	46.4	0.005	A	A	A	C	C	D	D	D	D	C	D	D	---	D	D	D	D	D	E	D	E	D	E	F	E	---	---	E	---	---	---	---	---	---	---
		[g] 5¾																																					
2A	63839	11	66.4	.002	A	A	B	C	B	D	D	D	D	C	D	D	---	E	D	E	D	D	E	E	E	E	E	F	F	---	---	E	---	---	---	---	---	---	---
3	63840	6¾	32.1	.003	A	A	B	B	B	C	D	D	D	C	C	D	D	E	D	D	D	D	F	E	E	E	---	F	E	---	E	---	---	---	---	---	---	---	---
4	63841	13¼	14.1	.003	A	A	B	B	B	C	E	D	D	C	C	E	D	E	E	D	D	D	E	D	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
5A	63842	17½	12.4	.004	B	A	B	B	B	C	E	C	D	D	C	D	D	E	D	D	D	D	E	E	E	E	E	F	F	---	E	---	---	---	---	---	---	---	---

Core hole 14 (SE¼SE¼ sec 9, T. 21 N., R. 11 E.) elev 3,015 ft (Johnson outlier)

[Sampled interval, 14 ft 6 in–22 ft 4¾ in]

1	53843	2	90.4	0.003	A	A	B	B	C	C	D	D	E	C	D	E	D	E	D	E	E	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
2	63844	6	20.3	.176	A	A	B	B	B	C	D	D	D	D	D	D	C	E	E	D	E	D	F	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
3	63845	6	18.2	.156	B	A	B	B	B	C	D	D	D	C	C	D	C	E	E	D	E	D	F	D	E	E	---	F	F	---	E	---	---	---	---	---	---	---	---
4	63846	6	16.8	.128	B	A	A	B	B	C	D	D	D	D	C	D	D	E	E	E	---	D	F	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
5	63847	6	18.0	.070	A	A	B	B	B	C	D	D	D	C	C	E	D	E	E	E	E	D	E	E	E	E	---	F	---	F	---	---	---	---	---	---	---	---	---
6	63848	6	20.0	.039	A	A	B	B	B	C	D	D	D	C	C	E	D	E	E	E	E	E	E	C	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
7	63849	6	24.5	.008	A	A	B	B	B	C	D	D	D	C	C	E	E	E	E	E	D	E	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
8	63850	6	9.7	.006	A	A	B	B	B	C	D	C	D	C	C	D	E	E	D	E	D	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
9	63851	6	21.7	.002	A	A	B	B	B	C	D	D	D	C	C	D	E	E	E	E	D	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
10	63852	6	22.5	.001	A	A	B	B	B	C	D	D	D	C	C	E	E	E	E	E	D	E	E	D	E	E	E	F	---	---	---	---	---	---	---	---	---	---	---
11	63853	6	16.5	.002	A	B	B	B	B	C	C	D	D	D	C	E	E	E	E	E	E	---	F	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
12	63854	6	28.5	.001	A	A	B	B	B	C	D	D	D	C	C	D	E	E	E	E	E	---	F	D	E	E	E	F	---	F	---	---	---	---	---	---	---	---	---
13	63855	3	14.8	.002	A	A	B	B	B	C	C	C	D	D	C	D	E	E	E	E	E	---	F	E	E	---	E	F	---	---	---	---	---	---	---	---	---	---	C
13A	63855A	1	63.3	.001	C	C	A	C	B	C	D	D	E	E	D	D	D	E	E	---	D	---	---	---	---	---	E	F	---	---	---	---	---	---	---	---	---	---	---
14	63856	6	13.8	.001	A	A	B	B	B	C	C	C	D	C	C	D	E	E	D	E	E	E	E	D	E	E	E	F	F	---	---	---	---	---	---	---	---	---	---
15	63857	6	12.4	.002	A	A	B	B	B	C	C	C	D	C	C	D	E	E	D	D	D	D	E	D	D	E	E	F	E	---	---	---	---	---	---	---	---	---	---
16	63858	8¾	27.9	.003	A	A	B	B	B	D	C	D	D	C	C	D	E	E	D	D	D	E	E	E	D	E	E	F	F	---	E	---	---	---	---	---	---	---	---

See footnotes on p. 79.

TABLE 4.—*Semiquantitative spectrographic and chemical analyses on ash from Dakota lignite cores*—Continued

Sample: Core hole TE No.	Sample: Laboratory No.	Sample: Length of core section (inches)	Chemical analyses (percent): Ash in sample	Chemical analyses (percent): Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
LODGEPOLE AREA AND JOHNSON OUTLIER, PERKINS COUNTY, S. DAK.—continued																																							
Core hole 15 (SE¼SW¼ sec 9, T. 21 N., R. 11 E.) elev 3,017 ft (Johnson outlier)																																							
[Sampled interval, 18 ft 2 in–24 ft ½ in]																																							
1	63859	6	19.9	0.040	A	A	B	B	B	C	D	D	D	C	C	E	C	E	D	D	E	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
2	63860	6	25.4	.018	B	A	B	B	B	D	D	D	D	D	C	E	D	E	E	E	---	D	---	E	E	---	---	F	---	---	---	---	---	---	---	---	---	---	---
3	63861	6	13.0	.030	A	A	B	B	B	C	D	D	D	C	C	E	D	E	E	E	E	D	F	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
4	63862	6	16.6	.003	A	A	B	B	B	C	C	C	D	C	C	E	D	E	D	E	D	E	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
5	63863	6	25.0	.001	A	A	B	B	B	D	D	D	D	C	C	E	E	E	D	E	D	E	F	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
6	63864	6	13.4	.001	A	A	B	B	B	C	D	D	D	C	C	E	D	E	E	E	D	---	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
7	63865	6	23.2	.001	A	A	B	B	B	D	D	D	D	C	C	E	E	E	E	E	D	---	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
8	63866	6	16.0	.001	A	A	B	B	B	C	C	D	D	C	C	E	E	E	D	E	D	---	E	D	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
9	63867	6	23.0	<.001	B	B	A	B	B	C	D	C	D	D	D	E	E	E	E	E	E	---	---	E	E	---	---	F	---	---	---	---	---	---	---	---	---	---	---
10	63868	6	19.7	<.001	A	A	B	B	B	D	D	D	D	B	C	E	E	E	D	E	E	---	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
11	63869	6	33.2	<.001	B	B	A	B	B	D	E	D	D	D	D	E	E	E	E	---	E	---	---	E	E	---	---	F	---	---	---	---	---	---	---	---	---	---	---
12	63870	4½	14.8	<.001	A	A	B	B	B	C	C	C	D	D	C	E	E	E	E	E	E	---	F	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
MEDICINE POLE HILLS AREA, BOWMAN COUNTY, N. DAK.																																							
Core hole 5 (SW¼SE¼ sec 35, T. 131 N., R. 104 W.) elev 3,427 ft																																							
[Sampled interval, 68 ft 9½ in–72 ft 10 in]																																							
1	63149	4¼	45.2	0.009	A	A	B	B	B	D	C	C	D	D	D	D	---	D	E	E	C	D	F	E	E	E	E	F	F	---	---	---	---	---	---	---	---	---	---
2	63150	7¾	39.5	.027	A	A	B	C	B	B	C	D	D	D	D	D	D	E	E	D	D	D	E	E	E	E	E	F	F	---	---	---	---	---	---	---	---	---	---
3	63151	9	16.3	.042	B	B	A	B	B	D	C	D	D	D	C	D	D	C	E	D	D	D	---	E	E	E	E	F	F	---	---	---	---	---	D	---	---	---	---
4	63152	8	14.1	.050	A	A	B	B	B	D	C	C	C	D	C	D	E	E	E	E	D	---	E	E	E	E	E	F	F	---	---	---	---	---	D	---	---	---	---
5	63153	8¼	11.9	.060	A	A	B	B	B	D	C	C	D	D	C	D	D	E	E	E	D	E	E	D	E	E	E	F	F	---	---	---	---	---	---	---	---	---	---
6	63154	11¼	18.3	.019	A	A	B	B	B	C	D	C	D	D	C	D	D	E	D	E	C	E	E	D	D	E	E	F	F	---	D	---	---	---	---	---	---	---	---

Core hole 6 (SE¼NE¼ sec 2, T. 130 N., R. 104 W.) elev 3,427 ft

[Sampled interval, 58 ft 3 in–64 ft 8 in]

0	63155A	2	85.4	0.002	A	A	B	B	B	C	C	D	D	C	D	D	E	D	D	E	D	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
1	63155	13¼	39.5	.009	A	A	B	B	B	C	C	C	D	D	D	D	E	D	E	E	C	D	E	D	E	E	E	F	F	---	---	E	---	---	---	---	---	---	---
2	63156	10¾	12.9	.032	B	C	A	B	B	C	D	C	D	D	C	D	D	E	E	D	D	D	F	E	E	E	E	F	F	---	---	---	---	---	C	---	---	---	---
3	63157	12	8.0	.080	A	B	B	B	B	C	C	C	D	D	C	D	D	E	E	E	D	D	E	E	E	E	E	F	F	---	E	---	---	---	D	---	---	---	---
4	63158	14¼	13.7	.034	A	A	B	B	B	C	C	C	D	D	C	E	D	E	E	E	D	E	E	E	E	E	E	F	F	---	---	---	---	---	D	---	---	---	---
5	63159	12	7.9	.074	A	B	B	B	B	C	C	C	D	D	C	D	D	E	E	E	D	D	E	E	E	E	E	F	F	---	---	---	---	---	---	---	---	---	---
6	63160	6	20.1	.048	A	A	B	B	B	C	C	C	D	D	C	D	E	E	D	E	D	E	E	E	E	E	E	F	F	---	E	---	---	---	D	---	---	---	---
7	63161	6½	91.2	.002	A	A	B	C	C	D	C	D	E	C	D	D	E	E	D	E	D	---	E	D	E	E	E	F	F	---	---	---	---	---	---	---	---	---	---

Core hole 8 (NW¼SW¼ sec 1, T. 130 N., R. 104 W.) elev 3,414 ft

[Sampled interval, 29 ft 6 in–32 ft]

1	63162	6	38.6	0.009	A	A	B	B	B	C	D	D	D	D	D	D	E	C	D	D	C	D	E	C	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
2	63163	12	23.8	.012	B	A	B	B	B	C	C	C	C	D	D	E	D	C	E	E	D	D	---	D	E	E	---	F	F	---	---	---	---	---	D	---	---	---	---
3	63164	12	23.9	.016	A	A	B	B	B	C	C	C	D	D	D	E	E	E	E	E	D	---	F	E	E	E	---	F	F	---	---	---	---	---	D	---	---	---	---

Core hole 9 (NW¼NE¼ sec 2, T. 130 N., R. 104 W.) elev 3,422 ft

[Sampled interval, 53 ft–58 ft ½ in]

1	63165	7¼	20.7	0.028	A	A	B	B	B	C	D	D	D	D	D	D	D	D	E	D	D	D	---	E	E	E	---	F	F	---	E	---	---	---	C	---	---	---	---
2	63166	8½	15.4	.042	B	B	A	B	B	D	D	D	D	D	C	E	D	D	E	E	D	E	---	E	E	E	---	F	F	---	---	---	---	---	C	---	---	---	---
3	63167	10	22.9	.022	C	C	A	B	B	D	D	D	D	D	D	E	D	E	E	E	D	---	---	E	E	E	---	F	---	---	---	---	---	---	C	---	---	---	---
4	63168	11½	17.4	.037	B	A	B	B	B	D	D	D	D	D	C	E	D	E	E	E	D	E	F	D	E	E	---	F	F	---	---	---	---	---	D	---	---	---	---
5	63169	11¼	10.5	.079	A	A	B	A	B	C	D	C	D	C	C	D	D	D	E	E	E	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
6	63170	12	18.8	.032	B	B	A	B	B	D	D	D	D	D	D	E	D	E	E	E	D	E	E	E	E	E	---	F	F	---	---	---	---	---	C	---	---	---	---

[a] Shale.
[b] Sandstone.
[c] Thorium reported as 0.01–0.1 percent.
[d] Gray siltstone and clay.
[e] Thorium reported as 0.1–1 percent.
[f] Gray clay.
[g] Gray siltstone.
[h] Gadolinium (0.1–1 percent) and dysprosium (0.001–0.01-percent) also reported.

TABLE 5.—*Fuel analyses of lignite in cores from the Dakotas*

[Analyses by the U. S. Bureau of Mines]

[Condition of sample: A, as received: B, moisture-free; C, moisture- and ash-free]

Core hole	Sample: Laboratory No.	Sample: Thickness of coal, Ft	Sample: Thickness of coal, In	Sample: Condition	Specific gravity	Heating value (Btu)	Ash softening temperature (° F)	Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Proximate: Ash	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Ultimate: Sulfur	Forms of sulfur: Sulfatic	Forms of sulfur: Organic	Forms of sulfur: Pyritic
	Bar H area, Slim Buttes, Harding County, S. Dak.																		
19	D-76408	2	5½	A	1.70	5,330		39.9	19.3	23.9	16.9					1.1			
				B		8,860			32.0	39.8	28.2					1.8			
				C		12,340	1,940		44.6	55.4						2.5			
	D-76409	2	3	A	1.67	5,580		41.3	21.1	24.0	13.6					1.7			
				B		9,510			36.0	40.8	23.2					2.9			
				C		12,380	1,930		46.8	53.2						3.7			
	D-76410	1	8½	A	1.66	5,630		38.4	21.5	25.7	14.4					.4			
				B		9,140			34.8	41.8	23.4					.6			
				C		11,930	2,080		45.5	54.5						.8			
21	D-89670	2	5	A	1.59	5,850		44.3	22.5	25.7	7.5	7.2	34.9	0.4	48.8	1.2	0.07	0.45	0.68
				B		10,510			40.4	46.1	13.5	4.0	62.6	.7	17.1	2.1	.13	.80	1.22
				C		12,150			46.7	53.3		4.7	72.4	.8	19.6	2.5	.15	.93	1.41
	D-89671	2	2¼	A	1.65	5,490		43.7	20.9	24.4	11.0	7.0	32.6	.4	48.2	.8	.03	.33	.42
				B		9,750			37.2	43.3	19.5	3.8	57.9	.7	16.7	1.4	.05	.59	.75
				C		12,110			46.2	53.8		4.7	71.8	.9	20.9	1.7	.06	.73	.93
	D-89672	4	11¼	A	1.70	5,500		43.3	20.5	25.3	10.9	6.8	32.7	.4	46.7	2.5	.02	2.10	.37
				B		9,700			36.2	44.5	19.3	3.6	57.7	.7	14.3	4.4	.04	3.71	.66
				C		12,020			44.8	55.2		4.4	71.4	.9	17.8	5.5	.05	4.59	.81
22	D-89995	1	6¾	A	1.65	5,300		46.4	20.4	24.1	9.1	7.3	31.4	.3	50.9	1.0	.19	.48	.32
				B		9,880			38.0	45.0	17.0	3.9	58.5	.6	18.2	1.8	.36	.89	.60
				C		11,900			45.8	54.2		4.7	70.5	.7	21.9	2.2	.44	1.07	.72
	D-89996	1	9⅝	A	1.65	5,070		46.9	19.8	22.8	10.5	7.4	29.8	.5	51.1	.7	.04	.24	.47
				B		9,560			37.3	42.9	19.8	4.0	56.2	.9	17.7	1.4	.07	.46	.88
				C		11,920			46.5	53.5		5.0	70.0	1.1	22.1	1.8	.08	.58	1.09

	D-89997	1	5	A	1.62	5,670		42.3	22.2	23.6	11.9	7.1	33.1	.4	46.1	1.4	.03	1.02	.37
				B		9,820			38.6	40.7	20.7	4.2	57.3	.7	14.6	2.5	.05	1.77	.64
				C		12,390			48.6	51.4		5.3	72.3	.9	18.4	3.1	.06	2.24	.81
23	D-90065		8	A	2.06	2,440		51.9	15.5	11.4	21.2	6.7	16.5	.3	54.9	.4			
				B		5,060			32.2	23.7	44.1	1.9	34.3	.6	18.2	.9			
				C		9,060			57.7	42.3		3.4	61.3	1.1	32.5	1.7			
	D-90066	1	4½	A	1.69	4,970		42.3	20.2	22.3	15.2	6.7	29.7	.4	47.7	.3	.04	.07	.24
				B		8,630			35.0	38.6	26.4	3.5	51.4	.6	17.5	.6	.07	.12	.41
				C		11,730			47.5	52.5		4.7	69.9	.8	23.8	.8	.10	.17	.56
	D-90067	2	6¼	A	1.66	5,460		43.5	20.7	25.5	10.3	6.8	32.9	.5	48.9	.6	.03	.25	.34
				B		9,660			36.7	45.1	18.2	3.6	58.1	.9	18.1	1.1	.06	.45	.60
				C		11,800			44.8	55.2		4.3	71.0	1.1	22.2	1.4	.07	.55	.73
24	D-90297	2	0	A	1.66	5,370		44.2	20.4	25.8	9.6	6.9	33.0	.3	49.9	.3	.01	.05	.20
				B		9,620			36.6	46.3	17.1	3.6	59.1	.5	19.2	.5	.02	.09	.35
				C		11,610			44.1	55.9		4.4	71.3	.6	23.1	.6	.02	.11	.43
	D. 90298	1	9½	A	1.81	4,740		37.1	19.5	21.2	22.2					2.0			
				B		7,540			30.9	33.8	35.3					3.1			
				C		11,650			47.8	52.2						4.8			
	D-90299	2	7	A	1.75	4,600		41.6	18.9	21.1	18.4					.8			
				B		7,880			32.3	36.2	31.5					1.3			
				C		11,510			47.3	52.7						1.9			
	D-90300	1	10½	A	1.70	5,040		41.7	20.4	22.2	15.7					1.2			
				B		8,640			34.9	38.1	27.0					2.1			
				C		11,840			47.8	52.2						2.9			
25	D-90758	2	7	A	1.60	5,890		40.2	22.9	26.8	10.1	6.8	34.9	.4	46.8	1.0			
				B		9,850			38.2	44.9	16.9	4.0	58.4	.6	18.5	1.6			
				C		11,850	2,150		46.0	54.0		4.8	70.3	.8	22.2	1.9			
	D-90759	4	2	A		5,700		44.5	21.9	26.3	7.3					1.5			
				B		10,280			39.5	47.3	13.2					2.7			
				C		11,840			45.5	54.5						3.1			
26	D-90760	7	11⅜	A	1.61	6,120		40.3	23.6	27.5	8.6	6.8	36.7	.2	46.5	1.2	.06	.77	.39
				B		10,250			39.6	43.0	14.4	3.9	61.4	.3	18.0	2.0	.10	1.28	.65
				C		11,980	2,130		46.2	53.8		4.5	71.8	.3	21.0	2.4	.11	1.50	.76
	D-90761	1	9¾	A		5,760		41.6	21.5	26.3	10.6					2.0			
				B		9,880			36.8	45.1	18.1					3.5			
				C		12,050			45.0	55.0						4.2			
27	D-90762	2	2¾	A	1.79	5,090		39.3	20.3	23.5	16.9	6.4	29.8	.4	43.3	3.2	.08	2.90	.23
				B		8,390			33.5	38.7	27.8	3.3	49.1	.6	13.9	5.3	.13	4.78	.38
				C		11,620	1,990		46.5	53.5		4.5	68.1	.9	19.2	7.3	.18	6.63	.53

TABLE 5.—*Fuel analyses of lignite in cores from the Dakotas*—Continued

Core hole	Laboratory No.	Sample: Thickness of coal, Ft	Sample: Thickness of coal, In	Sample: Condition	Specific gravity	Heating value (Btu)	Ash softening temperature (° F)	Analyses, in percent: Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Proximate: Ash	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Ultimate: Sulfur	Forms of sulfur: Sulfatic	Forms of sulfur: Organic	Forms of sulfur: Pyritic
Lodgepole area and Johnson outlier, Perkins County, S. Dak.																			
11	D-69688	2	6	A		5,950		32.3	25.2	23.3	19.2					4.2			
				B		8,790			37.2	34.4	28.4					6.2			
				C		12,280	2,050		51.9	48.1						8.7			
	D-69689	4	9	A		7,180		33.3	28.0	29.9	8.8					.9			
				B		10,770			42.0	44.9	13.1					1.3			
				C		12,400	2,150		48.4	51.6						1.5			
	D-69690	1	⅛	A		7,010		33.6	28.0	27.7	10.7					.7			
				B		10,560			42.2	41.7	16.1					1.1			
				C		12,580	2,210		50.3	49.7						1.3			
12	D-69687	7	7½	A		7,140		33.0	28.0	28.6	10.4	6.6	41.9	.6	39.6	.9			
				B		10,650			41.7	42.7	15.6	4.3	62.4	.9	15.4	1.4			
				C		12,620	2,180		49.4	50.6		5.1	74.0	1.0	18.2	1.7			
13	D-69737	2	7¾	A		6,830		36.6	27.3	27.4	8.7					2.2			
				B		10,770			43.0	43.3	13.7					3.4			
				C		12,470	2,070		49.8	50.2						3.9			
4	D-69738	7	7¾	A		4,090		46.0	26.1	15.5	12.4	6.8	26.2	.5	52.6	1.5			
				B		7,560			48.3	28.8	22.9	3.1	48.6	.9	21.6	2.9			
				C		9,810	2,210		62.6	37.4		4.1	63.0	1.1	28.1	3.7			
[1]15	D-69739	5	10½	A		4,250		45.6	25.4	16.6	12.4	6.8	27.3	.5	51.6	1.4			
				B		7,820			46.7	30.5	22.8	3.1	50.2	.9	20.3	2.7			
				C		10,120	2,230		60.5	39.5		4.1	65.1	1.2	26.2	3.4			

Medicine Pole Hills area, Bowman County, N. Dak.

5	D-68866	3	10¾	A		4,940		46.7	22.5	19.4	11.4	7.2	29.8	0.5	50.6	0.5			
				B		9,270			42.1	36.5	21.4	3.8	55.9	.9	17.1	.9			
				C		11,780	2,340		53.6	46.4		4.8	71.1	1.2	21.8	1.1			
6	D-68867	1	1¼	A		4,690		41.1	22.9	17.5	18.5					.3			
				B		7,960			38.9	29.6	31.5					.6			
				C		11,610	2,230		56.8	43.2						.9			
	D-68868	4	6⅞	A		5,450		46.7	23.8	22.1	7.4					1.5			
				B		10,240			44.7	41.4	13.9					2.8			
				C		11,890	2,370		51.9	48.1						3.3			
8	D-68870	2	6	A		3,730		45.8	22.6	15.1	16.5	6.6	24.3	.6	51.7	.3			
				B		6,890			41.7	27.9	30.4	2.7	44.8	1.0	20.6	.5			
				C		9,900	2,150		59.9	40.1		3.9	64.5	1.5	29.4	.7			
9	D-68871	5	½	A		5,860		41.0	26.2	22.5	10.3	6.8	34.6	.5	45.6	2.2			
				B		9,930			44.4	38.2	17.4	3.7	58.6	.9	15.6	3.8			
				C		12,020	2,210		53.8	46.2		4.5	71.0	1.1	18.8	4.6			

[1] Johnson outlier.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*

The lignites discussed in this report are dominantly banded coals. The banding is primarily a function of the occurrence of elongate lenses of large fragments of woody trunks and roots of ancient plants. In describing banded coals the important features are (1) the thickness of bands, and (2) the frequency of occurrence of these bands. Thickness and frequency are described in this table using the terms according to the following definitions:

(1) Thickness of woody bands (woody bands less than about 1/50 inch, or 0.5 mm, thick are regarded as a part of attrital coal)

- Thin bands........ about 1/50–1/12 in. (0.5–2.0 mm)
- Medium bands.... about 1/12–1/5 in. (2.0–5.0 mm)
- Thick bands....... about 1/5–2 in. (5.0–50.0 mm)
- Very thick bands.. more than 2 in. (more than 50.0 mm)

(2) Frequency of occurrence (percentage of the layer)

- Sparse........ less than 15 percent
- Moderate.... 15–30 percent
- Abundant.... 30–60 percent
- Dominant.... more than 60 percent

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.						
Core hole 19 (NE¼NE¼ sec. 32, T. 19 N., R. 8 E.) elev 3,503 ft						
--------	--------	337	6	------	3½	(Top of core sent to laboratory.) Clay, light-gray, silty, micaceous, soft.
--------	--------	337	9½	1	3½	Clay, as in above sample, but silty and interbedded with streaks of fine-grained sandstone, commonly ferruginous.
--------	--------	339	1	------	3	Clay, shaly, dark-gray, micaceous, sandy and soft.
--------	--------	339	4	------	7	Clay shale, tan- to olive-brown; sandy beds and lenses become more common and more consolidated downward.
--------	--------	339	11	------	7	Siltstone, light-gray to tan, sandy, micaceous, hard.
--------	--------	340	6	------	2	Shale, dark-tan to light-brown, becoming darker brown downward.
1	0.002	340	8	1	5	Shale, black, carbonaceous, thin-bedded.
2	.001	342	1	------	2½	Shale, reddish-brown, micaceous, oxidized zone(?) becoming black downward.
3	.001	342	3½	------	2½	Coal and black coaly shale.
4	.001	342	6	------	3	Shale, black, coaly.
--------	--------	342	9	------	9	Shale, clayey, medium-gray, soft; a few scattered plant fragments.
--------	--------	343	6	1	4	Shale, medium- to light-gray, slightly sandy.
--------	--------	344	10	------	2	(Loss in coring interval from 337 ft 6 in–345 ft.)
--------	--------	345	0	34	0	(No core sent for analyses to laboratory.)
5	.006	379	0	------	4½	Shale, coaly, black, somewhat broken, ⅛-in pyritic lenses in lower part.
6	.017	379	4½	------	8	Coal, attrital, soft, dull luster; thin section of coal at 379 ft 8½ in shows considerable opaque matter.
7	.037	380	½	------	11¼	Coal, mostly thin- and medium-banded; a 3½-in band of solid-wood at 380 ft 4½ in; ¼-in pyritic rosette is near the base.
8	.015	380	11¾	------	5¾	Coal, moderately thin- and medium-banded as in above sample.
9	.012	381	5½	------	4¼	Shale, carbonaceous, dark-brown; ¾-in woody band and small pyritic lenticles at base.
--------	--------	381	9¾	------	1½	Sand, soft, clayey, micaceous, dark.
--------	--------	381	11¼	1	2¼	Sandstone, dark-gray, fine- to medium-grained, soft; pyritic nodules and thin streaks of dark silty clay.
--------	--------	383	1½	------	11	Clay, dark-gray to black, somewhat sandy, with occasional small pyritic nodules toward the base.
--------	--------	384	½	1	4	Sandstone, medium-gray, soft, clayey, fine- to medium-grained.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole Ft	in	Length Ft	in	Lithologic description and remarks
						BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—continued
						Core hole 19—Continued
10	.009	385	4½	------	10	Coal, sparsely to moderately thin- and medium-banded; attrital layers are soft; small pyritic lenticles at the top.
11	.002	386	2½	------	11	Coal, moderately medium- to thick-banded.
12	.004	387	1½	------	6	Coal, mostly dull luster, attrital, very sparsely banded.
--------	--------	387	7½	------	10½	Sandy clay, gray, soft, becoming more shaly downward.
--------	--------	388	6	------	4	(Loss in coring interval from 379 ft to 388 ft 10 in.)
--------	--------	388	10	2	0	Shale, sandy, gray to dark-gray, a few woody lenticles in the lower part.
13	.004	390	10	------	2	Shale, dark brown, carbonaceous.
14	.002	391	0	------	11	Coal, sparsely thin- and medium-banded. Mostly dull, attrital in the top 5 in.
15	.005	391	11	------	9½	Coal, moderately thin- and medium-banded; ⅛-in fusain lenticles near the top.
--------	--------	392	8½	5	8½	Sandstone, shaly to silty, gray, fine-grained, soft, becoming harder and coarser grained downward.
--------	--------	398	5	------	------	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-76408 includes TE samples 5-8. D-76409 includes TE samples 10-12. D-76410 includes TE samples 14 and 15.

Core hole TE sample No.	Uranium (percent)	Depth Ft	in	Length Ft	in	Lithologic description and remarks
						Core hole 21 (SW¼ sec 8, T. 18 N., R. 8 E.) elev 3,285 ft
--------	--------	0	0	10	0	(Surface deposits; no core.)
--------	--------	10	0	10	0	(Badly weathered coal at drill hole but not sent to laboratory.)
--------	--------	20	0	10	10	(No core sent to laboratory; described at drill site as gray siltstone.)
--------	--------	30	10	------	5¾	(Top of core sent to laboratory.) Shale, gray, with thin lighter gray streaks.
--------	--------	31	3¾	------	¼	Thin pyritic layer.
1	<0.001	31	4	------	5	Coal, sparsely medium-banded, matrix is earthy; lower half was broken in drilling.
2	<.001	31	9	------	6¼	Coal; upper 4 in almost entirely woody; earthy below.
3	<.001	32	3¼	------	7⅛	Coal, dominantly woody, medium- to thick-banded, ⅛-in fusain bleb at 32 ft 8¾ in.
4	<.001	32	10⅜	------	10⅝	Coal, sparsely to moderately woody, medium- and thick-banded, ½-in pyritic bleb at 32 ft 11¾ in; core was partly broken in drilling.
--------	--------	33	9	------	3	(Loss in coring interval from 31 ft 4 in-34 ft.)
--------	--------	34	0	1	2	Clay, gray, soft and plastic.
--------	--------	35	2	5	10	(No core sent to laboratory; described at drill site as gray siltstone and clay.)
5	<.001	41	0	------	1⅛	Coal, earthy, probably impure.
--------	--------	41	1⅛	------	7⅜	Clay, dark-gray at top, grading downward to light-gray.
6	<.001	41	8½	------	8⅛	Coal, moderately woody, thin- and medium-banded; ¼-in pyrite lens below 42 ft ¾ in.
7	<.001	42	4⅝	------	9⅛	Coal, moderately woody, medium- to thick-banded; 2½-in woody layer below 42 ft 10 in; thin fusain bleb at top of section.
8	<.001	43	1¾	------	9	Coal, 2½-in woody piece at top; lower part dominantly attrital; middle part is badly broken.
--------	--------	43	10¾	------	1¼	(Loss in coring interval from 41 ft 8½ in-44 ft.)
--------	--------	44	0	------	10	Clay, dark-gray; somewhat lignitic, soft and plastic; woody lenses at the top; ¼-in pyrite bleb below 44 ft 4 in.
--------	--------	44	10	23	2	(No core sent to laboratory; described at drill site as gray siltstone.)
--------	--------	68	0	------	4¾	Clay, medium-gray, soft and plastic.
9	.001	68	4¾	------	2½	Coal, dominantly woody; irregular contact with clay below.
--------	--------	68	7¼	------	2½	Clay, dark gray, soft and plastic; irregular contact with coal below; contains some coal fragments from samples above and below.
10	.001	68	9¾	------	2	Coal, dominantly woody; earthy in lower portion.
--------	--------	68	11¾	------	¼	(Loss in coring interval from 68 ft-69 ft.)
--------	--------	69	0	------	9	Clay, dark-gray, soft and plastic.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
						BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—continued
						Core hole 21—Continued
11	0.001	69	9	------	9½	Coal, dominantly attrital; ⅛-in pyrite lenses at 69 ft 10¼ in and 70 ft ⅛ in; core was broken in drilling.
12	<.001	70	6½	------	9⅛	Coal, moderately thick- to medium- and sparsely thin-banded.
13	.001	71	3⅝	------	7¾	Coal, moderately thin- to thick-banded.
14	<.001	71	11⅜	------	7⅝	Coal, dominantly attrital with a few woody fragments; core badly broken.
15	.001	72	7	------	10⅛	Coal, upper half is dominantly attrital; lower half, medium- to thick-banded; ½-in attrital zone at base contains small buff clayey pellets.
16	<.001	73	5⅛	------	6⅞	Coal, completely crushed in coring; fragments dominantly attrital; woody fragments in uppermost 2 in.
17	.001	74	0	------	8¼	Coal, dominantly woody; wood fragments are irregular; central portion broken in coring; ⅛-in clay parting below 74 ft 6⅝ in.
--------	--------	74	8¼	1	1	Clay, dark-gray, coaly to 74 ft 9¼ in; medium-gray, soft and plastic to 75 ft 2¾ in; dark-gray, soft and plastic to 75 ft 4¼ in; light-gray, soft and plastic below.
--------	--------	75	9¼	------	------	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-89670 includes TE samples 1-4. D-89671 includes TE samples 6-8. D-89672 includes TE samples 11-17.

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
						Core hole 22 (SE¼NW¼ sec 8, T. 18 N., R. 8 E.) elev 3,260 ft
1	0.001	28	6	------	5½	(Top of core sent to laboratory.) Coal, abundantly woody, thick- to very thick-banded; upper and lower one-third badly broken in coring; middle ⅓ is solid-wood fragment; ⅜-in pyritic nodule in lower half.
2	.001	28	11½	------	4¼	Coal, dominantly woody, very thick-banded.
3	.001	29	3¾	------	9	Coal, uppermost 1-in dominantly woody; rest of sample is sparsely woody, thin-banded and badly broken in coring.
--------	--------	30	¾	------	10¼	Clay, silty, medium-gray, soft and plastic.
--------	--------	30	11	------	½	Coal, dominantly woody, thin- and thick-banded.
--------	--------	30	11½	------	½	Clay, same as clay above; complete recovery of core from 28 ft 6 in to 31 feet.
--------	--------	31	0	29	5	(No core sent to laboratory; described at drill site as gray siltstone.)
--------	--------	60	5	------	2⅞	Clay, silty, medium-gray, soft and plastic; lowest 1-in contains carbonaceous streaks about 1⁄16-in thick.
4	.001	60	7⅞	------	4⅛	Coal, moderately woody, thin- and thick-banded.
5	<.001	61	0	------	5¾	Coal, abundantly woody, thin- to thick-banded; lower half was slightly broken in coring.
6	.001	61	5¾	------	6	Coal, dominantly attrital, thin-banded; lower half was slightly broken in coring.
7	.002	61	11¾	------	5¾	Coal, abundantly woody, thin- to thick-banded.
--------	--------	62	5½	------	6½	Clay, medium-gray, soft and plastic; carbonaceous zone with coaly fragments at 62 ft 6¼ in-62 ft 6¾ in; complete recovery of core from 60 ft 5 in to 63 ft.
--------	--------	63	0	22	2	(No core sent to laboratory; described at drill site as gray siltstone.)
8	.001	85	2	------	5¾	Coal, abundantly woody, thin- to thick-banded; uppermost third was pulverized in coring.
9	.001	85	7¾	------	6	Coal, dominantly woody, thin- to very thick-banded; middle portion broken into 2½-in biscuits.
10	.001	86	1¾	------	5¼	Coal, dominantly attrital, thin- to thick-banded; pyritic lenticles in basal 1-in.
--------	--------	86	7	------	1½	(Loss in coring interval from 85 ft 2 in—86 ft 7 in.)
--------	--------	86	8½	------	7½	Clay, medium-gray, soft and plastic; uppermost ½-in has carbonaceous streaks.
--------	--------	87	4	------	------	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-89995 includes TE samples 1-3. D-89996 includes TE samples 4-7. D-89997 includes TE samples 8-10.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—continued						
Core hole 23 (SW¼SE¼ sec 8, T. 18 N., R. 8 E.) elev 3,216 ft						
--------	--------	20	6	1	3¾	(Top of core sent to laboratory.) Clay, silty, medium gray.
1	.010	21	9¾	------	4⅜	Coal and clay; in coring, silty clay apparently was pushed down into coal or coal squeezed up around the clay; silty clay is brown stained; coal is weathered and was pulverized in coring.
2	.006	22	2⅛	------	2⅛	Coal, weathered, pulverized in coring; silty clay pushed into coal as in above sample.
3	.003	22	4¼	------	2	Coal, weathered, pulverulent, friable; faint, oblique banding.
4	.003	22	6¼	------	2	Coal, weathered, pulverulent, friable, but in normal position; faint horizontal banding.
5	.003	22	8¼	------	2	Coal, weathered, pulverulent, friable but in normal position; sparsely medium-banded.
6	.006	22	10¼	------	1¾	Coal, weathered, friable, but in normal position; sparsely thin-banded.
7	.008	23	0	------	1¼	Coal, weathered, friable, but in normal position; sparsely thin-banded; clayey in lower ½ in.
--------	--------	23	1¼	------	4¾	Clay, dark brown; ½-in layer of weathered coaly material with thin woody streaks below 23 ft 1¼ in.
--------	--------	23	6	15	4	(No core sent to laboratory; described at drill site as gray siltstone and clay.)
--------	--------	38	10	------	3¼	Clay, medium-gray; ¾-in pyritic nodule at 39 ft 1 in.
8	.001	39	1¼	------	6	Coal, dominantly woody, upper half broken in coring; 1-in pyritic nodule at 39 ft 2¾ in.
9	.001	39	7¼	------	3¾	Coal, dominantly very thick-banded.
--------	--------	39	11	1	4¾	Clay, medium-gray, plastic.
--------	--------	41	3¾	------	10¼	Clay, medium-gray.
--------	--------	42	2	------	6	Clay, medium-gray, plastic.
10	<.001	42	8	------	7⅛	Coal, dominantly very thick-banded; upper third of core was broken in coring.
11	<.001	43	3⅛	------	3⅞	Coal, sparsely thin- to medium-banded; broken in coring; 1¾-in large pyritic nodule at top.
--------	--------	43	7	------	1	(Loss in coring interval at 42 ft 8 in–43 ft 8 in.)
12	.001	43	8	------	5½	Coal, dominantly thin- to thick-banded.
--------	--------	44	1½	------	½	(Loss in coring interval at 43 ft 8 in–44 ft 2 in.)
--------	--------	44	2	------	6	Clay, dark-gray, plastic, weathered; ¼-in weathered woody band ½ in from top.
--------	--------	44	8	23	6	(No core sent to laboratory; described at drill site as gray siltstone with some interbedded clay and sandstone.)
--------	--------	68	2	------	6	Clay, carbonaceous; ¼-in pyritic nodule at 68 ft 7½ in.
13	<.001	68	8	------	3	Coal, moderately medium-banded; ½-in pyritic nodule at 68 ft 8 in.
--------	--------	68	11	------	10	Clay, medium to dark gray, with thin woody streaks at 68 ft 11 in–68 ft 11½ in.
14	<.001	69	9	------	7½	Coal, sparsely thin- to thick-banded.
15	<.001	70	4½	------	4¼	Coal, moderately thin- to thick-banded; lower half was broken in coring.
16	.001	70	8¾	------	8½	Coal, abundantly thin- to very thick-banded.
18	.001	71	5¼	------	10½	Coal, sparsely thin- to medium-banded.
--------	--------	72	3¾	------	3¼	(Loss in coring interval at 69 ft 9 in–72 ft 7 in.)
--------	--------	72	7	------	7½	Clay, medium-gray; fine specks of pyrite at 72 ft 11 in.
--------	--------	73	2½	2	11½	(No core sent to laboratory; described at drill site as gray clay.)
19	.001	76	2	------	6	Coal, moderately thin- to thick-banded; uppermost third contains about 10 percent of pyritic streaks as much as ¼-in thick.
20	.002	76	8	------	2¼	Coal, thin-banded but dominantly woody; ½-in pyritic nodule at 76 ft 9⅛ in.
--------	--------	76	10¼	------	¾	(Loss in coring interval at 76 ft 2 in–76 ft 11 in.)
--------	--------	76	11	------	3	Clay, medium- to dark-gray; thin woody streaks at 76 ft 11 in–76 ft 11½ in.
--------	--------	77	2	11	10	(No core sent to laboratory; described at drill site as gray clay and siltstone.)
--------	--------	89	0	------	6	Clay, carbonaceous.
21	<.001	89	6	------	6½	Coal, sparsely thin- to thick-banded.
--------	--------	90	½	------	½	(Loss in coring interval at 89 ft 6 in–90 ft 1 in.)
--------	--------	90	1	------	1	Clay, medium-gray; carbonaceous streaks at 90 ft 1 in–90 ft 1½ in.
--------	--------	90	2	------	------	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-90065 includes TE samples 3–7. D-90066 includes TE samples 10–12. D-90067 includes TE samples 14–16 and 18.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Core section: Depth in hole, in	Core section: Length, Ft	Core section: Length, in	Lithologic description and remarks
Core hole 24 (NE¼ sec 5, T. 18 N., R. 8 E.) elev 3,270 ft						
--------	--------	105	6	------	2	(Top of core sent to laboratory.) Clay, silty, dark-gray.
1	0.009	105	8	------	2¼	Coal, dominantly thin- to medium-banded; interval at 105 ft 8 in–105 ft 9 in broken in coring.
2	.010	105	10¼	------	3	Impure coal, fibrous bands permeated with clayey mineral matter.
--------	--------	106	1¼	------	9	Clay, medium- to dark-gray; 1/16-in streak of attrital coal at 106 ft 8¾ in.
--------	--------	106	10¼	------	5⅛	Clay, medium to dark gray; thin woody streaks at 106 ft 11½ in, 107 ft, 107 ft 1½ in, and 107 ft 2½ in.
--------	--------	107	3⅜	------	2⅝	Clay, medium- to dark-gray; 2 thin woody streaks at 107 ft 5½ in.
3	.003	107	6	------	2	Clay, gray, carbonaceous streaks.
--------	--------	107	8	------	2	Clay, gray; 3 thin woody streaks at 107 ft 8 in–107 ft 8¾ in.
--------	--------	107	10	8	2	(No core sent to laboratory; described at drill site as gray siltstone.)
4	.002	116	0	------	5	Coal, dominantly thin- to thick-banded.
5	.001	116	5	------	6¾	Coal, moderately thin- to thick-banded.
6	.001	116	11¾	------	7½	Coal, moderately thin- to thick-banded; 1¼-in pyritic lens at 116 ft 11¾ in–117 ft 1 in.
7	.001	117	7¼	------	4¾	Coal, dominantly thick- to very thick-banded.
--------	--------	118	0	------	6¼	Clay, carbonaceous; thin to medium coaly streaks at 118 ft 2 in–118 ft 2½ in and 118 ft 3¾ in–118 ft 6¼ in.
--------	--------	118	6¼	21	5¾	(No core sent to laboratory; described at drill site as gray clay and siltstone.)
--------	--------	140	0	------	6½	Clay, medium- to dark-gray; carbonaceous at 140 ft ¾ in; thin woody streaks at 140 ft 4 in–140 ft 4½ in and at 140 ft 5½ in–140 ft 6½ in.
8	<.001	140	6½	------	6½	Coal, moderately thin- to very thick-banded.
9	<.001	141	1	------	5¾	Coal, moderately thin- to thick-banded.
10	<.001	141	6¾	------	9¼	Coal, moderately thin- to thick-banded; carbonaceous clay at 141 ft 8 in–141 ft 9¾ in and 141 ft 11 in–141 ft 11½ in included in fuel sample; ¼-in pyritic nodule at 142 ft 2½ in.
--------	--------	142	4	------	5½	Clay, medium-gray; thin carbonaceous streaks at 142 ft 4 in–142 ft 5¼ in.
--------	--------	142	9½	------	1	(Loss in coring interval at 142 ft 4 in–142 ft 10½ in.)
--------	--------	142	10½	------	7½	Clay, medium-gray; thin carbonaceous streaks at 143 ft 2½ in–143 ft 3½ in.
11	<.001	143	6	------	7½	Coal, solid wood.
--------	--------	144	1½	------	4¼	Clay, dark-gray; thin woody streaks at 144 ft 3¾ in and 144 ft 4¾ in; excluded from fuel sample.
12	<.001	144	5¾	------	7¾	Coal, moderately thin- to medium-banded; interval at 144 ft 8 in–144 ft 11½ in broken in coring.
13	<.001	145	1½	------	8½	Coal, dominantly thin- to very thick-banded; carbonaceous clay at 145 ft 1¾ in–145 ft 2¾ in included in fuel sample.
14	<.001	145	10	------	7¼	Coal, moderately thin- to thick-banded.
--------	--------	146	5¼	------	4¼	Clay, light-gray, thin woody streak at 146 ft 9 in.
--------	--------	146	9½	27	7½	(No core sent to laboratory; described at drill site as gray clay and siltstone.)
--------	--------	174	5	------	6	Clay, gray; thin carbonaceous streaks from 174 ft 5 in–174 ft 6 in.
15	<.001	174	11	------	9½	Coal, dominantly thin- to thick-banded; thin clayey streaks at 175 ft ¾ in–175 ft 1¼ in included in fuel sample.
16	<.001	175	8½	------	7¾	Coal, dominantly thin- to thick-banded; carbonaceous clay at 176 ft 0 in–176 ft ¾ in is included in fuel sample; coal broken in coring at 176 ft. ¾ in–176 ft 1¾ in.
--------	--------	176	4¼	------	1¼	Clay, dark-gray, ¾-in pyritic nodule at 176 ft 4¾ in excluded from fuel sample.
17	<.001	176	5½	------	3	Coal, dominantly thin- to thick-banded.
--------	--------	176	8½	------	1¾	Clay, dark gray, thin carbonaceous streaks; excluded from fuel sample.
18	.001	176	10¼	------	2¼	Coal, solid wood.
--------	--------	177	½	------	6½	Clay, dark-gray; thin carbonaceous streaks from 177 ft ½ in–177 ft 2 in.
--------	--------	177	7	------	------	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-90297 includes TE samples 4-7. D-90298 includes TE samples 8-10. D-90299 includes TE samples 11-14. D-90300 includes TE samples 15-18.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—continued

Core hole 25 (NE¼NE¼ sec 3, T. 18 N., R. 8 E.) elev. 3,177 ft

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
--------	--------	27	6	------	3½	(Top of core sent to laboratory.) Clay, dark-gray; white clayey flecks at 27 ft 8¼ in-27 ft 8½ in and at 27 ft 9 in-27 ft 9¼ in.
1	0.008	27	9½	------	7¼	Coal, sparsely to moderately thin- to thick-banded; sparse white clayey flecks at 28 ft 3 in-28 ft 4¼ in; broken in coring interval at 28 ft ¼ in-28 ft 3 in.
2	.005	28	4¾	------	10¼	Coal, abundantly thin- to thick-banded; solid wood from 28 ft 7⅛ in-28 ft 10¾ in; ⅛-in pyrite nodule at 29 ft 1 in.
--------	--------	29	3	------	8	Clay, medium-gray; thin carbonaceous streaks at 29 ft 3 in-29 ft 3¾ in; excluded from fuel sample.
3	.008	29	11	------	8¾	Coal, moderately to dominantly thin- to thick-banded; broken in coring intervals at 29 ft 11 in-30 ft 0 in and at 30 ft 3¼ in-30 ft 6 in.
4	.005	30	7¾	------	4¾	Coal, moderately to abundantly thin- to thick-banded; pyrite flecks at 30 ft 8½ in.
--------	--------	31	½	------	2½	(Loss in coring interval at 29 ft 11 in-31 ft 3 in.)
--------	--------	31	3	------	5½	Clay, carbonaceous, thin woody streaks at 31 ft 6¼ in and 31 ft 6½ in; ¼-in pyrite nodule at 31 ft 7½ in.
--------	--------	31	8½	2	2½	(No core sent to laboratory; described at drill site as clay and siltstone.)
--------	--------	33	11	------	4	Clay, gray; thin carbonaceous streaks at 34 ft ¼ in and 34 ft 1⅛ in.
5	.002	34	3	------	7⅜	Coal, moderately thin- to thick-banded; 1/16-in-¼-in fusain streaks at 34 ft 9 in-34 ft 10⅜ in; broken in coring interval at 34 ft 3¼ in-34 ft 4½ in.
6	.001	34	10⅜	------	8⅝	Coal, moderately thin- to thick-banded.
--------	--------	35	7	------	1	(Loss in coring interval at 34 ft 3 in-35 ft 8 in.)
7	.001	35	8	------	7½	Coal, sparsely to moderately thin- to medium-banded; 1/16-in-¼-in fusain streaks at 35 ft 8½ in, and at 35 ft 10½ in-36 ft ½ in; solid wood at 36 ft 1¾ in-36 ft 3½ in.
8	.001	36	3½	------	9¾	Coal, abundantly thin- to thick-banded; 1/16-in fusain streaks at 36 ft 9¾ in-37 ft 0 in; broken in coring interval at 36 ft 8 in-36 ft 9¾ in.
9	.001	37	1¼	------	8¾	Coal, moderately to dominantly thin- to thick-banded; broken in coring interval at 37 ft 1¼ in-37 ft 1¾ in and at 37 ft 5¾ in-36 ft 10 in.
10	.001	37	10	------	8	Coal, moderately thin- to thick-banded; 1/16-in-¼-in fusain streaks at 38 ft 0 in-38 ft 2 in and 38 ft 3¾ in-38 ft 5½ in; 1/16-in pyrite nodule at 38 ft 5¾ in.
--------	--------	38	6	------	3	Clay, silty, medium-gray; thin woody streaks at 38 ft 8 in.
--------	--------	38	9	21	4	(No core sent to laboratory; described at drill site as gray siltstone.)
--------	--------	60	1	------	6¼	Clay, dark-gray; tiny mica flakes at 60 ft 1 in-60 ft 2 in; thin woody streaks at 60 ft 3¼ in, and 60 ft 6¾ in-60 ft 7¼ in.
11	<.001	60	7¼	------	8¾	Coal, sparsely to moderately thin- to thick-banded; broken in coring interval at 60 ft 7¼ in-61 ft ½ in.
--------	--------	61	4	------	3	Clay, silty, medium-gray; thin woody streaks at 61 ft 4 in-61 ft 4½ in, at 61 ft 5¼ in, and at 61 ft 5½ in.
--------	--------	61	7	8	8	(No core sent to laboratory; described at drill site as silty clay.)
--------	--------	70	3	------	5½	Clay, silty, medium-gray.
12	<.001	70	8½	------	6½	Coal, moderately to abundantly thin- to thick-banded; 2¼-in pyrite nodules at 70 ft 8½ in-70 ft 9 in; thin fusain streaks at 71 ft 1½ in-72 ft 2¼ in.
--------	--------	71	3	------	2	(Loss in coring interval from 70 ft 8½ in-71 ft 5 in.)
--------	--------	71	5	------	9	Clay, gray, carbonaceous at 71 ft 5 in-71 ft 5¾ in, from 71 ft 6 in-71 ft 6¼ in, and 71 ft 8¼ in-71 ft 9¼ in; dark-brown clay at 71 ft 11 in-72 ft 2 in; thin woody streaks at 71 ft 9¼ in-71 ft 9½ in-72 ft 0 in-72 ft ½ in.
--------	--------	72	2	------	2½	Impure coal, sparsely thin-banded; intercalated carbonaceous clay; broken in coring interval from 72 ft 2 in-72 ft 4½ in.
--------	--------	72	4½	------	½	(Loss in coring interval from 72 ft 2 in-72 ft 5 in.)
--------	--------	72	5	------	5	Clay, medium brown-gray.
--------	--------	72	10	18	2	(No core sent to laboratory; described at drill site as siltstone and clay.)

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
						BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—continued
						Core hole 25—Continued
--------	--------	91	0	------	4¼	Clay, medium-brown to gray; thin woody streaks at 91 ft 3 in–91 ft 4¼ in.
13	<.001	91	4¼	------	4½	Coal, sparsely to moderately thin- and thick-banded; broken in coring interval at 91 ft 7 in–91 ft 7½ in.
--------	--------	91	8¾	------	2¼	Impure coal, sparsely thin-banded; intercalated carbonaceous clay; white clayey streaks at 91 ft 9½ in–91 ft 10 in.
--------	--------	91	11	------	6	Clay, medium-gray; carbonaceous; white clayey streaks from 91 ft 11½ in–92 ft 0 in; ½-in oblique coaly layer containing thin woody streaks at 92 ft 1 in–92 ft 4 in.
--------	--------	92	5	------		(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-90758 includes TE samples 1-4. D-90759 includes TE samples 5-10.

Core hole 26 (NW¼ sec 35, T. 19 N., R. 8 E.) elev 3,100 ft

Core hole TE sample No.	Uranium (percent)	Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
--------	--------	29	9	------	7⅝	(Top of core sent to laboratory.) Clay, medium-gray, contains thin woody streaks at 30 ft 3 in–30 ft 4⅝ in.
1	0.001	30	4⅝	------	8⅜	Coal, sparsely thin- and moderately medium-banded; solid wood at 30 ft 4⅝ in–30 ft 5½ in; 1-in pyrite nodule at 30 ft 9 in–30 ft 10 in; broken in coring interval at 30 ft 6½ in–31 ft 1 in.
2	.001	31	1	------	8	Coal, sparsely thin- to medium-banded; broken in coring from 31 ft 1¼ in–31 ft 9 in.
3	<.001	31	9	------	9	Coal, sparsely thin- to medium-banded; 1/16 in–¼ in fusain streaks at 32 ft 1½ in–32 ft 3½ in.
4	<.001	32	6	------	4½	Coal, sparsely thin- to medium-banded; 1-in pyrite nodule at 32 ft 7½ in–32 ft 8½ in.
5	<.001	32	10½	------	6¾	Coal, sparsely thin- to medium-banded; solid wood from 33 ft 2½ in–33 ft 5¼ in; broken in coring interval from 33 ft 1½ in—33 ft 2½ in.
6	<.001	33	5¼	------	3¾	Coal, sparsely thin- to medium-banded; broken in coring interval from 33 ft 5¼ in–33 ft 9 in.
--------	--------	33	9	------	1	(Loss in coring interval from 30 ft 4⅝ in–33 ft 10 in.)
7	<.001	33	10	------	6¾	Coal, sparsely thin- to thick-banded; ⅜-in pyrite nodule at 33 ft 10 in–33 ft 10⅜ in; broken in coring interval from 33 ft 10 in–34 ft 4¾ in.
8	<.001	34	4¾	------	6¾	Coal, moderately thin- and medium-banded, sparsely thick-banded.
9	<.001	34	11½	------	6½	Coal, dominantly medium-banded; sparsely thin-banded; 1/16-in–¼-in fusain streaks at 35 ft 4 in–35 ft 6 in.
10	<.001	35	6	------	6	Coal, sparsely thin- and medium-banded; 1/16-in–¼-in fusain streaks at 35 ft 7¼ in–35 ft 8½ in.
11	<.001	36	0	------	7½	Coal, moderately medium-banded and sparsely thin- or thick-banded; solid wood at 36 ft 1½ in–36 ft 2½ in.
12	<.001	36	7½	------	8½	Coal, sparsely medium-banded; ¼-in fusain streaks at 36 ft 8½ in–36 ft 9½ in; solid wood at 36 ft 10½ in–37 ft 4 in.
13	<.001	37	4	------	6½	Coal, moderately medium-banded, sparsely thin- and thick-banded; ¾-in pyrite nodule at 37 ft 4¼ in–37 ft 5 in; 1/16-in–¼-in fusain streaks at 37 ft 6½ in–37 ft 8½ in.
14	<.001	37	10½	------	6½	Coal, sparsely thin- to thick-banded; 1-in pyrite nodule at 38 ft 3½ in–38 ft 4½ in.
--------	--------	38	5	------	1½	Clay, carbonaceous; thin pyritic streaks at 38 ft 5¼ in.
--------	--------	38	6½	------	6½	Clay, medium-gray; small pyrite nodules and flecks at 38 ft 7 in–38 ft 7½ in, 38 ft 9½ in–38 ft 10 in, 38 ft 11½ in–39 ft.
--------	--------	39	1	------	5½	Clay, medium-gray; ⅛-in pyrite nodule at 39 ft 5½ in.
--------	--------	39	6½	21	7½	(No core sent to laboratory; described at drill site as gray siltstone.)
--------	--------	61	2	------	6	Clay, silty, medium dark-gray; 1/16-in gray sandy streaks throughout sample.
--------	--------	61	8	------	6½	Clay, silty, medium- to dark-gray; carbonaceous at 62 ft 2 in–62 ft 2½ in.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole Ft	Core section: Depth in hole in	Core section: Length Ft	Core section: Length in	Lithologic description and remarks
						BAR H AREA, SLIM BUTTES, HARDING COUNTY, S. DAK.—continued
						Core hole 26—Continued
15	<.001	62	2½	------	8¼	Coal, moderately thin-banded, sparsely medium-banded; broken in coring interval from 62 ft 3 in–62 ft 4½ in and from 62 ft 8½ in–62 ft 10¾ in.
16	<.001	62	10¾	------	8¾	Coal, sparsely thin- to thick-banded; solid wood at 63 ft ¾ in–63 ft 1¾ in; ⅛-in–½-in fusain streaks at 62 ft 11¼ in–63 ft ¾ in.
17	<.001	63	7½	------	3¾	Coal, abundantly medium-banded, sparsely thin- or thick-banded.
--------	--------	63	11¼	------	2¾	(Loss in coring interval from 62 ft 2½ in—64 ft 2 in.)
--------	--------	64	2	------	5¼	Clay, gray, brown; thin to medium woody streaks at 64 ft 3 in–64 ft 6 in.
--------	--------	64	7¼	------	4¾	Clay, silty, light- to medium-gray.
--------	--------	65	0	------	------	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-90760 includes TE samples 1-14. D-90761 includes TE samples 15-17.

						Core hole 27 (NW¼NE¼ sec 35, T. 19 N., R. 8 E.) elev 3,085 ft
1	0.001	10	0	------	2¾	(Top of core sent to laboratory.) Coal, pulverized in coring.
--------	--------	10	2¾	------	2¼	Coal, pulverized and mixed with chocolate-brown clay during coring; thin jarosite streaks at 10 ft 3¾ in–10 ft 4½ in.
--------	--------	10	5	------	3	Clay, chocolate-brown; thin jarosite streaks at 10 ft 5½ in and 10 ft 7¼ in.
--------	--------	10	8	------	2¼	Sand, fine-grained, stained yellow-brown.
--------	--------	10	10¼	------	7¾	Clay, chocolate-brown, intercalated yellow sandy streaks.
--------	--------	11	6	33	9	(No core sent to laboratory; described at drill site as gray siltstone and clay.)
--------	--------	45	3	------	4¼	Clay, silty, dark-gray.
2	<.001	45	7¼	------	9¾	Coal, sparsely thin- to thick-banded; ¼-in pyrite nodule at 46 ft ¼ in.
3	<.001	46	5	------	9	Coal, sparsely thin- to thick-banded; ½-in pyrite nodule at 46 ft 11¾ in–47 ft ¼ in.
4	<.001	47	2	------	8	Coal, moderately thin-banded, sparsely medium-banded; irregular 1¾-in pyrite nodule at 47 ft 2 in.
--------	--------	47	10	------	2	(Loss in coring interval from 45 ft 7 in–48 ft.)
--------	--------	48	0	------	7	Clay, dark-gray; carbonaceous streaks in uppermost ½-in.
--------	--------	48	7	------	7	Clay, dark-gray; thin woody streaks at 49 ft 1 in.
--------	--------	49	2	------	2½	Clay, dark-gray.
--------	--------	49	4½	------	9	Do.
--------	--------	50	1½	------	2½	Coal, sparsely thin- and medium-banded; broken in coring.
--------	--------	50	4	------	2½	Clay, gray.
--------	--------	50	6½	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines): D-90762 includes TE samples 2-4.

						LODGEPOLE AREA AND JOHNSON OUTLIER, PERKINS COUNTY, S. DAK.
						Core hole 11 (SE¼NE¼ sec 19, T. 21 N., R. 12 E.) elev 2,959 ft
--------	--------	40	11	------	6½	(Top of core sent to laboratory.) Clay, buff, plastic.
--------	--------	41	5½	------	½	Clay, black, plastic.
--------	--------	41	6	------	1	Clay, brown, silty.
1	0.002	41	7	------	7½	Coal, moderately woody; core is broken, reserved for petrographic study.
--------	--------	42	2½	------	¾	Clay, carbonaceous.
--------	--------	42	3¼	------	¾	Shale, carbonaceous.
2	.001	42	4	------	10¾	Coal, upper part moderately wood-banded, lower part is abundantly woody; pyritic areas at 42 ft 5½ in, 42 ft 8 in, 42 ft 10 in, 43 ft, and 43 ft 1 in.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

LODGEPOLE AREA AND JOHNSON OUTLIER, PERKINS COUNTY, S. DAK.—continued

Core hole 11—Continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
3	.001	43	2¾	1	¾	Coal, abundantly woody; pyritic zones at 43 ft 6½ in, 43 ft 8 in, 43 ft 10 in, and 44 ft; ½-in of shaly carbonaceous clay at 43 ft 11 in (excluded from fuel sample); black carbonaceous clay at 44 ft ½ in (excluded from fuel sample); core is somewhat broken.
--------	--------	44	3½	------	5½	Clay, dark-gray, plastic, grading to gray, silty; sparse carbonaceous streaks.
--------	--------	44	9	9	5	(No core sent to laboratory; described at drill site as gray clay.)
--------	--------	54	2	------	9½	Clay, gray, slightly silty, grading to plastic clay; pyritic zones found at 54 ft 5 in and 54 ft 6 in; ½-in woody band at 54 ft 9¼ in; ¼-in of carbonaceous shale at 54 ft 11¼ in.
4	.001	54	11½	------	9¼	Coal, dominantly woody; core broken
5	.001	55	8¾	------	11¾	Coal, abundantly wood-banded; pyritic streak at 55 ft 10½ in.
6	.001	56	8½	------	11	Coal, moderately woody; core is badly broken.
7	.001	57	7½	------	8	Coal, moderately wood-banded; core is broken.
--------	--------	58	3½	------	1½	Shale, black, coaly streaks.
8	.001	58	5	------	7½	Coal, abundantly woody; core is broken.
9	.001	59	½	------	9½	Coal, probably moderately woody; core is not coherent.
--------	--------	59	10	2	10	(No core sent to laboratory; described at drill site as gray sandy clay.)
10	.001	62	8	1	½	Coal, upper part is moderately wood-banded; lower part is dominantly woody; ¼-in dark-brown clay at 62 ft 9¾ in (excluded from fuel sample); ⅛-in clay at 62 ft 10½ in (excluded from fuel sample); lowest 1-in is probably impure.
--------	--------	63	8½	------	7¼	Siltstone, coaly, grading to carbonaceous siltstone, with thin white and gray siltstone bands.
--------	--------	64	3¾	1	7¼	Siltstone, gray, with carbonaceous streaks; brown siltstone area at 64 ft 4 in; 1-in diagonal band of coal at 64 ft 10½ in; lower part contains fewer carbonaceous areas.
--------	--------	65	11	------	------	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-69688 includes TE samples 1-3. D-69689 includes TE samples 4-9. D-69690 includes TE sample 10.

Core hole 12 (NW¼SE¼ sec 19, T. 21 N., R. 12 E.) elev 2,961 ft

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
1	<0.001	37	4	------	2¾	(Top of core sent to laboratory.) Shale, yellow, silty, very sparse lignitic spots.
2	.001	37	6¾	------	7¼	Clay; upper part is plastic, buff, gray and yellow clay; middle part is shaly clay; lower part is dark-brown clay; 1-in of coaly shale at 37 ft 10 in; ¾-in of coaly shale at 38 ft 1½ in.
3	<.001	38	2	1	0	Shale, gray, silty at top; upper part is silty clay; middle and lower parts are shaly silty clay with diffuse carbonaceous streaks; 1½-in carbonaceous shale, grading to coaly shale at bottom.
--------	--------	39	2	13	7	(No core sent to laboratory; described at drill site as gray clay.)
--------	--------	52	9	1	2½	Clay, gray, somewhat plastic; 2¼-in of coaly shale at bottom.
4	<.001	53	11½	1	2¼	Coal; upper half is dominantly woody; lower half is abundantly woody; thin pyritic streak at 54 ft 1¼ in; fusain streaks in middle part; ¼-in fusain streak at 54 ft 7¾ in; impure specks and thin impure streaks of fusain in lower part.
5	<.001	55	1¾	1	1	Coal, sparsely woody banded; many fusain streaks throughout; ½-in fusain streak at 56 ft; sparse impure fusain specks in upper part.
6	<.001	56	2¾	1	7½	Coal, moderately wood-banded; ⅛-in fusain streak at 56 ft 3¾ in, thin fusain streaks in lower part; ¼-in pyritic rosette at 56 ft 4 in, ½-in pyritic band at 56 ft 6 in.
7	<.001	57	10¼	1	1½	Coal, moderately wood-banded; ¼-in fusain band at 57 ft 10¾ in; ¼-in fusain rosette at 57 ft 11¼ in and 58 ft ¾ in; fusain streak at 58 ft 7¾ in.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
						LODGEPOLE AREA AND JOHNSON OUTLIER, PERKINS COUNTY, S. DAK.—continued
						Core hole 12—Continued
8	<.001	58	11¾	1	6¼	Coal; upper part is abundantly woody; lower part is dominantly woody; numerous fusain streaks and rosettes in upper part; ½-in fusain band at 59 ft 7¼ in; fusain lenticles at 59 ft 11 in and 59 ft 11½ in.
9	<.001	60	6	1	1	Coal, moderately woody; fusain lenticles at 60 ft 9½ in and 60 ft 11 in; lower part of core is broken, somewhat incoherent.
--------	--------	61	7	------	1	(Loss in coring interval from 52 ft 9 in–61 ft 8 in.)
10	<.001	61	8	1	6	Siltstone, carbonaceous, buff colored specks; coaly bands from 62 ft 4 in–62 ft 7 in; ¾-in coaly band at 63 ft.
--------	--------	63	2	------	7	Siltstone, gray; a few coaly streaks.
--------	--------	63	9	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines): D–69687 includes TE samples 4–9.

Core hole TE sample No.	Uranium (percent)	Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
						Core hole 13 (NW¼NE¼ sec 19, T. 21 N., R. 12 E.) elev 2,949 ft
--------	--------	32	11	------	5½	(Top of core sent to laboratory.) Clay, silty, gray, grading to plastic clay; pyritic specks throughout clay; ¾-in gypsum crystal at 32 ft 11½ in.
1	0.002	33	4½	------	1¼	Coal.
--------	--------	33	5¾	------	5¾	Siltstone, brown, carbonaceous.
2	.001	33	11½	------	10	Coal, impure, weathered, with gypsum crystal and pyritic specks; lower part is coaly clay; ¾-in pyritic rosette at 34 ft 4¾ in; ½-in tabular crystal of gypsum at 34 ft 6¼ in.
3	.001	34	9½	------	6¾	Coal, woody, weathered, irregular thin clay streaks; lower part is dominantly woody.
4	<.001	35	4¼	1	1¼	Coal, dominantly woody, highly weathered.
5	<.001	36	5½	1	6½	Coal, dominantly woody, highly weathered.
--------	--------	38	0	------	9	Shale, clayey; coaly at top; plastic brown clay in middle part; lower part is gray silty clay.
--------	--------	38	9	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines): D–69737 includes TE samples 4 and 5.

Core hole TE sample No.	Uranium (percent)	Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
						Core hole 14 (SE¼SE¼ sec 9, T. 21 N., R. 11 E.) elev 3,015 ft (Johnson outlier)
1	0.003	14	6	------	2	(Top of core sent to laboratory.) Clay, plastic, gray.
2	.036	14	8	------	6	Coal, highly weathered, pulverulent and crumbly.
3	.028	15	2	------	6	Do.
4	.021	15	8	------	6	Do.
5	.013	16	2	------	6	Do.
6	.008	16	8	------	6	Do.
7	.002	17	2	------	6	Do.
8	.001	17	8	------	6	Do.
9	<.001	18	2	------	6	Do.
10	<.001	18	8	------	6	Do.
11	<.001	19	2	------	6	Do.
12	<.001	19	8	------	6	Do.
13	<.001	20	2	------	6	Coal, highly weathered, pulverulent and crumbly, but a 1-in hard impure band at 20 ft 5 in (sent for TE analyses but excluded from fuel sample).
14	<.001	20	8	------	6	Coal, highly weathered, pulverulent and crumbly.
15	<.001	21	2	------	6	Do.
16	.001	21	8	------	8¾	Do.
--------	--------	22	4¾	------	3	Siltstone, hard.
--------	--------	22	7¾	------	4¼	Sandstone, clayey, hard.
--------	--------	23	------	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines): D–69738 includes TE samples 2–16.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
LODGEPOLE AREA AND JOHNSON OUTLIER, PERKINS COUNTY, S. DAK.—continued						
Core hole 15 (SE¼SW¼ sec. 9, T. 21 N., R. 11 E.) elev 3,017 ft (Johnson outlier)						
1	0.008	18	2	------	6	(Top of core sent to laboratory.) Coal, highly weathered, pulverulent, crumbly.
2	.005	18	8	------	6	Do.
3	.004	19	2	------	6	Do.
4	<.001	19	8	------	6	Do.
5	<.001	20	2	------	6	Do.
6	<.001	20	8	------	6	Do.
7	<.001	21	2	------	6	Do.
8	<.001	21	8	------	6	Do.
9	<.001	22	2	------	6	Do.
10	<.001	22	8	------	6	Do.
11	<.001	23	2	------	6	Do.
12	<.001	23	8	------	4½	Coal, same as above; lower ½-in is impure.
--------	--------	24	½	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines): D-69739 includes TE samples 1-12.)

Core hole TE sample No.	Uranium (percent)	Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
MEDICINE POLE HILLS AREA, BOWMAN COUNTY, N. DAK.						
Core hole 5 (SW¼SE¼ sec. 35, T. 131 N., R. 104 W.) elev 3,427 ft						
--------	--------	64	4	4	5½	(Top of core sent to laboratory.) Clay, brown, a little silt, blocky irregular fracture joints at 68 ft, grading to a less silty clay at 68 ft 5 in, then grading to highly plastic soft slightly darker brown clay; oblique irregular joints still present.
1	0.004	68	9½	------	¼	Coal badly crushed.
2	.011	69	1¾	------	7¾	Coal, attrital, a few woody streaks; upper part is coherent but weakened by horizontal and vertical cracks; lower part is broken.
3	.007	69	9½	------	9	Coal, sparsely thin- to medium-banded; dominantly attrital.
4	.007	70	6½	------	8	Coal, moderately wood-banded; very dull attrital coal.
5	.006	71	2½	------	8¼	Coal, similar to that in sample above, 2-in wood band at base.
6	.003	71	10¾	------	11¼	Coal, badly crushed, including one woody piece 1-in thick at about the middle; lower 6-in of crushed coal dried out in shipment; most of the coal appears to be attrital.
--------	--------	72	10	------	------	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines): D-68866 includes TE samples 1-6.

Core hole TE sample No.	Uranium (percent)	Depth in hole, Ft	Depth in hole, in	Length, Ft	Length, in	Lithologic description and remarks
Core hole 6 (SE¼NE¼ sec 2, T. 130 N., R. 104 W.) elev 3,247 ft						
0	0.002	58	3	------	2	(Top of core sent to laboratory.) Clay, plastic, slightly silty, iron-stained, brown to buff.
1	.004	58	5	1	1¼	Coal, pulverized and mud-smeared to 59 ft and badly broken below.
2	.004	59	6¼	------	10¾	Coal, moderately woody, medium- to thick-banded; an irregular pyritic streak ½-in thick in upper portion.
3	.006	60	5	1	------	Coal, sparsely to moderately wood-banded; more attrital coal than in above sample.
4	.004	61	5	1	2¼	Coal, moderately to dominantly woody; pyritic nodule 1 inch in diameter in lower part.
5	.006	62	7¼	1	¼	Coal, moderately woody; core slightly broken at the top; ½-in pyritic nodule at 63 ft 2½ in.
6	.009	63	7½	------	6	Coal, moderately medium-banded with ⅜-in black plastic clay parting at 63 ft 11⅝ in (excluded from fuel sample).
7	.002	64	1½	------	6½	Clay, buff, plastic, of grainy texture, and having tiny root fragments; a few dominantly woody fragments are also present.
--------	--------	64	8	------	9	Do.
--------	--------	65	5	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines): D-68867 includes TE sample 1. D-68868 includes TE samples 2-6.

TABLE 6.—*Lithologic descriptions of lignite cores from the Bar H area, Harding County, S. Dak., the Lodgepole area and Johnson outlier, Perkins County, S. Dak., and the Medicine Pole Hills area, Bowman County, N. Dak.*—Continued

Core hole TE sample No.	Uranium (percent)	Core section				Lithologic description and remarks
		Depth in hole		Length		
		Ft	in	Ft	in	
MEDICINE POLE HILLS AREA, BOWMAN COUNTY, N. DAK.—continued						
Core hole 8 (NW¼SW¼ sec 1, T. 130 N., R. 104 W.) elev 3,414 ft						
1	0.005	29	6	------	6	(Top of core sent to laboratory.) Coal apparently banded, probably mostly attrital, very badly weathered, too friable to saw.
2	.012	30	0	1	0	Do.
3	.016	31	0	1	0	Do.
--------	--------	32	0	2	11	Clay, silty, grading downward to clayey siltstone at about 34 ft; the clay and siltstone are brown, of grainy texture, and having a few small root traces and coaly lenticles.
--------	--------	34	11	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines): D-68870 includes TE samples 1-3.

Core hole TE sample No.	Uranium (percent)	Depth Ft	Depth in	Length Ft	Length in	Lithologic description and remarks
Core hole 9 (NW¼NE¼ sec 2, T. 130 N., R. 104 W.) elev 3,422 ft						
--------	--------	52	3	------	9	(Top of core sent to laboratory.) Claystone, brown, coherent, soapy.
1	0.005	53	0	------	7¼	Coal, considerably broken, probably mostly attrital.
2	.006	53	7¼	------	8½	Coal, somewhat broken, possibly 20 percent is woody; ½-in pyritic lens at 54 ft 2½ in.
3	.005	54	3¾	------	10	Coal; about 30 percent is woody; core is fairly coherent.
4	.006	55	1¾	------	11½	Coal; probably less than 20 percent is woody; much broken in the lower part.
5	.008	56	1¼	------	11¼	Coal; about 25 percent is woody.
6	.006	57	½	1	0	Coal, about 80 percent woody, to 57 ft 8½ in; then principally attrital coal, pyritic nodules and lenticles, diameter about ½-in, at 57 ft 3 in and 57 ft 7 in; core is coherent.
--------	--------	58	½	------	8¾	Claystone, silty, dark-brown in uppermost inch, grading to light brown; small sandy lenticles and a few coaly streaks.
--------	--------	58	9¼	------	2¾	(Loss in coring interval at 52 ft 3 in-59 ft.)
--------	--------	59	------	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines): D-68871 includes TE samples 1-6.

Core Drilling for Uranium-Bearing Lignite, Mendenhall Area, Harding County South Dakota

By J. R. GILL, H. D. ZELLER, *and* J. M. SCHOPF

URANIUM IN COAL IN THE WESTERN UNITED STATES

GEOLOGICAL SURVEY BULLETIN 1055-D

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CORE DRILLING FOR URANIUM-BEARING LIGNITE, MENDENHALL AREA, HARDING COUNTY, SOUTH DAKOTA

By James R. Gill, Howard D. Zeller, and James M. Schopf

ABSTRACT

Core drilling for data on uranium-bearing lignite in the Mendenhall area, near the center of the Slim Buttes, Harding County, S. Dak., was conducted by the Geological Survey in the summer of 1951 and by the Bureau of Mines during the period October 1952–July 1953. Samples from 49 core holes having a total footage of 11,146 feet, drilled in an area of about 9 square miles, indicate a reserve of about 127 million tons of lignite, of which about 49 million tons contain an average of 0.005 percent uranium or more. The uranium-bearing lignite averages 5.4 feet in thickness and occurs in the Ludlow member of the Fort Union formation of Paleocene age.

Fuel analyses of about 130 samples indicate that the lignite contains about 15 percent ash, 37 percent moisture, 24 percent fixed carbon, 24 percent volatile matter, and 1.5 percent sulfur and has a heating value of about 5,800 Btu (as received condition).

In the Slim Buttes, exclusive of the Mendenhall area, approximately 60 square miles are underlain by uranium-bearing lignite having an average thickness of five feet and an average uranium content of 0.007 percent or more, and having a potential reserve of 340 million tons of uranium-bearing lignite.

The core samples indicate only the stratigraphically highest lignite bed beneath the unconformity at the base of the Chadron formation of Oligocene age contains appreciable quantities of uranium. Data indicate that the uranium in the lignite is of secondary origin, having been leached and transported by ground water from the mildly radioactive tuffaceous rocks that unconformably overlie the lignite-bearing strata.

INTRODUCTION

Seven core holes were drilled for uranium-bearing lignite in the Mendenhall area, Harding Co., S. Dak., by a contractor for the U. S. Geological Survey during the summer of 1951; additional drilling was carried on by the U. S. Bureau of Mines, between October 1952 and July 1953, in the same area under the direction of Glen Walker, Bureau of Mines Mine Examination and Exploration Engineer. Forty-nine holes having a total footage of about 11,146 feet were drilled. Uranium-bearing lignite was found in cores from 38 holes.

LOCATION AND ACCESSIBILITY

The Mendenhall area includes 9 square miles in the central part of the Slim Buttes (fig. 13) in southeastern Harding County, and about 18 miles airline southeast of Buffalo, S. Dak. The west part of the area may be reached from Buffalo by traveling 12 miles east on State Route 8, then 7 miles south on a county road, and 4 miles east on an unimproved road. The central part of the Mendenhall area, occupying the flat tableland at the top of the Slim Buttes, can best be reached from J B Pass by a Forest Service dirt road that extends north along the crest of the divide for 4 miles. The nearest rail-shipping points are Reeder, N. Dak., 55 miles to the north, and Newell, S. Dak., 70 miles to the south.

PREVIOUS WORK

The geology and lignite deposits of the Slim Buttes area have been described by Winchester and others (1916), the structural geology in relation to oil and gas by Toepelman (1923), and the general geology by Baker (1952). In 1949, uraniferous lignite was discovered by Beroni and Bauer (written communication, 1952) in the vicinity of Reva Gap, about 4 miles north of the Mendenhall area. The following year, the work of Denson, Bachman, and Zeller (see chapter B, this bulletin) extended the area of known occurrence in the Slim Buttes and elsewhere in the Dakotas. As a result of this work, an exploratory drilling program was started in the Slim Buttes area in 1951.

Concurrently with exploratory drilling a petrographic examination of the uranium-bearing lignite was undertaken by Schopf (Schopf and Gray, 1954) and Koppe (T. F. Bates, written communication, 1952). The geochemistry of the lignite was investigated by I. A. Breger, Maurice Deul and Samuel Rubinstein (1955).

ACKNOWLEDGMENTS

George W. Moore logged cores and cuttings from the drilling in February 1953 and returned to the area in June to assist in the completion of the geologic studies related to the drilling. Roy C. Kepferle, Murray Levish, and Robert E. Melin joined the project in July and assisted J. R. Gill until its completion in August 1953.

James M. Schopf and other members of the Geological Survey laboratory at Columbus, Ohio, provided detailed descriptions and radioactivity logs of several of the lignite cores (table 9). Chemical analyses, radioactivity measurements, and semiquantitative spectographic determinations were made in the Washington, D. C., and Denver, Colo., laboratories of the Geological Survey (table 7). Proximate and ultimate analyses of lignite cores were made by the U. S. Bureau of Mines (table 8).

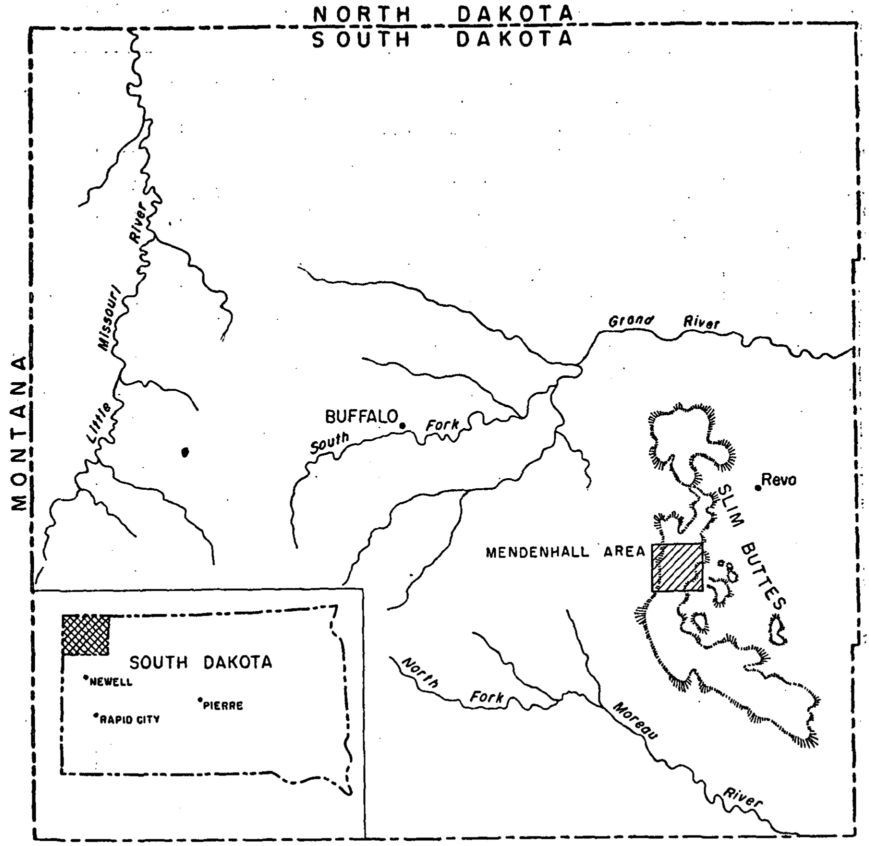

FIGURE 13.—Index map of Harding County, S. Dak., showing location of the Mendenhall area.

The writers express their appreciation to the local ranchers, particularly Vernon, William, and Esther Wammen, for the many courtesies extended.

DRILLING OPERATIONS

In the summer of 1951, 7 holes totaling 1,464 feet were drilled in the Mendenhall area, by a contractor for the Geological Survey, under the supervision of H. D. Zeller. The cores from these holes were split and described by James M. Schopf. Information obtained from this drilling indicated that the lignites in the Slim Buttes were potential sources of uranium and fuel. More extensive drilling exploration for uraniferous lignite in this area (pl. 22) was begun in October 1952 by the U. S. Bureau of Mines in cooperation with the U. S. Geological Survey. Forty-two holes totaling 9,682 feet were drilled. Drilling was completed in July 1953. Table 1 shows the location, surface ele-

TABLE 1.—*Summary of data for core holes drilled in the Mendenhall area, Harding County, South Dakota*

Core hole [1]	Location		Elevation [2] [surface] (Feet above sea level)	Total depth (Feet)	Solid-bit drilling (Feet)	Core drilling (Feet)
	Section	Township and range				
GS-1	SE¼SW¼ 1	T. 17 N., R. 7 E	3,300	50.0	15.0	35.0
GS-2	SW¼NE¼ 1	do	3,305	75.0	35.0	40.0
GS-3	SW¼SE¼ 36	T. 18 N., R. 7 E	3,325	141.0	20.0	121.0
GS-4	NW¼SE¼ 36	do	3,300	93.0	22.0	71.0
GS-16	SE¼NW¼ 31	T. 18 N., R. 8 E	3,570	348.0	216.0	132.0
GS-17	SW¼SW¼ 6	T. 17 N., R. 8 E	3,635	375.0	290.0	85.0
GS-18	SE¼NE¼ 1	T. 17 N., R. 7 E	3,610	382.0	300.0	82.0
SD-1	NE¼NW¼ 12	do	3,325	106.2	3.0	103.2
SD-2	SW¼SE¼ 1	do	3,410	194.3	96.2	98.1
SD-3	SE¼SW¼ 1	do	3,285	100.0	15.0	85.0
SD-3A	SE¼SW¼ 1	do	3,310	82.0	23.0	59.0
SD-4	NW¼SE¼ 1	do	3,295	135.0	41.0	94.0
SD-5	SW¼NE¼ 1	do	3,295	114.1	21.0	93.1
SD-6	NW¼NE¼ 1	do	3,305	93.0	13.0	80.0
SD-7	SE¼SW¼ 36	T. 18 N., R. 7 E	3,315	25.0	15.0	10.0
SD-7A	SE¼SW¼ 36	do	3,310	143.0	13.0	130.0
SD-7B	SE¼SW¼ 36	do	3,310	99.0	13.0	86.0
SD-8	SE¼NW¼ 36	do	3,330	163.0	13.0	150.0
SD-9	NW¼SW¼ 7	T. 17 N., R. 8 E	3,595	270.0	270.0	------
SD-9A	NW¼SW¼ 7	do	3,600	342.0	5.7	336.3
SD-10	NE¼SE¼ 12	T. 17 N., R. 7 E	3,630	391.5	260.0	131.5
SD-11	NE¼NE¼ 12	do	3,510	290.0	173.0	117.0
SD-12	SW¼NW¼ 7	T. 17 N., R. 8 E	3,490	321.0	130.0	191.0
SD-13	SW¼NE¼ 7	do	3,460	220.5	120.0	100.5
SD-14	SW¼SE¼ 6	do	3,370	143.0	83.0	60.0
SD-15	NW¼SW¼ 6	do	3,605	413.0	291.0	122.0
SD-16	NW¼NE¼ 6	do	3,600	397.0	270.0	127.0
SD-17	SE¼NE¼ 6	do	3,520	382.0	200.0	182.0
SD-17A	SE¼NE¼ 6	do	3,395	100.0	100.0	------
SD-18	SW¼NE¼ 5	do	3,370	183.0	100.0	83.0
SD-18A	SW¼NE¼ 5	do	3,320	150.0	65.0	85.0
SD-19	SW¼SW¼ 31	T. 18 N., R. 8 E	3,600	420.0	310.0	110.0
SD-20	SW¼SE¼ 31	do	3,600	378.2	292.0	86.2
SD-21	SE¼SE¼ 31	do	3,615	417.0	292.0	125.0
SD-22	SE¼NE¼ 31	do	3,585	400.0	290.0	110.0
SD-23	NE¼NW¼ 31	do	3,560	372.0	232.0	140.0
SD-24	NW¼NW¼ 31	do	3,590	379.9	10.0	369.9
SD-25	NE¼SE¼ 36	T. 18 N., R. 7 E	3,595	405.0	292.0	113.0
SD-26	NE¼SE¼ 7	T. 17 N., R. 8 E	3,365	170.0	81.0	89.0
SD-27	NE¼SW¼ 8	do	3,285	103.0	22.0	81.0
SD-28	SE¼NE¼ 7	do	3,435	228.7	143.0	85.7
SD-29	SW¼NW¼ 8	do	3,305	114.0	43.0	71.0
SD-30	SW¼SE¼ 6	do	3,320	143.0	10.0	133.0
SD-31	SE¼SE¼ 6	do	3,285	99.0	10.0	89.0
SD-32	NE¼SE¼ 6	do	3,310	149.0	35.0	114.0
SD-33	SE¼NW¼ 5	do	3,305	100.0	30.0	70.0
SD-35	NE¼SW¼ 6	do	3,585	400.5	300.0	100.5
SD-36	SW¼NE¼ 32	T. 18 N., R. 8 E	3,270	114.0	13.0	101.0
SD-38	SE¼SW¼ 32	do	3,330	135.0	13.0	122.0
SD-39	NW¼SE¼ 7	T. 17 N., R. 8 E	3,515	296.5	182.0	114.5

[1] Prefix GS denotes core holes drilled for the U. S. Geological Survey in 1951; prefix SD denotes holes drilled by the U. S. Bureau of Mines in 1952-53.
[2] Elevations established by single-base altimetry.

vation, total depth, and footage of core and solid-bit drilling done by the Geological Survey in 1951 and by the Bureau of Mines in 1952–53.

In drilling beds of uranium-bearing lignite, coring was started 20 feet or more above the stratigraphically highest bed of lignite and stopped at a depth of 60 feet below its base. All lignite beds, regardless of stratigraphic position, were sampled and analyzed. The lignite cores were securely wrapped in waxed paper and sample intervals, approximately one foot in length, for uranium analyses were indicated.

Lignite cores from holes SD–8, –10, and –19 were split and described by James M. Schopf, with the remaining cores being split at the Bureau of Mines laboratory at Grand Forks, N. Dak. Half of the core was forwarded to the Geological Survey laboratories for uranium determination; the other half was used by the Bureau for proximate and ultimate fuel analysis.

In this report the description of the geology of the area drilled includes an interpretation of the geological significance of the distribution of the uranium in the receptor beds, the structure and correlation of the lignite beds and associated strata, the vertical and areal extent of active aquifiers, and estimates of tonnage of uranium-bearing and other lignite.

STRATIGRAPHY

Lignite-bearing strata in the Mendenhall area are of Paleocene age. They are unconformably overlain by beds of bentonitic clay and tuffaceous sandstone of Oligocene and Miocene age and conformably overlie Cretaceous strata. The rocks are all of continental origin, but sedimentation ranged from the deposition of material to form lignite to the deposition of volcanic ash. The sequence of sedimentation was broken by at least two periods of uplift and erosion; one is indicated by the unconformity at the base of rocks of Oligocene age; the other, by the unconformity at the base of rocks of Miocene age.

TERTIARY ROCKS

FORT UNION FORMATION

Ludlow member.—The Ludlow member of the Fort Union formation conformably overlies the Hell Creek formation of Cretaceous age. The Ludlow member, the lowermost member of the Fort Union formation, is the only unit of Paleocene age in the Mendenhall area, as it is unconformably overlain by rocks of the Chadron formation of Oligocene age. In the northern part of Harding County, the Ludlow grades into the marine Cannonball formation and is conformably overlain by the Tongue River member of the Fort Union formation.

Rocks of the Ludlow member include poorly indurated yellowish-brown fine-grained sandstone and siltstone; gray clay shale; and lignite, in part, uranium bearing. The Ludlow is estimated to be about 200 feet thick in the Mendenhall area. At the type locality near the Ludlow Post Office (sec. 28, T. 22 N., R. 6 E.), S. Dak., its thickness is about 350 feet.

The rocks of the Ludlow member are covered at most places by vegetation and by landslide debris from the overlying White River group and Arikaree formation. The lignite beds are traceable for only short distances along the face of the Slim Buttes, but core-hole data indicate that they are the most persistent beds in the Ludlow.

However, closely spaced surface sections or core holes are necessary to avoid miscorrelation (pl. 23), because they differ considerably in thickness throughout the area and may either diverge or join within short distances. The sandstone, siltstone, and shale are lenticular and are not reliable for correlation (pls. 24–28).

Most of the sandstone and siltstone is poorly consolidated, and attempts to core these rocks were not always successful because the drilling water had a tendency to wash away the core. The lignite was cored with satisfactory core recovery, except in shallow holes where it is weathered. The determination of rock where cores were lost was difficult, as the water return was generally poor and cuttings could not be recovered. For shallow holes, determinations of loss in coring could generally be made by extrapolation from nearby surface exposures or adjacent core holes. Consistent loss of water in uncased holes made the determination of aquifers in the Ludlow member impossible.

The Ludlow member of the Fort Union formation is unconformably overlain by the Chadron formation of Oligocene age. The contact between the two formations is difficult to identify because the uppermost beds of the Ludlow are yellow stained and reworked material of a similar color occurs in the basal few feet of the Chadron.

WHITE RIVER GROUP

The White River group of Oligocene age is divided into the Chadron and Brule formations. The Chadron formation is present throughout the area, but the Brule formation is preserved only in dropped blocks (pl. 22) that represent landslides occurring before deposition of the overlying Arikaree formation.

Chadron formation.—The Chadron formation of Oligocene age unconformably overlies the Ludlow member of the Fort Union formation. In normal succession the Chadron is conformably overlain by the Brule formation. However, at most places in the Mendenhall area the Brule is absent and the Chadron is unconformably overlain by the Arikaree formation. The basal part of the Chadron formation consists of bright-yellow to dark yellowish-orange sandstone and siltstone reworked from the underlying rocks. The rest of the formation is composed of white fine- to coarse-grained pebbly sandstone and light olive-gray bentonite. Lenticular beds of tuffaceous sandstone and opalized clay are present locally.

The thickness of the Chadron formation ranges from 60 feet in the northeastern part of the area to more than 150 feet in the southwest. Impervious beds of bentonite near or at the top of the formation form the base of a perched water table. Springs issue at the top of these beds along the margins of the buttes. In the southern part of the Slim Buttes, carnotite-bearing sandstone has been found at this stratigraphic position (Gill and Moore, 1955). The sandstone and bentonite of the Chadron contain about 0.001 percent uranium, as compared to the average for sandstone of 0.00012 (Rankama and Sahama, 1950). The water from springs that issue from the Chadron formation contains from 10 to 200 parts per billion of uranium.

Brule formation.—The Brule formation of Oligocene age is exposed only as narrow northwest-trending pre-Arikaree landslide blocks in the northeast part of the Mendenhall area. The formation is composed of thin-bedded to massive, pink to tan, sandy, tuffaceous claystone, siltstone, and sandstone, and is similar in lithology and age to the Brule formation as exposed in the Big Badlands of Pennington County, South Dakota. The thickness of the Brule formation ranges from 20 to more than 140 feet, a part of the formation, of unknown thickness, having been eroded.

Valleys more than 300 feet deep were cut into the Brule, Chadron and Ludlow rocks of this area before deposition of the Arikaree formation. After valley cutting, large-scale landsliding occurred, massive blocks of Brule and Chadron rocks sliding into the valleys. These landslide blocks average about 300 yards in width and at many places are several miles long. The trend of the blocks is consistently northwest, with dips toward the plane of movement ranging from 5° to 30°. The Chadron rocks involved in the slumping are generally highly contorted; the more indurated Brule rocks show little evidence of movement other than having steep uniform dips.

Tuffaceous claystone, siltstone and sandstone of the Brule formation contain on the average about 0.001 percent uranium, and vertebrate fossils from these rocks commonly contain more than 0.01 percent uranium. At many places the fossils are coated with a yellow nonfluorescent uranium mineral.

ARIKAREE FORMATION

The Arikaree formation of Miocene age is composed dominantly of yellowish-gray very fine-grained tuffaceous sandstone. In the Mendenhall area it has a thickness of about 200 feet. The basal 50 feet contains much material reworked from the underlying Brule and Chadron formations and is thin-bedded, in contrast with the more massive upper part. Locally, one or more beds of conglomerate occur at or near the base of the formation. These beds of conglomerate are usually made up of claystone pebbles and cobbles averaging 2 inches in diameter, most of which appear to have been derived from the Brule formation.

Tuffaceous sandstone of the Arikaree formation forms the caprock and the steep upper cliffs at Slim Buttes. No fossils have been found in the Arikaree formation in the Slim Buttes region. However, Wood (1945) has described a beaver of late Miocene age from similar rocks in southeastern Montana which probably are correlative with the Arikaree formation in the Slim Buttes.

Rocks of the Arikaree formation, as well as those of the Chadron and Brule formations, contain an average of about 0.001 percent uranium. It is thought that this uranium is in the volcanic material which composes the greater part of the formation.

QUATERNARY DEPOSITS

Deposits of probable Pleistocene age consist of (1) alluvial fans extending outward from the bases of cliffs, (2) terraces along stream valleys, and (3) landslide material. Many of these deposits are similar in appearance to rocks in the White River group because much of their material was derived from those rocks. The terrace deposits have relatively flat upper surfaces, but recent erosion has cut into these surfaces at many places, leaving the deposits as isolated "tables." These deposits were not mapped. Landslides are extensive around the periphery of the Slim Buttes. The landslide blocks and masses are made up largely of Arikaree and White River rocks but at a few places may contain rocks of the Ludlow member of the Fort Union formation.

STRUCTURE

The broad regional structure of the Ludlow member of the Fort Union formation is that of a gentle homocline that dips about 1° to the northeast into the Williston basin. Structure contours on the top of the upper bench of the Olesrud lignite bed in the Mendenhall area show the presence of minor structures that are alined normal to the regional dip (pl. 22). These minor structures are small anticlines and synclines, the axes of which strike northeast. The Arikaree formation is essentially horizontal, as are the Chadron and Brule formations except where they form landslide blocks.

LIGNITE DEPOSITS

The Mendenhall area is underlain by four important lignite seams in the Ludlow member of the Fort Union formation. From top to bottom these are the Mendenhall rider lignite bed, the Mendenhall lignite bed, and the upper and lower benches of the Olesrud lignite bed. The lignite beds dip gently to the north and are truncated by rocks of the overlying Chadron formation. Therefore, the areal extent of the stratigraphically highest bed, the Mendenhall rider bed, is confined to the northern one-third of the area, the Mendenhall bed underlies the northern half of the area, and the upper and lower benches of the Olesrud bed underlie all of the area (fig. 14). Each bed is uranium bearing; however, only where it is the stratigraphically highest bed. Two beds occur below the lower bench of the Olesrud and are here designated the *Y* and *Z* lignite beds (pls. 24–28). They are present throughout much of the area, and at a few places are as much as 2.5 feet thick. In hole SD—6 (fig. 24) where the lignite beds are close together, lignite constitutes 30 feet of a stratigraphic interval of 34 feet.

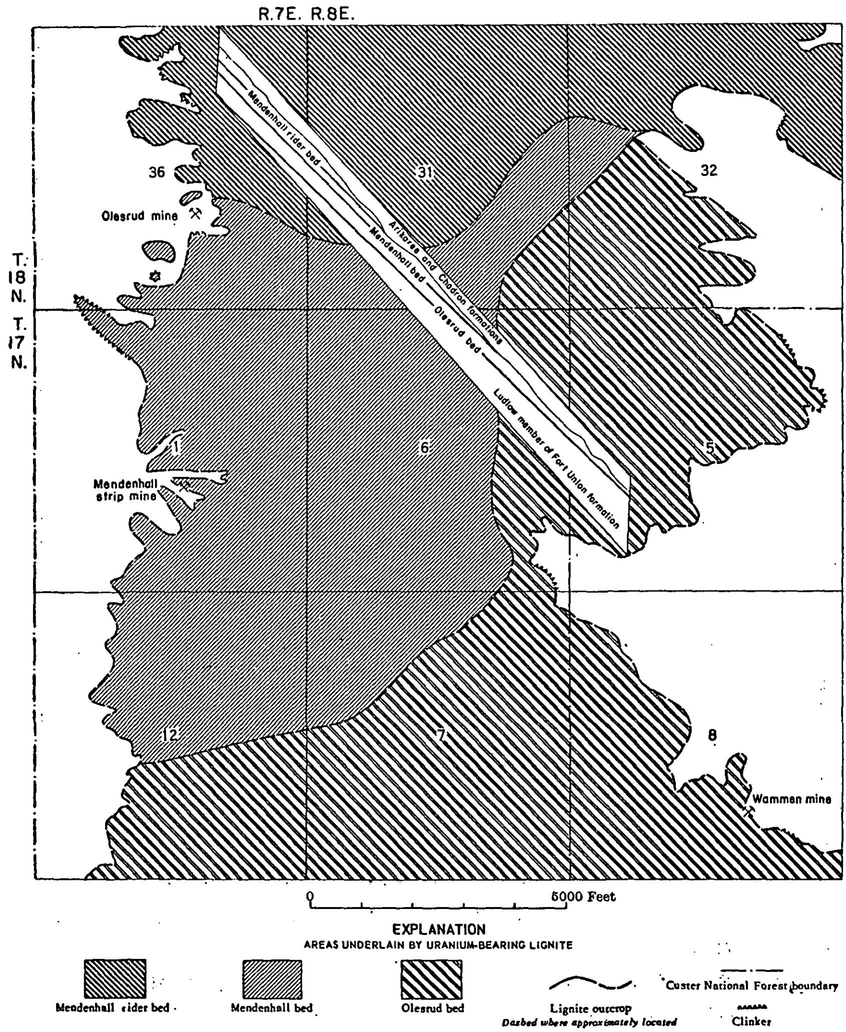

FIGURE 14.—Sketch map showing areal distribution of uranium-bearing lignite in the Mendenhall area, Slim Buttes, Harding County, S. Dak.

The lignites of the Mendenhall area are dominantly banded coals. The banding is primarily a function of the occurrence of elongate lenses of large fragments of woody trunks and roots of ancient plants. In describing (see table 9) banded coals the important features are (1) the thickness of bands, and (2) the frequency of occurrence of these bands. Thickness and frequency are described using the terms according to the following definitions:

(1) Thickness of woody bands[1]

- Thin bands__ about 1/50–1/12 inch (0.5–2.0 mm)
- Medium bands__ about 1/12–1/5 inch (2.0–5.0 mm)
- Thick bands__ about 1/5–2 inches (5.0–50.0 mm)
- Very thick bands__ more than 2 inches (more than 50.0 mm)

(2) Frequency of occurrence (percentage of the layer)

- Sparse__________ less than 15 percent
- Moderate______________ 15–30 percent
- Abundant______________ 30–60 percent
- Dominant_______ more than 60 percent

[1] Woody bands less than about 1/50 inch (0.5 mm) thick are regarded as a part of attrital coal.

The lithologic description of lignite cores (table 9) and the selection of samples for uranium and semiquantitative spectrographic analyses (TE) and for fuel analyses were made at the Geological Survey laboratory at Columbus, Ohio, under the direction of James M. Schopf. Chemical determination of percent uranium and semiquantitative spectrographic analysis for other elements in the lignite (table 7) was made by the U. S. Geological Survey, and the proximate and ultimate fuel analysis by the U. S. Bureau of Mines at Pittsburgh, Pa.

Cores were sawed to include about one-fourth the volume of the core in samples for chemical and semiquantitative spectrographic analyses. A similar quadrant of the coal in the core constituted the Bureau of Mines sample for fuel analysis of the lignite. The remainder of the core was reserved for the preparation of thin sections and for more detailed study of radioactive-material distribution in lignite constituents.

Semiquantitative spectrographic determinations were made of the ash of lignite and carbonaceous shale to determine vertical distribution and possible relationship of uranium to other trace metals. Preliminary study of spectrographic data indicates that only molybdenum shows consistent relationship to uranium. In samples of lignite ash with a large uranium content the molybdenum content is large and in samples of small uranium content the molybdenum content is small.

Table 7 lists semiquantitative spectrographic analyses of ash of lignite and carbonaceous shale from cores and bulk-sample pits. The minimum amounts of elements detectable with semiquantitative spectrographic methods are listed in table 6.

In conjunction with petrographic work on the lignite, the staff of the coal geology laboratory made a preliminary investigation of the plant microfossil assemblages. Their work indicates a distinctive group of plant spores and pollen is present in the lower bench of the Olesrud lignite bed and helps confirm correlations made in the field.

QUALITY

The lignite of the Mendenhall area is dark brown to black and has a dull luster on a fresh surface. On exposure to air the lignite loses moisture and slacks in a short time. Weathering also results in a change in luster from dull to vitreous. A detailed study of the various lignite constituents and their relationship to uranium was undertaken by the Geological Survey's coal geology laboratory (Schopf and Gray, 1954).

A total of 135 samples of lignite from the six beds in Mendenhall area were submitted to the U. S. Bureau of Mines for proximate and ultimate fuel analyses (table 8). Proximate and ultimate analyses for each bed have been averaged and are summarized in table 2. Five samples of lignite from Mendenhall rider lignite bed, E–32880, E–24658, E–24659, D–68859, and D–68860, were excluded from these averages because the lignite in these samples obviously was weathered; analyses of these samples show ash contents that are greater than in unweathered lignite and Btu measurements that are smaller.

TABLE 2.—*Average fuel analyses, in percent, of lignite[1] beds cored in the Mendenhall area*

Proximate analyses

Bed	Moisture	Volatile matter	Fixed carbon	Ash	Heating value (Btu)	Number of samples
Mendenhall rider lignite bed	36.6	24.8	24.3	14.3	5,590	[2] 5
Mendenhall lignite bed	37.7	23.3	26.7	12.3	5,870	33
Olesrud lignite bed (upper bench)	34.9	23.5	25.7	15.9	5,930	38
Olesrud lignite bed (lower bench)	36.6	23.8	25.6	14.0	5,630	29
Y lignite bed	33.6	23.5	26.0	17.3	5,830	11
Z lignite bed	35.7	23.7	27.0	13.6	5,990	11

Ultimate analyses

Bed	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Ash	Ash softening temperature (° F)	Number of samples
Mendenhall rider lignite bed	5.8	30.9	0.4	43.1	1.7	18.1	2,180	7
Mendenhall lignite bed	6.1	35.4	.4	42.3	1.9	13.9	1,990	22
Olesrud lignite bed (upper bench)	5.9	34.8	.4	41.6	1.1	16.2	2,060	34
Olesrud lignite bed (lower bench)	6 3	33.4	.4	43.2	1.6	15.1	2,150	28
Y lignite bed	5.9	34.4	.4	39.8	1.4	18.1	2,140	10
Z lignite bed	6.1	35.9	.5	41.7	1.5	14.3	2,080	10

[1] Analyses are on samples of lignite in the "as received" condition.
[2] Samples E–32880, E–24658, E–24659, D–68859 and D–68860 were excluded from the average because the lignite in these samples was highly weathered.

The Bureau of Mines analyses show that the lignite samples of the six beds in the Mendenhall area range from 35 to 38 percent in moisture content, 14 to 18 percent in ash, 20 to 27 percent in fixed carbon, and 1.4 to 1.9 percent in sulfur, with heating values ranging from 4,480 to 5,930 Btu. These are based on the "as received" condition.

Concurrently with drilling operations in the Mendenhall area, the Bureau of Mines collected five 5-ton bulk samples of lignite to test for ash and heating qualities. Location and graphic logs of Bureau of Mines sample pits are shown in figures 15 and 16. Table 3 shows the comparison between analyses of weathered lignite from sample pits with unweathered lignite from the same bed reached by nearby core holes.

TABLE 3.—*Comparison of fuel analyses, in percent, of samples*[1] *of weathered lignite (A) with those of unweathered lignite (B) from the same bed*

[Weathered-lignite (A) samples are from U. S. Bureau of Mines bulk-sample pits, unweathered-lignite (B) samples are from nearby core holes]

	Mendenhall bed				Mendenhall rider bed		Olesrud bed (upper bench)			
	A	B	A	B	A	B	A	B	A	B
	USBM-1	SD-1	USBM-2	SD-4	USBM-3	SD-8	USBM-4	SD-33	USBM-5	SD-27
Proximate analyses										
Moisture	44.3	36.3	45.1	24.9	43.9	39.0	49.0	34.6	45.8	35.8
Volatile matter	24.3	23.6	25.5	26.0	24.2	25.5	19.0	24.0	20.8	23.7
Fixed carbon	12.5	30.0	14.5	35.4	18.3	29.5	16.0	25.4	15.6	25.5
Ash	18.9	10.1	14.9	13.7	13.6	6.0	16.0	16.0	17.8	15.0
Ultimate analyses										
Hydrogen	6.1	6.2	6.2	5.5	6.2	6.9	6.7	6.0	6.3	6.2
Carbon	22.0	36.7	23.8	43.8	26.4	39.2	23.2	33.9	23.0	34.0
Nitrogen	.4	.4	.4	.6	.5	.5	.5	.5	.5	.4
Oxygen	50.7	44.4	52.6	34.6	51.7	46.4	53.3	42.5	51.6	43.6
Sulfur	1.9	2.2	2.1	1.8	1.6	1.0	.3	1.1	.8	.8
Ash	18.9	10.1	14.9	13.7	13.0	6.0	16.0	16.0	17.8	15.0
Btu	3,110	6,120	3,370	7,450	3,920	6,510	3,480	5,430	3,420	5,590

[1] "As received" condition.

LIGNITE RESERVES

In estimating the reserves of lignite in the Mendenhall area the authors have used the coal-reserve estimation procedures of the U. S. Geological Survey (Averitt and Berryhill, 1950). Maps showing thickness and distribution of the four mineable lignite beds in the area are shown on plate 29, *A*, *B*, *C*, and *D*. The continuity of the lignite beds and close spacing of core holes indicate that the computed tonnage is probably accurate to within 20 percent. A summary of lignite reserves for each of the four beds is given in table 4 below.

TABLE 4.—*Summary of lignite reserves, Mendenhall area, Harding County, S. Dak.*

Bed	Average thickness (ft)		Area (acres)	Lignite[1] (short tons)
Mendenhall rider bed	5.3	3.3	140	808,000
		8.1	275	3,898,000
		11.0	165	3,177,000
Total			580	7,883,000
Mendenhall bed	8.5	3.8	220	1,463,000
		7.3	1,210	15,458,000
		12.2	705	15,052,000
Total			2,135	31,973,000
Olesrud bed (upper bench)	6.8	4.0	730	5,110,000
		7.4	3,110	40,858,000
		12.4	45	976,000
Total			3,885	46,944,000
Olesrud bed (lower bench)	5.7	3.8	1,320	8,778,000
		6.7	2,705	31,716,000
Grand total			4,025	40,494,000
Grand total				127,294,000

[1] Calculations based on 1,750 short tons per acre foot—net result rounded to nearest 1,000 tons.

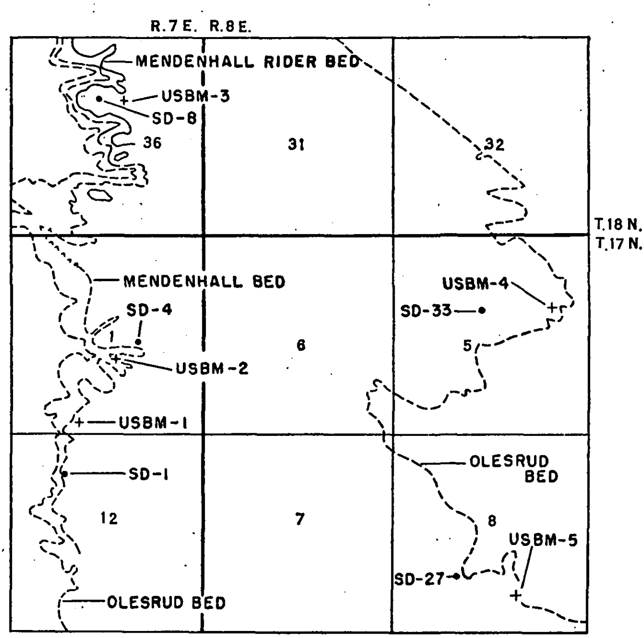

FIGURE 15.—Index map showing location of United States Bureau of Mines bulk-sample pits and selected core holes.

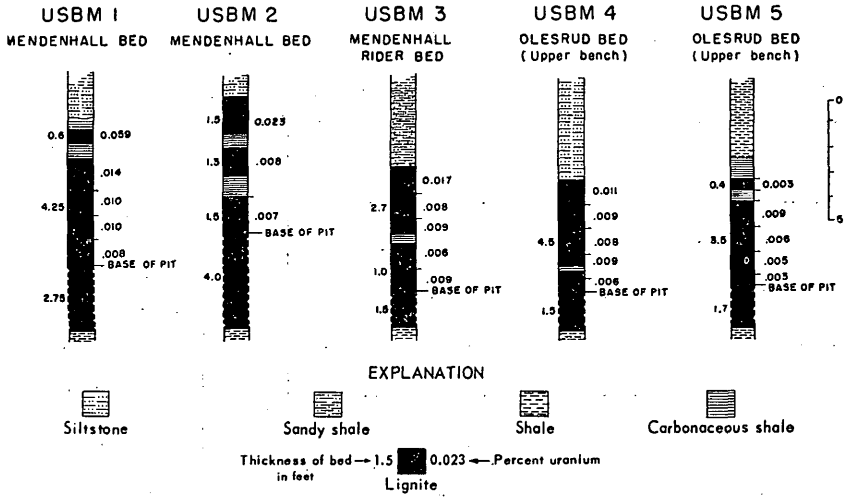

FIGURE 16.—Graphic logs showing uranium content and thickness of lignite in United States Bureau of Mines bulk sample pits.

URANIUM IN LIGNITE

The Mendenhall area is underlain by three beds of uranium-bearing lignite; they are, going downward in stratigraphic position, the Mendenhall rider bed, the Mendenhall bed, and the upper bench of the Olesrud bed. In most localities, the lignite nearest the base of the Chadron formation is the only lignite that contains much uranium (see pl. 29, *E*, *F*, *G*, and *H*, cross section). In the northern part of the area the Mendenhall rider bed, the stratigraphically highest lignite bed, occupies this position; in the central part of the area it is the Mendenhall bed. Although the upper bench of the Olesrud underlies all of the area, it is uranium bearing only in the southern part, where the Mendenhall rider and Mendenhall bed have been removed by erosion prior to the deposition of the overlying Chadron formation. Similarly the Mendenhall bed is uranium bearing only in the central part where the Mendenhall rider has been removed by erosion. Correlation of the lignite beds in the drill holes and the relationship of the beds to the unconformity at the base of the Chadron are shown in the correlation charts (pls. 24–28) and fence diagram (pl. 23).

In estimating the amount of uranium-bearing lignite, five categories showing different amounts of uranium in the lignite and in the ash of the lignite were used. Although the extent and thickness of the lignite beds are accurately known the uranium content is variable and the estimates of uranium content are only roughly approximate. These estimates are given in table 5. A thickness-of-overburden map (fig. 17) shows that an area of 680 acres is overlain by 60 feet or less of overburden.

In the Slim Buttes it is conservatively estimated that 60 square miles are underlain by uranium-bearing lignite beds that have an

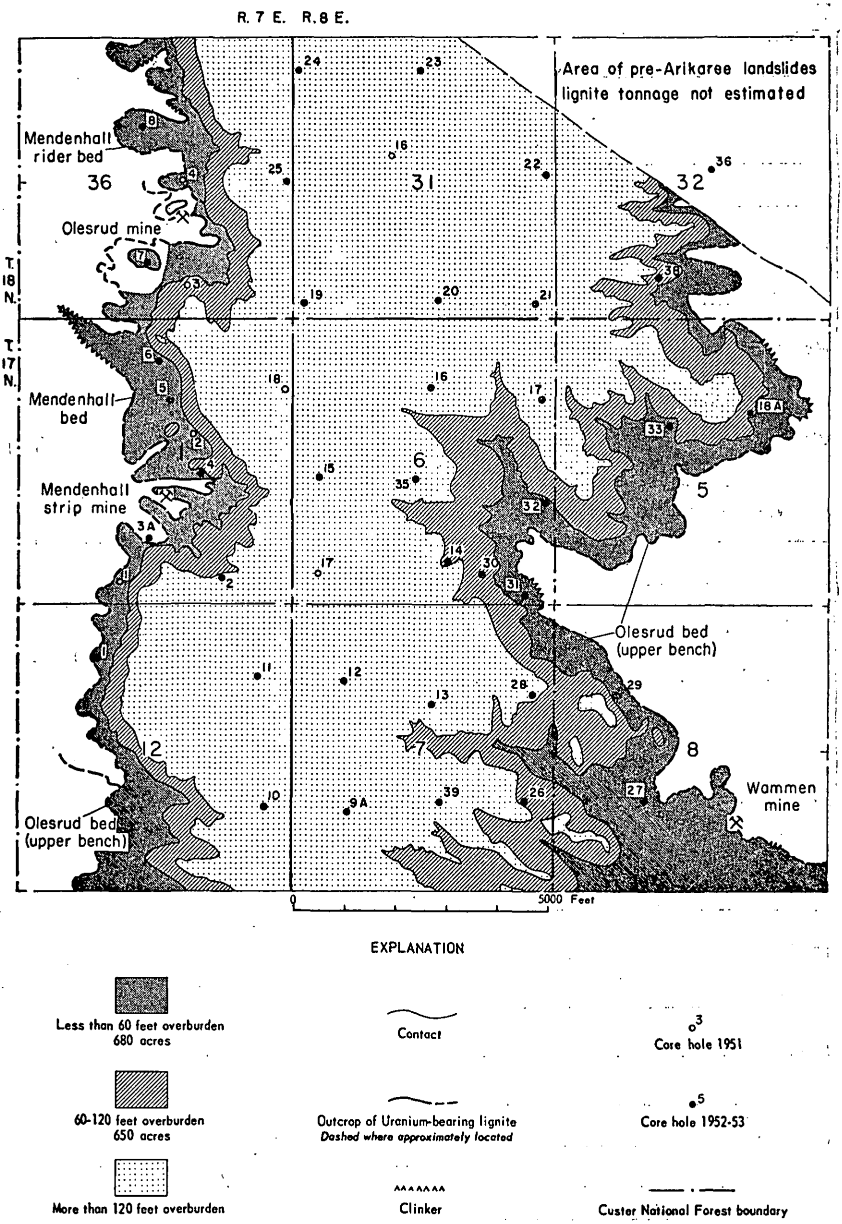

FIGURE 17.—Map showing areas of potentially strippable uranium-bearing lignite in the Mendenhall area, Slim Buttes, Harding County, S. Dak.

average thickness of 5 feet and a uranium content of 0.007 percent. Therefore, the Slim Buttes, exclusive of the Mendenhall area, perhaps is underlain by about 300 million tons of lignite that contains a few thousandths to a few hundredths percent uranium. These large low-grade concentrations of uranium might be of future interest as a pos-

TABLE 5.—*Estimates of tonnage of uranium-bearing lignite and approximate uranium content of the lignite in the Mendenhall area, Harding County, S. Dak.*

Bed	Averages thickness (ft)	Extent (acres)	Uranium (percent)	Ash (percent)	Lignite[1] (short tons)
Lignite containing at least 0.005 percent uranium					
Mendenhall rider	4. 9 { 3. 4 6. 9 10. 6	340 235 10	0. 015 . 007 . 012 } 0. 012	----------	2, 023, 000 2, 837, 000 186, 000
Total	---------	585	------------	----------	5, 046, 000
Mendenhall	6. 1 { 4. 2 7. 1 11. 0	465 645 40	. 005 . 008 . 008 } . 007	----------	3, 418, 000 8, 014. 000 770, 000
Total	---------	1, 150	------------	----------	12, 202, 000
Olesrud (upper bench)	5. 2 { 3. 9 6. 3	635 770	. 008 . 007 } . 007	----------	4, 334, 000 8, 489, 000
Total	---------	1, 405	------------	----------	12, 823, 000
Grand total	---------	3, 140	------------	----------	30, 071, 000
Lignite containing at least 0.010 percent uranium					
Mendenhall rider	5. 6 { 3. 1 8. 0 10. 6	60 45 10	0. 025 . 010 . 012 } 0. 018	----------	325, 000 630, 000 186, 000
Total	---------	115	------------	----------	1, 141, 000
Mendenhall	4. 5 { 3. 5 7. 2 10. 5	390 130 10	0. 010 . 010 . 010 } 0. 010	----------	2, 389, 000 1, 638, 000 184, 000
Total	---------	530	------------	----------	4, 211, 000
Olesrud	3. 3	795	. 010	----------	4, 591, 000
Grand total	---------	1, 440	------------	----------	9, 943, 000
Lignite furnishing ash containing at least 0.030 percent uranium					
Mendenhall rider	6. 1 { 3. 3 7. 9 10. 6	140 190 10	0. 054 . 030 . 128 } 0. 042	29. 0 23. 0 9. 4 } 25. 1	809, 000 2, 627, 000 185, 000
Total	---------	340	------------	----------	3, 621, 000
Mendenhall	6. 1 { 4. 0 6. 7 10. 9	370 690 50	. 036 . 043 . 047 } . 041	16. 7 16. 6 15. 9 } 16. 6	2, 590, 000 8, 090, 000 954, 000
Total	---------	1, 110	------------	----------	11, 634, 000
Olesrud (upper bench)	5. 0 { 3. 8 6. 6	770 560	. 049 . 042 } . 046	18. 6 17. 3 } 18. 0	5, 120, 000 6, 468, 000
Total	---------	1, 330	------------	----------	11, 588, 000
Grand total	---------	2, 780	------------	----------	26, 843, 000

[1] Footnote on p. 113.

TABLE 5.—*Estimates of tonnage of uranium-bearing lignite and approximate uranium content of the lignite in the Mendenhall area, Harding County, S. Dak.*—Continued

Bed	Average thickness (ft)	Extent (acres)	Uranium (percent)	Ash (percent)	Lignite [1] (short tons)
Lignite furnishing ash containing at least 0.050 percent uranium					
Mendenhall rider	4.0 {3.3 7.5 10.6}	165 15 10	0.063 .050 } 0.065 .128	26.9 15.0 } 25.5 9.4	953,000 197,000 185,000
Total		190			1,335,000
Mendenhall	5.0 {4.0 7.6 10.8}	565 200 10	.050 .057 } 0.052 .050	14.9 16.3 } 15.3 17.0	3,955,000 2,660,000 189,000
Total		775			6,804,000
Olesrud	4.3 {3.6 6.4}	675 215	.059 } 0.058 .055	16.2 } 15.9 15.0	4,252,000 2,408,000
Total		890			6,660,000
Grand total		1,855			14,799,000
Total uranium-bearing lignite					
Mendenhall rider	7.5	585	0.010	22.6	27,580,000
Mendenhall	9.2	1,555	.003	14.1	24,150,000
Olesrud (upper bench)	5.8	1,750	.006	18.0	17,800,000
Grand total		3,890			49,530,000

[1] Calculations based on 1,750 tons per acre foot; net result rounded to nearest 1,000 tons.

sible byproduct source of uranium. Relatively small parts of these deposits were found to contain higher grade uranium accumulations containing more than 0.1 percent uranium in the lignite, after the field and laboratory work of this report were completed. The small high-grade uranium occurrences are not discussed in this report.

GEOLOGICAL SIGNIFICANCE OF URANIUM IN LIGNITE

A brief consideration of the origin of the uranium in the lignite is necessary to understand the distribution of mineralized lignite.

A scaler equipped with a Geiger-Mueller counter tube and 400-foot coaxial cable was used to measure the radioactivity of the source beds in the Chadron and Arikaree formations unconformably overlying the uranium-bearing lignites in the core holes drilled in the Slim Buttes. Unfortunately most of the holes caved soon after the lignite was cored and a complete record of the radioactivity of wallrock in all the holes penetrating the Chadron and Arikaree formations was not obtained. The most complete log of radioactivity obtained by this method was for hole GS–17, the gamma counts of which are plotted and shown in figure 18. Although the Arikaree formation is lithologically uniform throughout its thickness at the drill hole, the radioactivity is above background throughout most of the wallrock of the hole and is notably higher near the base of the Arikaree formation. As water was reached in the hole a few feet above the Chadron-Arikaree contact, readings of the Chadron formation could not be calibrated for comparison with those taken higher in the section. The reason for the apparently higher concentration of uranium or other radioactive elements near the base of the Arikaree formation may be due to the occurrence of a widespread and persistent 10–40 foot thick bed

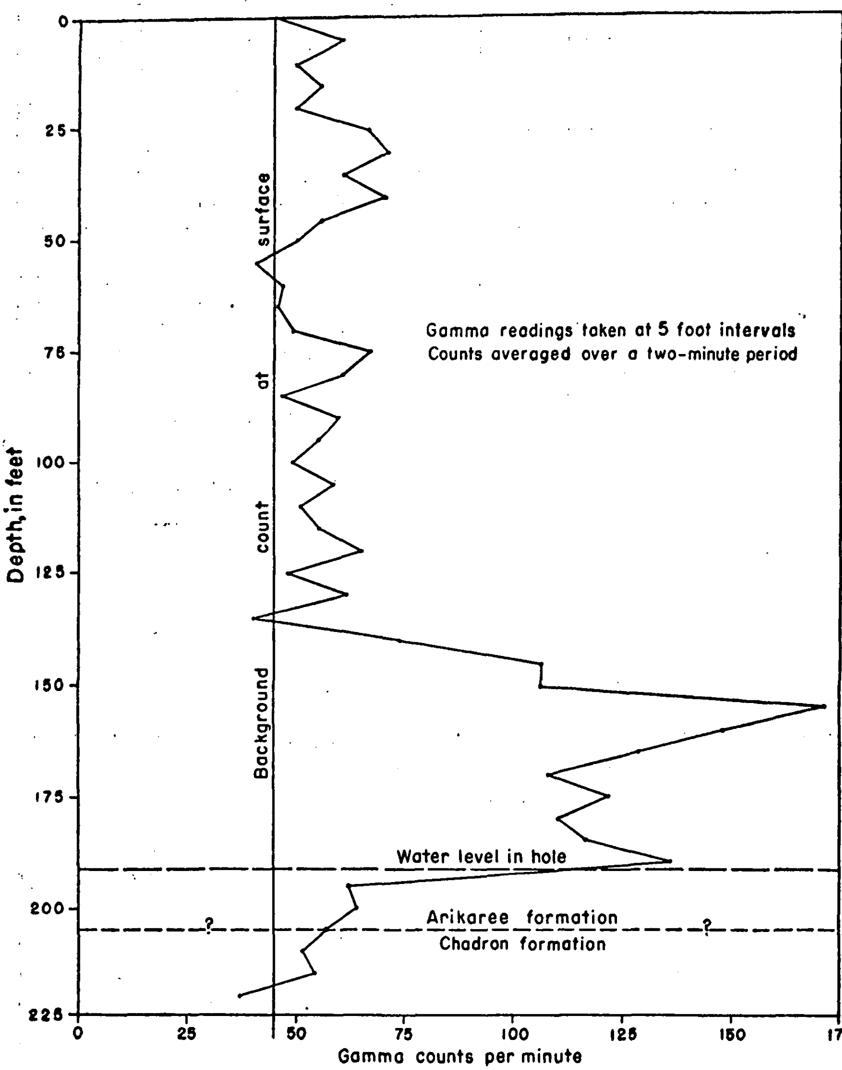

FIGURE 18.—Log showing radioactivity of Arikaree formation in core hole GS–17, Mendenhall area, Slim Buttes, Harding County, S. Dak.

of impervious bentonitic clay at the top of the Chadron formation which supports a perched water table.

It may be significant that gamma counts recorded in 3 of 4 deep holes showed a similar higher concentration of radioactivity in the lower part of the Arikaree formation. Leaching of uranium from the upper part of the Arikaree formation and concentration of uranium in the lower part of the formation, which seems to be uniform lithologically, is suggested but cannot yet be confirmed.

The uranium in the lignite of the Mendenhall area is believed to have been introduced into the lignites long after their formation. Enrichment may be going on today. Denson, Bachman, and Zeller (chapter B, this bulletin) first suggested that the uranium was leached by ground water from the Oligocene and Miocene tuffaceous rocks that unconformably overlie the lignite-bearing strata of the Ludlow member of the Fort Union formation. The ground water brought the uranium into contact with the lignite beds in which the uranium combined with carbon compounds to form a metallo-organic complex (I. A. Breger and Maurice Deul, written communication, 1952).

In the Slim Buttes area the Chadron and Arikaree formations contain on the average, about 0.001 percent uranium, in comparison with the average uranium content of the earth's crust of 0.0004 percent (Mason, 1952) and in comparison with the average for sedimentary rocks of 0.00012 (Rankama and Sahama, 1950). Therefore these formations contain nearly 10 times the average concentration of uranium and seem to be logical source beds for the uranium. It is estimated that a cubic mile of the Chadron and Arikaree formations with a uranium content of 0.001 percent would contain about 130,000 tons of uranium. Springs issuing from the Chadron and Arikaree formations contain 10 to 200 parts per billion of uranium, as compared to the average uranium content of the ocean of 1.5 parts per billion (Rankama and Sahama, 1950).

The distribution of uranium in uranium-bearing lignite beds (pls. 24–28) appears to be related to the accessibility of the beds to uranium-bearing solutions coming from the overlying Oligocene and Miocene rocks rather than to such features as changes in physical character of the lignite. The observed distribution does not appear to correspond to any reasonable interpretation of the conditions under which the lignites were deposited (Schopf and Gray, 1954).

The geologic factors that appear to control the occurrence of uranium in the lignites in the Mendenhall area are the following:

1. Stratigraphic proximity of lignite to the base of the Chadron formation.
2. Permeability of rocks directly overlying the lignite.
3. Physical character and adsorptive qualities of the lignite and

porosities of its constituents. In areas where the lignites have weathered and have greater permeability, there appears to be an increase in the uranium content. The thickness map of uranium-bearing lignite containing at least 0.005 percent uranium (pl. 29, *E*, *F*, *G*, *H*) shows that the areas of lignite with the greatest uranium content are generally in the areas of the least overburden. This may indicate that lignite of these areas is being enriched by uranium-bearing ground water draining from the Chadron and Arikaree formations.

4. Position of past and present water tables. Little is known about past ground-water conditions, but it is reasonable to expect that major fluctuations have taken place in past geologic time. Aside from the perched water table in the upper part of the Chadron and the lower part of the Arikaree formations in the Slim Buttes area the present water table is below the uranium-bearing lignite.

Data obtained during this study indicate that the uranium in the lignite is of secondary origin, having been introduced after formation of the lignite, and that the uranium has been and is being leached by ground water from the mildly radioactive tuffaceous rocks of the Chadron and Arikaree formations.

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TABLE 6.—*Threshold values in percent of elements included in the semi-quantitative spectrographic method*

[Revised June 4, 1951]

Element	Percent	Element	Percent	Element	Percent	Element	Percent
Ag	0.001	Dy	0.01	Mg	0.0001	Sn	0.01
Al	.0001	Eu	.01	Mo	.001	Sr	.01
As	.1	Er	.01	Mn	.001	Ta	.1
Au	.01	F [b]	.1	Na [a]	.001 (0.1)	Tb	.1
B	.001	Fe	.001	Nd	.01	Te	.1
Ba	.0001	Ga	.01	Ni	.001	Th	.1
Be	.0001	Gd	.01	P	.1	Ti	.001
Bi	.001	Ge	.001	Pb	.01	Tl	.1
Ca	.001	Hf	.1	Pr	.01	Tm	.01
Cb	.01	Hg	.1	Pt	.01	U	.1
Cd	.01	Ho	.01	Rb	10.0	V	.01
Ce	.1	In	.001	Re	.1	W	.1
Co	.01	K [a]	.01 (1.0)	Sb	.001	Y	.001
Cr	.001	La	.01	Sc	.1	Yb	.0001
Os	1.0	Li [a]	.0001 (0.1)	Si	.0001	Zn	.01
Cu	.0001	Lu	.01	Sm	.1	Zr	.001

[a] A second exposure is required for the high sensitivity test.
[b] A third exposure is required for the fluorine estimation.

TABLE 7.—*Chemical analyses for uranium and semiquantitative spectrographic analyses for other elements in the ash of lignite or carbonaceous shale in cores and bulk samples from the Mendenhall area, S. Dak.*

Spectrographic and chemical analyses by U. S. Geological Survey. Chemical analysts: Joseph Budinsky, Alice Caemmerer, Irving May, Thomas Murphy, Alice Padgett, Audrey Smith, and Joan Smith.

Spectrographic analysts: Mona Frank, K. E. Valentine, and C. L. Waring.

[Length of core section: entries in italics show parts of core not sampled, or lost in coring; range in percent of semiquantitative spectrographic analyses: A, more than 10; B, 1–10; C, 0.1–1.0; D, 0.01–0.1; E, 0.001–0.01; F, 0.0001–0.001.]

Sample			Analyses (percent)		Semiquantitative spectrographic analyses [elements in lignite ash]																																		
Core hole TE No.	Laboratory No.	Length of core section (ft.)	Ash in sample	Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
MENDENHALL RIDER LIGNITE BED																																							
Core hole GS-4 (NW¼SE¼ sec 36, T. 18 N., R. 7 E.) [Sampled interval, 23.10 ft–26.87 ft]																																							
1a	63133	0.61	31.1	0.135	A	A	B	C	B	B	C	C	D	D	D	D	D	E	D	D	C	D	E	D	E	E	---	E	F	---	---	E	---	---	---	---	---	---	---
		a *.33*																																					
2	63134	1.71	39.5	.026	A	A	B	C	B	B	C	D	D	C	D	E	D	E	D	D	D	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		a *.71*																																					
3	63135	.41	43.5	.008	B	A	B	C	B	C	C	D	D	C	D	E	E	E	E	E	D	---	F	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---	---
Core hole GS-16 (SE¼NW¼ sec 31, T. 18 N., R. 8 E.) [Sampled interval, 326.46 ft–341.98 ft]																																							
1	66644	0.64	88.8	0.001	A	A	B	B	C	B	C	D	D	C	D	D	---	E	D	D	D	D	E	D	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
2	66645	.67	86.1	.003	A	A	B	B	C	B	C	D	D	D	D	D	---	E	D	E	D	E	F	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---	---
		b *4.56*																																					
3	66646	.06	22.0	.042	B	B	A	B	B	B	C	D	D	D	C	D	D	D	D	D	D	D	E	D	D	E	---	F	F	---	D	---	---	---	---	---	---	---	---
		a *.85*																																					
4	66647	.35	76.6	.015	A	A	B	B	C	B	D	D	D	D	D	D	D	E	D	E	D	E	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
5	66648	1.07	36.9	.025	A	A	B	B	B	B	C	D	D	C	C	D	D	E	D	D	D	D	E	E	E	E	---	F	F	---	---	E	D	---	---	---	---	---	---
6	66649	.85	16.7	.029	A	A	B	B	B	B	C	D	D	D	C	D	D	E	D	E	D	E	F	E	E	E	---	F	F	---	---	E	D	---	---	---	---	---	---
7	66650	.96	12.0	.025	A	B	B	B	B	B	C	D	D	D	C	D	E	E	E	E	D	---	---	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	---
8	66651	.98	11.7	.018	A	B	B	B	B	B	C	D	D	D	C	D	E	E	E	E	D	---	---	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	---
9	66652	.62	12.6	.008	A	B	B	B	B	B	C	D	D	D	C	D	E	E	E	E	D	---	---	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	D
10	66653	.92	9.15	.007	A	B	B	B	B	B	C	D	D	D	C	D	E	E	E	E	E	E	---	E	E	---	---	F	---	---	---	---	D	---	---	---	---	---	---
11	66654	1.00	13.5	.004	A	A	B	B	B	B	C	D	D	D	C	D	E	E	E	E	D	E	---	E	E	---	---	F	F	---	---	---	D	---	---	---	---	---	---
12	66655	1.14	10.1	.004	A	B	B	B	B	B	C	D	D	D	C	D	E	E	E	E	D	E	F	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
13	66656	.84	15.8	.004	A	A	B	B	B	B	C	D	D	D	C	D	E	E	D	E	D	E	E	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---

Core hole SD-8 (SE¼NW¼ sec 36, T. 18 N., R. 7 E.)

[Sampled interval, 37.51 ft–48.25 ft]

1	113893	0.33	84.6	0.016	A	A	B	C	B	C	C	D	D	C	D	E	D	E	D	---	E	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
2	113894	.11	11.3	.800	B	B	A	B	B	B	C	C	D	D	C	D	C	D	D	C	D	C	E	D	E	E	E	F	F	E	D	E	---	---	---	---	---	D	---
		[c] *7.18*																																					
3	113895	.50	10.2	.112	B	B	A	B	B	B	C	D	C	D	C	D	C	E	D	D	E	---	F	D	E	E	E	F	F	F	D	---	---	---	---	---	---	---	---
		[d] *.34*																																					
5	113897	.29	6.8	.118	A	B	B	B	A	B	C	C	C	D	C	D	C	E	E	E	E	D	F	D	E	E	E	F	F	F	---	---	---	E	---	---	---	---	---
6	113898	.41	4.2	.119	A	B	B	B	A	B	C	C	C	D	C	D	C	E	E	E	E	D	F	D	E	E	E	F	F	F	---	---	---	E	---	---	---	---	---
7	113899	.50	7.0	.114	A	B	B	B	A	B	C	C	C	D	C	D	C	E	E	E	E	E	F	E	E	E	E	F	F	F	---	E	---	---	---	---	---	---	C
8	113900	.33	12.1	.047	B	B	A	B	B	B	C	D	C	D	C	D	C	E	D	D	E	E	F	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
9	113901	.30	14.1	.025	B	B	A	B	B	B	C	D	C	D	C	D	D	E	D	D	E	E	F	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
10	113902	.45	7.4	.122	B	B	B	B	A	B	C	D	C	D	C	D	C	D	D	D	E	D	E	D	D	E	E	F	F	F	D	---	---	---	---	---	---	---	---

U. S. B. M. sample pit 3 (NW¼NE¼ sec 36, T. 17 N., R. 7 E.)

[Top of sampled interval]

14	81803	1.00	7.8	0.11	B	B	A	B	B	B	C	C	C	D	D	D	D	C	D	E	D	E	D	D	D	E	D	F	F	E	---	---	---	---	---	---	---	---	---
15	81804	1.00	14.0	.064	B	B	B	B	B	B	C	C	C	C	C	E	D	C	E	E	D	E	E	F	D	F	E	---	F	F	---	---	---	---	---	---	---	---	---
16	81805	.70	19.3	.029	B	B	A	B	B	B	C	C	C	C	D	E	D	C	E	E	E	E	E	F	E	F	E	F	F	F	---	---	---	---	---	---	---	---	---
17	81806	1.00	11.7	.055	B	B	B	B	B	B	C	C	C	C	C	D	D	D	E	E	E	E	E	D	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---
18	81807	1.00	13.8	.073	B	B	B	B	B	B	C	D	C	C	D	D	D	C	D	E	D	E	E	F	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---

[Base of sampled interval]

MENDENHALL BED

Core hole GS-1 (SE¼SW¼ sec 1, T. 17 N., R. 7 E.)

[Sampled interval, 35.67 ft–37.96 ft]

1	63073	0.66	9.6	0.008	A	B	B	B	B	B	C	C	C	D	C	D	E	E	D	D	---	E	E	D	E	E	---	F	E	---	E	---	---	---	---	---	---	---	---
2	63074	.83	8.9	.007	A	B	B	B	B	B	C	C	C	C	C	D	D	D	D	D	---	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		[c] *.11*																																					
3	63075	.69	17.7	.004	A	A	B	B	B	B	D	C	D	C	C	D	E	D	D	E	---	D	E	D	D	E	---	F	F	---	---	---	---	---	---	---	---	---	---

See footnotes at end of table.

TABLE 7.—*Chemical analyses for uranium and semiquantitative spectrographic analyses for other elements in the ash of lignite or carbonaceous shale in cores and bulk samples from the Mendenhall area, S. Dak.*—Continued

Sample			Analyses (percent)		Semiquantitative spectrographic analyses [elements in lignite ash]																															
Core hole TE No.	Laboratory No.	Length of core section (ft.)	Ash in sample	Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
MENDENHALL BED—Continued																																				
Core hole GS-2 (SW¼NE¼ sec 1, T. 17 N., R. 7 E.) [Sampled interval, 51.00 ft–61.75 ft]																																				
1	63083	0.42 [a] *.12*	27.5	0.138	A	A	A	B	B	B	C	D	D	D	C	D	C	D	D	D	D	D	---	D	E	E	---	F	F	---	---	---	---	---	---	---	----	D	---
2	63084	.44 [a] *.54*	20.4	.084	A	A	B	B	B	B	C	C	D	D	C	D	D	D	D	D	D	E	D	E	E	E	---	F	F	---	---	---	---	---	---	---	----	D	---
3	63085	.87	14.2	.045	A	A	B	B	B	B	C	C	C	D	C	D	D	E	D	E	D	E	---	E	E	---	---	F	F	---	---	---	---	---	---	---	----	---	---
4	63086	.44	12.1	.078	A	B	B	B	B	B	C	C	D	D	C	D	D	D	D	E	D	D	D	E	E	E	---	F	F	---	---	---	---	---	---	---	----	D	---
5	63087	1.00	11.2	.062	A	B	B	B	B	B	C	C	D	D	C	D	D	D	E	E	E	E	D	E	E	E	---	F	F	---	---	---	---	---	---	---	----	---	---
6	63088	1.00	13.8	.036	A	B	A	B	B	B	C	C	D	D	C	D	D	D	D	D	E	D	D	E	E	E	---	F	F	---	---	---	---	---	---	---	----	---	---
7	63089	.96	16.0	.081	A	A	B	B	B	B	C	D	D	D	C	D	D	E	D	E	E	E	---	E	E	---	---	F	---	F	---	---	---	---	---	---	----	D	---
8	63090	1.00	16.3	.036	A	B	A	B	B	B	C	C	D	D	C	D	D	E	E	E	E	E	---	E	E	---	---	F	---	---	---	---	---	---	---	---	----	D	---
9	63091	.88	8.0	.051	A	B	B	B	B	B	C	C	D	D	C	D	D	D	E	E	E	E	D	E	E	E	---	----	F	---	---	---	---	---	---	---	----	---	---
10	63092	.41 [c] *1.42*	9.8	.033	A	B	B	B	B	B	C	C	D	D	C	D	D	D	E	E	E	E	D	E	E	E	---	----	---	---	---	---	---	---	---	---	----	---	---
11	63093	1.25	14.6	.011	A	A	C	B	B	B	C	C	D	D	---	----	E	---	D	E	---	---	D	E	D	E	---	F	F	F	---	---	---	---	---	---	----	---	---
Core hole GS-3 (SW¼SE¼ sec 36, T. 18 N., R. 7 E.) [Sampled interval, 88.62 ft–105.52 ft]																																				
1	63100	1.02	14.0	0.027	A	A	B	B	B	B	C	C	C	D	C	D	D	E	D	D	C	---	E	D	D	D	---	F	E	---	---	---	---	---	---	---	----	---	---
2	63101	1.00	13.5	.022	A	A	B	B	B	B	C	C	C	D	C	D	D	E	E	E	---	E	E	E	E	D	---	F	F	---	---	---	---	---	---	---	----	---	---
3	63102	.98 [c] *.38*	15.9	.019	A	B	B	B	B	B	C	D	D	D	C	D	E	D	E	E	D	---	---	E	E	---	---	F	F	---	---	---	---	---	---	---	----	---	---
4	63103	.85	10.2	.013	A	B	B	B	B	B	C	D	D	D	C	D	E	E	E	E	D	E	---	E	E	---	---	F	---	---	---	---	---	---	---	---	----	---	---
5	63104	1.00	8.4	.005	A	B	B	B	B	B	C	C	D	D	C	D	E	E	D	E	D	E	---	E	E	D	---	F	---	---	---	---	---	---	---	---	----	---	---
6	63105	.98	9.8	.001	A	B	B	B	B	B	C	D	D	D	C	D	E	E	E	E	D	E	E	E	E	D	---	F	F	F	---	---	---	---	---	---	----	---	---
7	63106	.39 [b] *2.11*	8.3	.005	A	B	B	B	B	B	D	D	D	C	C	D	E	D	D	D	C	D	E	D	D	D	---	F	F	---	---	---	---	---	---	---	----	---	---

8	63107	.79	11.3	.002	A	B	B	B	B	B	C	D	D	D	C	D	E	D	E	D	D	E	D	E	E	E	E	D	---	F	F	F	---	---	---	---	---	---	---	---	---
9	63108	.85	7.6	.002	A	B	B	B	B	B	C	D	D	D	C	D	E	D	E	E	D	E	---	E	E	E	E	D	---	F	F	---	---	---	---	---	---	---	---	D	---
10	63109	1.04	10.9	.002	A	C	A	B	B	B	C	D	D	D	C	E	E	E	E	E	E	D	---	---	---	E	E	---	---	F	---	---	---	---	---	---	---	---	---	---	---
11	63110	.87	10.9	.002	A	B	A	B	B	B	C	D	D	D	C	D	E	D	E	E	D	E	---	---	---	E	E	---	---	F	---	---	---	---	---	---	---	---	---	D	---
12	63111	.78	10.8	.002	A	B	B	B	B	B	C	C	D	C	C	D	E	D	E	E	E	E	D	E	E	E	E	---	---	----	---	---	---	---	---	---	---	---	---	---	---
		[c].33																																							
13	63112	1.04	23.1	.002	A	A	B	B	B	B	C	D	D	C	C	D	E	D	E	D	D	D	D	D	E	D	E	D	---	F	F	---	---	---	---	---	---	---	---	---	---
14	63113	.92	17.4	.001	A	B	B	B	B	B	C	D	D	D	C	D	E	D	E	D	E	E	D	E	---	E	E	D	---	F	---	---	---	---	---	---	---	---	---	---	---
15	63114	.79	11.7	.002	A	B	B	B	B	B	C	C	D	C	C	D	E	D	E	D	D	E	---	E	E	E	E	D	---	F	F	---	---	---	---	---	---	---	---	---	---
16	63115	.77	24.8	.001	A	A	B	B	B	B	C	D	D	C	C	D	E	D	E	D	D	D	C	E	E	D	E	D	---	F	F	---	---	---	---	---	---	---	---	---	---

Core hole GS-4 (NW¼SE¼ sec 36, T. 18 N., R. 7 E.)

[Sampled interval, 71.31 ft–85.67 ft]

4	63136	0.96	12.7	0.002	A	A	B	B	B	B	C	C	D	D	C	D	E	D	E	E	E	E	D	E	F	E	E	E	---	F	F	F	---	E	---	---	---	---	---	---	---
		[c].06																																							
5	63137	1.04	14.0	.001	A	A	C	B	B	B	C	D	D	D	C	D	E	D	E	E	E	E	C	---	---	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---	---
6	63138	1.19	12.7	.001	A	B	C	B	B	B	C	C	D	D	C	D	E	D	E	E	E	E	C	C	---	E	E	---	---	----	F	F	---	---	---	---	---	---	---	---	---
7	63139	.73	11.2	.001	A	B	B	B	B	B	C	C	D	D	C	D	E	D	E	E	E	E	D	---	---	E	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
8	63140	.58	15.3	.002	A	B	A	B	B	B	C	C	D	D	C	E	E	E	E	E	E	E	D	E	---	E	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
9	63141	.88	11.4	.004	A	---	C	B	B	B	C	C	D	D	C	D	E	D	E	E	E	E	D	---	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		[c].25																																							
		[a].33																																							
10	63142	.92	29.4	.003	A	A	B	B	B	B	C	D	D	C	C	E	E	E	E	E	E	E	C	E	E	D	D	E	---	F	F	---	---	E	---	---	---	---	---	---	---
11	63143	.89	28.5	.001	A	A	C	B	B	B	C	C	D	C	C	E	E	E	E	E	E	E	C	E	F	D	D	E	---	F	F	---	---	E	---	---	---	---	---	---	---
12	63144	.71	5.8	.003	A	B	C	B	B	B	C	C	D	D	C	D	E	D	E	E	E	E	D	D	---	E	D	E	---	F	F	---	---	E	---	---	---	---	---	---	---
13	63145	.88	13.4	.002	A	A	B	B	B	B	C	C	D	D	C	D	E	D	E	E	E	E	D	E	---	E	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
		[a].06																																							
14	63146	1.02	15.5	.002	A	A	B	B	B	B	C	D	D	D	C	D	E	D	E	E	E	E	D	E	---	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---	---
		[c]2.18																																							
15	63147	.79	12.2	.002	A	A	C	B	B	B	C	C	D	D	C	D	E	D	E	E	E	E	C	E	---	E	D	E	---	F	---	F	---	---	---	---	---	---	---	E	---
16	63148	.88	10.4	.004	A	A	B	B	B	B	C	C	D	C	C	D	E	D	E	E	D	E	D	D	E	D	D	E	---	F	---	---	E	---	---	---	---	---	---	---	---

Core hole GS-17 (SW¼SW¼ sec 6, T. 17 N., R. 8 E.)

[Sampled interval, 357.87 ft–368.42 ft]

1	67947	0.21	31.9	0.062	A	A	A	B	B	B	C	D	C	D	C	E	D	E	D	E	E	D	D	D	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
2	67948	.38	18.6	.054	A	B	B	B	B	B	C	C	C	D	C	D	C	D	C	E	E	D	D	D	E	D	D	E	---	F	F	---	D	E	---	---	---	---	---	D	---
3	67949	.33	64.5	.008	B	A	B	C	C	C	C	D	D	C	D	E	D	E	D	E	E	E	E	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
4	67950	.38	31.9	.048	A	A	B	B	B	B	C	D	D	C	C	D	C	D	C	D	D	D	D	D	E	D	E	E	---	F	F	---	E	E	D	---	---	---	---	---	---
		[a]1.56																																							
5	67951	1.10	16.1	.040	A	A	B	B	B	B	C	C	C	D	C	D	D	D	D	E	E	E	E	E	F	E	E	E	---	F	F	---	---	E	D	---	---	---	---	---	---
6	67952	.92	13.0	.032	A	A	B	B	B	B	C	C	C	D	C	D	D	D	D	E	D	D	D	D	E	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
7	67953	1.08	9.6	.020	A	B	B	B	B	B	C	D	C	D	C	D	D	D	D	E	E	E	E	E	---	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
8	67954	1.25	14.3	.007	A	B	B	B	B	B	C	D	C	D	C	D	D	D	D	E	E	E	E	---	---	E	E	---	---	F	---	---	---	---	D	---	---	---	---	---	---
9	67955	1.31	13.1	.002	A	B	B	B	B	B	C	D	C	D	C	D	E	D	E	E	E	E	E	E	---	E	E	---	---	F	---	---	---	---	D	---	---	---	---	---	---
		[c].03																																							
10	67956	1.00	11.5	.003	A	B	B	B	B	B	C	C	C	D	C	D	E	D	E	E	E	E	E	E	F	D	E	E	---	F	F	---	---	E	D	---	---	---	---	---	---
11	67957	.58	14.1	.002	A	B	B	B	B	B	C	D	C	D	C	D	E	D	E	E	E	E	D	---	F	D	D	---	---	F	F	---	---	---	D	---	---	---	---	---	---

See footnotes at end of table.

TABLE 7.—*Chemical analyses for uranium and semiquantitative spectrographic analyses for other elements in the ash of lignite or carbonaceous shale in cores and bulk samples from the Mendenhall area, S. Dak.*—Continued

Sample			Analyses (percent)		Semiquantitative spectrographic analyses [elements in lignite ash]																																		
Core hole TE No.	Laboratory No.	Length of core section (ft.)	Ash in sample	Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
MENDENHALL—continued																																							
Core hole GS-18 (SE¼NE¼ sec 1, T. 17 N., R. 7 E.)																																							
[Sampled interval, 356.83 ft–367.62 ft]																																							
1	68179	0.17	26.3	0.094	B	B	A	B	B	B	C	D	D	D	C	D	C	D	D	D	D	C	E	D	---	D	---	E	E	---	---	---	---	---	D	---	---	D	---
2	68180	.20	43.6	.044	A	A	B	B	B	B	C	D	D	C	D	E	C	E	D	D	D	D	E	D	E	E	---	F	F	---	---	---	---	---	D	---	---	---	---
3	68181	.57	20.2	.106	A	A	B	B	B	B	C	D	D	C	C	E	D	E	E	E	D	---	F	E	E	E	---	F	F	---	E	---	---	---	---	---	---	---	---
4	68182	1.04	10.3	.070	A	B	B	B	B	B	C	C	C	C	C	E	D	E	E	E	D	E	F	E	E	E	---	F	F	---	E	D	D	---	---	---	---	---	---
5	68183	1.00	16.2	.033	A	A	B	B	B	B	C	C	D	C	C	E	D	E	D	E	D	E	F	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
6	68184	.87	21.2	.032	A	A	B	B	B	B	C	C	D	C	C	E	D	E	D	E	D	E	F	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
7	68185	.84	15.4	.028	A	A	B	B	B	B	C	D	D	C	C	E	D	D	D	E	D	E	F	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
		a.91																																					
8	68186	.96	13.6	.018	A	A	B	B	B	B	C	C	D	C	C	E	D	D	D	D	D	D	E	E	E	E	---	F	F	F	---	---	D	---	---	---	---	---	---
9	68187	1.00	11.9	.011	A	B	B	B	B	B	C	C	D	D	C	E	D	E	E	E	D	E	F	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
10	68188	1.00	12.0	.004	A	A	B	B	B	B	C	D	D	C	C	E	D	E	E	E	D	E	F	D	E	E	---	F	F	---	---	---	D	---	---	---	---	---	---
		c.13																																					
11	68189	1.41	16.5	.002	A	A	A	B	B	B	C	D	D	C	C	E	E	E	E	E	E	---	---	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
12	68190	.79	12.3	.010	A	A	B	B	B	B	C	C	C	C	C	D	D	E	E	E	D	E	F	D	E	E	E	F	F	---	E	E	D	---	---	---	---	D	C

Core hole SD-19 (SW¼SW¼ sec 31, T. 18 N., R. 8 E.)

[Sampled interval, 333.83 ft–342.51 ft]

4	111475	0.25	16.0	0.13	A	A	B	B	B	B	C	D	C	D	C	D	C	E	D	D	D	C	F	D	E	E	E	F	F	F	D	---	E	---	---	---	---	---	---
5	111476	.34	16.0	.10	A	A	B	B	B	B	C	D	C	D	C	D	C	E	D	D	E	D	F	D	E	E	E	F	F	F	D	---	E	---	---	---	---	---	---
6	111477	.33	13.7	.084	B	B	A	B	B	A	C	C	C	D	C	E	C	E	D	D	E	D	F	D	E	E	E	F	F	---	D	E	---	---	---	---	---	---	---
7	111478	.34	11.8	.052	A	B	C	B	A	A	C	C	C	D	C	D	C	E	E	E	E	E	F	D	E	E	E	F	F	F	E	E	E	---	---	---	---	---	---
8	111479	.62	20.0	.031	B	B	A	B	B	B	C	C	C	D	D	D	C	E	D	D	E	---	---	E	---	---	E	F	F	---	---	---	---	---	---	---	---	---	---
9	111480	.64	10.2	.054	B	B	C	B	A	A	C	C	C	D	C	E	D	E	E	E	E	E	F	E	E	---	E	---	F	F	---	E	E	---	---	---	---	---	---
10	111481	.29	9.2	.11	B	B	B	B	A	A	C	C	C	D	C	D	D	E	D	E	E	E	F	E	E	E	E	F	---	F	E	---	E	---	---	---	---	---	---
11	111482	.18	9.4	.16	B	B	B	B	A	A	C	C	C	D	C	E	D	E	E	E	E	E	F	E	E	E	---	---	F	F	---	---	E	---	---	---	---	---	---
12	111483	.12	26.2	.024	B	B	A	C	C	B	D	D	D	D	D	---	D	E	D	D	E	E	---	E	E	---	---	E	---	---	---	---	---	---	---	---	---	---	---
13	111484	.18	15.1	.094	B	A	B	B	B	B	C	D	C	D	C	D	D	E	D	E	E	E	---	E	E	E	E	F	---	F	---	---	E	---	---	---	---	---	---
14	111485	.22	12.4	.054	B	B	B	B	B	A	C	C	C	D	C	D	D	E	D	D	E	E	F	E	E	E	---	F	F	F	---	---	E	---	---	---	---	---	---
15	111486	.20	8.0	.074	B	B	C	B	A	A	C	C	C	D	C	E	D	E	E	E	E	E	F	E	E	E	---	F	---	F	---	---	E	---	---	---	---	---	---
16	111487	.56	11.6	.050	B	B	B	B	A	A	C	C	C	D	C	E	D	E	E	E	E	E	E	D	E	E	E	F	F	F	---	---	E	---	---	---	---	---	---
17	111488	.57	11.0	.038	B	B	B	B	A	A	C	C	C	D	C	D	D	E	D	E	E	E	E	E	E	E	---	F	F	F	---	---	E	---	---	---	---	---	---
18	111489	.19	23.8	.012	B	A	C	B	B	B	C	D	D	D	C	E	E	E	E	E	E	E	E	E	E	E	E	F	F	---	---	---	E	---	---	---	---	---	---
19	111490	.26	10.9	.049	B	B	C	B	B	A	C	D	C	D	C	D	D	D	D	E	E	E	E	D	E	E	E	F	F	F	---	---	E	---	---	---	---	---	---
		a 1.80																																					
21	111491	.45	18.7	.022	A	A	B	B	B	----	C	C	C	D	C	D	E	E	D	E	D	E	E	E	E	E	---	F	F	F	---	E	D	---	---	---	---	---	---
		c .63																																					
22	111492	.21	7.9	.060	B	B	C	B	A	A	C	C	D	D	C	D	D	E	D	E	E	D	E	E	E	E	E	F	F	F	E	E	E	---	---	---	---	---	---
23	111493	.30	9.1	.029	B	B	C	B	A	A	C	C	C	D	C	E	D	E	E	E	---	E	E	E	E	E	---	F	F	F	---	---	E	---	---	---	---	---	---

U. S. B. M. sample pit 1 (NE¼NW¼ sec 12, T. 17 N., R. 7 E.)

[Top of sampled interval]

8	81797	0.60	36.7	0.16	B	A	A	C	B	C	C	C	D	C	D	D	D	E	E	D	E	E	E	D	F	E	F	F	F	---	---	E	---	D	D	D	E	---	---
		a .60																																					
9	81798	1.25	24.1	.039	B	A	A	C	B	C	C	C	D	C	D	D	B	D	E	E	E	E	F	D	F	E	F	F	F	---	E	---	---	---	---	---	---	---	---
10	81799	1.00	19.0	.044	B	B	A	B	B	B	C	C	D	D	D	E	C	E	E	E	---	E	E	E	F	E	F	F	F	---	---	---	---	D	---	---	---	---	---
11	81800	1.00	32.6	.028	B	B	A	C	B	C	C	C	D	C	D	E	D	E	E	E	---	E	F	E	F	F	F	F	---	---	---	---	---	D	---	---	---	---	---
12	81801	1.00	16.5	.039	B	B	A	C	B	B	C	C	D	C	D	D	D	E	E	E	---	E	F	D	F	E	F	F	F	---	---	---	---	D	---	---	---	---	---

[Base of sampled interval]

U. S. B. M. sample pit 2 (NW¼SE¼ sec 6, T. 17 N., R. 7 E.)

[Top of sampled interval]

5	81794	1.50	26.5	0.071	B	B	A	C	B	B	C	D	D	C	E	D	C	E	E	E	E	E	E	E	F	E	F	F	F	---	---	E	---	C	---	---	---	---	---
		a .50																																					
6	81795	1.30	20.4	.038	B	B	A	C	B	C	C	C	D	D	D	E	D	D	E	E	E	E	E	E	E	F	E	----	F	F	---	---	E	---	---	---	---	---	---
		a .80																																					
7	81796	1.50	16.5	.032	B	B	A	B	B	B	C	C	D	D	D	E	D	E	E	E	E	E	E	E	---	F	---	---	F	---	---	---	---	---	---	---	---	---	---

[Base of sampled interval]

See footnotes at end of table.

TABLE 7.—*Chemical analyses for uranium and semiquantitative spectrographic analyses for other elements in the ash of lignite or carbonaceous shale in cores and bulk samples from the Mendenhall area, S. Dak.*—Continued

Sample			Analyses (percent)		Semiquantitative spectrographic analyses [elements in lignite ash]																																	
Core hole TE No.	Laboratory No.	Length of core section (ft.)	Ash in sample	Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
OLESRUD BED (UPPER BENCH)																																						
Core hole GS-1 (SE¼SW¼ sec 1, T. 17 N., R. 7 E.) [Sampled interval, 38.20 ft.–44.0 ft.]																																						
4	63076	0.17	34.0	0.005	A	A	B	B	B	B	C	D	D	C	C	D	E	D	D	D	C	E	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	D	---
		[b].79																																					
5	63077	.90	38.9	.003	A	A	B	B	B	B	C	D	D	C	C	D	E	D	D	D	C	D	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	D	---
6	63078	.94	13.2	.003	A	A	B	B	B	B	C	C	C	D	C	D	E	E	E	E	C	---	E	E	E	E	---	F	F	F	---	---	---	---	---	---	---	D	---
7	63079	1.08	10.3	.004	A	B	B	B	B	B	C	C	C	C	C	D	E	D	D	E	D	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
8	63080	.90	6.7	.003	A	B	B	B	B	B	C	C	C	D	C	D	E	E	E	E	---	D	E	D	E	E	---	F	F	F	E	---	---	---	---	---	---	---	---
9	63081	.39	13.5	.002	A	B	A	B	B	B	C	C	D	D	C	D	E	D	D	D	C	E	E	D	E	F	---	F	E	---	---	---	---	---	---	---	---	D	---
		[a].32																																					
10	63082	.31	33.6	.004	A	A	B	B	B	B	D	D	D	C	C	D	E	D	D	D	C	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	D	---
Core hole GS-2 (SW¼NE¼ sec 1, T. 17 N., R. 7 E.) [Sampled interval, 65.33 ft–71.50 ft]																																						
12	63094	1.00	14.3	0.003	A	B	B	B	B	B	C	C	D	D	C	D	E	D	D	E	E	E	D	E	E	E	---	F	F	F	---	---	---	---	---	---	---	D	---
13	63095	.94	12.7	.003	A	B	B	B	B	B	C	C	D	C	C	D	E	D	E	E	D	E	D	E	E	---	---	F	F	---	---	---	---	---	---	---	---	---	---
14	63096	1.06	15.9	.003	A	B	B	B	B	B	C	C	D	D	C	D	E	D	E	E	D	E	D	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
15	63097	1.13	12.2	.002	A	B	B	B	B	B	C	C	D	D	C	D	E	D	E	E	D	E	D	E	E	E	---	---	F	---	---	---	---	---	---	---	---	D	---
16	63098	1.00	12.3	.001	A	B	B	B	B	B	C	C	D	D	C	D	E	D	E	E	D	E	D	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
17	63099	1.00	17.6	.002	A	A	B	B	B	B	C	D	D	D	C	D	E	D	D	E	D	E	D	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
Core hole GS-3 (SW¼SE¼ sec 36, T. 18, N., R. 7 E.) [Sampled interval, 117.92 ft–124.54 ft]																																						
17	63116	0.93	10.0	0.002	A	A	B	B	B	B	C	C	C	D	C	D	E	D	D	D	D	E	E	E	D	D	---	F	E	---	E	---	---	---	---	---	---	---	---
18	63117	.94	12.7	.003	A	A	B	B	B	B	C	C	C	D	C	D	E	E	E	E	C	---	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
19	63118	1.00	14.0	.003	A	A	B	B	B	B	C	C	C	D	C	D	E	D	D	E	C	---	E	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
20	63119	.54	11.5	.001	A	A	C	B	B	B	C	C	C	D	C	D	E	E	E	E	D	---	---	E	E	---	---	---	---	---	---	---	---	---	---	---	---	---	---
21	63120	1.04	17.5	.001	A	B	A	B	B	B	C	C	D	C	C	D	---	E	D	E	D	---	---	E	E	---	---	F	---	F	---	---	---	---	---	---	---	D	---
22	63121	.79	10.7	.001	A	A	B	B	B	B	C	C	D	D	C	D	---	D	E	E	D	---	---	E	E	---	---	F	F	F	---	---	---	---	---	---	---	---	---
23	63122	.92	11.2	.001	A	B	B	B	B	B	C	C	D	D	C	D	---	D	E	E	D	E	E	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
24	63123	.46	22.5	.003	A	A	B	B	B	B	C	D	D	C	C	D	E	D	D	E	D	E	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	D	---

Core hole GS-17 (SW¼SW¼ sec 6, T. 17 N., R. 8 E.)

[Sampled interval, 369.75 ft–372.75 ft]

12	67958	1.00	21.3	0.003	A	A	B	B	B	B	C	D	D	D	C	D	E	E	D	E	D	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
13	67959	.92	16.0	.001	A	A	B	B	B	B	C	C	C	D	C	D	E	E	E	E	D	---	---	E	E	---	---	F	---	---	---	---	---	---	---	---	---	---	---
14	67960	1.08	12.5	.001	A	B	B	B	B	B	C	C	C	D	C	D	E	E	E	E	D	---	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---

Core hole GS-18 (SE¼NE¼ sec 1, T. 17 N., R. 7 E.)

[Sampled interval, 374.75 ft–379.42 ft]

14	68192	0.50	17.6	0.002	A	A	B	B	B	B	C	D	C	D	C	D	E	E	D	E	D	E	E	E	E	E	E	F	F	---	---	E	D	---	---	---	---	---	---
15	68193	.91	14.5	.003	A	A	B	B	B	B	C	C	C	D	C	D	E	E	E	E	D	E	F	E	E	E	E	F	F	---	---	E	D	---	---	---	---	---	---
		c.17																																					
16	68194	.71	11.6	.003	A	A	B	B	B	B	C	C	C	D	C	D	E	E	E	E	D	E	F	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	C
17	68195	.88	9.0	.001	A	A	B	B	B	B	C	C	C	C	C	E	E	E	E	E	D	E	F	E	E	E	---	F	---	---	---	---	D	---	---	---	---	---	---
18	68196	.95	10.0	.001	A	B	B	B	B	B	C	C	C	D	C	D	E	E	E	E	D	E	F	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	C
19	68197	.55	15.5	.001	A	A	B	B	B	B	C	C	C	D	C	D	E	E	D	E	D	E	E	E	E	E	---	F	F	---	---	---	D	---	---	---	---	---	C

Core hole SD-10 (NE¼SE¼ sec 12, T. 17 N., R. 7 E.)

[Sampled interval, 313.42 ft–322.56 ft]

5	109497	0.62	56.9	0.004	A	A	B	C	B	B	C	D	D	C	D	D	E	E	E	D	D	D	E	D	E	E	E	F	E	---	---	---	---	---	---	---	---	---	---
		a3.36																																					
9	109498	.38	9.5	.027	A	A	B	C	B	B	C	---	D	D	C	D	D	E	E	E	E	E	---	E	E	E	---	F	E	---	---	---	---	---	---	---	---	---	---
		d.04																																					
10	109499	.26	7.2	.027	B	B	B	B	A	A	C	C	D	D	C	E	D	E	E	E	---	E	---	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
11	109500	.58	9.4	.024	B	B	B	B	A	A	C	C	D	D	C	D	D	E	E	E	---	F	---	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
12	109501	.55	9.0	.027	B	B	B	B	A	A	C	C	D	D	C	E	D	E	E	E	---	---	F	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
13	109502	.21	8.8	.027	B	B	B	B	A	A	C	C	D	D	C	D	D	E	E	E	---	E	---	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
		d.02																																					
14	109503	.27	10.2	.044	B	B	B	B	A	A	C	C	D	D	C	E	D	E	E	E	---	D	F	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
15	109504	.22	11.4	.044	B	B	B	B	A	A	C	C	D	D	C	D	D	E	D	D	---	D	E	---	E	E	E	F	F	F	---	---	---	---	---	---	---	---	---
16	109505	.24	16.4	.23	A	A	B	B	B	B	C	C	D	D	C	D	C	E	E	D	E	C	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
		a.44																																					
18	109506	.18	45.6	.010	A	A	B	C	B	B	C	D	D	C	C	D	E	E	D	D	E	D	E	D	E	E	---	F	F	F	E	E	---	---	---	---	---	---	---
		b.31																																					
20	109507	.26	73.9	.004	A	A	B	C	C	B	C	D	E	C	D	E	E	E	E	E	E	E	E	E	E	E	---	F	F	---	---	E	---	---	---	---	---	---	---
21	109508	.22	32.2	.015	A	A	B	C	B	B	C	D	D	C	C	D	D	E	D	D	E	D	E	D	E	E	---	F	F	F	E	E	---	---	D	---	---	---	---
22	109509	.33	7.1	.028	B	B	B	B	A	B	C	C	D	D	C	---	D	E	D	E	---	E	E	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
23	109510	.28	9.2	.030	A	A	B	B	B	B	C	D	D	D	C	D	D	E	E	E	---	E	E	E	E	E	---	F	F	F	E	---	---	---	---	---	---	---	---
		a.18																																					
24	109511	.19	26.8	.050	A	A	B	B	B	B	C	D	D	D	C	D	D	E	E	D	E	D	E	E	E	F	---	F	F	F	E	---	---	---	---	---	---	---	---

See footnotes at end of table.

TABLE 7.—*Chemical analyses for uranium and semiquantitative spectrographic analyses for other elements in the ash of lignite or carbonaceous shale in cores and bulk samples from the Mendenhall area, S. Dak.*—Continued

Sample			Analyses (percent)		Semiquantitative spectrographic analyses [elements in lignite ash]																																		
Core hole TE No.	Laboratory No.	Length of core section (ft.)	Ash in sample	Uranium in ash	Al	Si	Fe	Mg	Ca	Na	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Yb	Be	Ag	Ge	La	Li	K	As	Ce	Nd	Zn	P
OLESRUD BED (UPPER BENCH)—Continued																																							
U. S. B. M. sample pit 4 (SE¼NE¼ sec 5, T. 17 N., R. 8 E.)																																							
[Top of sampled interval]																																							
19	81808	1.00	36.2	0.020	B	A	A	C	B	C	C	D	D	C	E	D	C	D	E	D	E	D	F	D	F	E	F	F	F	---	E	E	---	C	---	---	E	---	---
20	81809	1.00	41.0	.027	B	A	B	C	B	C	C	D	D	C	E	D	C	E	E	E	E	E	F	D	F	E	---	F	F	---	E	---	---	C	---	---	---	---	---
21	81810	1.00	21.7	.032	B	A	A	B	B	C	C	C	C	C	D	D	D	E	E	E	E	E	F	D	F	E	---	F	F	---	E	---	D	---	---	---	---	---	---
22	81811	1.00	19.1	.033	B	B	A	B	B	B	C	C	C	C	D	D	D	E	E	E	E	E	F	D	F	E	---	F	F	---	---	---	D	---	---	---	---	---	---
23	81812	1.00	16.7	.032	B	B	A	B	B	B	C	C	C	C	D	D	D	E	E	E	E	E	F	D	---	E	---	F	F	---	---	---	D	---	---	---	---	---	---
[Base of sampled interval]																																							
U. S. B. M. sample pit 5 (SW¼SE¼ sec 8, T. 17 N., R. 8 E.)																																							
[Top of sampled interval]																																							
24	81813	0.40	30.9	0.007	B	B	A	C	C	B	C	D	D	D	E	D	E	D	E	D	E	E	E	D	F	E	F	F	E	E	---	E	---	B	C	---	E	D	---
		[b] .40																																					
25	81814	1.00	22.5	.039	B	B	B	C	B	B	C	C	D	D	E	D	C	E	E	D	E	D	F	D	F	E	---	F	E	E	---	E	---	C	---	---	E	D	---
26	81815	1.00	17.4	.038	B	B	B	C	B	B	C	C	D	C	D	D	C	E	F	D	E	D	F	D	F	E	---	F	E	---	---	---	---	C	---	---	---	D	---
27	81816	1.00	20.4	.019	B	B	A	C	B	B	C	C	D	C	D	D	D	E	E	D	E	D	F	E	F	E	---	F	F	---	---	E	---	C	---	---	E	D	---
28	81817	1.00	15.5	.018	B	B	B	B	B	B	C	C	D	C	D	D	E	E	E	D	E	D	F	E	E	E	---	F	F	---	---	---	D	C	---	---	---	D	---
[Base of sampled interval]																																							

OLESRUD BED (LOWER BENCH)

Core hole GS-3 (SW¼SE¼ sec. 36, T. 18 N., R. 7 E.)

[Sampled interval, 124.71 ft-133.14 ft]

25	63124	0.75	31.0	0.004	A	A	B	B	B	B	C	D	D	C	C	D	D	D	D	D	D	D	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
26	63125	.87	27.4	.004	A	A	B	B	B	B	C	D	D	D	C	D	E	E	D	E	C	---	---	E	D	---	---	F	F	---	---	---	---	---	---	---	---	---	---
		[e] 1.42																																					
27	63126	1.00	14.7	.003	A	A	B	B	B	B	C	C	D	D	C	D	E	E	D	D	D	E	E	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
28	63127	.92	12.3	.003	A	A	B	B	B	B	C	D	D	D	C	D	E	D	E	E	---	---	E	E	E	E	---	F	---	---	---	---	---	---	---	---	---	---	---
29	63128	.97	12.7	.002	A	A	C	B	B	B	C	D	D	C	C	D	E	E	E	E	---	E	---	E	E	---	---	---	F	---	---	---	---	---	---	---	---	---	---
30	63129	1.00	17.9	.002	A	A	B	B	B	B	C	C	D	C	C	D	E	D	D	E	D	E	E	D	D	E	---	F	F	---	---	---	---	---	---	---	---	---	---
31	63130	1.14	16.5	.002	A	A	A	B	B	B	C	D	D	C	C	D	---	D	D	D	D	E	E	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
32	63131	.39	18.2	.003	A	A	B	B	B	B	C	D	D	C	C	D	E	D	D	E	---	E	E	D	D	E	---	F	F	---	---	---	---	---	---	---	---	---	---

Core hole SD-10 (NE¼SE¼ sec. 12, T. 17 N., R. 7 E.)

[Sampled interval, 381.07 ft-389.16 ft]

28	109512	0.22	11.9	0.048	A	A	C	B	B	B	C	C	D	D	C	D	C	E	E	E	E	D	E	D	E	E	---	F	F	---	D	---	E	---	---	---	---	---	---
29	109513	.21	12.8	.032	A	A	C	B	B	B	C	C	D	C	C	E	C	E	E	E	E	E	E	D	E	E	---	F	F	F	D	---	E	---	---	---	---	---	---
30	109514	.28	18.0	.052	A	A	A	B	B	B	C	D	D	D	C	D	C	E	D	E	E	E	F	D	E	E	---	F	F	F	E	---	---	---	---	---	---	---	---
31	109515	.29	12.9	.116	A	A	C	B	B	B	C	C	D	D	C	D	C	E	E	D	D	D	E	D	E	E	---	F	F	F	---	D	D	---	---	---	---	---	C
32	109516	.23	7.9	.036	A	B	C	B	A	A	C	C	D	D	C	E	D	E	D	D	---	D	E	E	E	E	---	F	F	F	---	---	D	---	---	---	---	---	---
33	109517	.62	16.5	.047	A	A	B	B	B	B	C	C	D	C	C	D	C	D	D	D	E	D	E	D	E	E	---	F	F	F	---	D	---	---	---	---	---	---	---
34	109518	.32	9.5	.008	B	B	C	B	A	A	C	C	D	D	C	E	D	E	D	D	---	D	E	E	E	E	---	F	F	F	---	---	---	---	---	---	---	---	---
35	109519	.59	20.2	.021	A	A	C	B	B	B	C	C	D	C	C	D	D	E	E	D	D	E	E	E	E	E	E	F	F	F	---	---	---	---	---	---	---	---	---
36	109520	.47	7.5	.026	A	B	C	B	A	A	C	C	D	C	C	D	D	E	D	D	E	D	E	E	E	E	E	F	F	F	---	D	D	---	---	---	---	---	C
37	109521	.49	16.2	.013	A	A	C	B	B	B	C	C	D	C	C	D	D	E	D	D	E	E	E	D	E	E	E	F	F	F	---	---	E	---	---	---	---	---	---
38	109522	.58	11.6	.023	A	A	C	B	B	B	C	C	D	D	C	D	D	E	E	D	E	E	E	E	E	E	E	F	F	F	---	---	D	---	---	---	---	---	---
39	109523	.63	18.1	.044	A	A	B	B	B	B	C	C	D	D	C	D	D	E	D	D	E	E	F	D	E	E	E	F	F	---	E	---	---	---	---	---	---	---	---
40	109524	.56	10.2	.003	A	A	C	B	B	B	C	C	D	D	C	D	D	E	D	D	E	D	E	E	E	E	---	F	---	F	E	---	E	---	---	---	---	---	---
41	109525	.54	68.8	.001	A	A	B	B	C	C	C	D	D	C	D	E	E	E	D	D	E	D	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
42	109526	.17	41.7	.006	A	A	B	B	B	C	C	D	D	C	C	E	D	D	D	D	E	D	E	D	E	E	E	F	F	---	E	---	---	---	---	---	---	---	---
43	109527	.21	30.0	.050	A	A	B	B	B	B	C	D	D	C	C	D	C	E	D	D	E	D	E	E	E	E	E	F	F	---	---	---	---	---	---	---	---	---	---
44	109528	.53	76.0	.006	A	A	B	B	C	C	C	D	D	C	D	E	D	E	D	D	E	E	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
45	109529	.26	60.4	.001	A	A	B	B	C	C	C	D	D	C	D	E	E	E	D	D	E	E	E	E	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---
46	109530	.31	27.1	.006	A	A	B	B	B	B	C	D	D	C	C	D	D	E	D	D	D	D	E	E	E	F	---	F	F	F	---	---	---	---	---	---	---	---	---
47	109531	.58	77.5	.001	A	A	B	B	C	C	C	D	D	C	D	E	E	E	D	E	E	E	E	D	E	E	---	F	F	---	---	---	---	---	---	---	---	---	---

[a] Clay not sampled. [b] Shale not sampled. [c] Loss in coring. [d] Lignite not sampled. [e] Pyrite band not sampled.

TABLE 8.—*Fuel analyses of lignite from the Mendenhall area, South Dakota*

[Analyses by the United States Bureau of Mines. Condition of sample: A, as received; B, moisture-free; C, moisture- and ash-free]

Core hole	Sample			Analyses, in percent									Heating value (Btu)	Ash softening temperature °F.
				Proximate				Ultimate						
	Thickness (feet)	Laboratory No.	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Mendenhall rider bed														
SD-7	0.65	E-32880	A	20.5	29.5	14.0	36.0	3.7	25.2	0.5	32.3	2.3	3,590	2,380
			B	------	37.1	17.7	45.2	1.8	31.7	.6	17.8	2.9	4,510	------
			C	------	67.7	32.3	------	3.3	57.9	1.2	32.2	5.4	8,240	------
SD-8	3.1	E-19298	A	39.0	25.5	29.5	6.0	6.9	39.2	.5	46.4	1.0	6,510	2,260
			B	------	41.8	48.4	9.8	4.2	64.3	.7	19.3	1.7	10,670	------
			C	------	46.4	53.6	------	4.7	71.3	.8	21.3	1.9	11,840	------
	4.0	E-19299	A	45.0	21.9	27.6	5.5	7.2	35.5	.4	50.9	.7	5,850	2,250
			B	------	39.9	50.0	10.1	4.1	64.2	.8	19.5	1.3	10,640	------
			C	------	44.3	55.7	------	4.5	71.3	.9	21.9	1.4	11,830	------
K-26 [1]	2.4	E-24658	A	40.1	29.9	17.2	12.8	------	------	------	------	1.9	4,130	------
			B	------	50.0	28.6	21.4	------	------	------	------	3.1	6,880	------
			C	------	63.6	36.4	------	------	------	------	------	4.0	8,760	------
	3.5	E-24659	A	39.6	24.8	14.7	20.9	------	------	------	------	1.6	3,320	------
			B	------	41.0	24.3	34.7	------	------	------	------	2.7	5,490	------
			C	------	62.8	37.2	------	------	------	------	------	4.1	8,410	------
SD-24	1.1	E-33312	A	27.6	22.8	16.4	33.2	4.3	24.8	.5	35.2	2.0	3,560	2,220
			B	------	31.5	22.7	45.8	1.7	34.2	.7	14.9	2.7	4,920	------
			C	------	58.0	42.0	------	3.1	63.2	1.3	27.3	5.1	9,070	------
	6.3	E-33313	A	29.8	25.2	28.4	16.6	5.6	37.4	.4	38.3	1.7	6,250	2,030
			B	------	35.9	40.4	23.7	3.3	53.3	.6	16.6	2.5	8,900	------
			C	------	47.1	52.9	------	4.4	69.8	.8	21.8	3.2	11,660	------
GS-4	.6	D-68859	A	43.8	24.1	13.5	18.6	------	------	------	------	1.7	3,100	2,180
			B	------	42.9	24.0	33.1	------	------	------	------	3.1	5,510	------
			C	------	64.1	35.9	------	------	------	------	------	4.6	8,230	------
	1.7	D-68860	A	45.9	20.7	11.9	21.5	6.2	18.6	.3	51.5	1.9	2,680	2,130
			B	------	38.3	22.0	39.7	2.1	34.5	.6	19.7	3.4	4,950	------
			C	------	63.4	36.6	------	3.5	57.2	1.0	32.6	5.7	8,200	------
GS-16	8.4	D-71570	A	41.8	22.0	26.1	10.1	6.9	34.7	.4	47.1	.8	5,790	2,100
			B	------	37.9	44.8	17.3	3.8	59.7	.8	17.0	1.4	9,950	------
			C	------	45.8	54.2	------	4.6	72.2	.9	20.6	1.7	12,030	------
Mendenhall bed														
SD-1	1.7	E-32380	A	34.4	23.5	29.6	12.5	6.0	36.2	0.5	42.3	2.5	6,090	1,990
			B	------	35.9	45.1	19.0	3.3	55.2	.8	17.8	3.9	9,280	------
			C	------	44.3	55.7	------	4.1	68.2	.9	22.0	4.8	11,460	------
	2.1	E-32381	A	36.3	23.6	30.0	10.1	6.2	36.7	.4	44.4	2.2	6,120	1,970
			B	------	37.1	47.1	15.8	3.4	57.6	.7	19.1	3.4	9,600	------
			C	------	44.1	55.9	------	4.1	68.4	.8	22.6	4.1	11,410	------
	8.7	E-32382	A	41.0	23.7	27.8	7.5	6.8	35.9	.4	48.0	1.4	6,060	2,140
			B	------	40.1	47.1	12.8	3.8	60.8	.7	19.5	2.4	10,270	------
			C	------	46.0	54.0	------	4.4	69.7	.8	22.4	2.7	11,770	------
SD-2	1.45	E-32387	A	18.0	23.4	29.2	29.4	4.2	37.0	.5	26.4	2.5	6,070	2,210
			B	------	28.5	35.7	35.8	2.6	45.1	.6	12.8	3.1	7,400	------
			C	------	44.4	55.6	------	4.1	70.3	1.0	19.8	4.8	11,530	------
	5.3	E-32388	A	32.5	26.8	31.5	9.2	6.2	41.5	.5	41.1	1.5	6,900	2,050
			B	------	39.6	46.7	13.7	3.8	61.5	.7	18.1	2.2	10,220	------
			C	------	45.9	54.1	------	4.4	71.2	.8	21.1	2.5	11,830	------
SD-4	4.75	E-32401	A	24.9	26.0	35.4	13.7	5.5	43.8	.6	34.6	1.8	7,450	2,100
			B	------	34.6	47.2	18.2	3.7	58.3	.7	16.7	2.4	9,910	------
			C	------	42.3	57.7	------	4.5	71.4	.9	20.3	2.9	12,120	------
	6.55	E-32402	A	29.6	28.5	33.2	8.7	6.1	43.1	.5	40.4	1.2	7,180	2,220
			B	------	40.5	47.2	12.3	3.9	61.3	.7	20.1	1.7	10,210	------
			C	------	46.2	53.8	------	4.5	69.9	.8	22.8	2.0	11,640	------

[1] (Surface sample at SD-8).

TABLE 8.—*Fuel analyses of lignite from the Mendenhall area, South Dakota*—Con.

Core hole	Sample			Analyses, in percent									Heating value (Btu)	Ash softening temperature ° F.
				Proximate				Ultimate						
	Thickness (feet)	Laboratory No.	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Mendenhall bed—Continued														
SD-6	5.75	E-32807	A	39.3	23.8	28.8	8.1	6.7	38.3	0.5	45.2	1.2	6,360	2,130
			B	------	39.2	47.5	13.3	3.9	63.0	.8	17.0	2.0	10,480	------
			C	------	45.2	54.8	------	4.5	72.7	.9	19.6	2.3	12,100	------
	7.85	E-32871	A	37.4	24.2	30.1	8.3	6.5	39.3	.5	44.4	1.0	6,500	2,140
			B	------	38.7	48.0	13.3	3.7	62.7	.8	18.0	1.5	10,390	------
			C	------	44.7	55.3	------	4.3	72.4	.9	20.6	1.8	11,980	------
SD-14	1.1	E-32888	A	31.0	19.8	19.6	29.6	4.8	25.1	.4	36.9	3.2	3,920	2,040
			B	------	28.7	28.4	42.9	2.0	36.4	.6	13.4	4.7	5,680	------
			C	------	50.2	49.8	------	3.5	63.8	1.1	23.4	8.2	9,940	------
	6.0	E-32889	A	42.0	23.2	26.1	8.7	6.8	35.0	.4	48.1	1.0	5,690	1,970
			B	------	40.0	45.0	15.0	3.6	60.3	.7	18.6	1.8	9,810	------
			C	------	47.1	52.9	------	4.3	71.0	.8	21.8	2.1	11,550	------
SD-15	2.2	E-32891	A	39.7	23.7	26.2	10.4	6.6	35.9	.5	45.6	1.0	5,880	1,960
			B	------	39.2	43.5	17.3	3.7	59.5	.8	17.0	1.7	9,740	------
			C	------	47.5	52.5	------	4.4	71.9	.9	20.7	2.1	11,780	------
	1.25	E-32892	A	38.4	22.0	26.0	13.6	6.3	33.1	.3	44.0	2.7	5,560	1,910
			B	------	35.6	42.4	22.0	3.3	53.7	.5	16.1	4.4	9,020	------
			C	------	45.7	54.3	------	4.2	68.8	.7	20.6	5.7	11,570	------
	5.8	E-32893	A	40.5	23.1	26.4	10.0	6.7	35.1	.4	46.8	1.0	5,760	1,970
			B	------	38.8	44.4	16.8	3.6	59.0	.7	18.2	1.7	9,690	------
			C	------	46.7	53.3	------	4.4	70.8	.8	21.9	2.1	11,640	------
SD-19	5.3	E-12615	A	42.7	22.0	25.3	10.0	6.9	34.0	.5	46.9	1.7	5,790	2,010
			B	------	38.3	44.2	17.5	3.8	59.3	.8	15.6	3.0	10,110	------
			C	------	46.4	53.6	------	4.7	71.9	1.0	18.8	3.6	12,250	------
	6.38	E-12616	A	44.9	21.9	25.5	7.7	7.2	34.1	.4	49.8	.8	5,720	2,140
			B	------	39.8	46.1	14.1	4.0	61.8	.8	17.9	1.4	10,380	------
			C	------	46.3	53.7	------	4.6	71.9	.9	21.0	1.6	12,070	------
SD-23	1.25	E-33310	A	37.4	22.0	26.1	14.5	6.2	33.3	.4	42.5	3.1	5,610	1,940
			B	------	35.2	41.7	23.1	3.2	53.2	.6	14.9	5.0	8,960	------
			C	------	45.7	54.3	------	4.2	69.1	.8	19.5	6.4	11,650	------
	5.5	E-33311	A	42.0	22.8	26.8	8.4	6.9	35.3	.4	47.8	1.2	5,900	2,020
			B	------	39.3	46.3	14.4	3.8	60.9	.7	18.2	2.0	10,180	------
			C	------	45.9	54.1	------	4.5	71.1	.8	21.3	2.3	11,890	------
SD-24	8.3	E-33314	A	29.7	25.3	29.2	15.8	5.7	38.6	.5	38.3	1.1	6,420	2,080
			B	------	36.0	41.5	22.5	3.3	54.9	.6	17.1	1.6	9,130	------
			C	------	46.4	53.6	------	4.3	70.8	.8	22.1	2.0	11,780	------
SD-30	.3	E-33800	A	21.6	23.8	19.1	35.5	3.6	28.0	.8	28.3	3.8	4,210	1,970
			B	------	30.4	24.3	45.3	1.5	35.7	1.1	11.5	4.9	5,370	------
			C	------	55.6	44.4	------	2.8	65.3	2.0	21.0	8.9	9,820	------
	13.4	E-33801	A	39.0	23.8	26.5	10.7	6.6	35.3	.4	45.6	1.4	5,870	1,990
			B	------	39.0	43.5	17.5	3.7	57.9	.7	17.9	2.3	9,630	------
			C	------	47.3	52.7	------	4.5	70.2	.9	21.6	2.8	11,670	------
SD-35	8.95	E-33297	A	39.3	22.5	25.0	13.2	6.4	32.3	.5	46.0	1.6	5,330	2,040
			B	------	37.0	41.3	21.7	3.3	53.1	.8	18.4	2.7	8,770	------
			C	------	47.2	52.8	------	4.3	67.8	1.0	23.5	3.4	11,200	------
SD-36	2.2	E-33810	A	32.7	23.5	25.6	18.2	5.5	31.6	.4	39.7	4.6	5,250	1,940
			B	------	34.8	38.1	27.1	2.8	47.0	.5	15.8	6.8	7,800	------
			C	------	47.8	52.2	------	3.8	64.4	.7	21.8	9.3	10,690	------
GS-2	9.5	D-68851	A	37.8	24.2	27.8	10.2	------	------	------	------	1.6	6,150	2,060
			B	------	39.0	44.7	16.3	------	------	------	------	2.6	9,880	------
			C	------	46.6	53.4	------	------	------	------	------	3.1	11,800	------
GS-3	6.2	D-68853	A	40.8	24.0	27.4	7.8	------	------	------	------	1.1	6,260	2,070
			B	------	40.5	46.4	13.1	------	------	------	------	1.8	10,570	------
			C	------	46.7	53.3	------	------	------	------	------	2.1	12,160	------
	7.8	D-68854	A	40.3	24.7	26.2	8.8	------	------	------	------	1.6	6,030	2,080
			B	------	41.4	43.9	14.7	------	------	------	------	2.6	10,100	------
			C	------	48.5	51.5	------	------	------	------	------	3.1	11,840	------

TABLE 8.—*Fuel analyses of lignite from the Mendenhall area, South Dakota*—Con.

Core hole	Sample			Analyses, in percent									Heating value (Btu)	Ash softening temperature ° F.
				Proximate				Ultimate						
	Thickness (feet)	Laboratory No.	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Mendenhall bed—Continued														
GS-4	5.4	D-68864	A	42.4	24.7	24.5	8.4	--	--	--	--	1.3	5,800	2,150
			B	--	42.9	42.5	14.6	--	--	--	--	2.2	10,060	--
			C	--	50.3	49.7	--	--	--	--	--	2.6	11,780	--
	3.5	D-68863	A	42.4	22.9	26.2	8.5	--	--	--	--	1.4	5,780	2,080
			B	--	39.7	45.5	14.8	--	--	--	--	2.4	10,020	--
			C	--	46.5	53.5	--	--	--	--	--	2.8	11,760	--
	1.7	D-68862	A	41.5	24.2	27.0	7.3	--	--	--	--	.7	6,140	2,180
			B	--	41.4	46.1	12.5	--	--	--	--	1.3	10,480	--
			C	--	47.3	52.7	--	--	--	--	--	1.4	11,980	--
GS-17	.8	D-73496	A	40.9	20.5	25.6	13.0	--	--	--	--	--	--	2,130
			B	--	34.7	43.3	22.0	--	--	--	--	--	--	--
			C	--	44.5	55.5	--	--	--	--	--	--	--	--
	1.0	D-73497	A	43.0	21.3	27.3	8.4	--	--	--	--	--	--	2,100
			B	--	37.4	47.9	14.7	--	--	--	--	--	--	--
			C	--	43.8	56.2	--	--	--	--	--	--	--	--
	6.1	D-73498	A	43.5	22.2	26.7	7.6	--	--	--	--	1.1	5,890	2,130
			B	--	39.2	47.3	13.5	--	--	--	--	2.1	10,420	--
			C	--	45.4	54.6	--	--	--	--	--	2.4	12,050	--
GS-18	4.6	D-73909	A	43.2	21.7	24.5	10.6	6.9	33.6	0.4	47.2	1.3	5,570	2,050
			B	--	38.2	43.1	18.7	3.7	59.0	.8	15.5	2.3	9,800	--
			C	--	47.0	53.0	--	4.6	72.7	1.0	18.8	2.9	12,060	--
	4.4	D-73910	A	44.8	21.9	25.3	8.0	--	--	--	--	1.4	5,710	2,050
			B	--	39.6	45.9	14.5	--	--	--	--	2.6	10,330	--
			C	--	46.3	53.7	--	--	--	--	--	3.0	12,080	--
	.8	D-73911	A	46.1	21.3	24.7	7.9	--	--	--	--	--	--	--
			B	--	39.6	45.7	14.7	--	--	--	--	--	--	--
			C	--	46.4	53.6	--	--	--	--	--	--	--	--
Olesrud lignite bed (upper bench)														
SD-1	4.60	E-32383	A	30.1	27.5	33.3	9.1	6.0	43.5	0.5	39.8	1.1	7,230	2,140
			B	--	39.3	47.6	13.1	3.8	62.3	.7	18.5	1.6	10,350	--
			C	--	45.2	54.8	--	4.4	71.6	.8	21.4	1.8	11,910	--
	4.05	E-32384	A	31.8	26.4	31.9	9.9	6.1	40.7	.5	41.8	1.0	6,770	2,140
			B	--	38.8	46.7	14.5	3.8	59.7	.7	19.8	1.5	9,920	--
			C	--	45.3	54.7	--	4.4	69.8	.8	23.3	1.7	11,610	--
SD-2	3.55	E-32389	A	25.1	26.0	31.4	17.5	5.3	41.0	.5	34.3	1.4	6,760	2,150
			B	--	34.7	41.9	23.4	3.4	54.8	.7	15.8	1.9	9,020	--
			C	--	45.3	54.7	--	4.4	71.5	.9	20.7	2.5	11,780	--
	3.3	E-32390	A	27.4	24.5	27.4	20.7	5.3	35.3	.4	37.0	1.3	5,840	2,210
			B	--	33.8	37.7	28.5	3.1	48.7	.6	17.3	1.8	8,050	--
			C	--	47.3	52.7	--	4.3	68.1	.8	24.2	2.6	11,260	--
SD-3	5.95	E-32394	A	31.3	26.4	30.3	12.0	5.9	39.0	.5	41.1	1.5	6,440	2,100
			B	--	38.4	44.1	17.5	3.6	56.8	.7	19.2	2.2	9,380	--
			C	--	46.6	53.4	--	4.3	68.9	.8	23.3	2.7	11,370	--
SD-3A	2.65	E-32398	A	36.9	24.9	30.9	7.3	6.4	39.6	.5	45.3	2.9	6,440	2,150
			B	--	39.5	48.9	11.6	3.7	62.8	.7	19.8	1.4	10,210	--
			C	--	44.6	55.4	--	4.2	71.0	.8	22.4	1.6	11,550	--
	3.8	E-32399	A	38.1	26.2	29.0	6.7	6.6	38.7	.5	46.5	1.0	6,370	2,420
			B	--	42.4	46.8	10.8	3.9	62.5	.7	20.5	1.6	10,280	--
			C	--	47.5	52.5	--	4.4	70.0	.8	23.0	1.8	11,520	--
SD-4	7.5	E-32403	A	32.1	26.9	30.7	10.3	6.1	40.1	.5	41.7	1.3	6,670	2,100
			B	--	39.6	45.2	15.2	3.7	59.0	.7	19.5	1.9	9,810	--
			C	--	46.6	53.4	--	4.4	69.6	.8	23.0	2.2	11,570	--
SD-6	5.9	E-32872	A	36.0	20.8	23.1	20.1	6.0	30.0	.4	41.8	1.7	5,010	2,140
			B	--	32.4	36.3	31.3	3.1	46.9	.6	15.5	2.6	7,820	--
			C	--	47.2	52.8	--	4.5	68.3	.8	22.6	3.8	11,380	--

TABLE 8.—*Fuel analyses of lignite from the Mendenhall area, South Dakota*—Con.

Core hole	Sample: Thickness (feet)	Sample: Laboratory No.	Sample: Condition	Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Ash	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Ultimate: Sulfur	Heating value (Btu)	Ash softening temperature ° F.
						Olesrud lignite bed (upper bench)—Continued								
SD-7	5.65	E-32875	A	38.3	24.5	28.2	9.0	6.6	37.3	0.4	45.7	1.0	6,180	2,210
			B	------	39.7	45.7	14.6	3.8	60.5	.7	18.8	1.6	10,020	------
			C	------	46.4	53.6	------	4.4	70.8	.8	22.1	1.9	11,730	------
SD-7B	5.6	E-32881	A	40.1	23.9	26.1	9.9	6.8	35.0	.5	46.4	1.4	5,830	2,040
			B	------	39.9	43.5	16.6	3.8	58.4	.8	18.0	2.4	9,730	------
			C	------	47.8	52.2	------	4.6	70.0	.9	21.7	2.8	11,660	------
SD-8	5.34	E-19300	A	44.1	23.1	26.6	6.2	7.3	35.5	.4	49.6	1.0	5,920	2,190
			B	------	41.2	47.7	11.1	4.2	63.4	.8	18.7	1.8	10,580	------
			C	------	46.4	53.6	------	4.7	71.3	.9	21.0	2.1	11,900	------
SD-9A	.7	E-32885	A	19.2	17.6	10.0	53.2	3.3	15.5	.3	27.6	.1	------	2,700
			B	------	21.7	12.5	65.8	1.4	19.2	.4	13.1	.1	------	------
			C	------	------	------	------	------	------	------	------	------	------	------
	.4	E-32886	A	12.4	14.5	10.9	62.2	2.7	15.9	.2	18.6	.4	------	2,520
			B	------	16.6	12.4	71.0	1.5	18.1	.3	8.6	.5	------	------
			C	------	------	------	------	------	------	------	------	------	------	------
	3.65	E-32887	A	36.2	23.9	28.0	11.9	6.2	36.9	.4	42.4	2.2	6,060	2,040
			B	------	37.5	43.9	18.6	3.3	57.9	.7	16.1	3.4	9,510	------
			C	------	46.0	54.0	------	4.1	71.2	.8	19.7	4.2	11,680	------
SD-10	5.17	E-9832	A	44.2	20.2	25.7	9.9	7.0	32.8	.4	49.3	.6	5,470	2,020
			B	------	36.3	46.0	17.7	3.7	58.8	.7	18.1	1.0	9,790	------
			C	------	44.1	55.9	------	4.5	71.4	.8	22.1	1.2	11,890	------
SD-14	9.2	E-32890	A	38.7	24.3	27.0	10.0	6.5	36.1	.4	45.4	1.6	5,950	2,040
			B	------	39.7	44.0	16.3	3.6	58.9	.7	17.8	2.7	9,710	------
			C	------	47.5	52.5	------	4.3	70.3	.8	21.4	3.2	11,600	------
SD-15	8.5	E-32894	A	39.9	22.6	24.8	12.7	6.6	32.7	.4	46.5	1.1	5,390	2,070
			B	------	37.6	41.2	21.2	3.5	54.5	.6	18.3	1.9	8,970	------
			C	------	47.7	52.3	------	4.5	69.1	.8	23.2	2.4	11,380	------
SD-18	.6	E-33304	A	29.9	17.9	9.6	42.6	4.4	17.0	.5	35.3	.2	------	2,150
			B	------	25.5	13.8	60.7	1.5	24.2	.7	12.6	.3	------	------
			C	------	------	------	------	------	------	------	------	------	------	------
SD-19	7.8	E-12617	A	45.5	21.5	26.5	6.5	7.2	34.7	.4	50.5	.7	5,820	2,180
			B	------	39.4	48.7	11.9	4.0	63.6	.8	18.4	1.3	10,660	------
			C	------	44.7	55.3	------	4.5	72.2	.9	20.9	1.5	12,100	------
SD-21	.5	E-33307	A	21.7	23.3	14.7	40.3	3.6	24.3	.5	29.8	1.5	3,200	2,280
			B	------	29.8	18.7	51.5	1.5	31.0	.7	13.4	1.9	4,090	------
			C	------	61.5	38.5	------	3.0	64.0	1.3	27.9	3.8	8,440	------
	.95	E-33308	A	33.1	24.0	25.5	17.4	5.4	33.2	.5	40.5	3.0	5,300	1,930
			B	------	35.8	38.1	26.1	2.6	49.7	.8	16.3	4.5	7,920	------
			C	------	48.5	51.5	------	3.5	67.2	1.1	22.1	6.1	10,720	------
SD-26	5.2	E-33315	A	38.5	24.1	27.6	9.8	6.5	36.7	.5	45.8	.7	6,110	2,130
			B	------	39.2	44.9	15.9	3.7	59.8	.8	18.7	1.1	9,950	------
			C	------	46.6	53.4	------	4.4	71.1	1.0	22.1	1.4	11,830	------
	4.0	E-33316	A	35.1	21.5	21.9	21.5	6.0	29.8	.4	41.4	.9	5,010	2,160
			B	------	33.1	33.8	33.1	3.2	45.9	.6	15.7	1.5	7,730	------
			C	------	49.4	50.6	------	4.8	68.6	.9	23.5	2.2	11,560	------
SD-27	3.35	E-33792	A	35.8	23.7	25.5	15.0	6.2	34.0	.4	43.6	.8	5,590	2,100
			B	------	36.9	39.8	23.3	3.5	52.9	.7	18.4	1.2	8,720	------
			C	------	48.1	51.9	------	4.6	69.0	.9	23.9	1.6	11,370	------
SD-28	4.6	E-33796	A	36.9	22.3	24.4	16.4	6.2	31.1	.4	44.3	1.6	5,310	2,080
			B	------	35.3	38.6	26.1	3.3	49.3	.6	18.2	2.5	8,420	------
			C	------	47.8	52.2	------	4.5	66.6	.8	24.8	3.3	11,380	------
SD-29	6.4	E-33798	A	35.1	25.1	29.6	10.2	6.4	39.2	.5	43.1	.6	6,480	2,090
			B	------	38.7	45.6	15.7	3.8	60.3	.7	18.5	1.0	9,980	------
			C	------	45.9	54.1	------	4.5	71.6	.8	21.9	1.2	11,840	------

TABLE 8.—*Fuel analyses of lignite from the Mendenhall area, South Dakota*—Con.

Core hole	Sample			Analyses, in percent									Heating value (Btu)	Ash softening temperature °F.
				Proximate				Ultimate						
	Thickness (feet)	Laboratory No.	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Olesrud bed (upper bench)—Continued														
SD-30	13.4	E-33801	A	39.0	23.8	26.5	10.7	6.6	35.3	0.4	45.6	1.4	5,870	1,990
			B	------	39.0	43.5	17.5	3.7	57.9	.7	17.9	2.3	9,630	------
			C	------	47.3	52.7	------	4.5	70.2	.9	21.6	2.8	11,670	------
SD-32	2.0	E-33804	A	34.0	23.0	24.6	18.4	5.7	32.8	.6	41.4	1.1	5,200	2,300
			B	------	34.9	37.3	27.8	2.9	49.7	.9	17.0	1.7	7,880	------
			C	------	48.3	51.7	------	4.0	68.9	1.2	23.6	2.3	10,910	------
	3.0	E-33805	A	37.7	24.4	27.0	10.9	6.5	36.3	.4	44.3	1.6	6,030	2,000
			B	------	39.1	43.4	17.5	3.7	58.2	.7	17.4	2.5	9,680	------
			C	------	47.4	52.6	------	4.5	70.5	.8	21.1	3.1	11,730	------
SD-33	4.6	E-33808	A	34.6	24.0	25.4	16.0	6.0	33.9	.5	42.5	1.1	5,430	2,030
			B	------	36.7	38.8	24.5	3.2	51.8	.8	18.0	1.7	8,300	------
			C	------	48.6	51.4	------	4.3	68.6	1.0	23.9	2.2	10,990	------
SD-36	6.85	E-33811	A	38.7	24.4	29.2	7.7	6.6	38.4	.5	46.0	.8	6,290	2,100
			B	------	39.7	47.8	12.5	3.8	62.7	.7	19.0	1.3	10,260	------
			C	------	45.4	54.6	------	4.3	71.6	.9	21.7	1.5	11,730	------
SD-38	6.1	E-33813	A	37.0	25.2	28.1	9.7	6.4	38.1	.5	44.3	1.0	6,230	2,060
			B	------	39.9	44.8	15.3	3.5	60.5	.8	18.3	1.6	9,890	------
			C	------	47.2	52.8	------	4.2	71.4	.9	21.6	1.9	11,680	------
GS-1	1.7	D-68847	A	29.2	29.1	34.4	7.3	------	------	------	------	1.2	7,560	2,420
			B	------	41.1	48.7	10.2	------	------	------	------	1.6	10,680	------
			C	------	45.8	54.2	------	------	------	------	------	1.8	11,900	------
		D-68848	A	39.7	25.0	26.6	8.7	------	------	------	------	1.1	6,100	2,110
			B	------	41.5	44.2	14.3	------	------	------	------	1.9	10,100	------
			C	------	48.4	51.6	------	------	------	------	------	2.2	11,790	------
GS-2	6.1	D-68850	A	36.0	26.1	27.5	10.4	------	------	------	------	1.3	6,370	2,150
			B	------	40.8	42.9	16.3	------	------	------	------	2.1	9,960	------
			C	------	48.7	51.3	------	------	------	------	------	2.5	11,890	------
GS-3	7.9	D-68855	A	38.2	26.0	25.2	10.6	------	------	------	------	1.4	6,040	2,080
			B	------	42.0	40.9	17.1	------	------	------	------	2.2	9,760	------
			C	------	50.7	49.3	------	------	------	------	------	2.7	11,790	------
GS-17	2.7	D-73499	A	43.4	21.0	25.7	9.9	------	------	------	------	------	------	2,150
			B	------	37.1	45.5	17.4	------	------	------	------	------	------	------
			C	------	45.0	55.0	------	------	------	------	------	------	------	------
GS-18	4.5	D-73912	A	44.8	21.9	25.7	7.6	7.2	34.2	.4	49.7	.9	5,690	2,130
			B	------	39.7	46.5	13.8	4.0	61.9	.8	17.9	1.6	10,310	------
			C	------	46.0	54.0	------	4.7	71.8	.9	20.8	1.8	11,950	------
Olesrud bed (lower bench)														
SD-1	6.15	E-32385	A	34.2	24.9	28.9	12.0	6.2	37.1	0.5	42.9	1.3	6,220	2,050
			B	------	37.9	43.9	18.2	3.7	56.4	.7	19.0	2.0	9,460	------
			C	------	46.4	53.6	------	4.5	68.9	.9	23.3	2.4	11,570	------
SD-2	4.0	E-32391	A	29.3	26.0	28.9	15.8	5.7	36.9	.5	38.6	2.5	6,190	2,080
			B	------	36.7	40.9	22.4	3.4	52.2	.6	17.9	3.5	8,750	------
			C	------	47.3	52.7	------	4.4	67.3	.8	22.9	4.6	11,270	------
SD-3	7.35	E-32395	A	34.0	25.3	27.8	12.9	6.1	36.5	.5	41.7	2.3	6,110	2,000
			B	------	38.4	42.1	19.5	3.6	55.3	.8	17.4	3.4	9,250	------
			C	------	47.6	52.4	------	4.4	68.7	.9	21.8	4.2	11,490	------
SD-3A	5.15	E-32400	A	35.7	25.0	29.0	10.3	6.4	37.8	.4	43.8	1.3	6,290	2,060
			B	------	39.0	44.9	16.1	3.7	58.8	.7	18.7	2.0	9,790	------
			C	------	46.4	53.6	------	4.4	70.0	.8	22.4	2.4	11,660	------

TABLE 8.—*Fuel analyses of lignite from the Mendenhall area, South Dakota*—Con.

Core hole	Sample			Analyses, in percent									Heating value (Btu)	Ash softening temperature ° F.
				Proximate				Ultimate						
	Thickness (feet)	Laboratory No.	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Olesrud lignite bed (lower bench)—Continued														
SD-4	7.1	E-32404	A	28.6	27.6	30.8	13.0	5.7	40.6	0.5	38.8	1.4	6,740	2,130
			B	------	38.7	43.1	18.2	3.6	56.9	.7	18.5	2.0	9,440	------
			C	------	47.3	52.7	------	4.4	69.6	.8	22.8	2.4	11,540	------
SD-6	9.7	E-32873	A	39.8	23.1	26.6	10.5	6.7	35.0	.4	46.3	1.1	5,850	2,080
			B	------	38.4	44.1	17.5	3.8	58.2	.6	18.0	1.9	9,710	------
			C	------	46.6	53.4	------	4.6	70.5	.8	21.8	2.3	11,770	------
SD-7	5.1	E-32876	A	37.9	24.6	26.8	10.7	6.6	35.4	.4	45.0	1.9	6,020	1,980
			B	------	39.6	43.2	17.2	3.9	57.0	.6	18.3	3.0	9,700	------
			C	------	47.9	52.1	------	4.7	68.8	.8	22.1	3.6	11,710	------
SD-7B	6.8	E-32882	A	40.1	23.7	26.1	10.1	6.9	35.1	.4	46.3	1.2	5,860	2,080
			B	------	39.5	43.6	16.9	4.0	58.6	.7	17.7	2.1	9,790	------
			C	------	47.6	52.4	------	4.8	70.5	.8	21.4	2.5	11,780	------
SD-8	5.46	E-19301	A	43.4	23.1	25.4	8.1	7.2	34.9	.5	48.4	.9	5,900	2,210
			B	------	40.9	44.7	14.4	4.3	61.7	.8	17.1	1.7	10,430	------
			C	------	47.8	52.2	------	5.0	72.1	1.0	20.0	1.9	12,180	------
SD-10	5.5	E-9833	A	43.9	21.6	25.5	9.0	7.1	33.4	.4	49.3	.8	5,640	2,020
			B	------	38.4	45.5	16.1	3.9	59.5	.8	18.2	1.5	10,050	------
			C	------	45.8	54.2	------	4.6	70.9	.9	21.8	1.8	11,970	------
SD-14	9.2	E-32890	A	38.7	24.3	27.0	10.0	6.5	36.1	.4	45.4	1.6	5,950	2,040
			B	------	39.7	44.0	16.3	3.6	58.9	.7	17.8	2.7	9,710	------
			C	------	47.5	52.5	------	4.3	70.3	.8	21.4	3.2	11,600	------
SD-15	6.65	E-32895	A	39.7	21.4	24.6	14.3	6.4	31.9	.4	45.6	1.4	5,290	2,070
			B	------	35.5	40.8	23.7	3.4	52.9	.6	17.0	2.4	8,770	------
			C	------	46.4	53.6	------	4.4	69.4	.8	22.3	3.1	11,490	------
SD-16	5.5	E-33301	A	38.0	22.0	24.1	15.9	6.3	31.2	.4	44.5	1.7	5,250	2,130
			B	------	35.5	38.8	25.7	3.3	50.3	.6	17.4	2.7	8,470	------
			C	------	47.7	52.3	------	4.5	67.6	.8	23.5	3.6	11,400	------
SD-18	2.35	E-33305	A	37.1	22.9	24.3	15.7	6.4	32.6	.4	43.2	1.7	5,460	2,110
			B	------	36.4	38.6	25.0	3.5	51.8	.6	16.3	2.8	8,680	------
			C	------	48.6	51.4	------	4.7	69.1	.8	21.7	3.7	11,570	------
	1.9	E-33306	A	26.4	17.1	14.9	41.6	4.6	20.8	.3	30.9	1.8	------	2,310
			B	------	23.2	20.3	56.5	2.3	28.3	.3	10.1	2.5	------	------
			C	------	------	------	------	------	------	------	------	------	------	------
SD-19	5.46	E-13500	A	44.2	22.2	25.5	8.1	7.2	33.8	.4	49.6	.9	5,790	2,130
			B	------	39.8	45.7	14.5	4.1	60.7	.8	18.2	1.7	10,370	------
			C	------	46.6	53.4	------	4.8	71.0	.9	21.3	2.0	12,140	------
SD-21	3.95	E-33309	A	35.7	22.9	24.2	17.2	6.2	32.0	.4	43.0	1.2	5,380	2,180
			B	------	35.6	37.7	26.7	3.4	49.8	.7	17.6	1.8	8,360	------
			C	------	48.6	51.4	------	4.7	67.9	.9	24.0	2.5	11,410	------
SD-26	3.6	E-33317	A	36.5	21.5	22.7	19.3	6.2	30.4	.4	42.5	1.2	5,130	2,180
			B	------	33.8	35.9	30.3	3.3	47.8	.6	16.0	2.0	8,070	------
			C	------	48.6	51.4	------	4.7	68.7	.8	23.0	2.8	11,590	------
SD-27	3.1	E-33794	A	34.4	21.6	22.2	21.8	5.8	28.7	.4	41.5	1.8	4,870	2,130
			B	------	32.9	33.8	33.3	3.0	43.7	.6	16.6	2.8	7,420	------
			C	------	49.3	50.7	------	4.5	65.4	.9	25.0	4.2	11,120	------
SD-28	3.9	E-33797	A	35.1	23.4	25.9	15.6	6.0	36.0	.4	40.6	1.4	5,750	1,990
			B	------	36.0	39.9	24.1	3.3	55.4	.6	14.4	2.2	8,850	------
			C	------	47.4	52.6	------	4.3	73.0	.8	19.0	2.9	11,500	------
SD-29	2.9	E-33799	A	39.7	22.8	25.6	11.9	6.6	33.5	.4	46.1	1.5	5,620	1,980
			B	------	37.9	42.4	19.7	3.6	55.7	.6	17.9	2.5	9,320	------
			C	------	47.2	52.8	------	4.5	69.3	.8	22.3	3.1	11,610	------

TABLE 8.—*Fuel analyses of lignite from the Mendenhall area, South Dakota*—Con.

Core hole	Sample			Analyses, in percent									Heating value (Btu)	Ash softening temperature ° F.
				Proximate				Ultimate						
	Thickness (feet)	Laboratory No.	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Olesrud bed (lower bench)—Continued														
SD-30	4.3	E-33802	A	36.5	23.2	24.7	15.6	6.2	32.7	0.4	43.5	1.6	5,470	2,120
			B	------	36.6	38.9	24.5	3.4	51.4	.6	17.6	2.5	8,610	------
			C	------	48.5	51.5	------	4.5	68.2	.8	23.1	3.4	11,410	------
SD-31	4.45	E-33803	A	36.8	24.0	26.1	13.1	6.4	34.4	.4	44.0	1.7	5,800	2,060
			B	------	37.9	41.4	20.7	3.7	54.4	.6	17.9	2.7	9,190	------
			C	------	47.8	52.2	------	4.6	68.6	.7	22.7	3.4	11,580	------
SD-32	4.4	E-33806	A	39.2	23.1	25.2	12.5	6.5	33.4	.4	45.3	1.9	5,610	1,940
			B	------	38.0	41.4	20.6	3.5	55.0	.6	17.2	3.1	9,230	------
			C	------	47.8	52.2	------	4.4	69.3	.8	21.6	3.9	11,640	------
SD-33	3.25	E-33809	A	28.2	23.8	23.3	24.7	5.2	30.2	.4	36.1	3.4	5,110	2,010
			B	------	33.2	32.4	34.4	2.9	42.0	.6	15.3	4.8	7,120	------
			C	------	50.6	49.4	------	4.5	64.1	.8	23.3	7.3	10,850	------
SD-35	2.25	E-33298	A	39.6	22.4	27.9	10.1	6.5	35.9	.4	46.5	.6	5,920	2,130
			B	------	37.1	46.2	16.7	3.5	59.5	.7	18.6	1.0	9,790	------
			C	------	44.6	55.4	------	4.3	71.4	.8	22.3	1.2	11,760	------
SD-36	3.8	E-33812	A	35.8	22.0	23.4	18.8	6.1	30.9	.3	42.4	1.5	5,170	2,170
			B	------	34.3	36.4	29.3	3.3	48.2	.5	16.4	2.3	8,060	------
			C	------	48.6	51.4	------	4.7	68.2	.7	23.2	3.2	11,410	------
SD-38	3.7	E-33814	A	32.9	23.1	24.6	19.4	6.2	31.3	.4	39.5	3.2	5,270	2,020
			B	------	34.5	36.6	28.9	3.7	46.7	.6	15.3	4.8	7,860	------
			C	------	48.5	51.5	------	5.3	65.6	.8	21.5	6.8	11,040	------
GS-3	5.3	D-68856	A	40.8	22.6	26.8	9.8	------	------	------	------	1.2	5,940	2,070
			B	------	38.3	45.2	16.5	------	------	------	------	2.1	10,030	------
			C	------	45.8	54.2	------	------	------	------	------	2.5	12,020	------
***Y* lignite bed**														
SD-1	1.7	E-32386	A	39.7	24.6	28.2	7.5	6.8	37.6	0.4	47.0	.7	6,260	2,100
			B	------	40.7	46.9	12.4	3.9	62.4	.7	19.4	1.2	10,370	------
			C	------	46.5	53.5	------	4.4	71.2	.8	22.2	1.4	11,840	------
SD-2	1.05	E-32392	A	22.3	26.5	33.8	17.4	5.2	43.9	.6	32.1	.8	7,350	2,150
			B	------	34.1	43.5	22.4	3.5	56.5	.8	15.8	1.0	9,460	------
			C	------	43.9	56.1	------	4.6	72.9	1.0	20.2	1.3	12,190	------
SD-3	.95	E-32396	A	22.8	24.2	26.7	26.3	4.9	35.3	.5	32.3	.7	5,900	2,470
			B	------	31.4	34.5	34.1	3.0	45.7	.7	15.6	.9	7,650	------
			C	------	47.7	52.3	------	4.6	69.4	1.0	23.6	1.4	11,610	------
SD-6	.9	E-32874	A	37.3	23.7	26.6	12.4	6.6	35.3	.4	44.4	.9	5,990	2,130
			B	------	37.8	42.3	19.9	3.9	56.3	.6	17.8	1.5	9,560	------
			C	------	47.2	52.8	------	4.9	70.3	.7	22.3	1.8	11,930	------
SD-7	1.1	E-32877	A	36.9	21.9	23.6	17.6	6.3	31.4	.3	43.5	.9	5,340	2,210
			B	------	34.7	37.4	27.9	3.5	49.7	.5	16.9	1.5	8,470	------
			C	------	48.2	51.8	------	4.9	69.0	.7	23.3	2.1	11,750	------
SD-8	.5	E-32883	A	28 3	21.5	21.9	28.3	5.2	29.4	.4	34.2	2.5	5,010	2,090
			B	------	30.0	30.5	39.5	2.9	41.0	.5	12.7	3.4	6,980	------
			C	------	49.7	50.3	------	4.8	67.8	.9	20.8	5.7	11,540	------
SD-15	.95	E-32896	A	37 3	22.4	25 6	14.7	6.2	32.5	.4	43.0	3.2	5,490	1,970
			B	------	35.7	40.9	23.4	3.3	51.7	.7	15.8	5.1	8,760	------
			C	------	46.6	53.4	------	4.3	67.5	.9	20.7	6.6	11,430	------

TABLE 8.—*Fuel analyses of lignite from the Mendenhall area, South Dakota*—Con.

Core hole	Sample			Analyses, in percent									Heating value (Btu)	Ash softening temperature °F.
				Proximate				Ultimate						
	Thickness (feet)	Laboratory No.	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
				Y lignite bed—Continued										
SD-16	1.0	E-33302	A	30.4	27.8	30.1	11.7	6.1	40.3	.5	38.8	2.6	6,810	2,010
			B	------	39.9	43.2	16.9	3.9	57.9	.7	16.8	3.8	9,780	------
			C	------	48.0	52.0	------	4.7	69.6	.9	20.2	4.6	11,760	------
SD-27	3.75	E-33795	A	34.0	19.3	20.0	26.7	5.6	26.8	.4	39.5	1.0	4,530	2,190
			B	------	29.3	30.2	40.5	2.8	40.6	.6	14.1	1.4	6,860	------
			C	------	49.2	50.8	------	4.7	68.3	.9	23.7	2.4	11,530	------
SD-35	1.3	E-33299	A	37.1	22.1	24.4	16.4	6.3	32.1	.4	43.6	1.2	5,380	2,110
			B	------	35.1	38.9	26.0	3.5	51.1	.6	16.9	1.9	8,550	------
			C	------	47.4	52.6	------	4.7	69.0	.9	22.9	2.5	11,560	------
GS-3	1.0	D-68857	A	39.1	25.1	25.7	10.1	------	------	------	------	1.5	6,100	2,050
			B	------	41.2	42.2	16.6	------	------	------	------	2.4	10,020	------
			C	------	49.4	50.6	------	------	------	------	------	2.9	12,020	------
				Z lignite bed										
SD-2	1.5	E-32393	A	31.3	28.2	31.5	9.0	6.2	42.3	.5	40.4	1.6	7,080	2,070
			B	------	41.0	45.9	13.1	4.0	61.5	.8	18.3	2.3	10,310	------
			C	------	47.2	52.8	------	4.5	70.8	.9	21.2	2.6	11,850	------
SD-3	2.1	E-32397	A	30.3	25.9	30.9	12.9	5.7	39.2	.5	38.0	3.7	6,600	2,030
			B	------	37.2	44.3	18.5	3.4	56.2	.7	15.9	5.3	9,460	------
			C	------	45.6	54.4	------	4.2	68.9	.9	19.5	6.5	11,600	------
SD-4	2.3	E-32405	A	28.4	26.5	29.8	15.3	5.7	39.6	.5	37.4	1.5	6,650	2,050
			B	------	37.0	41.7	21.3	3.6	55.3	.7	17.0	2.1	9,280	------
			C	------	47.0	53.0	------	4.5	70.3	.9	21.6	2.7	11,800	------
SD-7	2.2	E-32878	A	39.2	22.2	28.2	10.4	6.6	36.7	.5	45.2	.6	5,980	2,100
			B	------	36.5	46.4	17.1	3.6	60.4	.8	17.1	1.1	9,840	------
			C	------	44.0	56.0	------	4.4	72.8	.9	20.6	1.3	11,870	------
	0.6	E-32879	A	37.8	21.5	21.7	19.0	6.2	28.9	.4	43.7	1.8	4,870	2,080
			B	------	34.5	34.9	30.6	3.3	46.5	.7	16.0	2.9	7,830	------
			C	------	49.7	50.3	------	4.7	66.9	1.0	23.3	4.1	11,280	------
SD-8	2.0	E-32884	A	40.8	22.7	26.7	9.8	6.7	36.2	.5	45.5	1.3	5,960	2,040
			B	------	38.4	45.1	16.5	3.6	61.1	.9	15.6	2.3	10,070	------
			C	------	45.9	54.1	------	4.3	73.2	1.0	18.8	2.7	12,060	------
SD-15	1.65	E-32897	A	36.7	25.4	29.3	8.6	6.5	39.5	.5	44.3	.6	6,510	2,110
			B	------	40.1	46.3	13.6	3.8	62.5	.8	18.3	1.0	10,280	------
			C	------	46.4	53.6	------	4.4	72.3	.9	21.2	1.2	11,890	------
SD-16	2.0	E-33303	A	31.4	22.5	23.5	22.6	5.7	31.2	.4	38.5	1.6	5,300	2,140
			B	------	32.8	34.2	33.0	3.2	45.4	.6	15.4	2.4	7,720	------
			C	------	48.9	51.1	------	4.8	67.8	.9	23.0	3.5	11,530	------
SD-19	1.83	E-13501	A	44.9	22.9	26.9	5.3	------	------	------	------	.6	6,180	------
			B	------	41.5	48.9	9.6	------	------	------	------	1.1	11,200	------
			C	------	45.9	54.1	------	------	------	------	------	1.3	12,390	------
SD-32	1.7	E-33807	A	34.0	20.1	20.2	25.7	5.6	27.4	.4	39.6	1.3	4,520	2,150
			B	------	30.4	30.7	38.9	2.8	41.5	.5	14.4	1.9	6,840	------
			C	------	49.7	50.3	------	4.6	67.9	.9	23.5	3.1	11,190	------
SD-35	2.0	E-33300	A	38.3	24.7	28.0	9.0	6.6	37.8	.5	44.8	1.3	6,280	2,030
			B	------	40.1	45.4	14.5	3.8	61.4	.8	17.4	2.1	10,190	------
			C	------	46.9	53.1	------	4.5	71.8	.9	20.3	2.5	11,920	------

TABLE 9.—*Lithologic description of lignite cores from core holes GS-1-4, -16-18, and SD-8, -10, and -19, Mendenhall area, Harding County, South Dakota*

Core hole TE-sample No.	Uranium (percent)	Core section: Depth in hole (feet)	Core section: Length (feet)	Lithologic description and remarks
				Core hole GS-1 (SE¼SW¼ sec 1, T. 17 N., R. 7 E.) elev 3,300 ft
--------	----------	19.5	1.17	Clay, yellow, silty; grading to siltstone at 19.69 ft; grading to brown silty clay, with streaks of yellow silty clay.
--------	----------	20.67	2.66	Lost in coring.
--------	----------	23.33	.75	Clay, light-buff.
--------	----------	24.08	1.66	Shale, brown, clayey, streaks of yellow clay.
--------	----------	25.74	.51	Shale, black.
--------	----------	26.25	1.16	Clay, gray.
--------	----------	27.41	7.25	Lost in coring.
--------	----------	34.67	1.00	Core section not sent to Laboratory.
1	0.001	35.67	.66	Coal, mostly attrital; sparsely woody; badly broken.
2	<.001	36.33	.83	Coal, moderately woody; 1½-in. wood band at 35.98 ft; pyritic streak at 35.94 ft; core is broken.
--------	----------	37.16	.11	Lost in coring.
3	<.001	37.27	.69	Coal, complete core taken for TE sample 3.
--------	----------	37.96	.12	Clay, gray grading to dark-gray, carbonaceous streaks.
--------	----------	38.08	.12	Shale, black.
4	.002	38.20	.17	Coal, abundantly woody; complete core taken for TE sample 4.
--------	----------	38.37	.23	Clay, dark-gray.
--------	----------	38.60	.56	Shale; clayey.
5	.001	39.16	.90	Coal, badly broken, probably attrital.
6	<.001	40.06	.94	Coal, attrital, a few woody streaks in lower part.
7	<.001	41.00	1.08	Coal, attrital, sparse woody streaks; thin fusain streaks at 44.22 ft, 40.42 ft, 40.54 ft and 40.81 ft; blebs of white mineral at 40.25 ft, 40.46 ft and 40.87 ft.
8	<.001	42.08	.90	Coal, moderately woody streaks in upper part; 4½ inches of solid wood at 41.20 ft, abundantly woody in lower part; white mineral blebs at 41.77 ft.
9	<.001	42.98	.39	Coal, sparse woody streaks; lower part is moderately woody; blebs of white mineral at 42.10 ft.
--------	----------	43.37	.32	Clay, gray; a few carbonaceous streaks.
10	.001	43.69	.31	Coal, moderately woody, broken.
--------	----------	44.00	----------	Clay, gray, silty, carbonaceous bands.

Fuel samples (U. S. Bureau of Mines): D-68847 includes TE samples 1 and 2. D-68848 includes TE samples 5-10.

Core hole TE-sample No.	Uranium (percent)	Depth in hole (feet)	Length (feet)	Lithologic description and remarks
				Core hole GS-2 (SW¼NE¼ sec. 1, T. 17 N., R. 7 E.) elev 3,305 ft
1	0.038	51.00	0.42	Coal, moderately woody, badly broken.
--------	----------	51.42	.12	Clay, dark-gray.
2	.017	51.54	.44	Coal, abundantly woody; badly broken.
--------	----------	51.98	.54	Clay, gray, sparse wood bands.
3	.006	52.52	.87	Coal, abundantly woody; broken into biscuits.
4	.010	53.39	.44	Do.
5	.007	53.83	1.00	Do.
6	.005	54.83	1.00	Coal, moderately woody; broken into biscuits.
7	.013	55.83	.96	Coal, abundant woody bands; badly broken.
8	.006	56.79	1.00	Do.
9	.004	57.79	.88	Coal, dominantly woody; badly broken.
10	.003	58.67	.41	Coal, pulverized.
--------	----------	59.08	1.42	Lost in coring.
11	.002	60.50	1.25	Coal, pulverized.
--------	----------	61.75	2.71	Clay, dark-gray; a few streaks of woody coal; 1½ inches of impure woody coal at 62.50 ft and 64.33 ft.
--------	----------	64.46	.91	Clay, dark-gray, thin carbonaceous streaks.
12	<.001	65.37	1.00	Coal, attrital, sparse woody bands.
13	<.001	66.37	.94	Coal, attrital, sparse woody bands; lower part is moderately woody, badly broken.
14	<.001	67.31	1.06	Coal, pulverized.
15	<.001	68.37	1.13	Do.
16	<.001	69.50	1.00	Coal, attrital, sparse woody bands; a thin impure-coal streak at 69.52 ft; core is badly broken.
17	<.001	70.50	1.00	Coal, probably attrital; evidences of impure coal streaks; core is broken and dry.
--------	----------	71.50	----------	Base of core sent to laboratory.

Fuel samples (U. S. Bureau of Mines): D-68851 includes TE samples 3-11. D-68850 includes TE samples 12-17.

TABLE 9.—*Lithologic description of lignite cores from core holes GS-1-4,-16-18, and SD-8, -10, and -19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section		Lithologic description and remarks
		Depth in hole (feet)	Length (feet)	
Core hole GS-3 (SW¼SE¼ sec 36, T. 18 N., R. 7 E.) elev 3,325 ft				
-------	---------	87.00	1.62	Clay, gray, a 1½-in. zone of ferruginous pebbles and similar material, possibly caved from above, at top, then gray silty clay with fine "soapy" texture grading into gray clay shale and reverting to silty clay at 87.67 ft; ½-inch hard pyritic sandstone lens at 87.87 ft; clay beneath, dark-gray, wavy bedded and with thin light-gray layers and lenses; lower part is slightly darker and more uniform in texture.
1	0.004	88.62	1.02	Coal, attrital, sparsely thin- and medium-banded, earthy texture; core is cracked and broken.
2	.003	89.64	1.00	Coal, platy and cracked; upper part is probably medium-banded; lower part is incoherent.
3	.003	90.64	.98	Coal, as in above sample; platy fragments with some of earthy coal.
-------	---------	91.62	.38	Lost in coring and handling(?), interval at 91.62 ft.-92.00 ft.
4	.001	92.00	.85	Coal, mostly attrital, thin-layered; ½-in. shaly parting at top of this sample (not rejected from sample); appears to be sparsely woody but determination was uncertain.
5	<.001	92.85	1.00	Coal, more woody than in above sample, trace of fusain; core is fairly coherent.
6	<.001	93.85	.98	Coal, moderately woody, thin- and medium-banded; many fusain lenticles at 94.25-94.42 ft.
7	<.001	94.83	.39	Coal, sparsely woody, thin- and medium-banded, fusain lens at 95.04 ft.
-------	---------	95.22	2.11	Shale, clay, upper inch is dark-gray, grading below to olive-gray, becoming silty at 95.5 ft; grading into argillaceous siltstone with a few coaly streaks; sandy beneath 96.0 ft; sandy beds contain thin carbonaceous streaks; becomes more clayey and carbonaceous below 97.0 ft approaching the underlying coal.
8	<.001	97.33	.79	Coal; core is fairly coherent but platy and fractured; ½-in. fusain zone at 97.48 ft; blebs of a white mineral, kaolinite(?) at 97.71 ft.
9	<.001	98.12	.86	Coal, mostly attrital; ½-in. zone of badly crushed and broken coal, probably high in fusain at 98.33 ft; dominantly woody below.
10	<.001	98.98	1.04	Coal, about 80 percent is woody; ½-in. fusain lens below 99.33 ft.
11	<.001	100.02	.87	Coal, dominantly woody; many ¼-in. pyritic rosettes in 2-in. zone below 100.33 ft.
12	<.001	100.89	.78	Coal, moderately woody, thin- to medium-banded; a number of small fusain lenticles in upper half of sample.
-------	---------	101.67	.33	Lost in coring; interval at 101.67-102.00 ft.
13	<.001	102.00	1.04	Coal, mud-smeared at top, platy, badly checked; probably medium-banded and sparsely or, possibly, moderately woody.
14	<.001	103.04	.92	Coal, badly checked as above; 1-in. woody band at 103.58 ft.
15	<.001	103.96	.79	Coal, as above; possibly with a little more wood, small kaolinite(?) lenses at 104.42 ft.
16	<.001	104.75	.77	Coal, similar to that of sample above; a few ¾-in. thick woody bands.
-------	---------	105.52	.23	Clay, buff to gray; coaly streaks.
-------	---------	105.75	11.75	Core in interval 105.75 ft to 117.50 ft not sent to laboratory.
-------	---------	117.50	.42	Clay, silty, gray, grading to clay shale, coaly fragments.
17	<.001	117.92	.93	Coal, mostly attrital, core is broken and dry.
18	<.001	118.85	.94	Coal, mostly attrital, a few woody streaks; 1-in zone is badly broken at 119.25 ft.
19	<.001	119.79	1.00	Coal, mostly attrital; a few woody streaks; core is broken in lower part.
20	<.001	120.79	.54	Coal, mostly attrital; ¼-in fusain streaks at 121.16 ft and 121.29 ft.
21	<.001	121.33	1.04	Coal, moderately woody in lower part; possibly attrital but badly broken in upper part.
22	<.001	122.37	.79	Coal, upper part is abundantly woody, broken and dry; lower part is badly broken but probably abundantly woody.
23	<.001	123.16	.92	Coal, dominantly woody; core broken.
24	<.001	124.08	.46	Do.
-------	---------	124.54	.17	Clay, dark-gray.
25	<.001	124.71	.75	Coal, dominantly woody; 2¾-in. clay bands at 124.92 ft and 125.16 ft, excluded from fuel sample.
26	<.001	125.46	.87	Coal, dominantly woody, clay bands at 125.69 ft and 126.00 ft. Upper clay band contains whitish mineral blebs; lower clay band is sandy; core considerably broken in lower part.
-------	---------	126.33	1.42	Lost in coring, interval at 126.33-127.75 ft.
27	<.001	127.75	1.00	Coal, dominantly woody.
28	<.001	128.75	.92	Coal, dominantly woody; ½-in brown plastic clay band at top excluded from fuel sample.

TABLE 9.—*Lithologic description of lignite cores from core holes GS–1–4, –16–18, and SD–8, –10, and –19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section: Depth in hole (feet)	Core section: Length (feet)	Lithologic description and remarks
				Core hole GS-3—Continued
29	<.001	129.67	0.97	Coal, abundantly woody at top; mostly attrital in middle and lower parts.
30	<.001	130.64	1.00	Coal, moderately woody at top; probably moderately woody at base; core is badly broken.
31	<.001	131.64	1.11	Coal, upper part is dominantly woody; lower part is attrital, with woody bands; ¼-in pyrite band at 132.71 ft.
32	<.001	132.75	.39	Coal, dominantly woody.
--------	----------	133.14	1.04	Clay, gray, grading to shaly clay, woody bands.
--------	----------	134.18	.28	Shale, coaly.
--------	----------	134.46	1.96	Clay, silty, sandy bands 1-in thick at 135.44 ft and ¾-in thick at 135.77 ft; ¼-in. pyritic band at 134.75 ft; white mineral bleb at 135.71 ft and 135.83 ft.
--------	----------	136.42	.52	Clay, coaly streaks.
--------	----------	136.94	.18	Shale, coaly.
33	<.001	137.12	1.02	Coal, dominantly woody, core is badly broken.
--------	----------	138.14	.86	Clay, dark-brown, grading to gray silty clay.
--------	----------	139.00	----------	Base of core sent to laboratory.

Fuel samples (U. S. Bureau of Mines): D–68853 includes TE samples 1–7; D–68854 includes TE samples 8–16; D–68855 includes TE samples 17–26; D–68856 includes TE samples 27–32; D–68857 includes TE sample 33.

Core hole TE-sample No.	Uranium (percent)	Core section: Depth in hole (feet)	Core section: Length (feet)	Lithologic description and remarks
				Core hole GS-4 (NW¼SE¼, sec 36, T. 18 N., R. 7 E.) elev 3,300 ft
--------	----------	22.42	0.27	Clay, light-buff, bentonitic, plastic.
--------	----------	22.69	.12	Sandstone, medium-grained, unconsolidated.
--------	----------	22.81	.21	Clay, light-buff, plastic.
--------	----------	23.02	.08	Clay, brown, shaly.
1	0.044	23.10	.61	Coal, pulverulent, when broken apart carefully it seems evident that it is mostly in place but badly shrunken and cracked from underground weathering.
--------	----------	23.71	.33	Clay, brown, shaly; small lenticles of light-yellow clay possibly from pyritic oxidation at base.
2	.010	24.04	1.71	Coal, pulverulent, extremely oxidized and weathered; light-yellow pellets in coal are probably a result of pyritic oxidation.
--------	----------	25.75	.58	Lost in coring; interval at 25.75–26.33 ft.
--------	----------	26.33	.13	Clay, light-buff to yellow, semifluid consistency.
3	.003	26.46	.41	Coal, weathered; too weak to be sawed, but apparently in normal relationship; excluded from fuel sample.
--------	----------	26.87	.21	Coaly shale.
--------	----------	27.08	.75	Clay shale, gray, slightly silty; bedding irregular, a few coaly lenticles.
--------	----------	27.83	42.75	Core in interval 27.83–70.58 ft not sent to laboratory.
--------	----------	70.58	.67	Shale, light-gray, grades to darker gray shale at 71 ft; well-preserved plant fossils.
--------	----------	71.25	.06	Clay, gray, plastic.
4	<.001	71.31	.96	Coal, broken and shaly at top; woody between 71.50 ft and 71.67 ft; earthy to 72 ft; moderately woody at base.
--------	----------	72.27	.06	Lost in coring; interval at 72.27–72.33 ft.
5	<.001	72.33	1.04	Coal, earthy, attrital; badly broken except for a 2-in. woody band at 72.83 ft.
6	<.001	73.37	1.19	Coal, dominantly attrital; less than 10 percent woody coal; ½-in. fusain streak at 74.5 ft.
7	<.001	74.56	.73	Coal, moderately woody, thin-banded with many small fusain chips in upper part; more woody in lower part.
8	<.001	75.29	.58	Coal, moderately woody, thin- and medium-banded, with pyritic lenticle at 75.3 ft.
9	<.001	75.87	.88	Coal, moderately woody, thin- and medium-banded; a few fusain lenticles in middle part; core split and broken.
--------	----------	76.75	.25	Lost in coring; interval at 76:75–77.00 ft.
--------	----------	77.00	.33	Clay, brown, shaly; a few plant fragments.
10	.001	77.33	.92	Shaly coal(?), earthy; blebs of buff clay in basal 1 inch; core broken into small biscuits; excluded from fuel sample.
11	<.001	78.25	.89	Coal, dominantly attrital, impure; 1-in woody band at 78.48 ft and ½-in woody band at 78.83 ft.
12	<.001	79.14	.71	Coal, solid wood, grain highly contorted.
13	<.001	79.85	.88	Coal, dominantly woody coal in middle part; upper part is mostly attrital coal with thin fusain lenticles; ⅛-in. pyritic lens at 80.42 ft.

TABLE 9.—*Lithologic description of lignite cores from core holes GS–1–4, –16–18, and SD–8, –10, and –19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section		Lithologic description and remarks
		Depth in hole (feet)	Length (feet)	
				Core hole GS-4—Continued
--------	----------	80.73	0.06	Clay shale, gray and buff.
14	<0.001	80.79	1.02	Coal, shaly in uppermost inch; pyrite lenticle at 80.94 ft associated with many thin fusain streaks; core badly broken below 81.0 ft, earthy in appearance, probably mostly attrital and possibly impure.
--------	----------	81.81	2.19	Lost in coring; interval at 81.81 ft–84.00 ft.
15	<.001	84.00	.79	Coal, moderately woody, thin- and medium-banded; core broken into thin biscuits; 2-in. woody lens at 84.5 ft.
16	<.001	84.79	.88	Coal, moderately woody in upper part; medium-banded; lowest 2 inches, solid wood.
--------	----------	85.67	1.00	Clay, dark gray, coaly fragments in uppermost 2 inches; grading below to brown shaly clay; numerous contorted woody lenticles at 86.0 ft; clay becomes light-gray and silty below 86.0 ft.
--------	----------	86.67	----------	Base of core sent to laboratory.

Fuel samples (U. S. Bureau of Mines): D–68859 includes TE sample 1. D–68860 includes TE sample 2. D–68864 includes TE samples 4–9. D–68863 includes TE Samples 11–14. D–68862 includes TE samples 15 and 16.

				Core hole GS-16 (SE¼NW¼ sec. 31 T. 18 N. R. 8 E.) elev. 3,570 ft.
--------	----------	325.33	0.84	Clay, gray, shaly; ¾-in. limonitic concretion at 325.33 ft; yellowish streaks at 325.96 ft and 326.08 ft.
--------	----------	326.17	.29	Shale, gray, clayey; yellowish streaks at 326.25 ft and 326.37 ft.
1	0.001	326.46	.64	Clay, black, carbonaceous.
2	.003	327.10	.67	Clay, black, carbonaceous; ¼-in. coaly streaks at 327.69 ft and 327.77 ft.
--------	----------	327.77	1.06	Clay, gray, shaly to sandy; a few limonitic stains in upper part.
--------	----------	328.83	3.00	Clay, gray; not sent to laboratory.
--------	----------	331.83	.50	Clay, gray, shaly.
3	.009	332.33	.06	Coal.
--------	----------	329.39	.03	Lost in coring; interval at 332.39 ft–332.42 ft.
--------	----------	332.42	.83	Clay, dark-gray; ¼-in. coaly bleb at 332.50 ft and 333.29 ft.
4	.011	333.25	.35	Clay, gray, grading downward to black, carbonaceous; ½-in. coaly bleb at 333.29 ft.
5	.009	333.60	1.07	Coal, moderately thin- and medium-banded; 1-in. of carbonaceous clay at 333.08 ft.
6	.005	334.67	.85	Coal, moderately woody, thin- and medium-banded.
7	.003	335.52	.96	Coal, sparsely woody, thin-banded; light-gray clay blebs at 336.06 ft, 336.12 ft and 336.37 ft.
8	.002	336.48	.98	Coal, sparsely thin-banded; small clayey flecks at 336.75 ft and 337.08 ft.
9	.001	337.46	.62	Coal, sparsely woody, thin- and medium-banded; ¾-in. pyritic rosette at 338.0 ft.
10	.001	338.08	.92	Coal, abundantly woody, thin- and medium-banded.
11	.001	339.00	1.00	Coal, abundantly woody; 2-in. band of solid wood at 339.14 ft, thin- and medium-banded below; ¼-in. irregular pyritic bands at 339.56 ft and 339.58 ft.
12	<.001	340.00	1.14	Coal, abundantly woody; largest band is 1¼-in. thick.
13	.001	341.14	.84	Coal, moderately woody, medium-banded.
--------	----------	341.98	.06	Clay, dark-gray, carbonaceous.
--------	----------	342.04	1.46	Clay, gray.
--------	----------	343.50	----------	Base of core sent to laboratory.

Fuel sample (U. S. Bureau of Mines): D–71570 includes TE samples 5–13.

				Core hole GS-17 (SW¼SW¼ sec. 6 T. 17 N. R. 8 E.) elev. 3,635 ft.
--------	----------	357.50	0.37	Clay, dark-gray, plastic.
1	0.020	357.87	.21	Coal, impure.
2	.010	358.08	.38	Coal, moderately woody.
3	.005	358.46	.33	Coal, impure; rejected from fuel sample.
4	.015	358.79	.38	Coal, dominantly woody.
--------	----------	359.17	1.33	Clay, gray to dark-gray; ½-in. coaly streak at 359.25 ft.
--------	----------	360.50	.08	Clay, black, carbonaceous.
--------	----------	360.58	.15	Shale, coaly.
5	.006	360.73	1.10	Coal, attrital; ¼-in. pyritic lenticle at 361.81 ft; 1-in. zone of impure coal at 360.96 ft, rejected from fuel sample.

TABLE 9.—*Lithologic description of lignite cores from core holes GS–1–4, –16–18, and SD–8, –10, and –19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section: Depth in hole (feet)	Core section: Length (feet)	Lithologic description and remarks
Core hole GS-17—Continued				
--------	----------	361.83	0.27	Clay, gray, silty.
--------	----------	362.10	.11	Shale, coaly.
--------	----------	362.21	.62	Clay, buff to brown with scattered coaly streaks; basal 2 in. is carbonaceous.
6	0.004	362.83	.92	Coal, thin-banded; ½-in. of interlaminated fusain and attrital coal at 363.50 ft.
7	.002	363.75	1.08	Coal, upper part sparsely woody; lower part dominantly woody, with a 4-in. woody band at 264.42 ft; ½-in. fusain streaks at 363.87 ft and 364.04 ft.
8	.001	364.83	1.25	Coal, upper part abundantly medium- and thick-banded; lower part attrital coal; fusain interlaminated with attrital coal at 365.00 ft–365.04 ft and 365.33 ft–365.46 ft.
9	<.001	366.08	1.31	Coal, sparsely thin-banded to 366.75 ft; moderately medium-banded to 367.08 ft; then attrital to base.
--------	----------	367.39	.03	Lost in coring; interval at 362.39 ft–367.42 ft.
10	<.001	367.42	1.00	Coal, sparsely medium- and thin-banded; ⅛-in. fusain lenticle at 367.87 ft.
11	----------	368.42	.58	Coal, sparsely, medium- and thin-banded; ¼-in. pyrite rosettes at 368.71 ft and 369.00 ft.
--------	----------	369.00	.75	Clay, gray, silty; 1-in. thick black carbonaceous clay bands at top and bottom.
12	.001	369.75	1.00	Coal, sparsely thin- and medium-banded.
13	<.001	370.75	.92	Coal, sparsely thin-banded; interlaminated with fusain below 371.17 ft.
14	<.001	371.67	1.08	Coal, sparsely woody; pyritic rosettes and lenticles abundant; fusain streaks abundant below 372.50 ft; 2¾ in. of black lignitic clay at 372.08 ft rejected from fuel sample.
--------	----------	372.75	----------	Base of core sent to laboratory.

Fuel samples (U. S. Bureau of Mines): D–73496 includes TE samples 2–4. D–73497 includes TE sample 5 D–73498 includes TE samples 6–11. D–73499 includes TE samples 12–14.

Core hole TE-sample No.	Uranium (percent)	Core section: Depth in hole (feet)	Core section: Length (feet)	Lithologic description and remarks
Core hole GS-18 (SE¼NE¼ sec. 1, T. 17 N., R. 7 E.) elev. 3,610 ft.				
--------	----------	355.46	1.37	Siltstone, gray, soft; more clayey in basal 6 in.
1	0.025	356.83	.17	Coal, soft and pulverulent in uppermost ¾ in., the rest is coherent and dominantly attrital.
2	.017	357.00	.20	Coal, attrital, small mineral flecks.
3	.021	357.20	.57	Coal, moderately thin- and medium-banded, with thin clayey stringers and pyritic joint-fillings.
4	.007	357.67	1.04	Coal, sparsely medium-banded, a few flecks of attrital fusain.
5	.005	358.71	1.00	Coal, moderately medium- and thin-banded, associated fusain and clayey flecks at 359.00 ft; fusain interlaminated with attrital coal at 359.16 ft.
6	.007	359.71	.87	Coal, dominantly attrital in upper part, moderately thin- and medium-banded in lower part; attrital part has many fusain blebs.
7	.004	360.58	.84	Coal, moderately to abundantly woody; ½-inch band of fusain with attrital coal partings at 361.04 ft; ½-in. pyritic lenticles beneath thick woody bands in lower part.
--------	----------	361.42	.91	Clay, grayish-buff, woody bands in the uppermost and basal inches; slickensides developed along the woody fragments and larger slip planes opposed at about 45 degrees in middle part; middle and lower parts show some evidence of bedding.
8	.002	362.33	.96	Coal, somewhat clayey in the uppermost inch; dominantly (about 95 percent) wood in middle part; moderately thin-banded in lower part, a few fusain lenticles.
9	.001	363.29	1.00	Coal, moderately thin- to thick-banded in upper half; dominantly woody in lower half.
10	<.001	364.29	1.00	Coal, moderately thin- to thick-banded; zones of fusain flecks interspersed with attrital coal in 4 bands.
--------	----------	365.29	.13	Lost in coring; interval at 365.29 ft–365.42. ft.
11	.001	365.42	1.41	Coal, sparsely medium-banded in uppermost foot; badly broken in lower part.
12	.001	366.83	.79	Coal, badly broken.
--------	----------	367.62	4.21	Lost in coring, presumed to be coal; 367.62 ft–371.83 ft.
--------	----------	371.83	1.96	Clay, brown, shaly, a few thin coaly streaks, becomes clayey shale at about 373 ft and more carbonaceous, well-preserved plant fossils in lower 4 in.

TABLE 9.—*Lithologic description of lignite cores from core holes GS–1–4, –16–18, and SD–8, –10, and –19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section		Lithologic description and remarks
		Depth in hole (feet)	Length (feet)	
				Core hole GS-18—Continued
13	0.002	373.79	0.31	Coal, attrital, with ½-in woody bands at top and base.
--------	----------	374.10	.65	Clay, brown, shaly; numerous plant fragments.
14	<.001	374.75	.50	Coal badly crushed in uppermost 3 in; chiefly attrital coal and sparsely thin-banded coal below; ⅛-in. fusain streak at 375.12 ft.
15	<.001	375.25	.91	Coal, badly crushed; most appears to be attrital coal.
--------	----------	376.16	.17	Clay, white, bentonitic with broken coal fragments (probably not a parting but caved material, excluded from fuel sample).
16	<.001	376.33	.71	Coal, moderately woody in thin- to thick-bands, with ¼-in. fusain lenticle at 376.71 ft.
17	<.001	377.04	.88	Coal, moderately thin- to thick-banded.
18	<.001	377.92	.95	Coal, moderately to abundantly medium-banded; core somewhat broken in middle part.
19	<.001	378.87	.55	Coal, sparsely thin- to medium-banded; possibly slightly clayey in basal inch.
--------	----------	379.42	.87	Clay, brown, silty, with a few small woody fragments in upper 2½ inches grading to grayish clay beneath and somewhat more silty at about 380 ft.
--------	----------	380.29	----------	Base of core sent to laboratory.

Fuel samples (U. S. Bureau of Mines): D–73909 includes TE samples 1–7. D–73910 includes TE samples 8–11. D–73911 includes TE sample 12. D–73912 includes TE sample 14–19.

				Core hole SD-8 (SE¼NW¼ sec. 36, T. 18 N., R 7 E.) elev. 3,330 ft.
--------	----------	36.05	0.67	Sandstone, yellow-tan, medium-grained; uppermost 2 inches is light-ocher silty clay.
--------	----------	36.72	.79	Clay, silty, ocher-tan.
1	0.014	37.51	.33	Clay, gray; impure coal below 37.74 ft.
2	.092	37.84	.11	Coal, abundantly medium-banded.
--------	----------	37.95	.60	Lost in coring; described as coal at drill site; interval at 37.95 ft–
--------	----------	38.55	4.45	Lost in coring; described as siltstone and sandstone at drill site; interval at 38.55 ft–43.0 ft.
--------	----------	43.00	2.13	Lost in coring, described as coal at drill site; interval at 43.00 ft–45.13 ft.
3	.011	45.13	.50	Coal, dominantly thick-banded.
4	.012	45.63	.34	Coal, abundantly thick- and medium-banded.
5	.008	45.97	.29	Coal, moderately thick-banded, fusain lenses.
6	.005	46.26	.41	Coal, a very thick wood band.
7	.008	46.67	.50	Coal, sparsely thick-banded, thin fusain lenses.
8	.006	47.17	.33	Coal, abundantly thick-banded, fusain lenses; pyritic.
9	.004	47.50	.30	Coal, moderately thick-banded, fusain lenses; pyritic.
10	.009	47.80	.45	Coal, sparsely thick- and thin-banded; 1½-in wood band at 48.07 ft.
--------	----------	48.25	.96	Clay, light-gray.
--------	----------	49.21	.78	Do.
--------	----------	49.99	1.12	Clay, silty, light-gray.
--------	----------	51.11	.79	Do.
--------	----------	51.90	.59	Coal, moderately thick-banded; irregular lenses of fusain and wood.
--------	----------	52.49	.59	Coal, abundantly very thick-banded; nonbanded part approximately 75 percent fusain.
--------	----------	52.86	.14	Lost in coring; interval at 52.86–53.00 ft.
--------	----------	53.00	.38	Clay, medium-gray, carbonaceous; excluded from fuel sample.
--------	----------	53.38	.39	Coal, dominantly very thick-banded; ¾-in. fusain parting at 57.71 ft.
--------	----------	53.77	.40	Coal, sparse thick to thin irregular wood lenses; ¼-in. fusain parting at base.
--------	----------	54.17	.28	Coal, sparsely medium-banded.
--------	----------	54.45	.29	Coal, abundantly thick-banded; ½-in fusain parting at base.
--------	----------	54.74	.49	Coal, moderately thick- and thin-banded, fusain lenses.
--------	----------	55.23	.27	Coal, dominantly medium-banded; ¼-in fusain parting below 55.44 ft.
--------	----------	55.50	.38	Coal, abundantly medium-banded, slightly pyritic; ¼-in wood band at top.
--------	----------	55.88	.34	Coal, impure; excluded from fuel sample.
--------	----------	56.22	.50	Coal, sparsely medium-banded; a few thick and medium woody lenses.

TABLE 9.—*Lithologic description of lignite cores from core holes GS–1–4, –16–18, and SD–8, –10, and –19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE sample No.	Uranium (percent)	Core section: Depth in hole (feet)	Core section: Length (feet)	Lithologic description and remarks
				Core hole SD–8—Continued
--------	----------	56. 72	0. 44	Coal, impure.
--------	----------	57. 16	. 39	Do.
--------	----------	57. 55	. 38	Do.
--------	----------	57. 93	. 48	Do.
--------	----------	58. 41	. 31	Do.
--------	----------	58. 72	. 40	Coal, impure; badly broken in coring.
--------	----------	59. 12	. 36	Coal, impure; pulverized in coring.
--------	----------	59. 48	. 38	Coal, impure; badly broken in coring.
--------	----------	59. 86	. 44	Do.
--------	----------	60. 30	. 99	Clay, light-gray; 1¼-in of black clay at top.
--------	----------	61. 29	1. 21	Clay, light-gray; few carbonaceous streaks.
--------	----------	62. 50	15. 25	Core in interval 62.50–77.75 ft not sent to laboratory.
--------	----------	77. 75	. 46	Clay, light-gray, slightly carbonaceous; more carbonaceous, with a few coaly streaks below 77.98 ft.
--------	----------	78. 21	. 33	Clay, gray, medium and thick coal bands.
--------	----------	78. 54	. 46	Coal, 1¼-in. of impure coal at top; ½-in. pyritic bands below 78.64 ft and 78.94 ft; 3-in. solid-wood band between pyrite zones.
--------	----------	79. 00	. 40	Coal, impure; clay, light-gray and slightly carbonaceous below 79.18 ft.
--------	----------	79. 40	26. 50	Core from interval 79.40–105.90 ft not sent to laboratory.
--------	----------	105. 90	. 58	Clay, light-gray, grading into black clay.
--------	----------	106. 48	. 35	Coal, impure, pyritic.
--------	----------	106. 83	. 49	Coal, abundantly thick- to medium-banded.
--------	----------	107. 32	. 41	Coal, abundantly thick- and thin-banded.
--------	----------	107. 73	. 54	Coal, impure, excluded from fuel sample.
--------	----------	108. 27	. 29	Coal, dominantly thick-banded; ½-in. fusain parting at base.
--------	----------	108. 56	. 37	Coal, abundantly thin-banded; 1-in. wood band below 108.62 ft; ¾-in. of impure coal at top excluded from fuel sample.
--------	----------	108. 93	. 28	Coal, abundantly thin-banded· pulverized in coring.
--------	----------	109. 21	. 36	Coal, moderately thin- and thick-banded.
--------	----------	109. 57	. 50	Coal, abundantly thin- to thick-banded; pyritic; thick fusain lens below 109.78 ft.
--------	----------	110. 07	. 46	Coal, abundantly thin- and medium-banded; fusain partings.
--------	----------	110. 53	. 35	Coal, dominantly thick- to medium-banded; thick fusain partings.
--------	----------	110. 88	. 50	Coal, abundantly thick- to medium-banded.
--------	----------	111. 38	. 46	Coal, abundantly thick- to medium-banded; ¼-in. fusain parting below 111.54 ft.
--------	----------	111. 84	. 29	Coal, moderately thick-banded; pyritic.
--------	----------	112. 13	. 39	Coal, sparsely thick-banded.
--------	----------	112. 52	. 25	Do.
--------	----------	112. 77	. 23	Clay, light-gray; plant fragments.
--------	----------	113. 00	. 28	Clay, medium-gray; plant fragments; ½-in. coaly zone at base.
--------	----------	113. 28	. 27	Coal, dominantly thin-banded.
--------	----------	113. 55	. 34	Coal, dominantly thin-banded; ¼-in. of impure coal at top; excluded from fuel sample.
--------	----------	113. 89	. 23	Coal, dominantly thin-banded; a few small fusain lenses; ⅛-in. of impure coal below 113.98 ft.
--------	----------	114. 12	. 40	Coal. impure; excluded from fuel sample.
--------	----------	114. 52	. 38	Do.
--------	----------	114. 90	. 40	Do.
--------	----------	115. 30	. 45	Do.
--------	----------	115. 75	. 44	Coal, dominantly very thick-banded; badly broken in coring below 115.93 ft.
--------	----------	116. 19	. 39	Coal, crushed in coring.
--------	----------	116. 58	. 62	Coal, impure; 2 in. of black clay below 116.83 ft; excluded from fuel sample.
--------	----------	117. 20	. 31	Coal, abundantly medium- and thick-banded.
--------	----------	117. 51	. 33	Coal, abundantly very thick-banded; ¾-in. fusain parting below 117.55 ft.
--------	----------	117. 84	. 34	Coal, abundantly very thick-banded; thin fusain lenses in uppermost ¾ in. of core.
--------	----------	118. 18	. 34	Coal dominantly very thick-banded; pyritic.
--------	----------	118. 40	. 55	Coal, attrital.
--------	----------	118. 95	. 29	Coal, dominantly thick-banded.
--------	----------	119. 24	. 37	Do.
--------	----------	119. 61	. 37	Coal, moderately woody, irregular lenses; 1-in. irregular zone of impure coal, light-gray clay and thick wood lenses below 119.72 ft.
--------	----------	119. 98	. 36	Coal, attrital, broken in coring, sparsely medium-banded below 120.23 ft.

TABLE 9.—*Lithologic description of lignite cores from core holes GS-1-4, -16-18, and SD-8, -10, and -19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section		Lithologic description and remarks
		Depth in hole (feet)	Length (feet)	
Core hole SD-8—Continued				
--------	----------	120.34	0.42	Coal, sparsely medium-banded; irregular fusain lenses at 120.45 ft.
--------	----------	120.76	.34	Coal, abundantly thick-banded.
--------	----------	121.10	.34	Coal, impure.
--------	----------	121.44	.39	Clay, dark-gray, coaly.
--------	----------	121.83	.73	Clay, light-gray, silty.
--------	----------	122.56	.44	Lost in coring; interval at 122.56-123.00 ft.
--------	----------	123.00	----------	Base of core sent to laboratory.

Fuel samples (U. S. Bureau of Mines): E-19298 includes TE sample 3-10. E-19299 includes core from interval 51.90 ft-56.72 ft. E-19300 includes core from interval 106.83 ft.-112.77 ft. E-19301 includes core from interval 113.28 ft-121.10 ft.

Core hole TE-sample No.	Uranium (percent)	Depth in hole (feet)	Length (feet)	Lithologic description and remarks
Core hole SD-10 (NE¼SE¼ sec. 12, T. 17 N., R. 7 E.) elev. 3,630 ft.				
--------	----------	281.70	0.55	Shale, silty, light-gray, and buff, fine-grained, soft sandstone.
1	0.0025	282.25	.25	Clay, black; a few interbedded light-buff sandy lenses.
--------	----------	282.50	.85	Siltstone, light-gray, moderately soft.
--------	----------	283.35	27.85	Clay, siltstone and sandstone, not sent to laboratory.
2	.0001	311.20	.73	Clay, light-buff, fragmented; some light-gray interstitial clay; light-buff angular fragments larger in lower part, and with clay matrix more abundant.
3	.007	311.93	1.01	Shale and clay, silty, gray to slightly limonitic.
4	.0048	312.94	.48	Clay, light-gray; abundant limonitic bands in upper part, less limonitic below.
5	.002	313.42	.62	Clay, medium-gray to black, grading to impure attrital coal below the uppermost 2 inches.
6	.0004	314.04	1.96	Clay, silty, brown in upper part, becoming somewhat more drab below; very thin coaly streaks and ⅛-in limonitic band near the base.
7	.0003	316.00	.27	Clay conglomerate; clay pebbles, light-tan to gray; one lignitic fragment occurs near the middle and larger more angular clay pieces at base; possibly caved from higher in core hole.
8	.0005	316.27	1.13	Clay, brown, with scattered thin woody streaks.
9	.003	317.40	.38	Coal, attrital coal in uppermost 1½ inch; dominantly woody below.
--------	----------	317.78	.04	Pyritic layer, coherent but somewhat earthy in appearance; excluded from fuel sample.
10	.002	317.82	.26	Coal, abundantly woody.
11	.002	318.08	.58	Coal, moderately woody; two ¼-in fusain lenticles near the middle.
12	.002	318.66	.55	Coal, attrital or very thin-banded; a 1-in woody band below 318.84 ft.
13	.002	319.21	.21	Coal, sparsely woody; ¼-in fusain layer at base.
--------	----------	319.42	.02	¼-in. pyritic laminae; excluded from fuel sample.
14	.004	319.44	.27	Coal, sparsely woody.
15	.005	319.71	.22	Do.
16	.038	319.93	.24	Coal, attrital.
17	.001	320.17	.44	Clay, coaly, black above 320.29 ft, grading to dark-gray, black with woody streaks below 320.27 ft; excluded from fuel sample.
18	.005	320.61	.18	Coal, moderately woody.
19	.007	320.79	.31	Shale, black, clayey, ¼-in hard siltstone band below 320.89 ft; excluded from fuel sample.
20	.003	321.10	.26	Coal, impure, grading to carbonaceous clay below 321.28 ft; excluded from fuel sample.
21	.005	321.36	.22	Coal, abundantly woody, thick bands; ⅛-in fusain parting below 321.49 ft.
22	.002	321.58	.33	Coal, abundantly woody, thick bands.
23	.003	321.91	.28	Coal, nearly solid carbonized wood.
--------	----------	322.19	.18	Clay, shaly, brown, with coaly fragments; excluded from fuel sample.
24	.014	322.37	.19	Coal, attrital, except for thick wood band in middle.
25	.0015	322.56	.98	Shale, brown, clayey.
26	.0002	323.54	2.28	Siltstone, gray, clayey; few thin coaly streaks in lower part.
--------	----------	325.82	54.58	Core in interval 325.82-380.40 ft not sent to laboratory; includes shale and siltstone, as decsribed at drill site.
27	.0001	380.40	.67	Clay, silty, light-buff, soft; ¼-in carbonaceous streak at the base.
28	.006	381.07	.22	Coal, moderately woody.
29	.004	381.29	.21	Do.
30	.009	381.50	.28	Coal, abundantly woody; ¼-in pyritic rosettes at base.
31	.016	381.78	.29	Coal, mostly attrital; 1½-in woody band at base.

TABLE 9.—*Lithologic description of lignite cores from core holes GS-1-4, -16-18, and SD-8, -10, and -19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section: Depth in hole (feet)	Core section: Length (feet)	Lithologic description and remarks
				Core hole SD-10—Continued
32	0.003	382.07	0.23	Coal, abundantly woody.
33	.008	382.30	.62	Coal, moderately woody, ¼-in pyritic lenticle at top; ¾-in. carbonaceous clay parting at base excluded from fuel sample.
34	.001	382.92	.32	Coal, abundantly woody.
35	.004	383.24	.59	Coal, sparsely banded above, moderately woody below 383.50 ft.
36	.002	383.83	.47	Coal, abundantly woody, in bands 1-2 in thick.
37	.002	384.30	.49	Coal, moderately thick-banded above, moderately thin-banded below 384.60 ft.
38	.003	384.79	.58	Coal, moderately woody, thin and thick bands.
39	.008	385.37	.63	Coal, moderately woody; ¼-in pyritic rosette above 385.69 ft.
40	.001	386.00	.56	Coal, moderately woody.
41	.0001	386.56	.54	Shale, carbonaceous, clayey, grading from 2 inches of impure coal at top.
42	.003	387.10	.17	Coal, moderately woody.
43	.015	387.27	.21	Do.
44	.004	387.48	.53	Shale, brown, clayey, numerous ⅛-½-in woody streaks.
45	.001	388.01	.26	Shale, coaly streaks.
46	.002	388.27	.31	Coal moderately woody.
47	<.001	388.58	.58	Shale, brown, coaly and woody fragments.
48	.0013	389.16	.47	Shale, black to gray and dark-brown; coaly streaks; basal ½-in appears to contain buff clayey pellets.
--------	----------	389.63	1.92	Lost in coring; interval at 389.63-391.55 ft.
--------	----------	391.55	----------	Bottom of drill hole.

Fuel samples (U. S. Bureau of Mines): E-9832 includes TE samples 9-16, 18, 21-24. E-9833 includes TE samples 28-40.

Core hole TE-sample No.	Uranium (percent)	Core section: Depth in hole (feet)	Core section: Length (feet)	Lithologic description and remarks
				Core hole SD-19 (SW¼SW¼ sec 31, T. 18 N., R. 8 E.), elev 3,600 ft
1	0.0055	332.00	1.41	Siltstone, gray; a few ⅛-in pyrite lenticles in upper part; coarser silty bands stained with limonite below 332.94 ft.
2	.0039	333.41	.31	Siltstone, clayey, gray, dips about 8 degrees.
3	.0285	333.72	.11	Clay, carbonaceous, dark-brown and black; not coaly.
4	.026	333.83	.25	Coal, attrital, ½-in woody band below 333.91 ft; no dip apparent in coal.
5	.016	334.08	.34	Coal, dominantly attrital.
6	.014	334.42	.33	Coal, sparsely thin-banded.
7	.006	334.75	.34	Do.
8	.006	335.09	.62	Coal, dominantly attrital, two ½-in woody lenses in lower part; thin pyritic facing on joint in upper part.
9	.006	335.71	.64	Coal, moderately medium-banded.
10	.010	336.35	.29	Coal, abundantly medium- and thin-banded.
11	.015	336.64	.18	Coal, a solid woody band.
12	.006	336.82	.12	Coal; ½-in woody band at top; includes several pyritic rosettes ¼-in-⅛-in thick, and one ⅛-in fusain lenticle.
13	.015	336.94	.18	Coal, mostly woody; core is slightly broken.
14	.007	337.12	.22	Coal, moderately woody.
15	.006	337.34	.20	Coal, dominantly woody; core is slightly broken.
16	.006	337.54	.56	Coal, moderately thin- and medium-banded.
17	.004	338.10	.57	Coal, moderately thin-, medium-, and thick-banded including a ¾-in woody band at 338.20 ft.
18	.003	338.67	.19	Coal, moderately medium-banded; core is somewhat broken.
19	.005	338.86	.26	Coal, moderately thin-banded; core is somewhat broken.
20	.0008	339.12	1.80	Clay, shaly, brown, a scattering of thin coaly plant fragments.
21	.004	340.92	.45	Coal, badly broken, perhaps slightly impure or broken by thin partings.
--------	----------	341.37	.63	Lost in coring; interval at 341.37-342.00 ft.
22	.005	342.00	.21	Coal, dominantly woody, one woody band 1¼ inch thick; apparently dipping 6 degrees.
23	.003	342.21	.30	Coal, sparsely thin- and medium-banded; core is slightly broken.
24	<.001	342.51	.97	Coal, dominantly woody; one band 2½ inches thick below 342.63 ft; ⅛-in fusain at 342.56 ft; a few ¼-in pyritic blebs in lower part.
25	<.001	343.48	.60	Coal, dominantly woody.
26	<.001	344.08	.23	Coal abundant wood bands; core is slightly broken; white clayey specks appear in one woody band.
27	<.001	344.31	.50	Coal, attrital in upper part; moderately woody in lower part; 1/16-in. fusain lenticle in a woody band near the base.
28	<.001	344.81	1.08	Coal, moderately thin-, medium-, and thick-banded; ¼-in fusain band below 345.01 ft, and 3/16-in fusain band below 345.70 ft.

TABLE 9.—*Lithologic description of lignite cores from core holes GS-1-4, -16-18, and SD-8, -10, and -19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section		Lithologic description and remarks
		Depth in hole (feet)	Length (feet)	
				Core hole SD-19—Continued
29	<0.001	345.89	1.00	Coal, sparsely thin- and medium-banded; woody band with white clayey specks in middle part.
30	<.001	346.89	1.03	Coal, moderately medium- and thin-banded, coal is somewhat broken in the middle part and possible more impure, largely attrital coal in lower 4 inches.
31	.0002	347.92	1.13	Clay, light-gray, with veinlike, vertical, black clay filling in upper part; sparse to moderate number of woody streaks in lower 5½ inches of this clay zone.
32	<.001	349.05	.58	Coal, impure, with 1¼ inches of coaly clay at top; lowest 3 inches is woody.
33	.0003	349.63	1.07	Shale, clayey, dark-brown; sparse and very thin coaly streaks; lowest two inches of sample is dark-brown to black.
34	<.001	350.70	.28	Coal, dominantly attrital; core is somewhat broken.
35	<.001	350.98	.59	Coal, sparsely thin- and medium-banded.
--------	----------	351.57	1.95	Lost in coring interval at 351.57-353.52 ft.
36	<.001	353.52	1.00	Coal, sparsely thin- and medium-banded; ½-in. pyritic rosette at 353.70 ft; core is slightly broken in upper part.
37	<.001	354.52	.29	Coal, dominantly woody; small white clay lenses in a 1-inch woody band at 354.55 ft.
38	<.001	354.81	.55	Coal, sparsely thin-banded; ¼-in. pyritic lens at 355.32 ft; core somewhat broken in upper part.
39	<.001	355.36	1.96	Coal, moderately thin- to medium- and thick-banded; 1-in. woody band below 356.85 ft and a 1½-in. band at 357.10 ft; ¼-in. fusain band at 356.34; core is slightly broken in upper part.
40	<.001	357.32	.61	Coal, abundantly thick-banded; ¼-in. fusain band below 357.84 ft; bedding of coal is apparently dipping about 11 degrees.
41	<.001	357.93	1.22	Coal, dominantly thin-, medium-, and thick-banded, with ¾-in. bands of fusain in several thin- to medium-banded layers below 358.63 ft; apparent dip is about 6 degrees.
42	<.001	359.15	1.30	Coal, predominantly woody; including two bands exceeding 3 inches in thickness; apparent dip of 5°-9°.
43	.0003	360.45	1.55	Shale, clayey, carbonaceous, dark-gray to black in uppermost 4 inches, grading to medium-gray clayey shale below; two ¾-in. pyritic rosettes occur between 361.70 ft and 361.80 ft; 1-in. silty layer below 361.06 ft.
--------	----------	362.00	1.00	Lost in coring; interval at 362.00-363.00 ft.
--------	----------	363.00	.90	No core set to laboratory, described at drill site as siltstone.
--------	----------	372.00	.75	Lost in coring; interval at 372.00 ft-372.75 ft.
--------	----------	372.75	9.25	Core in interval 372.75 ft-382.00 ft not sent to laboratory, described at drill site as shale.
--------	----------	382.00	1.08	Shale, black, carbonaceous and coaly; 1-in. coal parting at 382.00 ft.
45	<.001	383.08	.73	Coal, sparsely thin-banded to attrital; very thick wood bands at 383.38 ft and 383.62 ft; ¼-in. fusain parting with sand blebs at 383.68 ft and thin fusain parting with pyrite nodule below 383.35 ft; ½-in clay parting at 383.46 ft, excluded from fuel sample.
46	<.001	383.81	1.15	Coal, dominantly attrital with 3-in. wood band below 384.68 ft; ½-in coaly clay parting below 384.50 ft, excluded from fuel sample.
47	<.001	384.96	.19	Coal, impure, thin lens of sand blebs below 385.03 ft; excluded from fuel sample.
48	<.001	385.15	1.44	Coal, abundantly thick-banded; irregular medium- to thick-bands of wood in more attrital parts; uppermost 2½ inches contains clay blebs and fusain.
49	<.001	386.59	.10	Clay, black, carbonaceous; excluded from fuel sample.
50	<.001	386.69	1.14	Coal, moderately thick- to thin-banded.
51	<.001	387.83	1.10	Coal, dominantly very thick-banded.
52	.0003	388.93	2.46	Siltstone, carbonaceous, medium-gray; uppermost 1½ inches is black carbonaceous clay.
--------	----------	391.39	.35	Sandstone, fine-grained, light-gray, carbonaceous streaks.
--------	----------	391.74	.64	Lost in coring, described at drill site as siltstone; interval at 391.74-392.28 ft.
53	.0002	392.38	2.40	Siltstone, brownish-gray, carbonaceous streaks and a few lenses of light-tan sandstone; 3¼ inches of gray fine-grained sandstone below 392.38 ft; ½-in woody coal bands at 393.23 ft and below 394.75 ft.
54	<.001	394.78	.28	Coal, moderately thin- and thick-banded.
55	<.001	395.06	.80	Coal, impure, very thick woody bands at 395.31 ft and 395.70 ft.
56	<.001	395.86	.51	Clay, black to dark-gray, very carbonaceous.

TABLE 9.—*Lithologic description of lignite cores from core holes GS-1-4, -16-18, and SD-8, -10, and -19, Mendenhall area, Harding County, South Dakota*—Continued

Core hole TE-sample No.	Uranium (percent)	Core section		Lithologic description and remarks
		Depth in hole (feet)	Length (feet)	
				Core hole SD-19—Continued
57	0.0003	396.37	2.60	Siltstone, medium-gray, carbonaceous, with very thin coaly streaks.
58	.0003	398.97	1.62	Do.
59	.0002	400.59	1.21	Sandstone, fine-grained medium-gray with irregular medium-grained light-gray sandstone lenses.
--------	----------	401.80	.20	Shale, clayey, light-gray with thin coaly streaks; included with shale below as sample TE-60.
60	.0003	402.00	.85	Shale, clayey, light-gray; occasional very thin coal streaks; becomes black and more coaly towards base.
61	<.001	402.85	1.04	Coal, dominantly medium-banded.
62	<.001	403.89	1.70	Shale, black with a few thin coal streaks.
63	<.001	405.59	1.92	Shale, black and light-gray; 3½ inches of impure coal at base.
64	<.001	407.51	1.81	Coal, moderately thick-banded, ½-in. fusain parting below 408.42 ft; core slightly broken.
65	.0003	409.32	2.05	Shale, clayey, light- to medium-gray, with very light-gray sandstone lenses in middle part.
--------	----------	411.37	.54	Shale, light-gray, silty and sandy.
--------	----------	411.91	.09	Lost in coring; interval at 411.91-412.00 ft.
--------	----------	412.00	----------	Bottom of hole.

Fuel samples (U. S. Bureau of Mines): E-12615 includes TE samples 4-19. E-12616 includes TE samples 21-30. E-12617 includes TE samples 34-42. E-13500 includes TE samples 45-51. E-13501 includes TE sample 64.

Uranium-Bearing Lignite In Southwestern North Dakota

By GEORGE W. MOORE, ROBERT E. MELIN, *and* ROY C. KEPFERLE

URANIUM IN COAL IN THE WESTERN UNITED STATES

GEOLOGICAL SURVEY BULLETIN 1055-E

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URANIUM-BEARING LIGNITE IN SOUTHWESTERN NORTH DAKOTA

By George W. Moore, Robert E. Melin, and Roy C. Kepferle

ABSTRACT

Beds of uranium-bearing lignite were mapped and sampled in the Bullion Butte, Sentinel Butte, HT Butte, and Chalky Buttes areas in southwestern North Dakota; they occur at several stratigraphic positions in the Sentinel Butte member of the Fort Union formation of Paleocene age. A total of 261 samples from 85 localities were collected for uranium analysis. Lignite containing as much as 0.045 percent uranium, 10.0 percent ash, and 0.45 percent uranium in the ash was found; the average uranium content of the lignite is about 0.013 percent. About 27 million tons of lignite in beds about 2 feet thick underlie the four areas. Surface samples of the lignite average more than 30 percent ash.

The principal factor that seems to influence the concentration of uranium in the lignite beds is the stratigraphic position of the beds in relation to the base of the overlying White River group of Oligocene age. All uranium-bearing beds closely underlie the base of the White River group. The relative concentration of uranium is modified by other factors, however, as beds enclosed in permeable rocks are more uraniferous than beds in impermeable rocks, and thin beds have a greater uranium content than thick beds. In addition, a thick lignite bed commonly has a greater concentration in the top part of the bed. These and other factors suggest that the uranium is of secondary origin and that it was leached from volcanic ash in overlying rocks of Oligocene and Miocene age. Probably the uranium is held in the lignite as part of a metallo-organic compound.

INTRODUCTION

Beds of uranium-bearing lignite were examined in the Bullion Butte, Sentinel Butte, HT Butte, and Chalky Buttes areas in southwestern North Dakota during 1953 by the U. S. Geological Survey (fig. 19).

The common association of uranium with carbonaceous material has long been recognized, and one deposit of uranium-bearing coal at Leyden, Colo., has been known for 80 years (Berthoud, 1875). Other deposits of coal were found to be uranium-bearing in 1945 in the Red Desert, Sweetwater County, Wyo., by A. L. Slaughter and J. M. Nelson (written communication, 1946). Later work by D. G. Wyant and E. P. Beroni (written communication, 1950) resulted in the discovery of uranium in other lignite beds in North and South Dakota.

Each of the three areas investigated is dominated by one or more high buttes. Sentinel, Bullion, and HT (Black) Butte each rise more than 500 feet above surrounding gently rolling plains. One of the Chalky Buttes, with an altitude of 3,530 feet, is the highest point in North Dakota. The beds of uranium-bearing lignite lie at most places

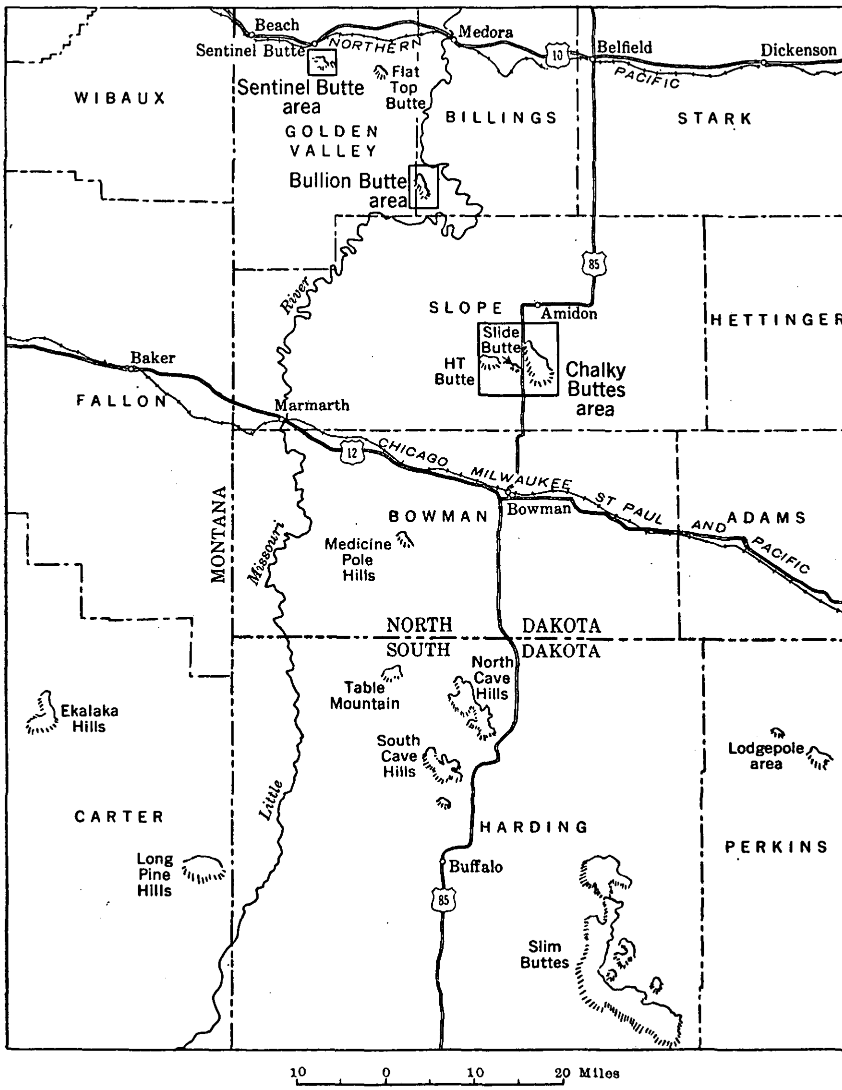

FIGURE 19.—Index map showing areas described in this report and adjacent areas of uranium-bearing lignite in North Dakota, South Dakota, and Montana.

near the tops of the buttes. The areas are all fairly accessible; U. S. Highway 85 passes through the Chalky Buttes area and U. S. Highway 10 passes within 3 miles of Sentinel Butte. The nearest rail shipping points are Bowman, N. Dak., 12 miles south of the Chalky Buttes area, and Sentinel Butte, N. Dak., 3 miles north of Sentinel Butte. Bullion Butte is about 30 miles by county-maintained road from the latter town.

Earlier geologic mapping in these areas was done by Leonard (1908), Leonard and Smith (1909), and Hares (1928). Later E. P. Beroni and H. L. Bauer (written communication, 1952) sampled and described uranium-bearing lignite in the Sentinel and Bullion Butte areas. Deposits of such lignite in adjacent parts of South Dakota have a similar geologic setting and are described by Denson, Bachman, and Zeller (chapter B, this bulletin).

J. R. Gill organized the present field party and participated in the early stages of the work. Unpublished data on the uraniferous lignite deposits of South Dakota by Denson, Bachman, and Zeller were made available and permit the relating of the North Dakota deposits to their regional setting. Stratigraphic studies of rocks of Miocene age by Denson and Gill were also made available before they were published. Personnel of the U. S. Geological Survey analyzed the samples of rock and water collected during the present study.

STRATIGRAPHY

The rocks exposed in the Sentinel, Bullion, and Chalky Buttes areas are of continental origin. The beds of uranium-bearing lignite are in the upper part of the Fort Union formation of Paleocene age. The Fort Union formation is divided into the Ludlow, Tongue River, and Sentinel Butte members in ascending order. Only the latter two, the Tongue River and Sentinel Butte members, crop out in the mapped areas. The White River group of Oligocene age, made up of the Chadron and Brule formations, unconformably overlies the Fort Union formation. The White River group, in turn, is overlain unconformably by the Arikaree formation of Miocene age.

Stratigraphic sections of the rocks exposed in the Sentinel, Bullion, and Chalky Buttes areas are shown in figure 20.

TERTIARY ROCKS

FORT UNION FORMATION

Tongue River member.—The Tongue River member of the Fort Union formation of Paleocene age is the oldest rock unit exposed in each of the three areas mapped. A total thickness of 600 feet is assigned to the member by Hares (1928, p. 47). The Tongue River is made up predominantly of light yellowish gray very fine grained sand-

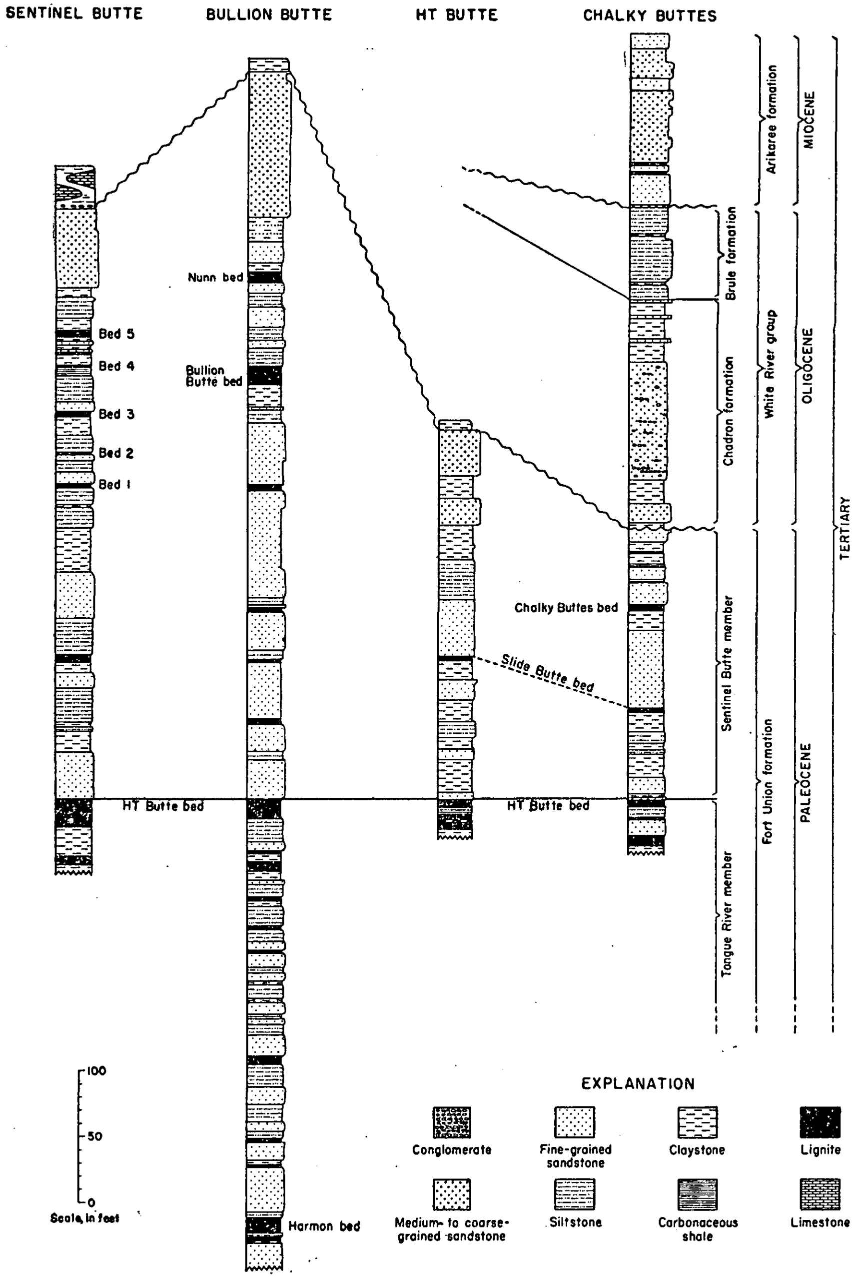

FIGURE 20.—Stratigraphic sections of rocks associated with uranium-bearing lignite in southwestern North Dakota.

stone and siltstone and lesser amounts of claystone, carbonaceous shale, and lignite. The contact between the Tongue River and the overlying Sentinel Butte member is placed arbitrarily at the top of the HT Butte lignite bed.

Sentinel Butte member.—The uranium-bearing lignite deposits in the areas studied are in the Sentinel Butte member of the Fort Union formation. This unit overlies the Tongue River member and is considered to be of Paleocene age (Brown, 1948). It ranges in thickness from about 500 feet at Bullion Butte to 280 feet at HT Butte, owing to erosion which produced a surface that truncates progressively older rocks from northeast to southwest.

The Sentinel Butte member is composed principally of siltstone and very fine grained sandstone. In addition, claystone, lignite, and carbonaceous shale make up a somewhat larger part of the total than they do in the Tongue River member, and the overall color is darker than the Tongue River.

A vertebrate fossil identified by J. R. Macdonald of the South Dakota School of Mines as *Champsosaurus* sp. was found in the Chalky Buttes area about 180 feet stratigraphically above the base of the Sentinel Butte member and 18 feet below the overlying Chadron formation in the SE 1/4 sec. 15, T. 134 N., R. 101 W. *Champsosaurus* is one of the last of a primitive order of water-dwelling reptiles that appeared in Permian time and did not survive the Eocene.

CHADRON FORMATION

The Chadron formation, the lower formation of the White River group of Oligocene age, is about 170 feet thick and in each of the areas investigated unconformably overlies the Sentinel Butte member of the Fort Union formation of Paleocene age. Twenty-five miles to the east, where a greater thickness of the underlying rocks has been preserved, the Chadron rests on the Golden Valley formation of Eocene age (Benson, 1951). At most places examined, the formation consists of a basal unit of light greenish gray sandy claystone, about 20 feet thick; a middle unit of yellowish-gray coarse-grained locally conglomeratic sandstone, about 100 feet thick; and an upper unit of light olive gray bentonitic claystone and white freshwater limestone, about 50 feet thick. Fossil fish have been described from some of the claystone beds (White, 1883). The top of the Chadron formation is marked by the uppermost limestone bed in the section.

BRULE FORMATION

The Brule formation, more than 70 feet thick, is the upper formation of the White River group and is exposed only in the Chalky Buttes. The formation is predominantly composed of grayish orange pink tuffaceous siltstone. Mammal remains were collected about 20 feet above the base of the Brule formation in the NW¼ sec. 31, T. 134., R. 100 W. These were identified by M. J. Hough of the U. S. Geological Survey. The collection is regarded as Whitneyan in age.

Miohippus sp., parts of two lower jaws
Hyracodon sp., lower molar
Eporeodon (?), lower jaw fragment
Protoceras (?), lower jaw fragment
Leptomeryx sp., parts of three lower jaws
Leptauchenia sp., anterior portion of skull and jaws, mandible, posterior portion of skull
Cedromus (?), upper tooth
Eumys sp., portions of three lower jaws
Paleolagus sp., portions of four lower jaws
Paradjidaumo (?) sp. (?), portions of three lower jaws
Prosciurus sp., lower jaw fragment

ARIKAREE FORMATION

About 70 feet above the base of the Brule formation in the Chalky Buttes area, an erosion interval is marked by an unconformity at the base of a bed of conglomerate. Above this bed the rocks are principally dusky yellow green medium- to coarse-grained sandstone and are assigned to the Arikaree formation on the basis of their lithology. A fossil collection from the base of the Arikaree formation in the Ekalaka Hills, 70 miles to the southwest, indicates an early or middle Miocene age for the formation (J. R. Gill, written communication, 1953).

QUATERNARY DEPOSITS

Deposits of terrace gravel as much as 10 feet thick are present on the flanks of Bullion Butte at an altitude of 220 feet above the Little Missouri River. These deposits were not mapped. Landslide material derived mostly from massive sandstone of the Fort Union formation is common along the sides of the buttes. These deposits were mapped in the Chalky Buttes area but were not mapped in the Bullion Butte and Sentinel Butte areas. Deposits of alluvium and slope-wash occur along the major streams and on many of the hills, but none of this material was mapped.

STRUCTURE

The rocks in the areas investigated lie on the northeast flank of the Cedar Creek anticline, a low narrow uplift trending northwest through the southwest corner of North Dakota. The rocks dip to the northeast into the Williston basin at about 25 feet per mile. No faults have been recognized in the mapped areas.

URANIUM-BEARING LIGNITE

All beds of uranium-bearing lignite in the three areas studied are in the Sentinel Butte member of the Fort Union formation. The relative stratigraphic position of the lignite beds is shown by figure 20, and their areal distribution is shown by the geologic maps, plates 30 and 31. The discussion of uranium distribution is based on 261 samples collected for uranium analysis and on data from 85 measured sections of the uraniferous beds. Samples were also submitted for analysis from the underlying nonradioactive beds.

BULLION BUTTE AREA, BILLINGS AND GOLDEN VALLEY COUNTIES

Only two lignite beds in the Bullion Butte area (pl. 31) contain significant amounts of uranium. The most radioactive bed in this area is the Nunn lignite bed, being named from the Nunn Ranch in sec. 6, T. 137 N., R. 102 W. The bed crops out on the upper slopes of the butte and is about 400 feet stratigraphically above the base of the Sentinel Butte member. It is stratigraphically the highest lignite bed exposed in the area. The Nunn lignite bed ranges in thickness from 3 to 12 feet, the average being 4.8 feet, and underlies an area of about 500 acres. The greatest concentration of uranium found in the bed is 0.036 percent. The average uranium content of the bed is not uniform, being greatest at the places where the bed is thin and decreasing where it is thick. The quantity of uranium contained in the bed per square unit of area remains approximately the same, however, so that the thickness of the bed may be taken as an inverse measure of its relative grade. The uranium is not evenly distributed through the lignite bed but is commonly concentrated in the upper part, the grade decreasing downward. A similar progressive decrease downward in uranium content of thick radioactive lignite beds was noted by Denson, Bachman, and Zeller (chapter B, this bulletin) in nearby parts of South Dakota.

The other bed, the Bullion Butte lignite bed, 60 feet stratigraphically below the Nunn lignite bed, contains small amounts of uranium at some places in the Bullion Butte area. This bed ranges in thickness from 7–22 feet and averages 11 feet. The uppermost 1–2 feet of the Bullion Butte bed locally has as much as 0.007 percent uranium, but the lower part contains less than 0.001 percent. Other lignite beds in the Bullion Butte area are not uraniferous.

The Nunn lignite bed contains about 4.2 million short tons of lignite. The bed has an average thickness of 4.8 feet, and the average uranium content of the lignite is 0.007 percent. The average ash content of the lignite is about 20 percent and the ash contains an average of 0.037 percent uranium. The Bullion Butte bed contains more than 16 million tons of lignite, and it has an average uranium content of less

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than 0.001 percent. Maps and sections showing uranium content and extent of the Nunn and Bullion Buttes beds are given in figure 21.

SENTINEL BUTTE AREA, GOLDEN VALLEY COUNTY

Five beds of uranium-bearing lignite crop out near the top of Sentinel Butte. These beds, from oldest to youngest, are numbered from 1 through 5 (pl. 31). They are all in the upper part of the Sentinel Butte member of the Fort Union formation.

The uppermost, bed 5, which closely underlies the Chadron formation, has the greatest uranium content per unit area, though lower beds locally have a greater concentration of uranium. Within a bed the vertical distribution of uranium is somewhat irregular, the greatest concentrations occurring near the tops of the thicker beds, but in the beds 2 feet or less in thickness the greatest concentrations occur near the base.

Lignite beds in the lower part of the Sentinel Butte member and the underlying Tongue River member contain less than 0.001 percent uranium.

Lignite beds 1–5 contain about 5 million short tons of lignite. The lignite contains an average of about 0.007 percent uranium, 32 percent ash, and 0.022 percent uranium in the ash. The average thickness of the lignite beds is about 2.5 feet. Figures 22 and 23 show the extent of the individual lignite beds and the sampled sections and analytical data on which the estimates are based.

CHALKY BUTTES AREA, SLOPE COUNTY

In the Chalky Buttes area, Slope County, North Dakota, two beds of uranium-bearing lignite occur in the lower part of the Sentinel Butte member of the Fort Union formation. They are here named the Chalky Buttes lignite bed and the Slide Butte lignite bed (pl. 30) from exposures on the respective buttes. These beds underlie a total of 8 square miles.

The Chalky Buttes lignite bed underlies only the northern part of Chalky Buttes (fig. 24). In the southern part of the area the bed has been removed by pre-Chadron erosion. The bed ranges in thickness from 0.5 to 4 feet and averages about 2 feet. Its uranium content is not uniform, reaching a maximum of 0.018 percent near the place where the lignite bed is truncated by the Chadron formation. The Chalky Buttes lignite bed in the northern part of the Chalky Buttes area contains about 5,220,000 short tons of lignite containing an average of 0.008 percent uranium and 30 percent ash in which uranium averages about 0.023 percent.

The Slide Butte lignite bed is 80 feet stratigraphically below the Chalky Buttes lignite bed and 70 feet above the base of the Sentinel

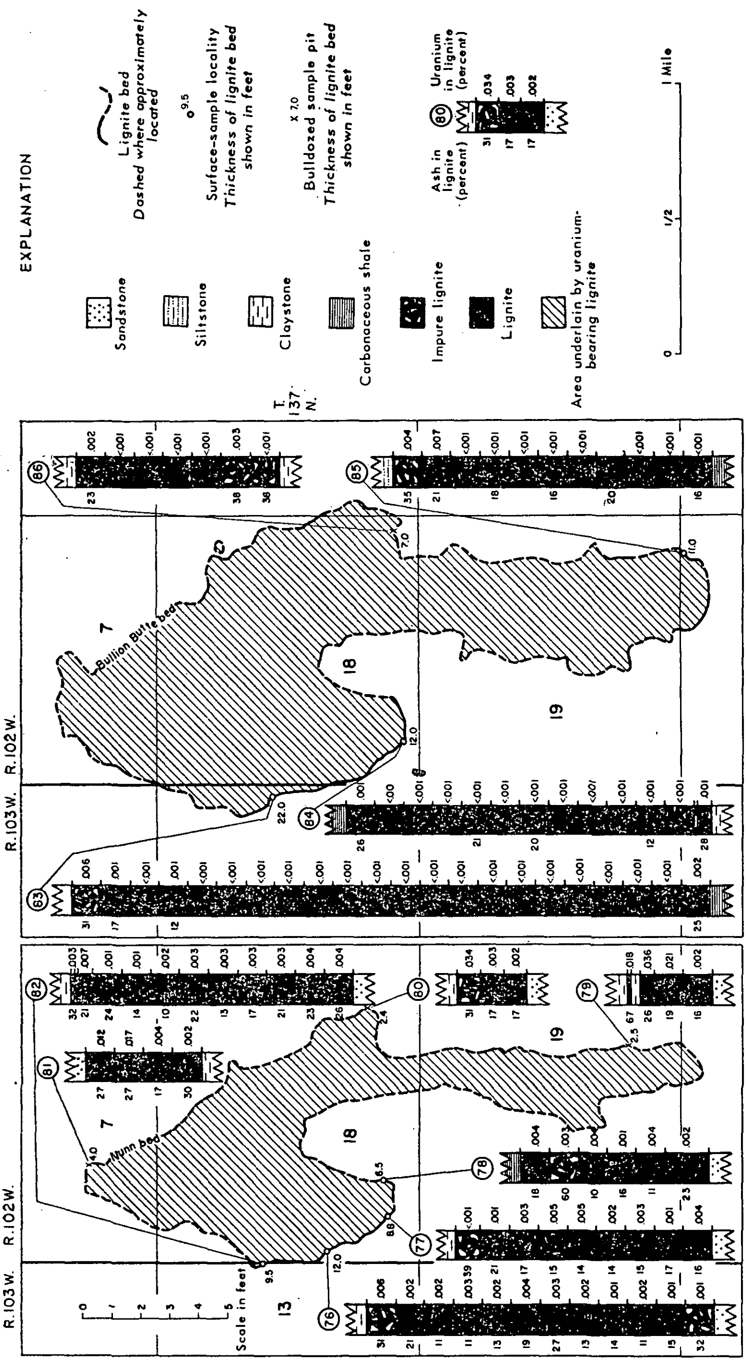

FIGURE 21.—Uranium-bearing lignite in the Bullion Butte area, Billings and Golden Valley Counties, N. Dak.

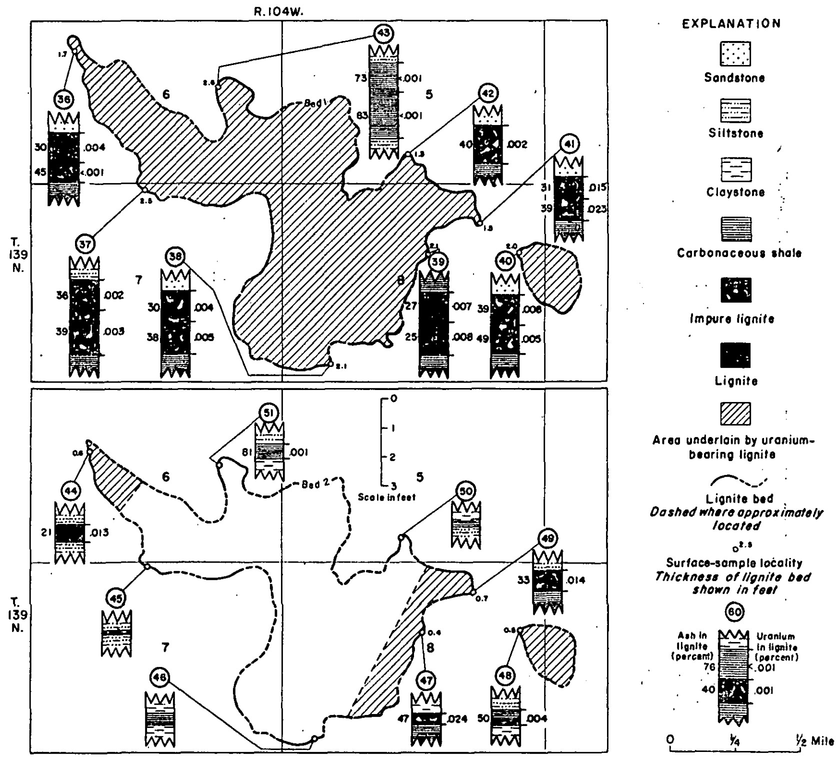

FIGURE 22.—Uranium-bearing lignite in beds 1 and 2, Sentinel Butte area, Golden Valley County, N. Dak.

Butte member. It is the stratigraphically highest lignite bed at HT and Slide Buttes and in the southern part of Chalky Buttes. The maximum thickness of the bed is 7 feet and the average thickness, about 2 feet. A sample from this bed collected at the east end of HT Butte contains 0.045 percent uranium and 10 percent ash containing 0.45 percent uranium. The average uranium content of the bed, however, is considerably less, and in the northern part of Chalky Buttes, where the overlying Chalky Buttes lignite bed is present, the uranium content may be only 0.003 percent.

In the southern part of the Chalky Buttes area (fig. 25), the Slide Butte lignite bed contains a total of about 10 million short tons of lignite. The average uranium content of the lignite is about 0.022 percent; the ash content is about 30 percent, and the ash contains about 0.063 percent uranium. Of the above lignite, about 2,900,000 short tons has an overburden of less than 30 feet and could be recovered by strip mining. The lignite that could be recovered by stripping averages about 2.6 feet in thickness and has an average uranium

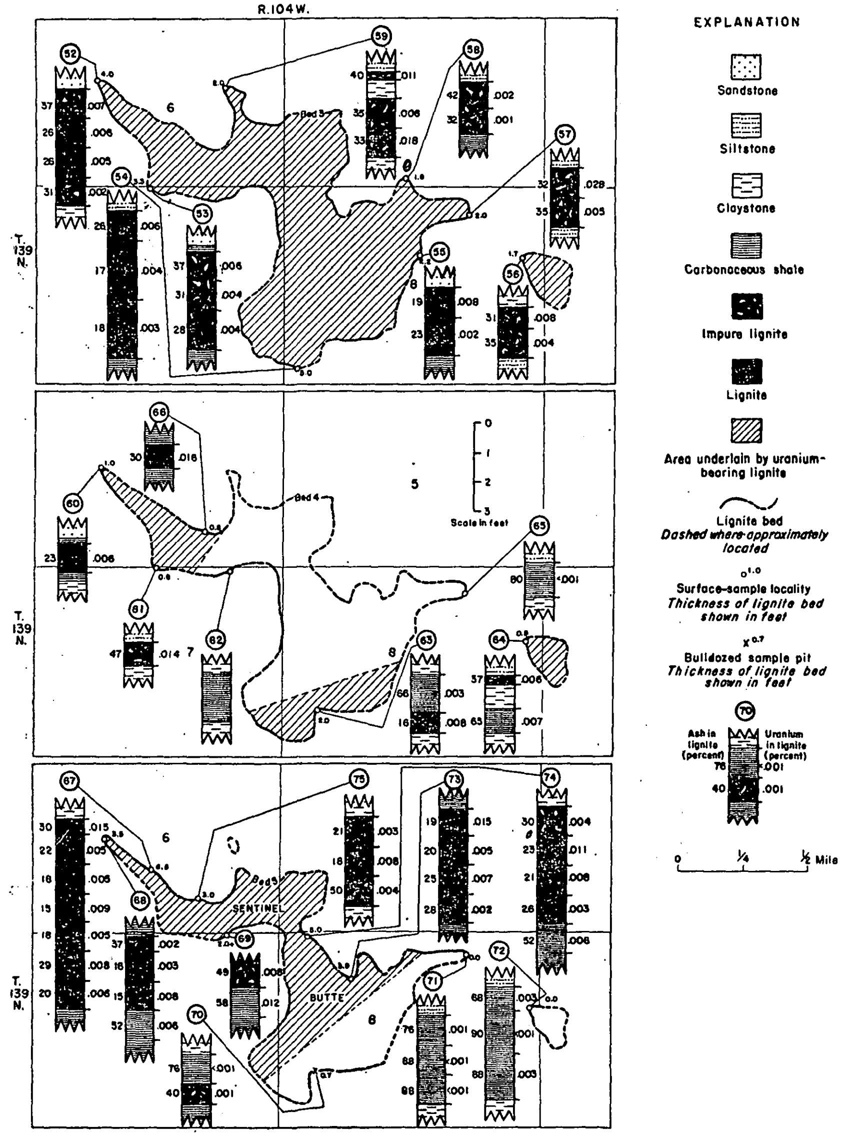

FIGURE 23.—Uranium-bearing lignite in beds 3–5, Sentinel Butte area, Golden Valley County, N. Dak.

content of 0.016 percent. The average ash content is about 25 percent and the ash contains about 0.06 percent uranium.

In the HT Butte area, including both HT Butte and Slide Butte, the Slide Butte lignite bed contains about 2.5 million short tons of lignite (fig. 26). The bed is about 2 feet thick on both buttes and contains about 20 percent ash. On HT Butte the lignite contains about

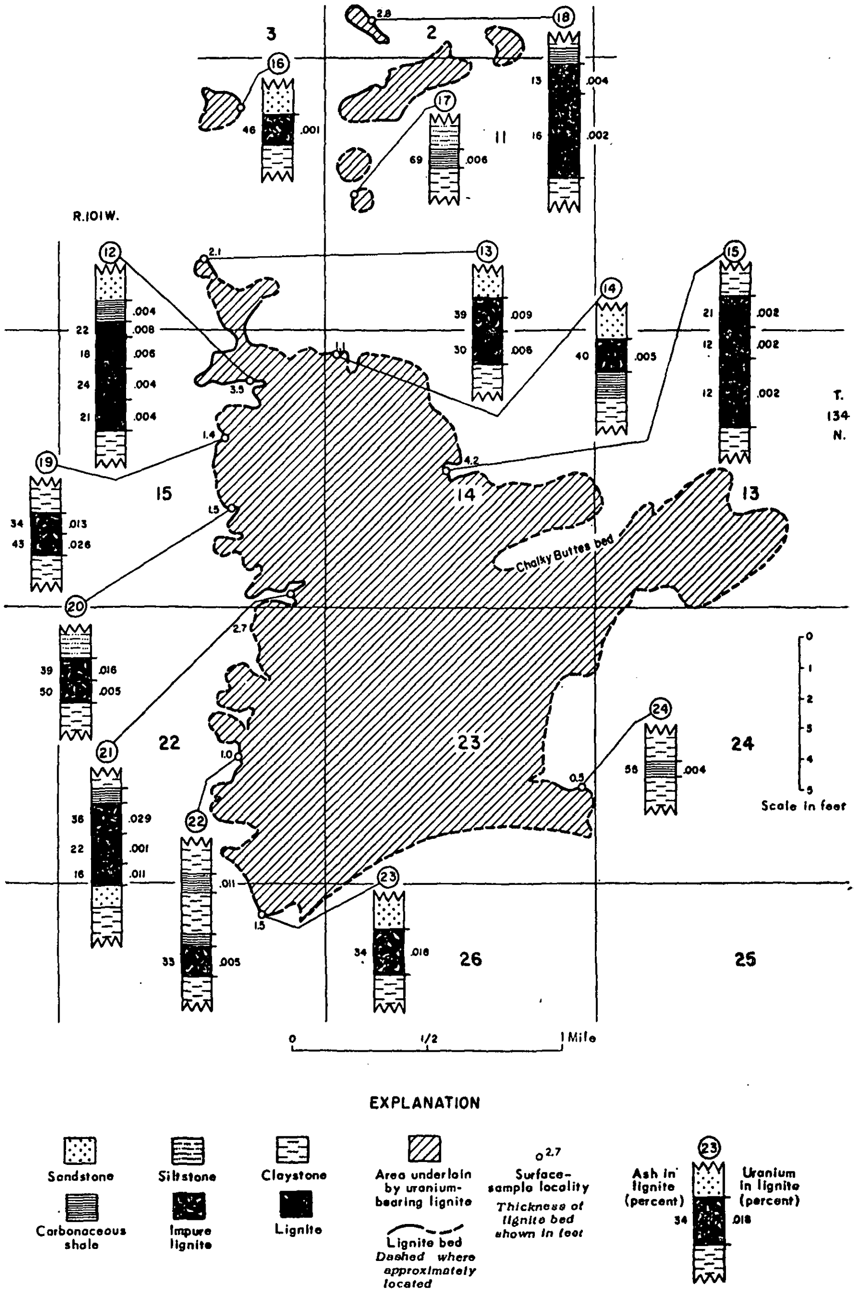

FIGURE 24.—Uranium-bearing lignite in the northern part of the Chalky Buttes area, Slope County, N. Dak.

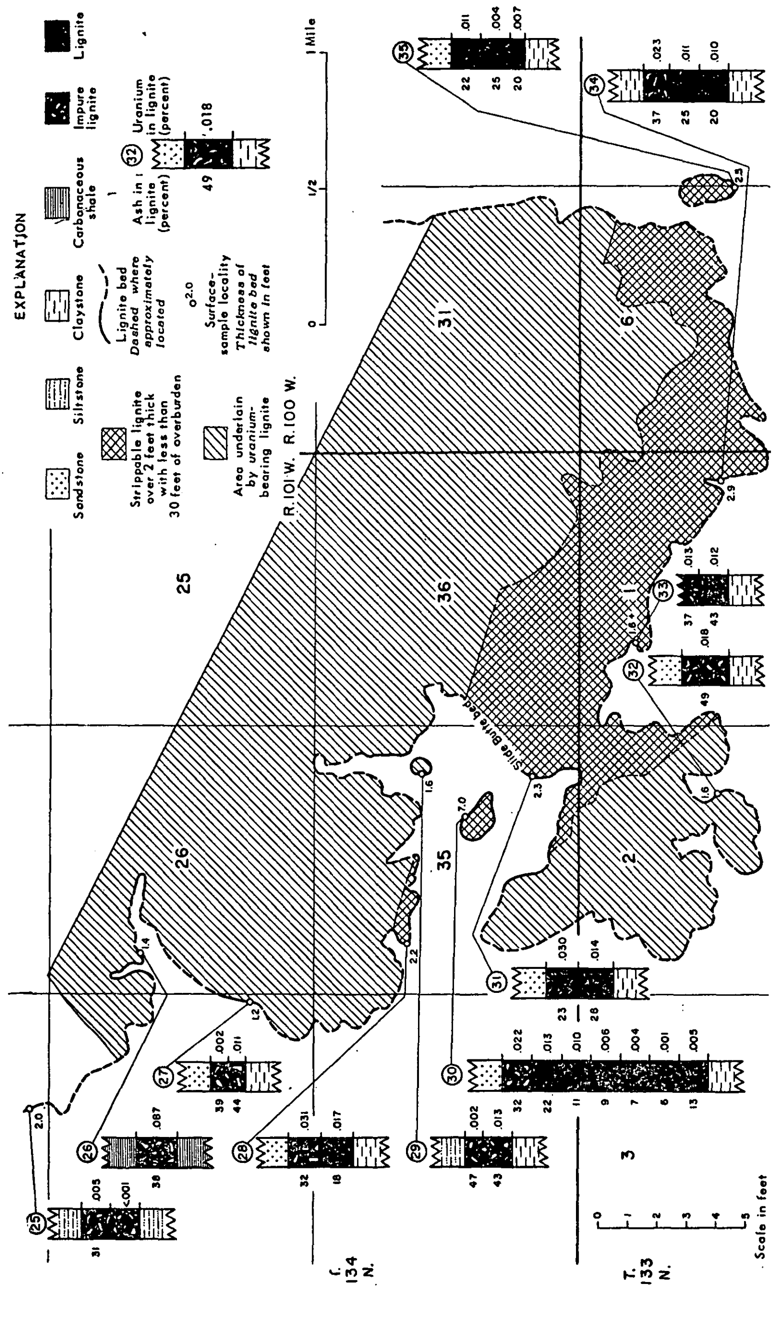

FIGURE 25.—Uranium-bearing lignite in the southern part of the Chalky Buttes area, Slope County, N. Dak.

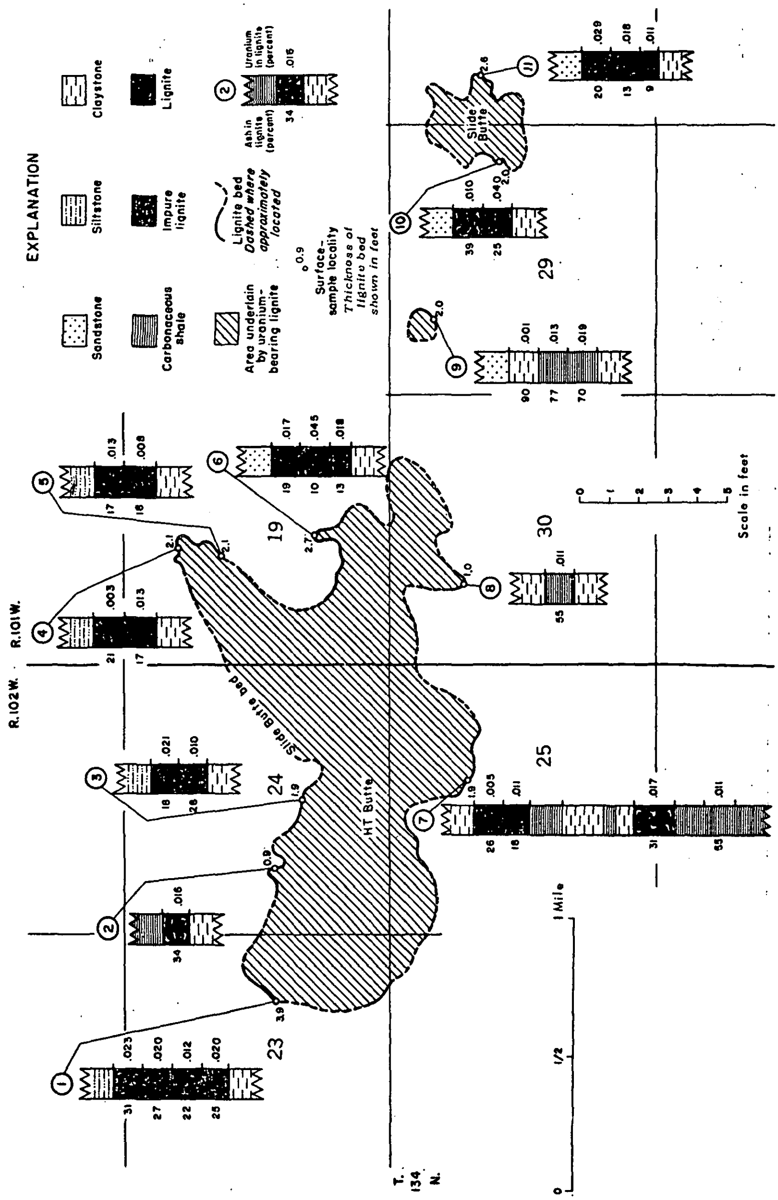

FIGURE 26.—Uranium-bearing lignite in the HT Butte area, Slope County, N. Dak.

0.015 percent uranium and 0.075 percent uranium in the ash. On Slide Butte, where the bed contains about 230,000 short tons of lignite, the lignite contains about 0.024 percent uranium and 0.12 percent uranium in the ash.

TONNAGE OF URANIUM-BEARING LIGNITE

The tonnage and uranium content of uranium-bearing lignite in the areas investigated in southwestern North Dakota are summarized in table 1. A total of 6,990 acres is underlain by 27,220,000 tons of lignite in beds averaging 2.3 feet in thickness. This lignite contains an average of 0.013 percent uranium in the lignite and 0.045 percent uranium in the lignite ash. Except for a small area in the Chalky Buttes, all lignite beds examined would have to be mined by underground methods. About 2,900,000 tons of lignite in the Chalky Buttes area lie under less than 30 feet of overburden. A number of these lignite beds might be of interest as a possible future byproduct source of uranium.

TABLE 1.—*Estimated tonnage of uranium-bearing lignite*

Bed	Area (acres)	Average thickness (feet)	Lignite (short tons)	Uranium in lignite (percent)	Uranium in lignite ash (percent)
Bullion Butte area, Billings and Golden Valley Counties, N. Dak.					
Nunn lignite bed	501	4.8	4,210,000	0.007	0.037
Sentinel Butte area, Golden Valley County, N. Dak.					
Lignite bed 1	502	2.0	1,760,000	0.005	0.017
Lignite bed 2	88	0.5	80,000	.013	.041
Lignite bed 3	370	2.8	1,810,000	.006	.020
Lignite bed 4	95	1.1	180,000	.010	.028
Lignite bed 5	159	4.4	1,220,000	.007	.028
Total	1,214	2.4	5,050,000	.007	.022
Chalky Buttes area, Slope County, N. Dak.					
Slide Butte lignite bed	2,913	2.0	10,200,000	0.022	0.063
Chalky Buttes lignite bed	1,571	1.9	5,220,000	.008	.023
Total	4,484	2.0	15,420,000	.017	.049
HT Butte area, Slope County, N. Dak.					
Slide Butte lignite bed	791	1.8	2,540,000	0.016	0.078
Grand total	6,990	2.3	27,220,000	.013	.045

ORIGIN OF THE URANIUM

Two principal hypotheses have been proposed to explain occurrences of uranium in the lignite beds of North and South Dakota. Denson, Bachman, and Zeller (chapter B, this bulletin), working in South Dakota, conclude that uranium was leached by ground water from volcanic ash of the White River group and the overlying Arikaree formation and was introduced into the lignite after its coalification. E. P. Beroni and H. L. Bauer (written communication, 1952), who studied the uranium-bearing lignite at Sentinel and Bullion Buttes, suggested that the uranium was extracted from surface water by organisms during their life cycle or shortly after burial; this material was subsequently carbonized to form lignite. They suggested that the uranium was derived from volcanic ash deposited contemporaneously with the lignite and now represented by beds of bentonitic claystone and siltstone found at several stratigraphic horizons within the Sentinel Butte member of the Fort Union formation. Evidence accumulated during the present investigation seems to support the hypothesis of origin advanced by Denson, Bachman and Zeller.

Plate 31 illustrates local variations in the areal distribution of uranium in lignite beds at Bullion, Sentinel, and Chalky Buttes. Generally, the lignite bed which directly underlies rocks of the White River group is more radioactive than other beds lower in the same stratigraphic sequence. Thus, at Bullion Butte, the Nunn lignite bed is uranium-bearing, the underlying Bullion Butte lignite bed contains but minor amounts of uranium and only locally, and beds below the Bullion Butte bed have no uranium. At Sentinel Butte, lignite bed 5 is the stratigraphically highest lignite bed and contains the most uranium at the west end of Sentinel Butte, but at the east end of the butte, where bed 5 lenses out, the uranium content of underlying lignite beds 3 and 1 is markedly increased. Similarly at Chalky Buttes, the Slide Butte lignite bed contains only small amounts of uranium where it is overlain by the Chalky Buttes lignite bed, but much larger amounts where the latter has been removed by pre-Chadron erosion.

Figure 27 is a graphic section of the Slide Butte bed showing the progressive decrease downward in uranium typically displayed by thick uranium-bearing lignite beds in the three areas studied. The distribution pattern suggests not only that the uranium is secondary, but that most of the uranium was introduced from above. A slight increase of uranium at the base of the bed is not uncommon, and many of the thinner lignite beds are most uraniferous at their bases. Such reversal of the distribution pattern may occur if the coal bed itself acted as an aquifer.

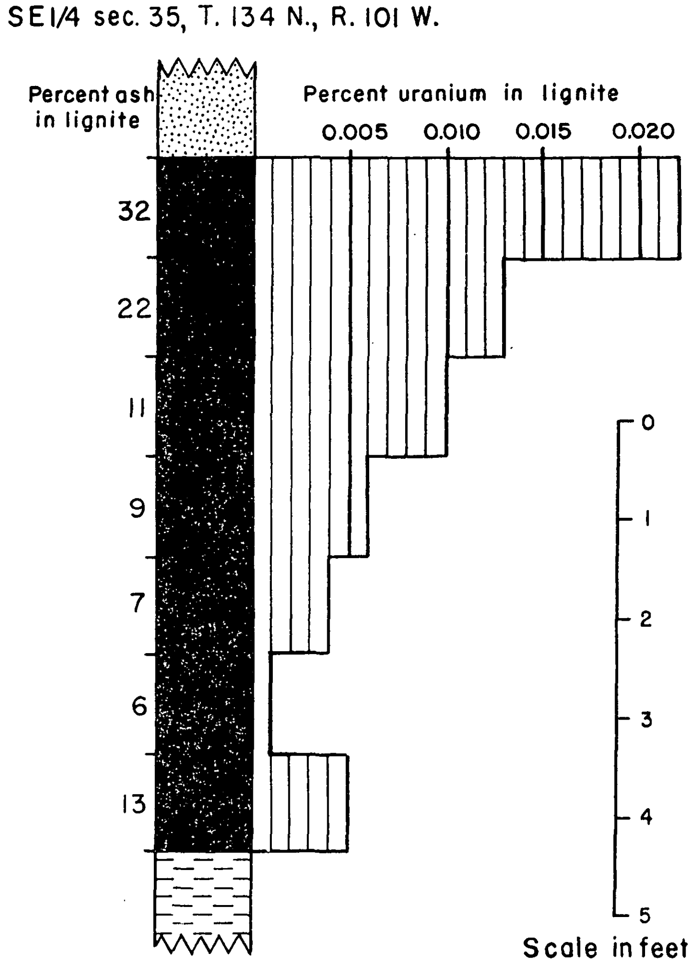

FIGURE 27.—Graphic section of the Slide Butte lignite bed at Chalky Buttes, N. Dak., illustrating downward decrease in distribution of uranium.

The amount of uranium deposited seems to be due in part to the permeability of rocks enclosing the lignite beds. Beds with relatively large uranium content commonly are overlain by permeable beds of sandstone. One of the most uraniferous lignite beds studied, the Slide Butte lignite bed, is overlain by a bed of sandstone 60 feet thick where the lignite is most uraniferous, and the several thin beds of uranium-bearing lignite exposed in the Sentinel Butte area are associated with permeable rocks.

Perhaps the most convincing proof for the derivation of uranium from the rocks of the White River group and Arikaree formation is the regional relationship between the White River group and the underlying uranium-bearing lignite. Plate 32 is a block diagram showing the truncation of Paleocene and Upper Cretaceous rocks by the erosion surface at the base of the White River group, and the relation of uraniferous lignite to this unconformity. At Sentinel and Bullion Buttes, the White River group overlies the Sentinel Butte member of the Fort Union formation, and only the lignite in the upper part of the Sentinel Butte member contains uranium. As successively older beds of lignite are cut out beneath the pre-White River unconformity, the next lower bed in the stratigraphic sequence becomes uraniferous so that at Slim Buttes in South Dakota rocks of the White River group overlie a uranium-bearing bed near the base of the Ludlow member of the Fort Union formation. At the south end of Slim Buttes thin lenticular beds of lignite in the Hell Creek formation of Late Cretaceous age are also radioactive.

Northeast of the area shown by the diagram the White River group unconformably overlies the Golden Valley formation of Eocene age (Benson, 1951). In the NW¼ sec. 31, T. 139 N., R. 97 E., Stark County, N. Dak., the Golden Valley formation contains a lenticular bed of lignite, 0.6-foot thick, which crops out within 10 feet stratigraphically of the base of the White River group. This lignite bed contains 0.12 percent uranium, 6.1 percent ash, and 1.9 percent uranium in the ash. Thus, lignite beds having a stratigraphic range of more than 1,000 feet and ranging in age from Eocene to Late Cretaceous, may contain uranium, but they are uraniferous only where closely overlain by rocks of the White River group.

Denson, Bachman, and Zeller (see chapter B, this bulletin) note that ground water from the White River group contains unusually large amounts of uranium. Later detailed sampling of water in the Slim Buttes area added corroborative evidence (Gill and Moore, 1955). Two spring-water samples from the Chadron formation collected during the present investigation contain 29 and 10 parts per billion uranium at Chalky Buttes in the NW¼ sec. 31, T. 134 N., R. 101 W., and at HT Butte in the SE¼ sec. 24, T. 134 N., R. 102 W. By way of comparison, Sheldon Judson and Kenneth Osmond (written communication, 1953) obtained an average of only 0.4 parts per billion uranium from 42 well samples in Wisconsin, and the uranium content of the ocean is about 1 part per billion (Koczy, 1950).

OCCURRENCE OF URANIUM IN LIGNITE

R. A. Ewing and others (written communication, 1950) have shown that the uranium in lignite from Sentinel Butte, N. Dak., is not associated with mineral matter in the lignite but is related to organic constitutents. Breger, Deul, and Rubinstein (1955), on the basis of ion-exchange studies of uranium-bearing lignite from Slim Buttes, S. Dak., have further demonstrated that the uranium is held as a metallo-organic compound. In additional laboratory studies, non-uraniferous lignite from Slim Buttes was found to extract 99 percent of the uranium from a 200 parts per million solution of uranyl sulfate (Moore, 1954). Under the same conditions wood (white pine) extracted only 40 percent of the uranium, which suggests that uncoalified organic material is less effective as an extracting agent for uranium than lignite.

The graphic section of the Slide Butte lignite bed shown by figure 27 indicates a notable relationship between the ash content and the uranium content of the lignite; the layers having the most ash also have the most uranium. A similar relationship between contents of ash and uranium seems to exist in many of the other uraniferous lignite beds studied. It is thought that other impurities were introduced into the lignite with the uranium, but because the ash content of the lignite is related directly to the freshness of the sample, and because all lignite beds were sampled at weathered outcrops, no consistent ash-uranium correlation can be demonstrated by the data from North Dakota.

The simple progressive downward decrease in uranium in thick lignite beds observed when 1-foot vertical samples through the beds are compared is in part modified when beds are sampled in greater detail. If samples are a fraction of a centimeter to several centimeters thick, variations in uranium content are found between individual samples which do not always reflect their position in the bed. This fact suggests that certain coal constituents may have a greater affinity for uranium than other components. J. M. Schopf and others have made extensive petrographic studies of lignite from the Slim Buttes area, South Dakota, to determine the nature of the uraniferous constituents. Preliminary results of these studies show that no quantitative correlation exists between uranium content and the coal petrologic constituents that are normally determined for coal classification (Schopf and Gray, 1954). They note, however, that the samples richest in uranium contain relatively large amounts of humic matter resulting from decomposition and microbial decay, an indication that plant material that has been most subjected to decay is the most favorable for extraction of uranium. It is also possible, however, that variations in permeability of the coal constituents may have controlled the movement of uranium-bearing solutions within the lignite beds thereby causing variations in uranium content not directly related to the chemical nature of the coal constituents.

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Reconnaissance for Uranium In the Ekalaka Lignite Field, Carter County Montana

By JAMES R. GILL

URANIUM IN COAL IN THE WESTERN UNITED STATES

GEOLOGICAL SURVEY BULLETIN 1055-F

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[Plates are in box]

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RECONNAISSANCE FOR URANIUM IN THE EKALAKA LIGNITE FIELD, CARTER COUNTY, MONTANA

By James R. Gill

ABSTRACT

Beds of uranium-bearing lignite 1.5 to 8 feet thick occur in the Fort Union formation of the southern part of the Ekalaka Hills, Carter County, Mont. Data from surface outcrops indicate that an area of about 1,400 acres is underlain by 16.5 million tons of uranium-bearing lignite. The uranium content of the lignite beds ranges from 0.001 to 0.034 percent, the average being about 0.005 percent.

Ironstone concretions in the beds of massive coarse-grained sandstone in the upper part of the Fort Union formation contain 0.005 percent uranium in the northern and eastern parts of the area. These beds of standstone are favorable host rocks for uranium occurrences and are lithologically similar to beds of massive coarse-grained sandstone of the Wasatch formation in the Pumpkin Buttes area of the Powder River Basin.

INTRODUCTION

Uranium in lignite was discovered by the writer in the southern part of the Ekalaka Hills (fig. 28) in September 1953. An area of about 120 square miles was mapped in reconnaissance (pl. 33) and 127 samples were collected for uranium determinations.

LOCATION AND ACCESSIBILITY

The Ekalaka lignite field includes approximately 1,100 square miles in northeastern Carter and southern Fallon Counties in southeastern Montana. Uranium-bearing lignites are known in only about 120 square miles in Carter County in the southern part of the field. The area studied is largely within Custer National Forest. Ekalaka (population 904), the county seat of Carter County, is the only town in the area. The nearest rail shipping point is Baker, about 36 miles to the north. The area is readily accessible by State Route 7, which crosses the area in a generally southeastward direction, and by graded county roads and Forest Service trails.

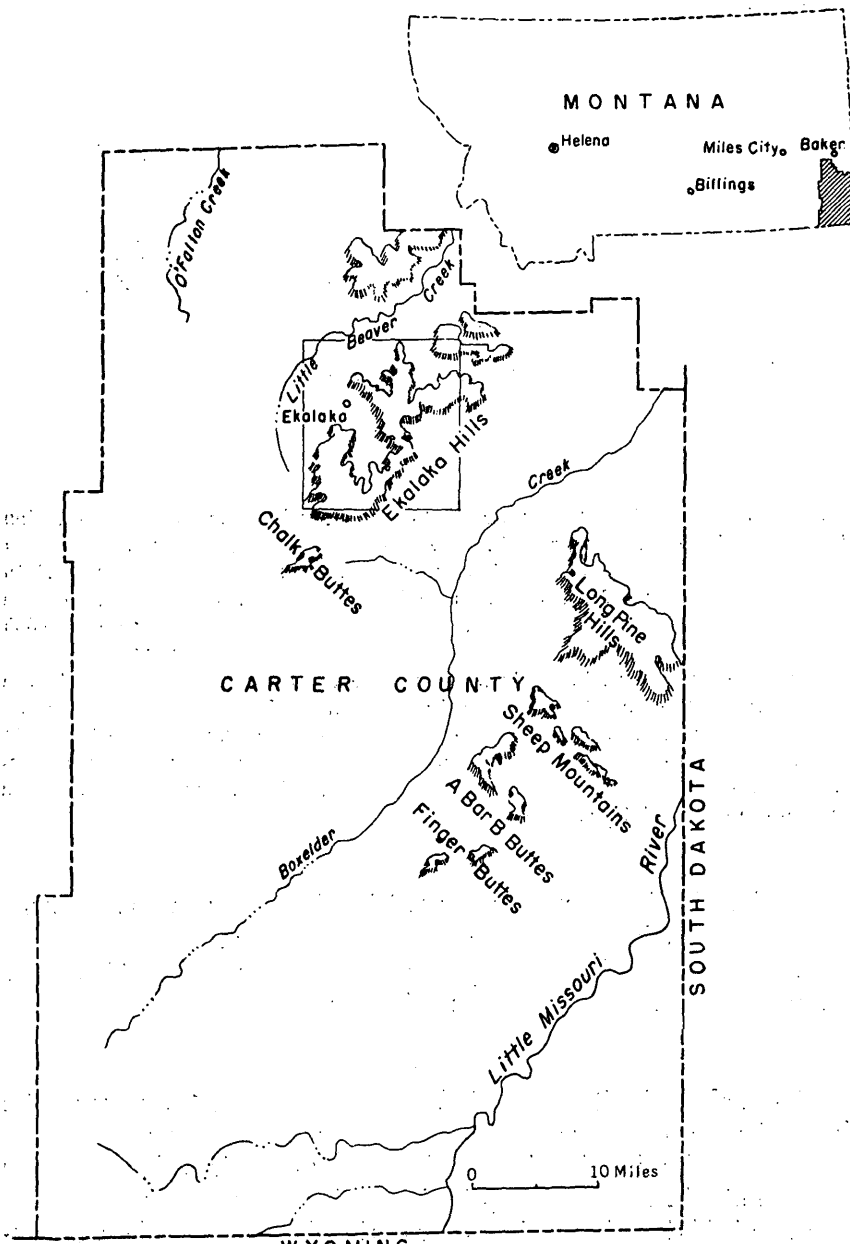

FIGURE 28.—Index map of Carter County, Mont., showing location of Ekalaka Hills area.

The Ekalaka Hills, rising 400 to 500 feet above the surrounding country, are the most imposing topographic feature in the area. Vegetation other than grass is sparse except on the steep slopes and relatively flat tops of these hills, where western yellow pine forms dense growths.

GEOLOGIC WORK

The geology and lignite resources of the Ekalaka Hills have been described by Bauer (1924) and the ground-water resources by Perry (1935). The investigation in the southern part of the Ekalaka Hills (fig. 28) on which this report is based was done by the writer in September 1953 as a part of a program of investigation of uranium-bearing coal and carbonaceous rocks in the western United States. An area of about 120 miles was mapped in reconnaissance (pl. 33). Some beds of lignite were found to be uranium bearing, and 127 samples from them and other rock material were collected for anlyses for uranium.

GEOLOGY

The Ekalaka Hills lie along the western margin of a broad shallow syncline between the northwest-trending extension of the Black Hills uplift on the southwest and the Cedar Creek anticline on the northeast. The Cretaceous Hell Creek formation and the Tertiary Fort Union (Paleocene) and Arikaree (Miocene) formations form the bedrock of the area. The lignite-bearing rocks, the Hell Creek and Fort Union formations, are equally slightly deformed; in the mapped area they dip from 1 to 3 degrees northeast. The flat-lying rocks of the Arikaree formation lie on the bevelled edges of these formations.

STRATIGRAPHY

HELL CREEK FORMATION (UPPER CRETACEOUS)

The oldest rocks exposed in the Ekalaka Hills are assigned to the Hell Creek formation of Late Cretaceous age. These rocks consist of gray to buff claystone with lenses of rusty-brown fine-grained poorly indurated sandstone and a few thin lenticular beds of lignite. Ellipsoidal concretions of sandstone ranging from one inch to more than five feet in diameter are common. The formation averages 500 feet in thickness (Bauer, 1924, p. 239) and is conformably overlain by the Fort Union formation. The soft, poorly indurated claystone and sandstone of the Hell Creek erode to form badland topography.

FORT UNION FORMATION (PALEOCENE)

The Fort Union formation of Paleocene age consists of light-yellow and gray fine- to medium-grained massive sandstone, gray shale, claystone, and thick lenticular beds of lignite. The formation ranges from 180 to 500 feet or more in thickness and is unconformably overlain by the Arikaree formation of Miocene age.

In the southern part of the area of the Fort Union formation is exposed beneath the cliff-forming tuffaceous sandstones of the Arikaree formation that form the upper surface of the Ekalaka Hills. In the northern part of the area (T. 2 N., Rs. 58 and 59 E.) the massive, well-indurated sandstones of the upper part of the Fort Union formation form the upper surface of the Ekalaka Hills.

Ironstone concretions in beds of massive coarse-grained sandstone in the upper part of the Fort Union formation near Ekalaka contain 0.005 percent uranium. The sandstone is favorable as a host rock for possible deposits of uranium and is lithologically similar to the beds of massive, coarse-grained, uranium-bearing sandstone of the Wasatch formation in the Pumpkin Buttes area of the Powder River Basin (Love, 1952).

ARIKAREE FORMATION (MIOCENE)

Unconformably overlying the rocks of the Fort Union formation is the Arikaree formation of Miocene age. The formation is composed of more than 250 feet of slightly radioactive light-gray, fine-grained, tuffaceous sandstone. Samples of the sandstone contain an average of 0.002 percent uranium. It is thought that the uranium is in the volcanic material of which the formation is largely composed. The sandstone is one of the more resistant rock units in the area and causes the Ekalaka Hills to rise more than 500 feet above the surrounding country.

In the Long Pine Hills (fig. 28) and adjacent areas the Arikaree formation unconformably overlies rocks of the Brule formation of middle and late Oligocene age suggesting that the unconformity at the base of the Arikaree is younger than late Oligocene.

In southeastern Montana and adjacent parts of South Dakota few fossils have been found in this formation (Bauer, 1924, p. 245). The age of the Arikaree is based largely on a fossil beaver collected approximately 350 feet stratigraphically above the base of the formation on Fighting Butte, 9 miles southwest of the Ekalaka Hills, and described by Wood (1945) as of late Miocene age.

During the present investigation vertebrate fossils were collected from a bed of green fissile shale within 20 feet of the base of the formation in the SW¼NW¼NW¼ sec. 24, T. 1 N., R. 57 E. These fossils were studied by G. E. Lewis who states:

The specimens from locality DM-1F consist of (1) fragments of foot bones of equids of undetermined genus and species, and (2) fragments of entelodont milk teeth. The geologic age could be anything from late Oligocene to middle Miocene.

In view of the regional stratigraphic relationship of the Arikaree formation and of the reported ages of the few fossils collected from it, it seems probable that the unit represents most of Miocene time.

URANIUM-BEARING LIGNITE

The lignite beds of the Ekalaka Hills are in the lower part of the Fort Union formation. The beds are best exposed in the southern part of the mapped area in secs. 35 and 36, T. 1 N., R. 58 E., and in sections 19 and 30, T. 1 N., R. 59 E. (pl. 33). Bauer (1924, p. 250) mapped three beds of lignite named, from oldest to youngest, the Keefer, Elder, and Wilder beds. The beds mapped are actually zones of lenticular beds of lignite. In the present study, a fourth zone, the Cleveland zone, was mapped between the Elder and Wilder zones, and the Elder was separated into upper and lower parts (pl. 34). The Cleveland zone is named after the Cleveland Ranch (NW¼ sec. 30, T. 1 N., R. 59 E.) in Carter County, Mont., where these beds attain their greatest thickness. The stratigraphic relations of these zones are shown in the following generalized section.

Geologic unit or interval	*Thickness (feet)*
Arikaree formation.	
Unconformity.	
Fort Union formation:	
sandstone and shale interval	1–140
Wilder lignite zone (1–3 lignite beds)	1–35
sandstone and shale interval	30–45
Cleveland lignite zone (1–3 lignite beds)	2–30
sandstonee and shale interval	30–45
Elder lignite zone:	
upper part (1–4 lignite beds)	16–60
lower part (1–6 lignite beds)	8–30
sandstone and shale interval	70–120
Keefer lignite zone (1–3 lignite beds)	5–15
Hell Creek formation.	

Individual beds of lignite are lenticular and are difficult to trace for any great distance. The zones, however, are persistent mappable units, even though the beds at many places are represented by carbonaceous shale. Lignite sections were measured at 18 localities, and about 130 samples collected for uranium analyses (table 1, pl. 35).

TABLE 1.—*Summary of analytical data for surface samples of uranium-bearing lignite beds of the Ekalaka Hills area, Carter County, Mont.*

[Analysts: I. Barlow, H. Bivens, M. Delevaux, S. Furman, M. Joslyn, B. A. McCall and A. Pietsch, U. S. Geological Survey]

[Locality numbers refer to numbers on pl. 33; most samples containing less than 0.003 percent equivalent uranium were not analyzed chemically for uranium

Sample				Analyses, in percent			
Field No.	Laboratory No.	Thickness (feet)	Description	Equivalent uranium	Uranium— in sample	Uranium— in ash	Ash
T. 1 S., R. 58 E.							
Locality 1, SW¼NE¼ sec 2							
GM-138	201092	1.1	Carbonaceous shale	0.003			78.1
GM-139	201093	2.9	do	.001			
GM-140	201094	1.0	2-ft bed of lignite, uppermost 1 ft	.001			
GM-141	201095	1.0	2-ft bed of lignite, basal 1 ft	.001			
T. 1 N., R. 58 E.							
Locality 6, SW¼SE¼ sec 25							
GM-77	98594	2.4	Clay shale	0.004	0.001		
GM-78	98595	.4	Lignitic shale	.008	.005	0.009	54.0
GM-79	98596	.4	Clay shale	.005	.001		
GM-80	98597	1.0	10-ft bed of lignite, uppermost ft	.003	.005	.012	39.8
GM-81	98598	1.0	10-ft bed of lignite, 2d ft from top	.001	.002	.004	42.4
GM-82	98599	1.0	10-ft bed of lignite, 3d ft from top	.002	.003	.008	33.6
GM-83	98600	1.0	10-ft bed of lignite, 4th ft from top	.003	.004	.011	33.5
GM-84	98601	1.0	10-ft bed of lignite, 5th ft from top	<.001			32.0
GM-85	98602	1.0	10-ft bed of lignite, 6th ft from top	.007	.007	.017	43.0
GM-86	98603	1.0	10-ft bed of lignite, 7th ft from top	<.001			33.6
GM-87	98604	1.0	10-ft bed of lignite, 8th ft from top	.002	<.001	.001	33.5
GM-88	98605	1.0	10-ft bed of lignite, 9th ft from top	<.001			32.0
GM-89	98606	1.0	10-ft bed of lignite, basal 1 ft	<.001			44.9
Locality 7, SE¼SE¼ sec 25							
GM-30	95526	0.5	1.5-ft bed of lignite, uppermost 0.5 ft	0.006	0.006	0.017	27.7
GM-31	95527	.5	1.5-ft bed of lignite, 2d 0.5 ft from top	.021	.034	.014	24.0
GM-32	95528	.5	1.5-ft bed of lignite, basal 0.5 ft	.007	.007	.015	51.9
GM-33	95529	1.0	Carbonaceous shale	.004	.004	.004	71.8
GM-34	95530	.7	Lignite	.004	.004	.012	34.3
GM-35	95531	.3	Carbonaceous shale	.003	.002	.002	86.9
GM-36	95532	1.0	2-ft bed of lignite, uppermost 1 ft	.002	.002	.005	35.5
GM-37	95533	1.0	2-ft bed of lignite, basal 1 ft	.003	.003	.008	38.2
GM-38	95534	.8	Carbonaceous shale	.010	.007	.008	91.8
GM-39	95535	.3	Lignite	.011	.011	.027	39.3
GM-40	95536	1.0	Carbonaceous shale	.005	.003	.003	86.3
GM-41	95537	.5	2-ft bed of lignite, uppermost 0.5 ft	.011	.015	.045	33.7
GM-42	95538	.5	2-ft bed of lignite, 2d 0.5 ft from top	.002	.002	.005	34.5
GM-43	95539	1.0	2-ft bed of lignite, basal 1 ft	.001	.001	.004	30.7
GM-44	95540	1.0	4-ft bed of lignite, uppermost 1 ft	.002	.002	.006	35.1
GM-45	95541	1.0	4-ft bed of lignite, 2d ft from top	.002	.003	.007	40.5
GM-46	95542	1.0	4-ft bed of lignite, 3d ft from top	.005	.008	.024	33.7
GM-47	95543	1.0	4-ft bed of lignite, basal 1 ft	.005	.008	.018	44.6
GM-48	95544	1.2	Lignite	.003	.005	.018	27.3
GM-49	95545	.8	do	.002	.003	.012	25.4

TABLE 1.—*Summary of analytical data for surface samples of uranium-bearing lignite beds of the Ekalaka Hills area, Carter County, Mont.*—Continued

Sample				Analyses, in percent			
Field No.	Laboratory No.	Thickness (feet)	Description	Equivalent uranium	Uranium— in sample	Uranium— in ash	Ash
T. 1 N., R. 58 E.—Continued							
Locality 4, SE¼SE¼, sec 26							
GM-66	98583	1.0	6-ft bed of lignite, uppermost 1-ft	0.007	0.010	0.021	46.4
GM-67	98584	1.0	6-ft bed of lignite, 2d ft from top	.003	.004	.009	45.2
GM-68	98585	1.0	6-ft bed of lignite, 3d ft from top	.004	.004	.008	47.1
GM-69	98586	1.0	6-ft bed of lignite, 4th ft from top	.002	.002	.004	49.4
GM-70	98587	1.0	6-ft bed of lignite, 5th ft from top	.005	.005	.013	38.8
GM-71	98588	1.0	6-ft bed of lignite, basal 1 ft	.003	.003	.007	38.0
GM-72	98589	.9	Clay shale	.005	.002		
GM-73	98590	.3	Lignitic shale	.010	.006	.010	60.0
GM-74	98591	1.5	Clay shale	.005	.002		
Locality 3, NW¼NE¼, sec 35							
GM-75	98592	2.0	Lignitic shale	0.003			53.8
GM-76	98593	2.7	do	.001			62.7
Locality 2, NE¼NW¼, sec 35							
GM-147	201101	1.1	Lignite	0.001			
GM-148	201102	1.0	Carbonaceous shale	.003	0.002	0.003	65.9
GM-149	201103	.4	Lignite	.002			
Locality 5, NW¼NE¼, sec 36							
GM-5	98543	1.0	Clay shale	0.005	0.003	0.003	94.3
GM-6	98544	.3	Lignitic shale	.015	.018	.030	61.1
GM-7	98545	.5	Carbonaceous shale	.011	.012	.016	74.5
GM-8	98546	.5	2.5-ft bed of lignite, uppermost 0.5 ft	.007	.010	.024	43.7
GM-9	98547	.5	2.5-ft bed of lignite, 2d 0.5 ft from top	.004	.004	.011	40.4
GM-10	98548	.5	2.5-ft bed of lignite, 3d 0.5 ft from top	.002	.003	.007	46.1
GM-11	98549	.5	2.5-ft bed of lignite, 4th 0.5 ft from top	.003	.004	.013	30.9
GM-12	98550	.5	2.5-ft bed of lignite, basal 0.5 ft	.008	.008	.017	49.7
GM-13	98551	.5	Lignitic shale	.005	.006	.010	56.0
GM-14	98552	1.0	Carbonaceous shale	.002			
GM-15	98553	.5	Lignite	.003	.002	.004	49.3
GM-16	98554	1.0	Carbonaceous shale	.002			
GM-17	98555	1.0	Lignitic shale	<.001			58.3
GM-18	98556	1.0	do	.001			60.4
GM-19	98557	1.0	Lignite	.004	.004	.008	47.3
GM-20	98558	1.0	Carbonaceous shale	.004	.005	.007	65.8
GM-21	98559	1.0	Lignitic shale	.002			55.3
GM-22	98560	1.0	do	.003			54.8
GM-23	98561	1.0	Lignite	.003	.003	.007	45.3
GM-24	98562	1.0	do	.002	.002	.006	39.0
GM-27	98563	.5	1.5-ft bed of lignite, uppermost 0.5 ft	.002	.002	.006	41.4
GM-28	98564	.5	1.5-ft bed of lignite, 2d 0.5 ft from top	.004	.005	.014	33.5
GM-29	98565	.5	1.5-ft bed of lignite, basal 0.5 ft	.005	.004	.011	40.7

TABLE 1.—*Summary of analytical data for surface samples of uranium-bearing lignite beds of the Ekalaka Hills area, Carter County, Mont.*—Continued

Sample				Analyses, in percent			
Field No.	Laboratory No.	Thickness (feet)	Description	Equivalent uranium	Uranium— in sample	Uranium— in ash	Ash
T. 1 N., R. 59 E.							
Locality 15, NW¼SW¼ sec 3							
GM-134	201087	3.4	Lignite	0.004	0.001	0.005	34.7
GM-135	201088	1.0	Carbonaceous shale	.002			
GM-136	201089	1.5	3 ft bed of shale, uppermost 1.5 ft	.002			
GM-137	201090	1.5	3 ft bed of shale, basal 1.5 ft	.004		.001	79.4
Locality 13, SE¼NW¼ sec 8							
GM-142	201096	1.8	Lignite	0.002			
GM-143	201097	.9	do	.001			
GM-144	201098	1.8	Carbonaceous shale	.001			
GM-145	201099	1.3	do	.002			
GM-146	201100	.4	do	.002			
Locality 14, SW¼NE¼ sec 8							
GM-108	201061	2.5	Lignite	0.002			
GM-109	201062	.6	do	.001			
GM-110	201063	.7	do	.002			
GM-111	201064	.6	Analcite	.006	0.002	0.003	86.0
GM-112	201065	.4	Carbonaceous shale	.004	.002	.003	78.5
Locality 9, SE¼SW¼ sec 19							
GM-96	98607	1.1	2.2 ft bed of lignite, uppermost 1.1 ft	0.003	0.003	0.009	38.2
GM-97	98608	1.1	2.2 ft bed of lignite, basal 1.1 ft	.006	.007	.020	36.6
GM-98	98609	1.0	Clay shale	.003			
GM-99	98610	.7	Lignite	.002	.002	.005	48.5
Locality 11, SW¼NW¼ sec 24							
GM-50	98566	1.0	5.8 ft bed of lignite, uppermost 1 ft	0.004	0.004	0.011	39.2
GM-51	98567	1.0	5.8 ft bed of lignite, 2d ft from top	.004	.004	.008	47.0
GM-52	98568	3.8	5.8 ft bed of lignite, basal 3.8 feet	.001	.002	.007	30.7
Locality 12, NW¼NE¼ sec 24							
GM-100	98611	1.0	6 ft bed of lignite, uppermost 1 ft	0.005	0.005	0.020	26.6
GM-101	98612	1.0	6 ft bed of lignite, 2d ft from top	.002	.002	.006	36.0
GM-102	98613	1.0	6 ft bed of lignite, 3d ft from top	.001	.001	.002	41.9
GM-103	98614	1.0	6 ft bed of lignite, 4th ft from top	.001	.002	.014	14.1
GM-104	98615	1.0	6-ft bed of lignite, 5th ft from top				17.1
GM-105	98616	1.0	6-ft bed of lignite, basal 1 ft	.001	.001	.005	16.4

TABLE 1.—*Summary of analytical data for surface samples of uranium-bearing lignite beds of the Ekalaka Hills area, Carter County, Mont.*—Continued

Sample				Analyses, in percent			
Field No.	Laboratory No.	Thickness (feet)	Description	Equivalent uranium	Uranium— in sample	Uranium— in ash	Ash
			T. 1 N., R. 59 E.—Continued				
			Locality 17, SW¼SE¼ sec 29				
GM-120	201073	2.0	Carbonaceous shale	0.002			
GM-121	201074	1.9	Lignite	.002			
GM-122	201075	2.6	Lignitic shale	.003	0.001	0.003	53.6
GM-123	201076	.3	Lignite	.004	.004	.009	43.0
GM-124	201077	1.0	do	.002			
GM-125	201078	1.0	Carbonaceous shale	.003		<.001	91.2
GM-126	201079	1.0	3.5-ft bed of lignite, uppermost 1-ft	.003	.001	.004	35.1
GM-127	201080	1.0	3.5-ft bed of lignite, 2d ft from top	.004	.002	.013	16.6
GM-128	201081	1.5	3.5-ft bed of lignite, basal 1.5 ft	.003	.002	.009	28.2
GM-129	201082	2.4	Carbonaceous shale	.003		<.001	91.0
GM-130	201083	1.5	Lignite	.006	.005	.010	44.7
GM-131	201084	1.0	Carbonaceous shale	.004		<.001	93.2
GM-132	201085	2.3	do	.002			
			Locality 8, center of west line, sec 30				
GM-53	98569	1.0	Lignitic shale	0.005	0.007	0.012	56.2
GM-54	98570	1.0	2-ft bed of lignite, uppermost 1-ft	.003	.004	.010	41.4
GM-55	98571	1.0	2-ft bed of lignite, basal 1-ft	.002	.004	.011	39.1
GM-56	98572	1.0	Lignite	.007	.009	.019	48.9
GM-57	98573	.4	Carbonaceous shale	.007	.010	.012	81.0
GM-58	98574	.2	do	.011	.009	.014	63.5
GM-59	98575	.8	Carbonaceous shale	.008	.008	.009	86.6
GM-62	98578	1.0	Shale	.004	.001		
GM-60	98576	1.0	2.5-ft bed of lignite, basal ft	.007	.005	.014	37.8
GM-61	98577	1.0	2.5-ft bed of lignite, 2d ft above base	.002	.003	.007	42.6
GM-63	98579	.5	2.5-ft bed of lignite, uppermost 0.5 ft	.005	.004	.008	52.2
GM-64	98580	.7	Carbonaceous shale	.003			72.1
GM-64A	98581	.3	do	.008	.006	.007	90.1
GM-65	98582	.3	Lignite	.003	<.001	.001	41.6
			Locality 16, SE¼NW¼ sec 33				
GM-133	201086	1.5	Ironstone concretion	0.008	0.005	0.005	81.0
			T. 2 N., R. 58 E.				
			Locality 18, NE¼NE¼ sec 30				
GM-115	201068	0.7	Lignite	0.001			
GM-116	201069	1.5	do	.002			
GM-117	201070	.9	do	.003	0.001	0.003	36.0
GM-118	201071	.9	Carbonaceous shale	.004			92.1
GM-120	201072	1.2	Lignite ash	.002			
			Locality 19, NW¼NW¼ sec 13				
GM-113	201066	2.1	Carbonaceous shale	0.003	0.001	0.001	76.1
GM-114	201067	1.0	Lignite	.001			

The uranium content of the lignite beds ranges from 0.001 to 0.034 percent, the average being 0.005 percent. The greatest concentration of uranium is in the beds of the Wilder, Cleveland, and upper part of the Elder lignite zones in the southern part of the area at localities 4–12 (pl. 35), where they are unconformably overlain by the mildly radioactive tuffaceous sandstone of the Arikaree formation. Elsewhere in the area to the north and east, the same lignite beds are separated from the overlying Arikaree formation by younger rocks of the Fort Union formation and the lignite is less radioactive.

In the southern part of the area at localities 11 and 12, the Wilder lignite zone contains an average of about 0.003 percent uranium throughout its entire thickness of 5.9 feet and the Cleveland lignite zone contains several thin beds ranging from 1.5 to 3.5 feet in thickness that contain an average of 0.006 percent uranium. The upper part of the Elder lignite zone is highly lenticular, ranging from less than one foot to more than 20 feet in thickness. A maximum thickness of 8 feet contains 0.005 percent uranium.

Fresh, unweathered samples suitable for fuel analysis could not be collected from outcrops and there are no mines in the area. Determinations made on weathered samples containing the visible impurities, analcite, barite and gypsum, show 14 to 50 percent ash. Because some of these impurities probably were introduced during the weathering of the lignite, it is not unreasonable to assume that unweathered lignite will have a much lower ash content and will have a heating value comparable to most lignite.

ORIGIN OF THE URANIUM

Investigations of uranium-bearing lignite deposits in North and South Dakota by Denson, Bachman, and Zeller (see chapter B, this bulletin) suggest that the uranium in the lignite was brought by ground water from the uranium-bearing tuff in the overlying White River group of Oligocene age and Arikaree formation of Miocene age. Subsequently, secondary minerals of uranium were found in Oligocene rocks in the Slim Buttes area (Gill and Moore, 1955) and in the Big Badlands of South Dakota (Moore and Levish, 1955).

Some of the conditions that seem to control the concentration of uranium in the lignite are: stratigraphic proximity of the lignite to the base of the potential source rock, permeability of rocks overlying the lignite, and the adsorptive properties of the lignite. In general, the stratigraphically highest lignite bed beneath the source rock contains the most uranium, and the greatest concentration of uranium is in the upper part of beds three feet or more thick. Beds less than 3 feet thick may contain uranium equally distributed through their entire thickness.

The distribution of uranium in the lignite beds is shown on plate 35. The effect of permeability of rocks overlying the lignite is indicated at localities 11 and 12 where the Wilder lignite zone is directly overlain by impervious shale. The uranium content is low despite the fact that the lignite closely underlies the source rocks of the Arikaree formation. At localities 4, 5, 7 and 8 (pl. 34) the upper part of the Elder lignite zone is overlain by a thick sandstone and though the lignites are 90 to 150 feet stratigraphically below the base of the Arikaree formation the upper parts of the lignite bed are more than twice as uraniferous as the Wilder zone at localities 11 and 12 (pl. 35).

Minor variations in the distribution of urarium within the lignite bed can be expected where the lignite is directly overlain by an impervious shale and underlain by a permeable sandstone, as for example, the Cleveland lignite zone at locality 8 (pl. 35). There, an increase at the base rather than a downward decrease from the top suggests that the uranium may have been introduced under hydrostatic pressure into the base of the lignite from the underlying sandstone.

Where the lignite beds are separated from the Arikaree formation by impervious overlying rocks of the Fort Union formation, as in the northern and eastern parts of the area, the beds are not radioactive.

Analyses of spring waters from the Arikaree formation in the Ekalaka Hills indicate that uranium is being leached from this formation and is being transported by ground waters. The uranium content in parts per billion of six representative ground-water samples from springs in the area are listed below. Some of the springs shown on the map as being in the uppermost part of the Fort Union actually are in small unmapped alluvial deposits, but the springs derive their water from the Arikaree formation.

TABLE 2.—*Analyses of water samples from springs in the Arikaree formation, Ekalaka Hills, Carter County, Mont.*

Field No.	Laboratory No.	Name of spring	Location (Tp.)	Location (R.)	Location (Sec.)	Uranium (ppb)
GM-138	201091	Kinsey	1 N.	59 E.	6	6
-152	201106	Dugan Draw	1 N.	58 E.	19	4
-153	201107	Sugar Bowl	1 N.	58 E.	33	7
-154	201108	Stagville	1 N.	58 E.	21	3
-155	201109	Ben Russell	1 N.	58 E.	24	3
-156	201110	Martin	1 N.	58 E.	13	8

TONNAGE OF URANIUM-BEARING LIGNITE

Approximately 16.5 million tons of uranium-bearing lignite having an average uranium content of about 0.0045 percent underlie the southern part of the Ekalaka Hills (fig. 29) in beds of the Wilder,

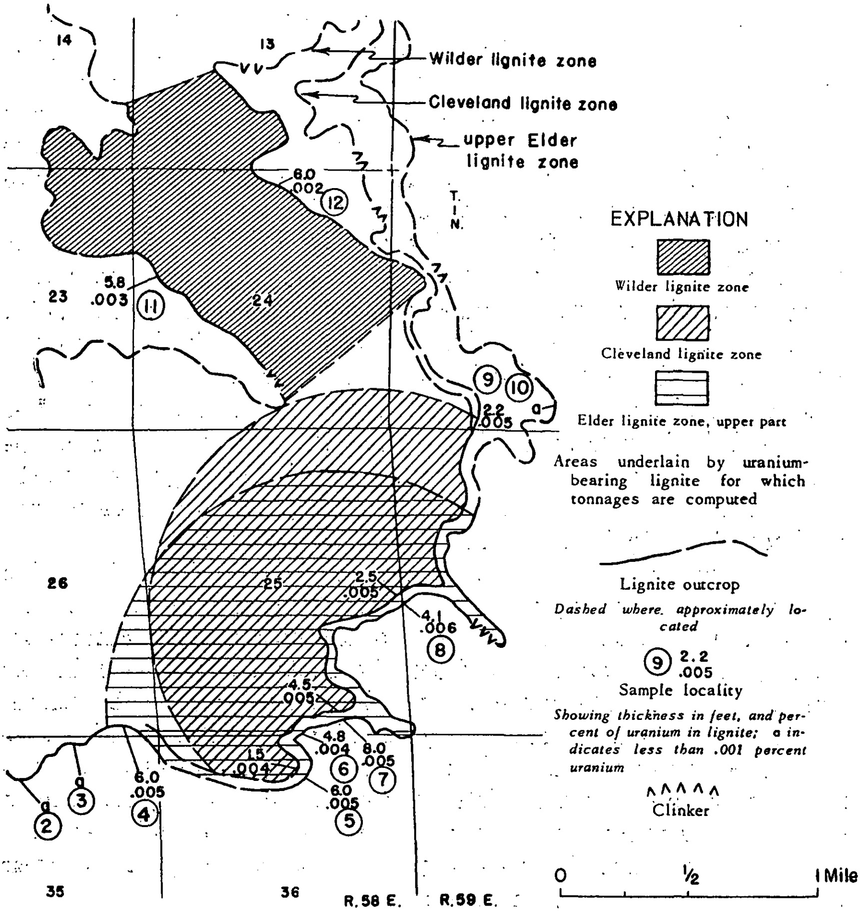

FIGURE 29.—Map showing area underlain by uranium-bearing lignite, Ekalaka Hills, Carter County, Mont.

Cleveland and upper part of the Elder lignite zones. The uranium-bearing lignite beds have an average ash content of 37 percent; these ash determinations were made of weathered lignite samples and may not reflect correctly the ash content of unweathered lignite.

A summary of tonnage estimates of uranium-bearing lignite for the Wilder, Cleveland, and upper part of the Elder lignite zones in the southern part of the Ekalaka Hills is given in the following table:

TABLE 3.—*Tonnage of uranium-bearing lignite in the southern part of the Ekalaka Hills, Carter County, Mont.*

Lignite zone	Average thickness (feet)	Average ash content (percent)	Uranium in lignite (percent)	Area (acres)	Lignite [1] (short tons)
Wilder	5.9	30	0.003	560	5,782,000
Cleveland	2.7	43	.006	760	3,591,000
Elder, upper part	5.8	40	.005	700	7,105,000
Total				2,020	16,478,000

[1] Based on 1,750 tons per acre-foot, net result rounded to nearest 1,000 tons.

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Uranium-Bearing Coal in the Red Desert Area Sweetwater County Wyoming

By HAROLD MASURSKY *and* GEORGE N. PIPIRINGOS

URANIUM IN COAL IN THE WESTERN UNITED STATES

GEOLOGICAL SURVEY BULLETIN 1055-G

469117—59——14

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URANIUM-BEARING COAL IN THE RED DESERT AREA, SWEETWATER COUNTY, WYOMING

By Harold Masursky and George N. Pipiringos

ABSTRACT

Uranium-bearing coal occurs in the Red Desert area of Sweetwater County, Wyo., in a zone 15 miles wide which extends in a northwesterly direction for 30 miles north of Wamsutter, Wyo. The thickest coal is found along the transition zone between the fluviatile sandstone of the Wasatch formation and the lacustrine shale of the Green River formation, both of Eocene age. Each coal bed is lenticular and grades into shale to the northeast and southwest.

The greatest concentrations of uranium in the coal occur locally where the beds are overlain by conglomerate of possible Miocene age. Widespread but lesser concentrations of uranium occur in coal where a bed is in proximity to intercalations of coarse-grained, permeable, fluviatile sandstone which were derived from a source area to the northeast. The close relationship between uranium in the coal and the permeability of the adjacent beds indicates that the uranium is of epigenetic origin.

Preliminary estimates indicate that the rocks in the mapped area contain about 700 million short tons of subbituminous B coal in beds not less than 2.5 feet thick and overlain by not more than 75 feet of overburden. The Luman No. 1 coal bed, the principal objective of a drilling program in 1952, contains about 12 million short tons of subbituminous coal that averages 3.9 feet in thickness, under not more than 75 feet of overburden. The uranium content of the Luman No. 1 bed averages about 0.006 percent, the ash content averages about 20 percent, and the uranium content of the ash averages about 0.030 percent. The average heating value of the coal in the "as received" condition is 7,600 Btu. The average uranium content of other coal in the rest of the area is about 0.003 percent, although locally, as at Creston Ridge in the southeastern part of the area, impure coal contains as much as 0.051 percent uranium.

The study indicates that the coal in the Red Desert area is of interest primarily as a fuel resource and contains only small concentrations of uranium. Thin carbonaceous shale interbedded with coarse-grained sandstone to the north and east of the principal area underlain by coal, however, may contain high-grade deposits of uranium.

INTRODUCTION

A study was made in 1951 of uranium-bearing coal along the northeast margin of the Red Desert area, in the Great Divide Basin, Sweetwater County, Wyo. As a result, exploratory core drilling was carried on for the U. S. Geological Survey in 1952 to determine more accurately the areal distribution, thickness, and uranium content of the coal in the northern part of the area. Another objective of the investigation was to determine the origin of the uranium in the coal and use the knowledge as a guide to exploration for other deposits.

Preliminary results based on this work are herein presented. Extensive additional core drilling in the eastern part of the area, carried out in 1953, has considerably modified the correlation of coal beds and the estimation of tonnage of uranium-bearing coal in the southeastern part of the area.

LOCATION OF THE AREA

The Red Desert area, in Sweetwater County, Wyo., lies in the central part of the Great Divide Basin, a structural and topographic basin lying between the Rawlins and Rock Springs uplifts on the east and west, respectively, and the Green Mountains and the Laney Rim of the Washakie Basin on the north and south. The area of this report includes about 600 square miles and extends from the town of Wamsutter for 30 miles to the north (fig. 30). The altitude ranges from 6,500 to 7,200 feet. Owing to the semiarid climate, only

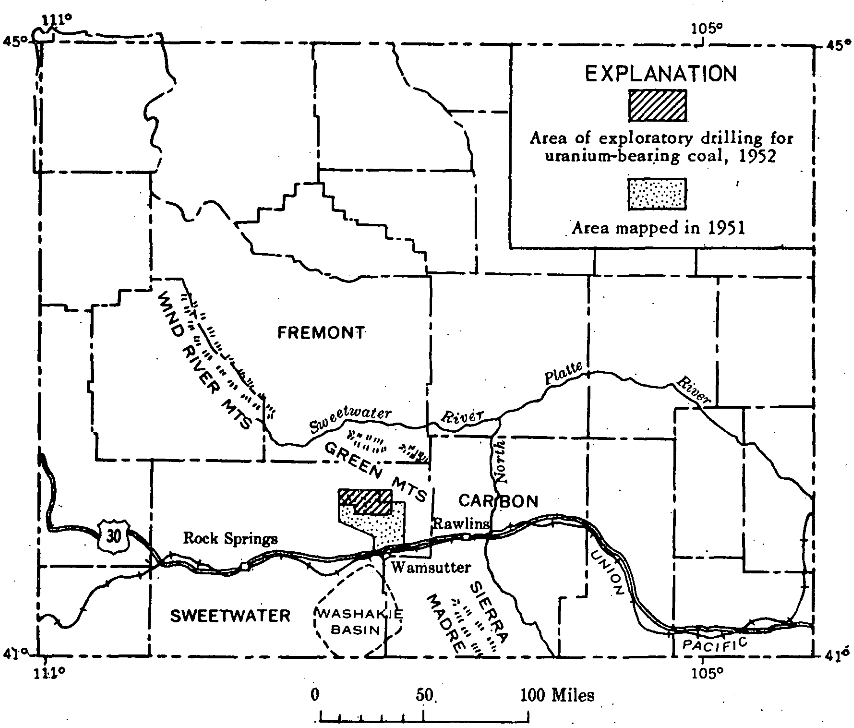

FIGURE 30.—Index map of Wyoming, showing location of the Red Desert area, Sweetwater County.

intermittent streams and playa lakes are present; the Sweetwater River on the north side of the Green Mountains, 25 miles north of the area, is the nearest perennial stream. The nearest shipping point is Wamsutter, on the Union Pacific Railroad which crosses the southern part of the area. Many graded dirt roads and trails make other parts of the area easily accessible by automobile.

FIELDWORK

July to December of 1951 was spent in mapping the coal beds in the central part of the area. At that time, channel samples were collected with pick and shovel at exposures of coal, and a truck-mounted auger was used to establish the persistence of coal beds into covered areas. From June to November 1952 a four-man party mapped and sampled the coal beds in more detail. Core drilling in the northern part of the area (fig. 30) was done in September and October 1952 by the Minerals Engineering Co.

Geology was mapped and General Land Office section-corner markers were plotted on aerial photographs at a scale of about 1:36,000 and compiled at a scale of 1:31,680 on a grid constructed from township plats of the General Land Office resurvey of 1937.

ACKNOWLEDGMENTS

In the fieldwork of 1952 the writers were assisted by Arthur E. Burford, Howard D. Gower, George W. Moore, J. R. Pierson, Jr., and James Sindelar. Gower also assisted the writers in the office for several months after the fieldwork. Theodore Botinelly, Maurice Deul, and Irving Breger of the Geological Survey contributed helpful discussions in the field on the mineralogy of the coal; Roland Brown and H. R. Christner collected and identified plant fossils.

James M. Schopf processed and made detailed descriptions of all coal cores. Chemical analyses for uranium and determinations of equivalent uranium were made in Geological Survey laboratories, and proximate and ultimate fuel analyses of the coal from cores were done by the U. S. Bureau of Mines.

The writers are especially indebted to Raymond Larsen and Kaj Hansen for providing housing facilities for Geological Survey personnel during the 1952 fieldwork.

GEOLOGY

PREVIOUS WORK

The geology of the coal-bearing rocks in the Red Desert area was described by Smith (1909). Studies of adjacent areas were made by Schultz (1907) and Ball (1909). Tertiary strata, especially in relation to the occurrence of oil shale, was investigated and described by Sears and Bradley (1924), and Bradley (1926, 1945). Oil and gas possibilities along the east and west margins of the Great Divide Basin were discussed by Schultz (1920), Fath (1924), and Dobbin (1928, 1929).

Uranium in coal was discovered in the Red Desert area by A. L. Slaughter and J. M. Nelson (written communication, 1946), while investigating the Lost Creek schroeckingerite deposit. Subsequent studies of the uranium deposits of the area were made by R. A. Nelson, W. N. Sharpe, and F. W. Stead (written communication, 1951), D. M. Sheridan, J. T. Collier, and R. S. Sears (written communication, 1952), and D. G. Wyant, W. N. Sharpe, and D. M. Sheridan (1957). A preliminary copy of the map by Wyant and Sharpe of part of the coal-bearing rocks was available to the writers before fieldwork started in 1951.

STRATIGRAPHY

The Wasatch and Green River formations of Eocene age are the only stratigraphic units studied in detail in the mapped area (pl. 36) pertinent to this report. The Wasatch formation is divided into two parts in ascending order: the main body of the Wasatch formation (the Hiawatha member of local usage, Nightingale, 1930; Wood and others, 1941; Wyo. Geol. Assoc. Nomenclature Committee, 1951), and the Cathedral Bluffs tongue of the Wasatch formation (fig. 31).

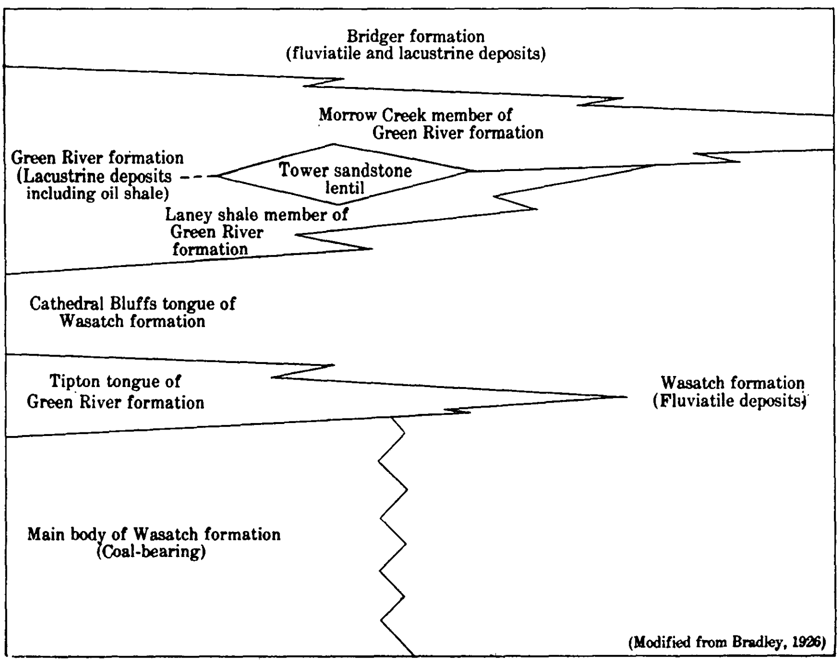

FIGURE 31.—Diagrammatic section showing intertonguing of Eocene rocks in the Red Desert area, Sweetwater County, Wyo., and adjoining areas.

The units of the Green River, in ascending order, are the Tipton tongue, the Laney shale member, and the Morrow Creek member. Only the upper part of the main body of the Wasatch formation, the lower part of the Cathedral Bluffs tongue, and the Tipton tongue of the Green River formation are exposed in the mapped area and have an aggregate thickness of more than 1,200 feet. Younger rocks of Eocene, Miocene, and Pliocene(?) age were examined in reconnaissance in adjacent areas. Pleistocene and Recent lake deposits, alluvium, and sand dunes mantle the bedrock over large areas of the Red Desert.

The Wasatch formation of the northeastern part of the area is composed of coarse-grained arkose and sandy claystone; both rock types commonly are buff to tan but are variegated at some localities. They are irregularly bedded and cross-laminated and probably of fluviatile origin. To the southwest the rocks of the main body of the Wasatch formation are finer grained, more evenly bedded, very light gray in color, and coal bearing. Rocks of the Cathedral Bluffs tongue also become finer grained and even bedded to the southwest but are variegated and weather to typical badland forms. The Wasatch rocks represent floodplain and swamp deposits and intertongue with rocks of lacustrine origin, consisting of papery organic shale, laminated siltstone, and fossiliferous calcareous sandstone belonging to the Green River formation. The restored section (pl. 36) shows the stratigraphic relations of the interfingering units within the mapped area. Similar relationships in adjacent areas have been described by many workers, including Schultz (1909), Sears and Bradley (1924), Bradley (1926, 1945, and 1948), Nightingale (1930), and Nace (1939).

Plant and vertebrate fossils indicate an early Eocene age for the main coal-bearing sequence of the Wasatch formation. They are listed in the table on the following page.

Beds of lacustrine shale and siltstone similar to rocks of the Green River formation are mapped separately in the central and northwestern part of the area and are tentatively included in the main body of the Wasatch formation. Brown limy sandstone containing freshwater fossils is common in these lacustrine rocks. Two key zones were helpful in mapping: a 10-foot zone near the top of the Tipton tongue, which includes calcareous onion-layered algal balls about 0.5 foot in diameter, and a 5-foot zone of pastel-weathering limestone concretions, each about 2 feet in diameter, that is usually present at the base of the shale tongue above the Battle No. 3 coal bed.

High level terraces in the southern part of the area are covered by conglomerate that is tentatively correlated with the basal conglomerate of the Browns Park formation of Miocene age. However, conglomerate also occurs in nearby areas in beds of Oligocene and Pliocene age, and gravels of Pleistocene age occur locally. The possible

Fossil collections from the main body of the Wasatch formation in the Red Desert area

Map locality (pl. 37)	Location	Identifications	Age
Plants [identified by R. W. Brown]			
14	SE¼SW¼ sec. 24, T. 24 N., R. 96 W.	*Equisetum* sp.	Earlier half of Eocene.
		Lygodium kaulfussi Heer	Do.
		Salvinia preauriculata Berry	Do.
		Lemna scutata Dawson	Do.
186	SW¼SW¼ sec. 4, T. 21 N., R. 94 W.	*Salvinia preauriculata* Berry	Eocene.
		Sparganium antiquum (Newberry) Berry.	Do.
		Platanus raynoldsi Newberry	Do.
Invertebrates [identified by Teng-Chien Yen]			
49	SW¼SE¼ sec. 36, T. 23 N., R. 95 W.	*Unio* sp. undet	Early Eocene.
		Sphaerium sp. undet	Do.
		Viviperus sp. undet	Do.
		Valvata sp. undet	Do.
		Goniobasis nodulifera (Meek)	Do.
		Goniobasis cf. *G. tenera* (Hall)	Do.
		Gyraulus sp. undet	Do.
1 mile west of 121	SW¼SW¼ sec. 15, T. 22 N., R. 94 W.	*Unio* sp. undet	Do.
		Valvata sp. undet	Do.
		Viviparus cf. *V. paludinaeformus* (Hall).	Do.
		Goniobasis cf. *G. tenera* (Hall)	Do.
		Gyraulus cf. *G. militarus* (White)	Do.

Miocene age of these beds is based on intermittently exposed similar terrace deposits that extend to the east and pass under tuffaceous sandstone of the Browns Park formation in the vicinity of Rawlins.

STRUCTURE

The Red Desert area is generally one of low structural relief; however, two large structures are recognizable in the area of core drilling. One is a basin, the southern limit of which is marked by the Eagles Nest Rim, at the northern edge of the mapped area (pl. 36), and which is here called the Niland basin. The other, a syncline, continues southeastward from the Niland basin and is probably continuous with the Red Desert syncline of Schultz (1920, p. 40); it is shown by structure contours on plate 45. The axis of the syncline trends about N. 30° W.

Along the north margin of Lost Creek Flat are several minor folds that trend N. 30° E., and an anticline trends N. 75° E. at Chain Lakes Flat.

High-angle faults of minor displacement and trending N. 75° E. occur at many places; faults of lesser importance trend N. 30° E.

COAL

OCCURRENCE

The coal beds are thickest, 5–20 feet (fig. 32), in a northwest-trending zone about 30 miles long in the central part of the area. The zone coincides with the transition zone between the Wasatch formation of fluviatile origin and the Green River formation of lacustrine origin. Each coal bed is lens-shaped in cross section and thins within a few miles to the northeast and southwest of the zone, grading into carbonaceous shale which in turn grades into green-clay shale. Not only

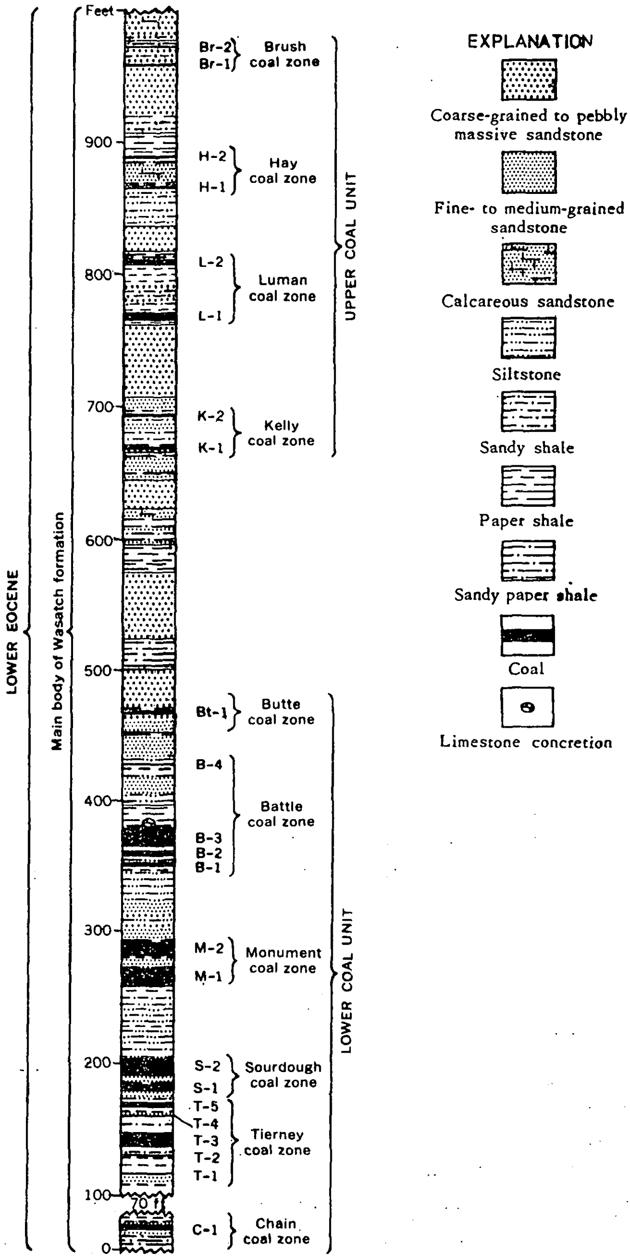

FIGURE 32.—Generalized columnar section, showing relative positions of principal coal beds, Red Desert area, Sweetwater County, Wyo.

the coal beds but the entire stratigraphic sequence is thickest along this transition zone and thins considerably to the west and slightly to the east (pl. 36).

The coal in outcrop ranges in physical character from hard, banded, black coal having conchoidal fracture to light-weight, soft porous coal containing many fragments of carbonized wood. On weathering the coal breaks down into small fragments. It has burned along the outcrop at many places, but the burning did not extend far back underground from the outcrop. Evidently the soft siltstone overlying the coal caved and smothered the fires.

In the area of core drilling there are four zones of uranium-bearing coal of potential economic interest: the Sourdough, Monument, Battle, and Luman zones, and several minor zones of coal and carbonaceous shale in which beds are thin and of little or only local importance (fig. 32). In the central part of the area of drilling the thickest carbonaceous zone is 21 feet in thickness and the thickest coal bed, 9 feet; in the southern part of the Red Desert area the thickest zone, the Tierney, is as much as 16 feet thick. Fuel analyses by the U. S. Bureau of Mines, 30 proximate and 12 ultimate, are given in table 1. Calculations from these analyses, based on the Parr formula (ASTM, 1938), indicate that the coal is subbituminous B grade. The average heating value in the "as received" condition is 7,600 Btu; in the moisture- and ash-free condition, it is 9,900 Btu. The average ash content is 15.5 percent, and the average sulfur content is 1.8 percent. Detailed descriptions of the coal cores by James M. Schopf are listed in table 4 (see page 198). Plate 37 shows the generalized graphic logs of the core holes.

DISTRIBUTION OF URANIUM

The uranium content of the coal reached by the 11 core holes is shown in detail in plate 38, which also shows the percent of ash and uranium in the ash. The distribution of uranium in individual coal beds, as determined from surface and auger samples, is shown in plates 39–44, each figure showing stratigraphic sections of the coal beds in an east-west tier of townships.

The greatest concentrations of uranium in coal occur locally in the topographically higher parts of the area, at an unconformity where the coal beds are overlain by conglomerate of possible Miocene age. Along the south rim of Bison Basin, 20 miles north of the mapped area, a coal bed in the Fort Union formation of Paleocene age, directly below the unconformably overlying conglomerate, contains 0.056 percent uranium; a bed 12 feet below it contains 0.005 percent, and a bed 40 feet below it contains 0.001 percent. At Creston Ridge, in the southeastern part of the area, a coal bed in the main body of the Wasatch formation of early Eocene age, and immediately

TABLE 1.—*Proximate and ultimate fuel analyses of coal from core holes in the Red Desert area, Wyoming*

[Analyses by the U. S. Bureau of Mines. Condition of sample: A, as received; B, moisture-free; C, moisture- and ash-free; volatile matter determined by the modified method.]

Core hole	Sample: Laboratory No.	Sample: Thickness of coal (feet)	Sample: Condition	Specific gravity	Heating value (Btu)	Ash softening temperature (° F)	Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Proximate: Ash	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Ultimate: sulfur	Forms of sulfur: Sulfatic	Forms of sulfur: Pyritic	Forms of sulfur: Organic
1	D-97526	1.1	A				22.8	33.5	31.5	12.2								
			B					43.5	40.6	15.9								
			C					51.6	48.4									
	D-97527	4.5	A	1.51	8,430	2,260	22.9	32.4	31.0	13.7	6.3	46.5	1.4	29.9	2.2	0.07	1.39	0.78
			B		10,930			42.0	40.3	17.7	4.9	60.3	1.8	12.4	2.9	.09	1.80	1.01
			C		13,280			51.1	48.9		5.9	73.3	2.2	15.1	3.5	.10	2.19	1.23
2	D-96784	1.2	A	1.55	8,200		23.8	29.7	34.2	12.3					1.7			
			B		10,770			39.0	44.9	16.1					2.3			
			C		12,840			46.5	53.5						2.7			
	D-96785	.6	A	1.57	7,770		22.7	30.7	28.2	18.4					1.9			
			B		10,060			39.7	36.5	23.8					2.5			
			C		13,200			52.1	47.9						3.2			
	D-96786	1.7	A	1.52	8,480		24.3	31.5	32.2	12.0					2.6	.05	1.74	.80
			B		11,210			41.6	42.5	15.9					3.4	.07	2.30	1.06
			C		13,320			49.5	50.5						4.1	.09	2.73	1.26
	D-96787	.7	A	1.46	8,860		23.1	32.2	34.1	10.6					.8			
			B		11,520			41.9	44.3	13.8					1.0			
			C		13,360			48.7	51.3						1.2			
	D-96788	2.7	A	1.54	7,990	2,630	22.3	30.3	30.6	16.8	6.1	42.4	1.2	32.4	1.1	.03	.39	.71
			B		10,280			39.0	39.3	21.7	4.6	54.6	1.5	16.2	1.4	.04	.50	.91
			C		13,120			49.8	50.2		5.9	69.7	1.9	20.7	1.8	.05	.64	1.17
3	D-96781	1.7	A	1.54	8,190		23.0	31.1	31.7	14.2					2.4			
			B		10,640			40.3	41.3	18.4					3.2			
			C		13,040			49.4	50.6						3.9			
	D-96782	.7	A	1.56	7,890		21.2	30.6	30.0	18.2					1.2			
			B		10,010			38.8	38.1	23.1					1.6			
			C		13,010			50.4	49.6						2.0			

TABLE 1.—*Proximate and ultimate fuel analyses of coal from core holes in the Red Desert area, Wyoming*—Continued

	Sample						Analyses, in percent											
							Proximate				Ultimate					Forms of sulfur		
Core hole	Laboratory No.	Thickness of coal (feet)	Condition	Specific gravity	Heating value (Btu)	Ash softening temperature (°F)	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Sulfatic	Pyritic	Organic
3	D-96783	3.9	A	1.53	8,330	2,580	20.3	32.4	30.5	16.8	6.1	46.3	1.2	28.2	1.4	0.02	0.62	0.72
			B		10,450			40.7	38.2	21.1	4.8	58.1	1.6	12.7	1.7	.03	.78	.91
			C		13,240			51.5	48.5		6.0	73.6	2.0	16.2	2.2	.04	.98	1.15
4	D-96789	4.1	A	1.56	7,840		19.7	31.7	28.1	20.5	5.8	46.4	1.2	24.7	1.4	.04	.66	.67
			B		9,750			39.5	35.0	25.5	4.5	57.8	1.5	9.0	1.7	.05	.82	.84
			C		13,100			53.0	47.0		6.0	77.6	2.0	12.1	2.3	.06	1.10	1.12
	D-97235	9.2	A	1.47	9,240	2,140	21.7	33.6	36.0	8.7	6.2	52.1	1.4	29.8	1.8	.06	1.10	.61
			B		11,800			42.8	46.1	11.1	4.8	66.6	1.7	13.5	2.3	.08	1.40	.77
			C		13,270			48.2	51.8		5.4	74.9	1.9	15.3	2.5	.09	1.58	.87
	D-97236	1.4	A				23.4	30.3	30.7	15.6								
			B					39.5	40.1	20.4								
			C					49.6	50.4									
	D-97237	5.7	A	1.48	8,860	2,150	24.2	29.1	37.8	8.9	6.3	50.1	1.3	31.8	1.6	.04	1.02	.59
			B		11,690			38.3	49.9	11.8	4.7	66.0	1.8	13.5	2.2	.05	1.34	.78
			C		13,250			43.5	56.5		5.4	74.9	2.0	15.2	2.5	.06	1.52	.89
5	D-96790	2.6	A	1.69	6,560		18.9	26.8	24.7	29.6	5.3	36.7	.9	26.8	.7	.01	.18	.54
			B		8,090			33.0	30.5	36.5	3.9	45.3	1.2	12.2	.9	.02	.22	.67
			C		12,740			52.0	48.0		6.1	71.4	1.8	19.3	1.4	.02	.34	1.05
6	D-96791	4.0	A	1.91	4,600	2,800	14.1	23.1	16.0	46.8	4.2	25.8	.6	21.9	.7	.02	.30	.38
			B		5,350			26.9	18.6	54.5	3.1	30.0	.7	10.9	.8	.02	.35	.45
			C		11,750			59.1	40.9		6.8	65.9	1.6	23.9	1.8	.05	.78	.98
7	D-97233	4.8	A	1.48	8,710	2,440	22.1	33.3	40.4	4.2	6.3	48.5	1.5	38.4	1.1	.02	.37	.70
			B		11,190			42.8	51.9	5.3	5.0	62.3	1.9	24.1	1.4	.03	.48	.90
			C		11,820			45.2	54.8		5.2	65.8	2.0	25.5	1.5	.03	.50	.95
8	D-97528	4.0	A	1.54	8,100		25.9	31.0	30.8	12.3					4.0			
			B		10,930			41.9	41.6	16.5					5.4			
			C		13,100			50.2	49.8						6.4			
9	D-97530	1.1	A		6,590		15.1	26.3	27.1	31.5					3.9			
			B		7,750			30.9	32.0	37.1					4.5			
			C		12,320			49.1	50.9						7.2			

10	D-98226	6.9	A	1.49	9,180		20.7	32.8	37.0	9.5					1.2			
			B		11,570			41.3	46.7	12.0					1.5			
			C		13,150			47.0	53.0						1.8			
	D-98227	2.5	A	1.56	8,660		18.3	30.9	35.8	15.0	5.6	49.0	.9	26.6	2.9	.10	2.10	.70
			B		10,590			37.8	43.9	18.3	4.4	60.0	1.1	12.7	3.5	.13	2.57	.85
			C		12,970			46.3	53.7		5.3	73.4	1.3	15.7	4.3	.15	3.14	1.04
	D-98228	2.2	A	1.55	8,500		18.4	31.1	34.3	16.2					1.6			
			B		10,420			38.2	42.0	19.8					1.9			
			C		13,000			47.6	52.4						2.4			
	D-98229	2.8	A	1.53	8,650		21.9	29.9	37.0	11.2					1.9			
			B		11,080			38.3	47.3	14.4					2.5			
			C		12,930			44.7	55.3						2.9			
	D-98230	2.5	A	1.52	9,190		20.8	31.1	38.8	9.3					1.6			
			B		11,600			39.2	49.0	11.8					2.0			
			C		13,150			44.5	55.5						2.2			
	D-98231	5.4	A	1.48	9,290		20.2	32.4	37.6	9.8	6.1	52.5	1.1	29.1	1.4	.03	.65	.71
			B		11,650			40.6	47.1	12.3	4.8	65.9	1.4	13.9	1.7	.04	.82	.89
			C		13,280			46.3	53.7		5.4	75.1	1.6	15.9	2.0	.04	.93	1.01
11	D-98232	3.4	A	1.57	8,100		23.2	30.6	33.4	12.8					2.8			
			B		10,550			39.9	43.5	16.6					3.6			
			C		12,660			47.9	52.1						4.4			
	D-98233	2.1	A	1.53	8,450		22.1	30.9	33.9	13.1					1.5			
			B		10,860			39.7	43.4	16.9					1.9			
			C		13,060			47.7	52.3						2.2			
	D-98234	5.8	A	1.68	6,970		12.2	27.6	28.8	31.4					1.8	.06	1.25	.53
			B		7,940			31.4	32.8	35.8					2.1	.07	1.43	.60
			C		12,370			49.0	51.0						3.3	.10	2.23	.93
	D-98235	1.8	A	1.49	9,040		22.5	31.6	37.4	8.5					1.8			
			B		11,660			40.7	48.4	10.9					2.4			
			C		13,100			45.7	54.3						2.7			
	D-98236	4.5	A	1.53	8,970		10.1	41.6	36.4	11.9	5.8	50.4	1.0	27.9	3.0	.05	2.25	.73
			B		9,980			46.2	40.5	13.3	5.2	56.0	1.1	21.0	3.4	.06	2.51	.82
			C		11,510			53.3	46.7		6.0	64.6	1.3	24.2	3.9	.07	2.89	.94

below a conglomerate contains as much as 0.051 percent uranium, whereas a bed 40 feet below it contains less than 0.001 percent.

The graphs in figure 33 show the thickness, uranium content, and percent ash of the coal, and the permeability of the rocks enclosing the coal bed, and are based on data from six core holes reaching the Luman No. 1 coal bed. These data show that in the less intensely

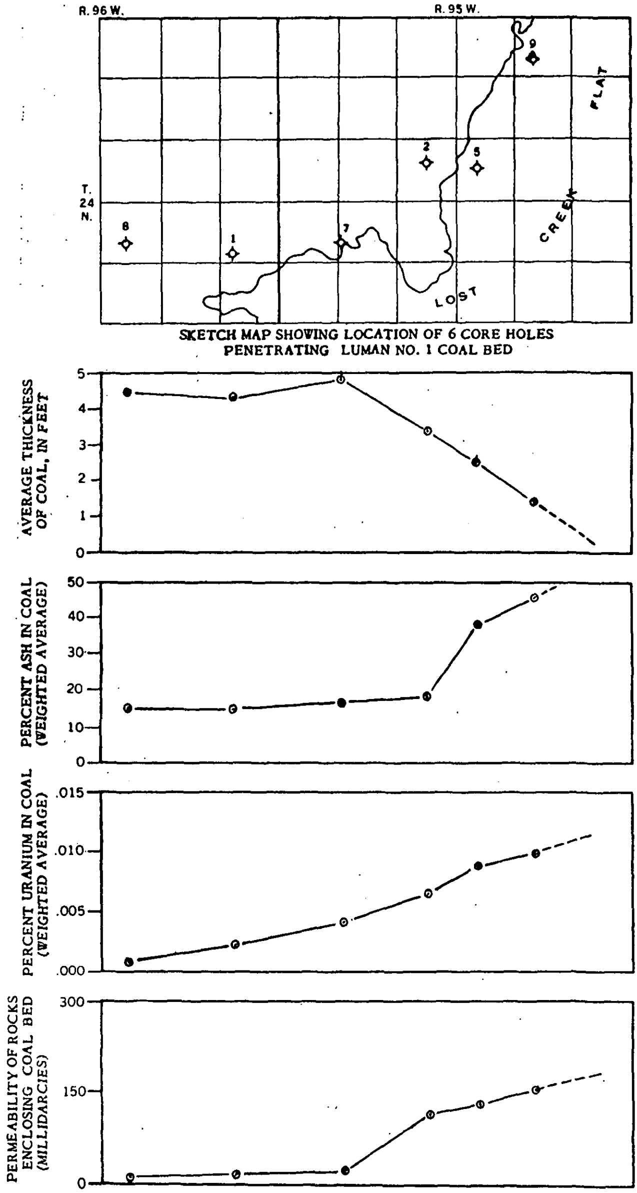

FIGURE 33.—Graphs showing the interrelation of thickness, ash content and uranium content of coal, and the permeability of associated rocks in the Luman No. 1 coal bed, Red Desert area, Sweetwater County, Wyo.

mineralized parts of the coal bed the uranium content increases from west to east and closely coincides with the change in facies of the rocks from less permeable lacustrine shale and coal-bearing shale, siltstone, and fine-grained sandstone in the western part of the area to coarse-grained, more permeable, fluviatile sandstone in the eastern part. The uranium content of the Luman No. 1 coal bed appears to be directly related to the presence of tongues of coarse-grained sandstone extending from the northeast.

That the distribution of uranium within a coal bed is related to the permeability of the associated rocks is shown by figure 34, in which the uranium content of the Sourdough No. 2 coal bed is plotted at two localities. In core hole 11, where the coal bed is underlain by sandstone, the uranium content is greatest at the base of the bed. At locality 134, where the coal bed is underlain and overlain by sandstone, the uranium content is greatest at the top and base of the bed, adjacent to the sandstone.

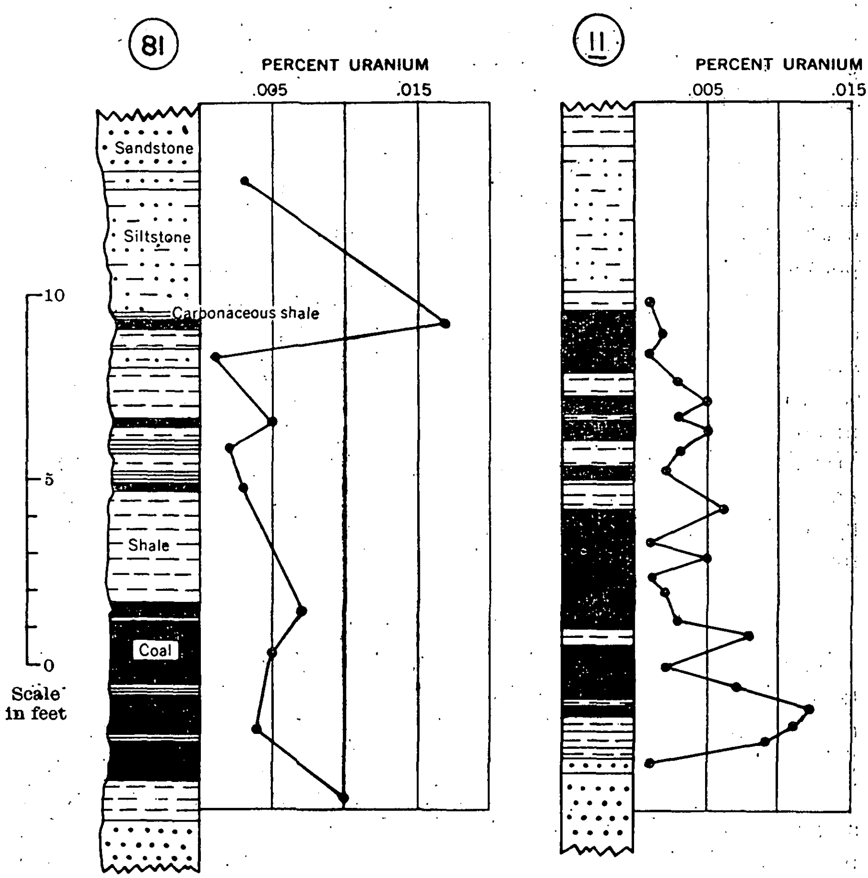

FIGURE 34.—Graphs showing influence of stratigraphic position and permeability of enclosing rocks on the distribution of uranium within the Sourdough No. 2 coal bed.

At Eagles Nest, at the northern border of the mapped area, beds of low-grade oil shale are interbedded with coarse-grained, permeable sandstone. At the contact of the shale with the sandstone there is a fourfold increase in the uranium content of the shale. North of Eagles Nest, there is a three- to four-fold increase in uranium content of sandy claystone at the contact with well-sorted channel sandstone.

The close relationship between the uranium content of the coal, organic shale, and claystone, and the permeability of the adjacent beds indicates that the uranium is of epigenetic origin.

This relationship suggests that geologic associations favorable for uranium-bearing coal occur not only where coal beds that can be mineralized with uranium are in contact with overlying source rocks furnishing uranium to mineralizing ground-water (type *A*, fig. 35), as is postulated for the lignite beds in the Dakotas (Denson, Bachman, and Zeller, chapter B, this bulletin), but also where such coal beds are perhaps miles from source rocks but are in contact with beds of permeable sandstone that can act as conduits for uranium-bearing ground water moving laterally and downward from areas of source rocks (type *B*, fig. 35).

Figure 35 illustrates both types of favorable geologic association. Type *A* is typical of the areas of uranium-bearing lignite in the Dakotas and is found where source rocks directly overlie coal, which extracts uranium leached from source rocks and carried downward by percolating ground water. Type *B* is more common in the Red Desert area and is found where coal is in association with beds of coarse-grained permeable sandstone through which uranium-bearing groundwater has moved downward and laterally for miles from the source rocks. The coal beds are more intensely mineralized with uranium adjacent to overlying and underlying permeable sandstone. Uranium-bearing coal in areas of type *A* or *B* may be found by prospecting along coal exposures or by shallow drill holes. In areas of type *B*, where there is no surface indication of mineralization, uranium-bearing coal may also be found by deep drill holes.

DRILLING OPERATIONS

The primary objective of the 1952 core-drilling program was to obtain samples of unweathered coal for analyses on which to base estimates of tonnage of uranium-bearing coal in beds more than 2.5 feet thick in the areas in which geological factors discussed in the preceding paragraph were most favorable for uranium mineralization. A secondary objective was to determine the relationship of distribution of uranium in the coal beds to permeable zones and to major and minor tectonic structures, and its value as a guide in search for uranium deposits of higher grade in the Red Desert area.

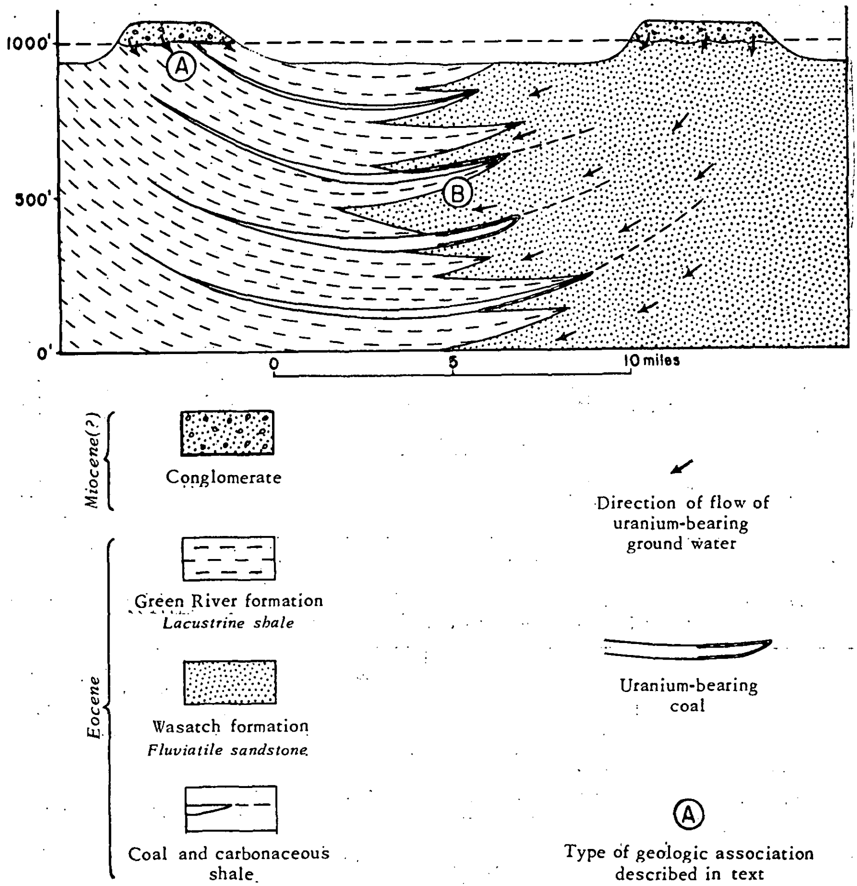

FIGURE 35.—Idealized geologic section showing two types of geologic association favorable for prospecting for uranium-bearing coal, Red Desert area, Wyoming.

Core holes were drilled in two adjacent areas (pls. 36 and 45); 9 holes penetrated the beds in the upper coal unit in the vicinity of the Eagles Nest Rim in the northern part of the area; 2 holes, drilled about 8 miles to the southeast near the southern margin of Battle Springs Flat, tested the lower coal unit which is about 250 feet stratigraphically lower. Hole 4, in the northern part of the area, was drilled to a depth of 600 feet to determine the interval between the two coal units, to confirm the geologic mapping, and to provide data for estimation of tonnage of coal in this part of the mapped area. The average drill-hole depth was 227 feet; the deepest core hole being 600 feet; the shallowest, 55 feet (table 2). With a few exceptions, core recovery was good.

TONNAGE AND URANIUM CONTENT

Tonnage of uranium-bearing coal in beds at least 2.5 feet thick and under not more than 75 feet of overburden have been estimated and tabulated by townships. Thickness and uranium content of the coal are based on weighted averages of 425 analyses for uranium on samples from core holes and 770 analyses of samples from surface sections and auger holes.

About 700 million short tons of coal underlie the mapped area (table 3), of which about 300 million contain at least 0.003 percent uranium.

TABLE 2.—*Statistical data on core holes, Red Desert area, Sweetwater County, Wyo.*

Core	Location	Elevation (feet above sea level)	Aggregate thickness of coal (feet)	Depth of hole (feet)
1	SW¼SW¼ sec. 24, T. 24 N., R. 96 W	6,645	6.9	142
2	SE¼NW¼ sec. 16, T. 24 N., R. 95 W	6,630	9.5	266
3	NW¼SW¼ sec. 21, T. 24 N., R. 95 W	6,610	8.2	173
4	SE¼NW¼ sec. 28, T. 24 N., R. 95 W	6,610	26.4	600
5	SE¼NW¼ sec. 15, T. 24 N., R. 95 W	6,580	3.7	202
6	SW¼NE¼ sec. 10, T. 24 N., R. 95 W	6,605	6.2	263
7	NW¼SW¼ sec. 20, T. 24 N., R. 95 W	6,560	5.1	55
8	NW¼SW¼ sec. 22, T. 24 N., R. 96 W	6,715	4.7	119
9	NW¼SW¼ sec. 2, T. 24 N., R. 95 W	6,620	4.7	206
10	NE¼SW¼ sec. 17, T. 23 N., R. 94 W	6,510	26.8	245
11	NW¼NW¼ sec. 27, T. 23 N., R. 94 W	6,660	26.1	226
	Total		128.3	2,497

TABLE 3.—*Tonnage of uranium-bearing coal in beds at least 2.5 feet thick and under no more than 75 feet of overburden, Red Desert area, Wyo.*

Township	Coal bed	Area (acres)	Thickness (feet)	Uranium (percent)	Tonnage of coal[a] (short tons)
Northern part of Red Desert area					
T. 24 N., R. 96 W	Luman No. 2	1,477	3.5	0.002	9,151,000
T. 24 N., R. 95 W	Luman No. 1	1,705	3.9	.006	11,770,000
T. 23 N., R. 95 W	Monument No. 2	152	4.0	.002	1,076,000
Do	Monument No. 1	5,183	4.3	.002	39,448,000
T. 23 N., R. 94 W	Battle No. 3	2,583	10.9	.004	49,834,000
Do	Monument No. 2	499	2.6	.004	2,296,000
Do	Monument No. 1	3,642	5.8	.005	37,388,000
Do	Sourdough No. 2	1,587	3.5	.006	9,831,000
Total[b], northern part of Red Desert area					160,800,000
Southern part of Red Desert area					
T. 23 N., R. 96 W	Battle No. 1	640	2.5	0.001	2,832,000
T. 22 N., R. 95 W	Battle No. 2	640	2.5	.001	2,832,000
Do	Battle No. 1	810	3.0	.003	4,301,000
Do	Monument No. 1	1,440	6.5	.001	9,360,000
Do	Sourdough No. 2	1,340	3.5	.001	8,301,000
Do	Sourdough No. 1	1,528	4.5	.001	12,171,000
Do	Tierney No. 5	1,080	3.0	.002	5,735,000
T. 22 N., R. 94 W	Battle No. 1	2,080	3.0	.001	11,045,000
Do	Monument No. 1	6,719	9.5	.001	112,979,000
Do	Sourdough No. 2	11,627	6.4	.003	131,688,000
Do	Tierney No. 5	3,248	4.0	.001	22,992,000
T. 22 N., R. 93 W	Sourdough No. 2	877	5.0	.003	7,761,000
T. 21 N., R. 95 W	Sourdough No. 1	205	2.5	.001	907,000
Do	Tierney No. 5	528	5.0	.002	4,673,000
T. 21 N., R. 94 W	Monument No. 1	653	3.0	.010	3,467,000
Do	Sourdough No. 2	5,675	4.3	.001	43,188,000
Do	Tierney No. 5	760	5.0	.001	6,726,000
T. 21 N., R. 93 W	Battle No. 1	934	4.5	.006	7,439,000
Do	Monument No. 1	3,939	5.4	.009	37,494,000
Do	Sourdough No. 2	2,095	5.2	.002	19,275,000
T. 21 N., R. 92 W	Monument No. 1	640	4.0	.003	4,531,000
T. 20 N., R. 93 W	do	256	4.5	.002	2,039,000
Do	Tierney No. 5	2,285	16.0	.001	64,711,000
T. 20 N., R. 92 W	do	488	16.0	.001	13,820,000
Do	Tierney No. 3	1,798	5.7	.001	18,139,000
Total[b], southern part of Red Desert area					558,400,000

[a] Tonnage estimates based on 1,770 tons of coal per acre foot. [b] Rounded.

The Luman No. 1 coal bed, the most favorable potential source of uranium in the area, contains about 12 million short tons of coal averaging 3.9 feet in thickness and containing an average of 0.005 percent uranium and 20 percent ash, with 0.030 percent uranium in the ash. Areas of potentially strippable coal in the northern part of the Red Desert area are shown in plate 45. Estimates for the northern part of the area, Tps. 23 and 24 N., Rs. 94 and 95 W., are based on data obtained by core drilling in 1952. Estimates of tonnage and uranium content of coal in the other townships of the area are based on samples from surface sections and auger holes obtained in 1951. These latter estimates are probably less reliable, owing to the weathering effects and concealed beds in surface sections and to contamination of the auger hole samples by caving from the sides of the holes.

DESCRIPTION OF CORES

Lithologic descriptions of coal cores and PMG determinations were made by James M. Schopf at the Geological Survey laboratory at Columbus, Ohio.

PMG values, which are a measure of the beta-gamma radiation in pulses per minute per gram, were made for all sampled intervals using a cup-mounted IB85 GM tube connected to an AEC CGM-3B scaler. The nature and significance of PMG values are explained by Schopf (1954).

Fuels samples listed below each core hole were analyzed by the U. S. Bureau of Mines and data are shown in table 1.

The samples labeled "TE" were analyzed by the Geological Survey for equivalent uranium, uranium, ash, and uranium in ash. Equivalent uranium is an expression of percent uranium that a sample would contain if all the radioactivity were due only to uranium and its daughter products in equilibrium.

The coals discussed in this report are dominantly banded. The banding is primarily a function of the occurrence of elongate lenses of large fragments of woody trunks and roots of ancient plants. In describing banded coals the important features are (1) the thickness of bands, and (2) the frequency of occurrence of these bands. Thickness and frequency are described using the terms according to the following definitions:

(1) Thickness of woody bands:[1]

Banding	*Approx. thickness (inches)*
Thin	1/50–1/12
Medium	1/12–1/5
Thick	1/5–2
Very thick	>2

(2) Frequency of occurrence—

	Percentage of the layer
Sparse	<15
Moderate	15–30
Abundant	30–60
Dominant	>60

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
Core hole 1 (SW¼SW¼ sec. 24, T. 24 N., R. 96 W.) elev. 6,645 ft								
TE S1	0.4	0.001	<0.001	63	5¼		4¾	(Top of core sent to laboratory.) Shale, medium- and dark-gray; abundant shell fragments; ½-in of slightly coaly shale at 63 ft 9½ in.
TE S2	2.4	.004	.002	63	10		2	Shale, coaly, grading to shaly coal.
TE S3	1.6	.003	.003	64	0		6	Coal, moderately thin- and medium-banded; core is slightly broken.
TE S4	.2	<.001	<.001	64	6		4¼	Coal, moderately thin- and medium-banded.
TE S5	.4	.001	.001	64	10¼		3	Coal, abundantly thin- and medium-banded.
	------	------	------	65	1¼		¾	(Loss in coring interval from 64 ft to 65 ft 2 in.)
Lab S6	.5	------	------	65	2		9½	Shale, light- to medium-gray; carbonaceous in uppermost 1 in.
Lab S7	.4	------	------	65	11½		5¼	Shale, medium- to light-gray.
Lab S8	.5	------	------	66	4¾		7¼	Shale, light- to medium-gray; ½-in of coal at 66 ft 11½ in.
TE S9	.9	.003	.001	67	0		7	Shale, medium- and dark-gray, carbonaceous.
TE S10	1.9	.005	.005	67	7		2½	Shale, medium to dark-gray, coaly.
TE S11	.7	.004	.001	67	9½		7	Shale, medium-gray, carbonaceous; 1-in dark-gray clay at 68 ft 3½ in.
TE S12	1.1	.003	.002	68	4½		6	Coal, abundantly thin-banded.
TE S13	1.4	.003	.002	68	10½		6	Coal, abundantly thin- and medium-banded.
TE S14	.7	.001	.001	69	4½		5	Coal, abundantly thin-banded.
TE S15	1.7	.004	.003	69	9½		5½	Coal, moderately thin- and medium-banded.
TE S16	.9	.001	.001	70	3		6	Coal, abundantly thin- and medium-banded, ¼ to ½ in pyritic nodules; core is broken.
TE S17	.8	.001	.001	70	9		5¼	Coal, abundantly medium- and thin-banded; slightly pyritic throughout; core is broken.
TE S18	.9	.002	.002	71	2¼		3¼	Coal, abundantly thin-banded; ¼ in pyritic lens at 71 ft 2¾ in.
TE S19	.8	.001	.001	71	6½		5	Coal, abundantly thin-banded.

[1] Woody bands less than 1/50 inch are regarded as a part of attrital coal.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
				Core hole 1—Continued				
TE S20	2.6	0.005	0.005	71	11½		5¼	Coal, abundantly thin- and medium-banded.
TE S21	2.5	.004	.003	72	4¾		6	Coal, abundantly thin-banded.
TE S22	1.0	.001	<.001	72	10¾		9¼	Shale, light-gray, abundant disseminated pyrite; core is broken and displaced; heavily pyritic above 73 ft 2 in.
	-------	-------	-------	73	8½		7	(Loss in coring interval from 67 ft to 74 ft 3½ in.)
	-------	-------	-------	74	3½	-----	-----	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines) from core hole 1:
D-97526 includes TE samples S3–S5.
D-97527 includes TE samples S12–S21.

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
				Core hole 2 (SE¼NW¼ sec. 16, T. 24 N., R. 95 W.) elev. 6,630 ft				
CGL 1	1.5	-------	-------	38	0		10¾	(Top of core sent to laboratory.) Sandstone, clayey, light- to medium-gray; abundant plant impressions; irregular yellow-brown stains; upper ¼-in includes coarse sand grains loosely cemented.
CGL 2	1.1	-------	-------	38	10¾	1	1¼	Sandstone, clayey, as in above sample; zone of coarse sand grains, loosely cemented, from 39 ft 2½ in to 39 ft 5¼ in.
CGL 3	1.4	-------	-------	40	0	1	0	Sandstone, clayey, as in above samples; ¼-in. gypsum lens in uppermost ½ in and in ½-in loosely cemented coarse-sand layer at 39 ft 11¼ in.
CGL and TE 4.	2.0	0.005	0.003	41	0	1	1	Sandstone, gray, to 41 ft 4 in, carbonaceous below; lowest 6 in is badly broken and dislocated.
CGL and TE 5.	1.4	.003	.001	42	1	1	1	Sandstone, clayey, to 42 ft 4 in, then grading to sandy, light-gray clay; core is badly broken and dislocated above 42 ft 11½ in; clay is sandy, very carbonaceous, medium to dark-gray; lowest ¾ in of clay is carbonaceous, dark-gray, 1/16-in coal streaks.
	-------	-------	-------	43	2	4	10	(Loss in coring interval from 41 ft 7 in to 48 ft; probably greatest loss is at about the 42 ft 4 in mark indicated above. The 42 ft 11½ in–43 ft 2 in clay unit may directly overlie the coal.)
TE 1	1.9	.004	.003	48	0		6¼	Coal, abundantly thin- and medium-banded; ¼-in discontinuous fusain zone 1½ in below top.
TE 2	3.1	.005	.005	48	6¼		8½	Coal, sparsely thin- and medium-banded, a few thick vitrain bands, thin clay streaks at base.
CGL 6	.4	-------	-------	49	2¾		9¼	Sandstone, clayey, and sandy clay, light-buff, soft, irregularly bedded; sparse thin coaly streaks below 49 ft 6½ in.
CGL 7	.5	-------	-------	50	0		10	Clay, sandy, light-gray to buff; ¼-in vitrain streak at top; ¼-in nodules of pyrite at 50 ft 5½ in and 50 ft 7 in.
CGL 8	.9	-------	-------	50	10		6	Sandstone, clayey, light-buff to light-gray, crumbly, poorly cemented.
	-------	-------	-------	51	4		2	(Loss in coring interval from 48 ft to 51 ft 6 in.)
	-------	-------	-------	51	6	88	6	(No core sent to laboratory.)
CGL 9	.7	-------	-------	140	0		11	Shale, clayey, medium-gray, hard; abundant invertebrate fossils and some fish scales (?).

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole (Ft)	Depth in hole (In)	Length (Ft)	Length (In)	Description and remarks
								Core hole 2—Continued
CGL 10	0.9			140	11		7½	Shale, clayey, dark-gray, carbonaceous; minute shell fragments throughout and some fish scales; core is somewhat broken, but there is little loss.
				141	6½		2	Shale, black; abundant ostracodes and flattened large shell fragments.
CGL and TE 11.	2.9	0.003	0.001	141	8½		1½	Shale, black; shell fragments as in above sample.
CGL 12	.04			141	10		1	Limestone, hard, dark-gray, very fossiliferous.
				141	11		1	Shale, black; large flattened shell fragments.
CGL and TE 13.	.8	.003	.001	142	0		3¼	Shale, black, as in above sample.
TE 3	1.7	.002	.002	142	3¼		4½	Coal, moderately thin-banded; ¼-in band of vitrain at 142 ft 6¾ in.
TE 4	1.8	.003	.002	142	7¾		3¼	Coal, abundantly medium-banded in uppermost ¾ inch, moderately thin-banded below.
CGL 14	1.1			142	11		1½	Claystone, brown; coaly streaks.
CGL 15	.8			143	½		8½	Shale, clayey, light-gray; scattered plant fragments.
CGL 16	.6			143	9		7¼	Shale, as in above sample.
				144	4¼		½	(Loss in coring interval from 142 ft 11 in to 144 ft 4¾ in.)
				144	4¾	21	9	(No core sent to laboratory.)
CGL 17	.7			166	1¾		3	Shale, clayey, light-gray to light olive-brown.
CGL 18	.9			166	4¾		3¼	Shale, clayey, medium- to dark-gray, carbonaceous.
TE 5	.2	<.001	<.001	166	8		1½	Coal, sparsely thin- to medium-banded.
				166	9½		1	Clay, dark, coaly streaks; excluded from fuel sample.
TE 6	1.7	.002	.001	166	10½		4½	Coal, moderately thin-banded.
TE 7	1.7	.003	.002	167	3		4¼	Coal, moderately thin-banded.
TE 8	1.3	.002	.002	167	7¼		4½	Coal, abundantly medium-banded.
TE 9	2.3	.003	.002	167	11¾		4¼	Coal, moderately thin-banded.
				168	4		1	Clay parting, carbonaceous, medium-gray; plant fragments; excluded from fuel sample.
TE 10	1.2	<.001	.001	168	5		1	Coal, sparsely thin-banded.
CGL 19	.7	.001	<.001	168	6		7¾	Shale, clayey, carbonaceous, medium chocolate-brown; small plant fragments and a few thin coaly streaks.
TE 11	1.0	.002	.001	169	1¾		5	Coal, dominantly thin- and medium-banded.
CGL and TE 20.	1.5	.004	.003	169	6¾		3	Shale, clayey, carbonaceous, dark-gray; thin and medium coaly streaks; ⅛-in pyrite lens in middle.
CGL and TE 21.	.9	.003	.001	169	9¾		6	Claystone, light-gray, carbonaceous streaks, soft and plastic.
CGL and TE 22.	.9	.003	.002	170	3¾		3½	Shale, carbonaceous, dark-gray; numerous coaly streaks in uppermost 2 inches.
CGL and TE 23.	1.2	.002	<.001	170	7¼		7¼	Shale, clayey, light-gray.
				171	2½		3½	(Loss in coring interval from 166 ft 1¾ in to 171 ft 6 in; probably most in coal from 166 ft 8 in to 168 ft 4 in.)
				171	6	25	3	(No core sent to laboratory.)
CGL 24	.8			196	9		5½	Sandstone, fine to medium-grained, light-gray to light olive-brown, crumbly; grades below into dark-gray sandy carbonaceous shale containing a few ¼-inch nodules of pyrite.
CGL 25	.9			197	2½		5¾	Shale, sandy, carbonaceous, dark-gray.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections				
Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	Ft	In	
Core hole 2—Continued								
CGL and TE 26.	3.0	0.008	0.006	197	8¼		4¼	Shale, carbonaceous, dark-gray, thin streaks of coal and black clay.
CGL and TE 27.	3.2	.010	.008	198	½		8	Shale, carbonaceous, dark-gray.
CGL and TE 28.	4.0	.013	.011	198	8½		4¼	Shale, black, clayey, highly carbonaceous.
CGL and TE 29.	5.1	.015	.012	199	¾		5¼	Do.
TE 12	4.7	.009	.008	199	6		1¾	Coal, dominantly thin- to medium-banded.
CGL and TE 30.	2.4	.008	.005	199	7¾		2¾	Shale, clayey, carbonaceous; coaly bands and thin sandy lenses; ½-inch zone of pyrite in middle part.
CGL and TE 31.	2.2	.008	.005	199	10½		7½	Shale, medium-gray, slightly carbonaceous in uppermost one-third, lighter gray below.
CGL 32	1.7	-----	-----	200	6		11½	Shale, light-gray.
-----	-----	-----	-----	201	5½	1	3	(Loss in coring interval from 196 ft 9 in to 202 ft 8½ in.)
-----	-----	-----	-----	202	8½	49	9½	(No core sent to laboratory.)
CGL and TE 33.	2.3	.008	.005	252	6		7	Shale, medium-gray, probably carbonaceous.
CGL and TE 34.	3.3	.007	.006	253	1		7¼	Shale, black, clayey, occasional thin lenses of light-gray shale.
TE 13	.5	.001	.001	253	8¼		3¾	Coal, abundantly thin- and medium-banded.
TE 14	1.7	.004	.003	254	0		4½	Coal, moderately thin- and medium-banded; lowest inch is sparsely thin-banded.
CGL and TE 35.	4.1	.007	.006	254	4½		2¾	Shale, carbonaceous; numerous thin coaly streaks in uppermost 1¼ inch.
CGL and TE 36.	3.8	.009	.006	254	7¼		9¼	Shale, dark-gray; grades below 254 ft 9 in to black shale; core is badly broken and somewhat mixed.
CGL and TE 37.	3.1	.007	.005	255	4½		5¾	Shale, black; core is badly broken and mixed.
	-----	-----	-----	255	10¼		1	(Loss in coring interval from 254 ft 7¼ in to 255 ft 11¼ in.)
TE 15	7.2	.011	.010	255	11¼		3¾	Coal, dominantly thin- to thick-banded.
TE 16	4.8	.011	.009	256	3		5½	Coal, abundantly thin- to medium-banded.
TE 17	3.7	.006	.005	256	8½		4	Coal, dominantly thick- and medium-banded.
TE18	2.0	.004	.003	257	½		6¼	Coal, thick-banded.
TE 19	5.8	.010	.007	257	6¾		4¾	Coal, moderately thin-banded; lowest 2-inches is sparsely thin-banded.
TE 20	5.2	.010	.007	257	11½		4¾	Coal, thin-banded; ¼-in carbonaceous-clay parting at 258 ft 1¼ in excluded from fuel sample.
TE 21	5.0	.007	.008	258	4¼		3¼	Coal, moderately (top) to abundantly (base) thin- and medium-banded.
CGL and TE 38.	1.0	.003	.001	258	7½		9	Shale, black, highly carbonaceous.
CGL and TE 39.	.5	.001	<.001	259	4½		2	Pyritic zone, a solid granular mass of pyrite.
CGL 40	.9	-----	-----	259	6½		10	Sandstone, medium- to fine-grained, light-gray, crumbly; upper half of sample is broken, probably when core bit broke through hard pyritic zone above.
CGL 41	1.1	-----	-----	260	4½		9½	Sandstone, as in above sample.
	-----	-----	-----	261	2		2¾	(Loss in coring interval from 259 ft 6½ in to 261 ft 4¾ in.)
	-----	-----	-----	261	4¾	-----	-----	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines) from core hole 2:
D-96784 includes TE samples 1-2.
D-96785 includes TE samples 3-4.
D-96786 includes TE samples 5-10.
D-96787 includes TE samples 13-14.
D-96788 includes TE samples 15-21.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections				
Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	Ft	In	
Core hole 3 (NW¼SW¼ sec. 21, T. 24 N., R. 95 W.) elev. 6,610 ft.								
CGL 1	0.6			24	0		6	(Top of core sent to laboratory.) Shale, clayey, light-buff to olive; pulverized.
CGL 2	.8			24	6		9	Shale, clayey, light-buff; core is broken and displaced.
				25	3	1	9	(Loss in coring interval from 24 ft to 27 ft.)
TE 1	1.7	0.004	0.004	27	0		4¼	Coal, badly broken and intermixed with dark carbonaceous clay; gypsum rosettes in lowest 1¼ in. This coal is reported to be 1.1 ft thick at a nearby outcrop.
				27	4¼		9	Presumed loss in coring interval from 27 ft to 28 ft 1¼ in; appearance of core indicates that the true loss may not be so great.
CGL and TE 3.	2.2	.002	.001	28	1¼		11¼	Clay, sandy at top, light-buff to gray; plant fragments; gypsum crystals between 28 ft 3 in and 28 ft 5½ in; ¼-inch streak of jarosite at 28 ft 9½ in.
CGL 4	.5			29	½		9½	Clay, gray, sandy streaks, grading below 29 ft 4 in into silty ocherous clay with ferruginous veins and gypsiferous streaks; clay is buff and more sandy below 29 ft 8 in; microfaults are seen on sandstone laminae.
				29	10	2	2	(Loss in coring interval from 28 ft 1¼ in to 32 ft.)
				32	0	18	7¼	(No core sent to laboratory.)
CGL 5	.6			50	7¼		8¾	Clay, silty, light-gray, light-yellow to brown stain.
CGL 6	.5			51	4		9½	Clay, as in above sample; ¼-in pyrite lens at the top.
CGL 7	.6			52	1½		7½	Clay, as in above samples.
CGL and TE 8.	1.4	.002	.001	52	9		1½	Shale, clayey, dark-gray, platy, plant fragments.
TE 2	.8	.002	.001	52	10½		3	Coal, dull, moderately thin-banded, somewhat broken.
				53	1½		¾	Shale, clayey, light-gray, sparsely banded, thin streaks of dull coal; excluded from fuel and TE samples.
TE 3	.7	.002	.001	53	2¼		4	Coal, attrital; moderately thin-banded in upper half of sample.
TE 4	1.4	.003	.002	53	6¼		6½	Coal, attrital to sparsely thin- and medium-banded; broken into ¼-in to ¾-in layers.
				54	¾		¼	Carbonaceous-clay parting; excluded from fuel and TE samples.
TE 5	1.5	.001	.002	54	1		4½	Coal, attrital to sparsely thin- and medium-banded; broken into irregular pieces.
TE 6	2.2	.002	.002	54	5½		2½	Coal, moderately thin-banded, broken into thin plates.
				54	8		½	Clay, slightly silty, medium-gray; thin coaly bands.
CGL 9	.5			54	8½		7	Clay, slightly silty, medium-gray; flecks of mica and numerous plant fragments.
CGL 10	.6			55	3½		7	Clay, as in above sample but more silty.
				55	10½		8¾	(Loss in coring interval from 52 ft 10½ in to 56 ft 7¼ in probably mostly within the coal.)
				56	7¼	36	3	(No core sent to laboratory.)
CGL 11	.5			92	10¼		4¾	Shale, black; abundant shells of mollusks and ostracodes.
CGL 12	.5			93	3		5	Shale, black, as in above sample.
CGL and TE 13.	3.3	.007	.009	93	8		3½	Shale, black, carbonaceous and clayey.
TE 7	3.4	.008	.008	93	11½		5¼	Coal, dominantly thin- and medium-banded; lowest 1¾ in is sparsely thin-banded.
CGL and TE 14.	4.6	.014	.013	94	4¾		4¼	Shale, black, carbonaceous, sparse thin coaly streaks to 94 ft 7 in.
CGL and TE 15.	5.8	.013	.012	94	9		4	Shale, black, carbonaceous.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
								Core hole 3—Continued
CGL and TE 16.	1.6	0.006	0.004	95	1		10½	Clay, medium-gray, grading into shale below 95 ft 4 in; core is badly broken and somewhat mixed.
CGL and TE 17	1.4	.005	.004	95	11½		9½	Shale, clayey, medium-gray.
CGL and TE 18.	2.2	.007	.005	96	9		5	Shale, carbonaceous, medium-gray, thin light-gray laminae; thin coaly streaks below 97 ft 1½ in.
CGL and TE 19.	1.2	.005	.004	97	2		4½	Shale, clayey, light- to medium-gray.
	----------	----------	----------	97	6½		1¼	(Loss in coring interval from 95 ft 1 in to 97 ft 7¾ in.)
	----------	----------	----------	97	7¾	3	3	(No core sent to laboratory.)
CGL and TE 20.	1.4	.004	.004	100	10¾		5¾	Shale, medium-gray, slightly carbonaceous.
CGL and TE 21.	3.2	.006	.007	101	4½		4½	Shale, medium-gray; occasional thin streaks of vitrain; darker and carbonaceous below 101 ft 6¾ in, scattered coarse quartz grains.
CGL and TE 22.	1.3	.005	.003	101	9		4	Shale, gray to light-brown, silty; grading to sandstone below 102 ft.
	----------	----------	----------	102	1	2	3¾	(Loss in coring apparently accumulated in interval from 100 ft 10¾ in to 104 ft 4¾ in.)
	----------	----------	----------	104	4¾	24	4¾	(No core sent to laboratory.)
	----------	----------	----------	128	9½		3½	(Core section apparently omitted from shipment.)
CGL and TE 23.	1.5	.005	.004	129	1		5½	Shale, medium-gray, light-gray streaks.
CGL and TE 24.	3.1	.006	.005	129	6½		2	Shale, dark-gray, carbonaceous, lighter streaks at top; lowest ⅛ in is coaly.
TE 8	1.4	.003	.002	129	8½		4	Coal, sparsely thin-banded above and abundantly thin-banded below 129 ft 10 in.
TE 9	4.3	.007	.006	130	½		4	Coal, moderately thin- and medium-banded.
CGL and TE 25.	3.0	.008	.007	130	4½		3¼	Shale, black; uppermost 1½ in is coaly.
CGL and TE 26.	1.4	.004	.003	130	7¾		4½	Shale, carbonaceous, dark-gray.
CGL and TE 27.	2.9	.007	.005	131	¼		2¼	Shale, black; thin coaly streaks.
CGL and TE 28.	1.5	.005	.003	131	2½		3¾	Shale, carbonaceous, dark-gray; core is somewhat broken and displaced.
CGL and TE 29.	2.3	.006	.006	131	6¼		6	Shale, coaly or carbonaceous; core is badly broken and mixed.
CGL and TE 30.	1.9	.006	.004	132	¼		4½	Shale, medium-gray; core is badly broken and mixed.
CGL and TE 31.	2.5	.006	.004	132	4¾		4¼	Shale, carbonaceous, dark- to light-gray; core is badly broken and mixed.
TE 10	2.2	.004	.004	132	9		4¾	Coal, and carbonaceous shale; core is badly broken and mixed.
TE 11	.1	<.001	<.001	133	1¾		3	Coal, moderately thin- and thick-banded.
TE 12	1.5	.003	.002	133	4¾		5¼	Coal, sparsely thin- and thick-banded; core is somewhat broken.
TE 13	4.2	.006	.005	133	10		2	Coal, sparsely thin-banded.
CGL and TE 32.	2.8	.009	.007	134	0		6¾	Shale, carbonaceous, clayey, dark- to medium-gray; sparse thin coal streaks; excluded from fuel sample.
TE 14	2.4	.006	.005	134	6¾		6¼	Coal, sparsely thin-banded; 1-16-in pyritic lenticle at bottom.
TE 15	3.9	.009	.008	135	1		5	Coal, sparsely thin- and medium-banded, pyritic facings; ½-in vitrain band at 135 ft 5 in.
TE 16	1.6	.008	.008	135	6		5¾	Coal, moderately thin-banded, a total of 1½ in of vitrain in three thick bands.
TE 17	1.4	.003	.003	135	11¾		6¼	Coal, dominantly thin- to medium-banded; ½-in vitrain band at 136 ft 4½ in.
TE 18	2.7	.004	.005	136	6		4½	Coal, abundantly thin- and medium-banded.
TE 19	5.2	.007	.007	136	10½		4¾	Coal, dominantly bright; three ¼-in bands; lowest 1 in is attrital coal.
TE 20	2.4	.004	.004	137	3¼		3¾	Coal, moderately thin- and medium-banded.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
Core hole 3—Continued								
CGL and TE 33.	0.9	0.003	0.002	137	7		6	Shale, black, occasional coaly streaks.
CGL 34	.5			138	1		7	Shale, medium-gray, light-gray streaks.
CGL 35	.4			138	8		1	Shale, as in above sample, becoming darker, merging with sample below.
CGL 36	.5			139	9	1	1	Shale, carbonaceous, dark-gray; 1-in. pyritic nodule at 139 ft 10½ in.
CGL 37	.9			140	10		¾	Pyritic zone, granular.
CGL 38	.7			140	10¾	1	1¼	Sandstone, fine- to medium-grained, crumbly, loosely cemented; a few ¼-in. pyritic nodules.
				142	0			(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines) from core hole 3:
D-96781 includes TE samples 2-6.
D-96782 includes TE samples 8-9.
D-86783 includes TE samples 11-20 and 32.

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
Core hole 4 (SE¼NW¼ sec. 28, T. 24 N., R. 95 W.) elev. 6,610 ft.								
TE 1	1.5	0.006	0.004	42	6		6	(Top of core sent to laboratory.) Shale, medium-gray, carbonaceous.
TE 2	1.9	.006	.003	43	0		6½	Shale, medium-gray, carbonaceous.
TE 3	5.0	.010	.006	43	6½		4	Shale, dark-gray at top, becoming progressively darker and coaly downward.
TE 4	2.4	.003	.003	43	10½		3¼	Coal, moderately thin- and medium-banded; core is split into thin laminae.
TE 5	.9	.002	.001	44	1¾		4¾	Coal, abundantly thin- and medium-banded; most of core is represented by chips.
TE 6	3.4	.005	.003	44	6½		5¾	Coal, sparsely thin-banded; core is badly broken in upper half; ¼-in parting of carbonaceous shale at 44 ft 11½ in excluded from fuel sample; impure coal below parting.
TE 7	5.1	.008	.006	45	¼		3¾	Shale, black, small gray clayey blebs; excluded from fuel sample.
TE 8	2.7	.005	.003	45	4		4	Shale, coaly; excluded from fuel sample.
TE 9	4.5	.007	.006	45	8		4¾	Coal, sparsely thin-banded and attrital.
TE 10	3.9	.008	.006	46	¾		6¼	Coal, sparsely thin-banded to dominantly attrital; core is split and broken.
TE 11	4.5	.006	.005	46	7		5½	Coal, impure; core is broken.
TE 12	2.0	.003	.002	47	½		6	Coal, sparsely thin-banded; core, in part, is badly broken, with some displacement.
TE 13	3.3	.005	.004	47	6½		5½	Coal, moderately thin-banded.
TE 14	2.9	.004	.003	48	0		6	Coal, sparsely thin-banded, some medium banding; core is broken and displaced in upper portion.
TE 15	1.4	.002	.002	48	6		2	Coal; core composed of less-than-¼-in fragments.
TE 16	1.0	.004	.002	48	8		4	Shale, carbonaceous, dark-gray; core is nearly pulverized.
TE 17	.7	.002	.001	49	0		8	Shale, buff to medium-gray, carbonaceous.
TE 18	.6	.002	.001	49	8		8	Shale, silty, dark, buff to gray, carbonaceous.
				50	4		1½	(Loss in coring interval from 42 ft 6 in to 50 ft 5½ in.)
				50	5½	429	11¼	(No core sent to laboratory.)
Lab S19	.6			480	4¾		7¾	Shale, carbonaceous.
Lab S20	.5			481	½		4½	Do.
TE S21	.7	.001	.002	481	5		6	Coal, sparsely thin-banded.
TE S22	.4	.001	.001	481	11		5	Coal, dominantly attrital.
TE S23	.6	.001	.001	482	4		5½	Coal, dominantly attrital; core is broken below 482 ft 8 in.
TE S24	.7	.002	.001	482	9½		3½	Coal, sparsely thin-banded; core is badly broken.
TE S25	.5	<.001	.001	483	1		5¼	Coal, moderately thin-banded.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections				
Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	Ft	In	
				Core hole 4—Continued				
TE S26	0.7	<0.001	0.001	483	6¼		5¾	Coal, sparsely thin-banded.
TE S27	.1	.001	.001	484	0		5¼	Coal, sparsely thin-banded; 1¼-in parting of medium-gray shale at top is excluded from fuel sample.
TE S28	.3	<.001	<.001	484	5¼		4¾	Coal, dominantly attrital.
TE S29	.4	.001	.001	484	10		6	Do.
TE S30	1.0	.002	.001	485	4		5½	Do.
TE S31	.4	.001	.002	485	9½		5½	Coal, moderately thin-banded.
TE S32	.7	.001	.001	486	3		4¾	Coal, moderately thin- and medium-banded.
TE S33	.6	<.001	.001	486	7¾		5¼	Coal, moderately thin-banded.
TE S34	1.3	.002	.002	487	1		5½	Coal, moderately thin- and medium-banded.
TE S35	1.5	.002	.002	487	6½		5½	Coal, abundantly medium- and thin banded.
TE S36	.8	.002	.001	488	0		5½	Coal, moderately thin- and medium-banded.
TE S37	.3	<.001	.001	488	5½		3½	Coal, abundantly thin-banded except for one 1¾-inch band of vitrain at 488 ft 6¾ in.
TE S38	.5	<.001	.001	488	9		5	Coal, sparsely thin-banded.
TE S39	.6	.002	.002	489	2		4½	Coal, dominantly medium- and thin-banded.
TE S40	3.1	.006	.005	489	6½		5¼	Coal, sparsely thin-banded; uppermost 3 inches was broken in coring.
TE S41	3.2	.006	.005	489	11¾		5¾	Coal, sparsely thin- and medium-banded.
TE S42	1.1	.001	.001	490	5½		3¼	Do.
Lab S43	.4	----------	----------	490	8¾		7¾	Sandstone, fine-grained, light-gray; occasional thin coaly streaks; grades to light-gray siltstone below 491 ft ½ in.
Lab S44	.2	----------	----------	491	4½		6½	Siltstone, light-gray, occasional coaly streaks; ½ in of fine-grained very light-gray sandstone below 491 ft 10½ in.
	----------	----------	----------	491	11		3½	(Loss in coring interval from 484 ft to 492 ft 2½ in.)
	----------	----------	----------	492	2½	34	9½	(No core sent to laboratory.)
Lab S45	.6	----------	----------	527	0		10½	Shale, light-gray, occasional dark-gray streaks.
Lab S46	.7	----------	----------	527	10½		8	Shale, light-gray.
	----------	----------	----------	528	5½		6½	Shale and impure coal; 3 in of coaly shale at top, then 3¼ in of partly thin-banded impure coal, and ¼ in of light-gray shale with small fragments of coal at base.
TE S48	1.2	.003	.003	529	0		9	Shale, medium-gray, slightly carbonaceous.
TE S49	2.3	.004	.003	529	9		1	Shale, very carbonaceous, black.
TE S50	.5	.002	<.001	529	10		5½	Coal, sparsely medium- and thin-banded.
TE S51	1.1	.002	.002	530	3½		5¾	Do.
TE S52	.7	.001	.001	530	9¼		5½	Coal, moderately medium- and thin-banded.
TE S53	1.4	.003	.003	531	2¾		5¼	Coal, sparsely medium- and thin-banded.
TE S54	.9	.002	.002	531	8		6	Coal, moderately medium- and thin banded.
TE S55	1.1	.002	.002	532	2		5	Coal, sparsely thin-banded; core is broken.
TE S56	.3	.001	.001	532	7		5¼	Coal, sparsely thin-banded.
TE S57	1.2	.003	.002	533	¾		4¾	Coal, sparsely thin-banded; core is badly broken.
TE S58	1.7	.003	.003	533	5½		5	Coal, abundantly thin- and medium-banded.
TE S59	1.3	.004	.004	533	10½		5½	Coal, abundantly medium- and thick-banded; core is broken.
TE S60	2.3	.004	.003	534	4		6	Coal, moderately thin- and medium-banded; core is broken.
	----------	----------	----------	534	10		2	(Loss in coring interval from 529 ft 10 in to 535 ft.)
TE S61	1.4	.002	.001	535	0		1½	Shale, coaly, medium-gray, broken; coal fragments (possibly from layer below); excluded from fuel sample.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections				
Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
								Core hole 4—Continued
TE S62	1.0	0.002	0.002	535	1½		4½	Coal, abundantly medium- and thin-banded; upper 1½ in was broken in coring.
TE S63	.7	.001	.001	535	6		3¾	Coal, sparsely thin-banded; core is broken.
TE S64	.8	.002	.001	535	9¾		6	Shale, silty, light-gray, slightly carbonaceous.
TE S65	.7	.003	.001	536	3¾		8¼	Shale, silty, light-gray, occasional coal fragments.
------	------	------	------	537	0	47	9	(No core sent to laboratory.)
Lab S66	.6	------	------	584	9		4½	Shale, silty, light-gray; lower ¼ in is slightly carbonaceous.
Lab S67	.1	------	------	585	1½		6	Coal, moderately thin-banded.
Lab S68	.3	------	------	585	7½		6	Coal, abundantly thin- and medium-banded.
TE S69	1.4	.003	.004	586	1½		4¾	Coal, moderately medium- and thin-banded.
TE S70	.8	.003	.001	586	6¼		7¾	Shale, medium-gray; slightly coaly.
	------	------	------	587	2	------	------	(Base of core sent to laboratory.)
								Fuel samples (U. S. Bureau of Mines): D–96789 includes TE samples 4–15. D–97235 includes TE samples S21–S42. D–97237 includes TE samples S50–S63. D–97236 includes TE samples S67–S69.
								Core hole 5 (SE¼NW¼ sec. 15, T. 24 N., R. 95 W.) elev. 6,580 ft
TE 1	3.5	0.007	0.006	99	3⅓		2⅔	(Top of core sent to laboratory.) Coal, shaly.
TE 2	2.4	.006	.005	99	6		3	Shale, clayey, slightly carbonaceous, coaly.
TE 3	4.0	.009	.007	99	9		2½	Shale, black, coaly.
TE 4	2.2	.006	.005	99	11½		6	Coal, sparsely thin- and medium-banded; ½-in. band of vitrain at 100 ft 3 in.
TE 5	3.9	.011	.008	100	5½		4½	Shale, black, coaly; becomes shaly coal in lowest in.
CGL 1	2.7	.008	.005	100	10		3½	Shale, medium-gray, slightly carbonaceous.
TE 6	3.9	.008	.006	101	1½		6½	Shale, black, coaly streaks; more coaly toward base.
TE 7	4.2	.011	.008	101	8		4	Coal, abundantly thin-banded.
TE 8	3.8	.014	.014	102	0		5	Coal, moderately thin- and medium-banded; attrital-coal zone from 102 ft 1½ in to 102 ft 2½ in.
TE 9	5.7	.011	.008	102	5		6	Coal, mostly sparsely thin-banded.
TE 10	6.9	.015	.012	102	11		6	Coal, sparsely to moderately thin-banded; ½-in band of vitrain at 103 ft 3 in.
TE 11	3.1	.006	.006	103	5		5	Coal, moderately thin- and medium-banded; ¼-in band of vitrain at 103 ft 8¾ in.
TE 12	3.0	.006	.006	103	10		4¾	Coal, attrital or sparsely thin-banded.
TE 13	3.7	.015	.013	104	2¾		5¼	Clay, dark-gray, soft, carbonaceous; grading to dark-gray carbonaceous shale below 104 ft 5 in; some disturbance of top clay during drilling.
TE 14	3.2	.012	.009	104	8		6	Shale, clayey, dark-gray, carbonaceous.
TE 15	2.5	.010	.008	105	2		5½	Shale, dark-gray, carbonaceous.
CGL 2	.6	------	------	105	7½		8½	Sandstone, poorly sorted, greenish.
------	------	------	------	106	4		¾	(Loss in coring interval from 99 ft 3½ in to 106 ft 4¾ in.)
------	------	------	------	106	4¾	------	------	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines):
D–96790 includes TE samples 7–12.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections				
Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	Ft	In	
Core hole 6 (SW¼NE¼ sec. 10, T. 24 N., R. 95 W.) elev. 6,605 ft								
TE 1	2.9	0.008	0.006	194	10¾		3¼	(Top of core sent to laboratory.) Shale black, carbonaceous; ⅜-in vitrain lens at 195 ft 1½ in.
TE 2	2.5	.003	.003	195	2		5½	Coal, moderately thin-banded, shaly.
TE 3	3.8	.008	.006	195	7½		6	Do.
TE 4	3.1	.006	.006	196	1½		2¼	Shale, black, clayey, coaly.
TE 5	8.5	.009	.011	196	7¾		6¾	Coal, sparsely thin- and medium-banded.
TE 6	5.8	.008	.009	196	10½		4¼	Coal, shaly, breaks into thin laminae.
TE 7	4.9	.009	.008	197	2¾		6¼	Coal, dominantly attrital, impure coal, with ¼-in layer of interbedded fusain and vitrain at 197 ft 6½ in.
TE 8	4.1	.009	.006	197	9		3½	Shale, black, coaly.
TE 9	4.4	.009	.007	198	½		4½	Do.
	-------	-------	-------	198	5	1	7	(Loss in coring interval from 194 ft 10¾ in to 200 ft.)
TE 10	12.1	.016	.016	200	0		3	Shale, black, coaly.
TE 11	10.2	.012	.015	200	3		3	Coal, shaly.
TE 12	6.3	.009	.008	200	6		3½	Coal, shaly, broken, possibly mixed with shale from below.
TE 13	2.5	.007	.004	200	9½		4	Shale, black, carbonaceous.
TE 14	5.2	.010	.008	201	1½		3½	Clay, greenish-gray.
	-------	-------	-------	201	5		4½	(Loss in coring interval from 200 ft to 201 ft 9½ in.)

Fuel sample (U. S. Bureau of Mines) from core hole 6:
D-96791 includes TE samples 2–12.

Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth Ft	Depth In	Length Ft	Length In	Description and remarks
Core hole 7 (NW¼SW¼ sec. 20, T. 24 N., R. 95 W.) elev. 6,560 ft								
TE S1	1.7	0.005	0.003	37	½		6½	(Top of core sent to laboratory.) Shale, dark-gray, carbonaceous; ½-in black and coaly shale at 37 ft 6½ in.
TE S2	2.7	.003	.003	37	7		3½	Coal, dominantly attrital.
TE S3	2.0	.002	.002	37	10½		4	Coal, sparsely thin-banded.
TE S4	2.4	.007	.004	38	2½		3½	Shale, black, coaly, uppermost ¼ in is pyritic; excluded from fuel sample.
TE S5	1.3	.002	.002	38	6		6	Coal, sparsely thin-banded, ½-in band of vitrain at 38 ft 8¼ in.; core is broken into ½-in. layers and disarranged.
TE S6	3.8	.004	.003	39	0		2	Coal, sparsely thin-banded.
TE S7	2.8	.007	.004	39	2		2	Shale, carbonaceous, dark-gray; excluded from fuel sample.
TE S8	2.5	.004	.003	39	4		4	Coal, dominantly attrital.
TE S9	1.4	.002	.003	39	8		4	Do.
TE S10	2.6	.004	.004	40	0		6	Coal, uppermost 2½ in abundantly thin- and medium-banded; lower 3½ in is dominantly attrital coal.
TE S11	2.0	.005	.005	40	6		6½	Coal, dominantly attrital.
TE S12	4.2	.008	.008	41	½		6	Coal, sparsely thin-banded.
TE S13	1.6	.003	.002	41	6½		6	Coal, dominantly attrital.
TE S14	1.0	.002	.002	42	½		7½	Coal, dominantly attrital; ½-in clayey-shale parting at 42 ft 4¼ in excluded from fuel sample.
TE S15	1.7	.002	.002	42	8		3	Coal, dominantly attrital.
Lab S16	.7	-------	-------	42	11		6	Shale, dark-buff; uppermost 1 in is carbonaceous.
Lab S17	.9	-------	-------	43	5		4	Shale, clayey, light- and medium-gray.
Lab S18	.7	-------	-------	43	9		8	Shale, dark- to medium-buff.
Lab S19	.7	-------	-------	44	5		2½	Shale, dark-buff.
	-------	-------	-------	44	7½		4½	(Loss in coring interval from 40 ft to 45 ft.
Lab S20	.8	-------	-------	45	0		5½	Shale, buff.
Lab S21	.6	-------	-------	45	5½		5½	Do.
	-------	-------	-------	45	11	-----	-----	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines) from core hole 7: D-97233 includes TE samples S2–S3, S5–S6, and S8–S15

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections				
Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	Ft	In	
Core hole 8 (NE¼SW¼ sec. 22, T. 24 N., R. 96 W.) elev. 6,715 ft								
TE S1	0.4	<0.001	<0.001	90	4¾		6¼	(Top of core sent to laboratory.) Coal, moderately thin-banded; ½-in pyritic lens at 90 ft 8¼ in.
TE S2	.3	.001	.001	90	11		5½	Coal, dominantly attrital.
TE S3	.6	<.001	.001	91	4½		5	Do.
TE S4	.8	.002	.001	91	9½		5½	Coal, moderately thin-banded, slightly pyritic throughout; ½-in zone of small pyritic lenticles below 91 ft 10¼ in.
TE S5	.4	.001	.001	92	3		6	Coal, sparsely thin-banded, slightly pyritic; 1-in. shale parting, black and highly carbonaceous, at 92 ft 5¾ in; parting excluded from fuel sample.
Lab S6	.7	---------	---------	92	9		1½	Shale, black and highly carbonaceous; ¼ in of light-gray shale at 92 ft 10¼ in; excluded from fuel sample.
--------	--------	---------	---------	92	10½		1½	(Loss in coring interval from 90 ft 4¾ in to 94 ft.)
Lab S7	.6	---------	---------	94	0		6¾	Shale, light-gray and clayey; 1 in of carbonaceous shale at 94 ft 1¾ in and also at 94 ft 5¾ in; excluded from fuel sample.
TE S8	.6	.001	.001	94	6¾		6¼	Coal, sparsely thin-banded; core is broken into biscuits and is slightly displaced.
TE S9	.4	<.001	.001	95	1		5	Coal; pulverized in drilling.
TE S10	.7	.001	.001	95	6		5	Coal, pyritic; pulverized in drilling.
TE S11	.8	.002	.002	95	11		5	Do.
TE S12	.5	.001	.001	96	4		6	Coal and carbonaceous shale; pulverized and mixed in coring.
	--------	---------	---------	96	10		2	(Loss in coring (?) interval from 94 ft to 97 ft.)
	--------	---------	---------	97	0	-----	-----	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines) from core hole 8:
D-97528 includes TE samples S1–S5 and S8–S11.

Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth Ft	Depth In	Length Ft	Length In	Description and remarks
Core hole 9 (NE¼SW¼ sec. 2, T. 24 N., R. 95 W.) elev. 6,620 ft								
TE S1	4.8	0.016	0.013	190	3½		4¾	(Top of core sent to laboratory.) Shale, medium-gray, slightly carbonaceous.
TE S2	5.9	.014	.013	190	8¼		3	Shale, black, highly carbonaceous.
TE S3	4.7	.008	.010	190	11¼		5¾	Shale, coaly; core is broken below 191 ft 3½ in.
TE S4	4.2	.008	.008	191	5		2½	Shale, black, carbonaceous.
TE S5	2.7	.007	.006	191	7½		5½	Shale, medium-gray, slightly carbonaceous; ½-in band of black shale at 192 ft ½ in.
TE S6	5.8	.010	.009	192	1		2¼	Shale, coaly, and impure coal.
TE S7	4.1	.010	.009	192	3¼		2¼	Shale, black.
TE S8	2.7	.009	.008	192	5½		3½	Shale, medium-gray.
TE S9	3.0	.009	.007	192	9		6½	Shale, black; clayey below 193 ft.
TE S10	3.5	.011	.009	193	3½		6	Shale, black.
TE S11	4.0	.009	.009	193	9½		3¼	Coal, shaly; ¾-in of coaly shale at top.
TE S12	3.5	.005	.006	194	¾		5	Coal, abundantly thin- and medium-banded.
TE S13	2.8	.003	.005	194	5¾		2¼	Coal, principally thick woody band containing uniformly finely dispersed pyrite; ½-in of black shale at top.
TE S14	4.7	.005	.009	194	8		3	Coal and black shale; core is pulverized and mixed.
	--------	---------	---------	194	11	1	1	(Loss in coring interval from 190 ft. 3½ in to 196 ft; probably most of the loss is due to the condition of sample S14.)
TE S15	7.6	.018	.018	196	0		3½	Shale, black.
	--------	---------	---------	196	3½	-----	-----	(Base of core sent to laboratory.)

Fuel sample (U. S. Bureau of Mines) from core hole 9:
D-97530 includes TE samples S11–S14.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections				
Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	Ft	In	
Core hole 10 (NE¼SW¼ sec. 17, T. 23 N., R. 94 W.) elev. 6,510 ft								
	----------	----------	----------	-----	-----	54	7¼	(No core sent to laboratory.)
TE S1	0.7	0.002	0.001	54	7¼		5¾	(Top of core sent to laboratory.) Shale, black.
TE S2	.4	.002	.001	55	1		5	Coal, dominantly thick-banded; core is broken.
TE S3	1.4	.002	.001	55	6		5½	Coal, sparsely thin-banded.
TE S4	1.1	.003	.002	55	11½		3	Coal, moderately thin and thick-banded.
TE S5	1.8	.002	.007	56	2½		5	Coal, moderately thin-banded; 1¼-in band of vitrain at 56 ft 3¼ in core is broken.
TE S6	2.1	.004	.002	56	7½		6½	Coal, moderately thin- to thick-banded.
TE S7	.4	<.001	.001	57	2		4½	Coal, dominantly thick-banded.
TE S8	1.0	.001	.001	57	6½		5½	Coal, sparsely thin- and medium-banded.
TE S9	.3	.001	.001	58	0		4¼	Coal, moderately thin-banded.
TE S10	.5	.001	.001	58	4¼		4¼	Coal, moderately medium-banded.
TE S11	1.1	.003	.001	58	8½		5	Coal, sparsely thin-banded.
TE S12	.3	.001	.001	59	1½		5½	Coal, sparsely thin-banded; ¾-in. band of vitrain at 59 ft 2¾ in.
TE S13	.7	.002	<.001	59	7		4½	Coal, abundantly medium- and thick-banded.
	----------	----------	----------	59	11½		½	(Loss in coring interval from 54 ft 7¼ in to 60 ft.)
TE S14	2.0	.004	.004	60	0		6	Coal, sparsely thin-banded; 1 in of black shale at 60 ft; shale excluded from fuel sample.
TE S15	1.8	.002	.002	60	6		5	Coal, sparsely thin-banded.
TE S16	2.1	.004	.003	60	11		3	Coal, moderately thin- and medium-banded.
TE S17	1.9	.005	.003	61	2		6½	Shale, black, coaly, and sparsely medium- and thin-banded coal; excluded from fuel sample.
TE S18	1.7	.004	.004	61	8½		6½	Shale black, coaly; excluded from fuel sample.
TE S19	2.4	.005	.005	62	3		5	Coal, moderately thin- and medium-banded; 2-in band of vitrain below 62 ft 5¼ in.
TE S20	1.6	.005	.008	62	8		5	Coal, moderately medium- and thin-banded; ⅛-in parting of fusain at 62 ft 9⅜ in; ¾-in band of vitrain at 62 ft 11¼ in.
TE S21	2.1	.005	.003	63	1		6	Shale, black, slightly coaly.
TE S22	1.5	.005	.003	63	7		4½	Shale, black, coaly.
TE S23	2.6	.006	.004	63	11½		4½	Shale, black, and coal; core is broken and mixed.
	----------	----------	----------	64	3		½	(Loss in coring interval from 60 ft to 64 ft 3½ in.)
TE S24	2.2	.006	.004	64	3½		6½	Shale, black, coaly.
TE S25	2.0	.003	.003	64	10		4½	Coal, sparsely thin-banded; 1½-in band of vitrain at 64 ft ¾ in.
TE S26	2.1	.003	.002	65	2½		6	Coal, sparsely thin-banded.
TE S27	.6	.001	.001	65	8½		5½	Coal, sparsely thin-banded; ½-in bands of vitrain at 65 ft 8½ in and 66 ft.
TE S28	.9	.002	.002	66	2		6	Coal, sparsely thin-banded; 1-in band of vitrain below 66 ft 6¼ in.
TE S29	3.3	.008	.005	66	8		4	Shale, dark-gray, carbonaceous; core is broken; excluded from fuel sample.
TE S30	4.0	.008	.006	67	0		6	Coal, abundantly thick- and thin-banded; ½-in of black shale at 67 ft 5½ in excluded from fuel sample.
TE S31	7.7	.011	.009	67	6		2¼	Coal, moderately thin-banded.
TE S32	2.1	.004	.003	67	8¼		6¾	Shale, black, gray streaks, carbonaceous.
TE S33	2.9	.004	.004	68	3		5½	Shale, black, coaly, and shaly coal.
TE S34	2.4	.004	.003	68	8½		4	Coal, moderately thin-banded, and shale (possibly from sample above); core is broken and mixed.
TE S35	1.5	.003	.002	69	½		6	Coal, abundantly thin- and medium-banded; ½ in of coaly shale at 69 ft 2¾ in excluded from fuel sample.
TE S36	3.1	.005	.003	69	6½		4¾	Coal, abundantly thin- and medium-banded.
TE S37	1.5	.003	.002	69	11¼		4¼	Coal, sparsely thin-banded; ⅜-in band of vitrain below 70 ft 3⅛ in.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	Ft	In	
Core hole 10—Continued								
TE S38	1.6	0.003	0.002	70	3½		4½	Coal, moderately thin-banded.
TE S39	.9	.002	.001	70	8		5½	Coal, sparsely thin-banded.
TE S40	2.6	.006	.003	71	1½		4½	Coal, sparsely thin-banded; 2¾ in of black coaly shale at 71 ft 2¼ in excluded from fuel sample.
TE S41	1.9	.005	.003	71	6		5	Coal, sparsely thin- and medium-banded ¼-in parting of fusain at 71 ft 9¼ in.
TE S42	1.4	.005	.005	71	11		5	Shale, black, coaly; thick vitrain bands.
TE S43	3.0	.006	.004	72	4		2¾	Coal, sparsely thin-banded; ½-in band of vitrain at 72 ft 5½ in.
TE S44	1.7	.004	.003	72	6¾		5	Coal, shaly; 1¼ in of carbonaceous black shale at 72 ft 6¾ in.
				72	11¾		5	(Loss in coring interval from 67 ft 6 in to 73 ft 4¾ in.)
TE S45	1.4	.003	.001	73	4¾		4¾	Coal, abundantly thin- and medium-banded.
TE S46	1.0	.003	.002	73	9½		6	Coal, dominantly medium-banded.
TE S47	1.5	.005	.003	74	3½		4	Coal, dominantly medium-banded; ¼-in parting of fusain at 74 ft 3½ in, 2-in band of vitrain at 74 ft 3¾ in; 1 inch of carbonaceous black shale at 74 ft 6½ in, shale parting excluded from fuel sample.
TE S48	1.4	.002	.002	74	7½		5¾	Coal, abundantly medium- and thick-banded; ⅜-in parting of fusain at 74 ft 11⅝ in.
TE S49	1.3	.002	.001	75	1¼		4½	Coal, moderately thin- and thick-banded.
TE S50	2.7	.004	.003	75	5¾		4	Coal, dominantly attrital; ½-in band of vitrain at 75 ft 8¼ in.
TE S51	1.0	.002	.002	75	9¾		5¼	Coal, abundantly medium-banded.
TE S52	.8	.002	.001	76	3		3	Clay, medium-gray, carbonaceous.
TE S53	.6	.003	.001	76	6		8	Clay, shaly, medium-gray, coaly streaks.
TE S54	1.0	.003	.002	77	2		2½	Clay, dark-gray, carbonaceous.
TE S55	.8	.003	.001	77	4½		7½	Clay, shaly, medium-gray.
TE S56	.9	.002	<.001	78	0		6	Do.
				78	6		1¼	(Loss in coring interval from 76 ft 6 in to 78 ft 7¼ in.)
				78	7¼	62	10¾	(No core sent to laboratory.)
TE S57	.8	.002	<.001	141	6		5½	Shale, light-gray, slightly carbonaceous.
TE S58	.8	.002	<.001	141	11½		5½	Do.
TE S59	.7	.002	<.001	142	5		5½	Do.
				142	10½		1½	(Loss in coring interval from 141 ft 6 in to 143 ft.)
TE S60	.7	.002	<.001	143	0		8	Shale, clayey, dark-gray, carbonaceous; ¼-in of coaly black shale at 143 ft 7¾ in.
TE S61	.3	.002	.001	143	8		5½	Coal, sparsely thin-banded; 1¼-in band of vitrain at 143 ft 9⅞ in; ¾-in band of vitrain at 144 ft ⅜ in.
TE S62	.8	<.001	.001	144	1½		5	Coal, sparsely thin-banded.
TE S63	.6	.001	.001	144	6½		5	Coal, moderately thin- and medium-banded.
TE S64	1.0	.001	.001	144	11½		5	Do.
TE S65	1.8	.006	.003	145	4½		5	Coal, sparsely thin- and medium-banded; 1¼ in of coaly black shale at 145 ft 4½ in excluded from fuel sample.
TE S66	1.5	.004	.003	145	9½		4½	Coal, moderately thin- and medium-banded; ½-in band of vitrain at 145 ft 11½ in.
TE S67	2.7	.005	.004	146	2		3	Shale, black, carbonaceous.
TE S68	1.1	.004	.002	146	5		2½	Coal, shaly.
TE S69	2.4	.005	.003	146	7½		5½	Coal, moderately thin- and medium-banded.
TE S70	3.3	.008	.006	147	1		6½	Coal, shaly, and coaly shale.
TE S71	2.4	.005	.004	147	7½		5½	Coal, moderately thin-banded; ½-in band of vitrain at 147 ft 7¾ in.
TE S72	.5	<.001	.001	148	1		5	Coal, abundantly thin- to thick-banded.
TE S73	1.5	.003	.002	148	6		6	Coal, moderately thin- and medium-banded.
TE S74	.7	<.001	.001	149	0		5½	Coal, sparsely thin-banded.
TE S75	.7	.002	.001	149	5½		5	Coal, dominantly thin-banded; 1¼-in band of vitrain at 149 ft 9¼ in.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
Core hole 10—Continued								
TE S76	0.8	0.001	0.001	149	10½		3	Coal, dominantly thin-banded; ½-in band of vitrain at 150 ft ½ in.
TE S77	3.0	.007	.008	150	1½		4½	Coal, dominantly thin- and thick-banded.
TE S78	3.5	.007	.007	150	6		4½	Coal, dominantly thin-banded.
				150	10½		2¾	(Loss in coring interval from 143 ft to 151 ft 1¼ in.)
TE S79	.5	.001	.001	151	1¼		4¼	Coal, sparsely thin-banded; 1¼-in band of vitrain at 151 ft 5¼ in.
TE S80	1.7	.002	.003	151	5½		6	Coal, sparsely thin-banded.
TE S81	2.3	.007	.005	151	11½		6	Do.
TE S82	4.9	.007	.007	152	5½		4¼	Coal, dominantly attrital.
				152	9¾		2¼	(Loss in coring interval from 151 ft 1¼ in to 153 ft.)
TE S83	3.8	.011	.008	153	0		5½	Shale and clay, black, carbonaceous.
TE S84	1.7	.006	.004	153	5½		7	Shale, dark-gray, carbonaceous.
TE S85	1.4	.006	.003	154	½		7½	Shale, medium-gray, carbonaceous.
				154	8			(Base of core sent to laboratory)

Fuel samples (U. S. Bureau of Mines) from core hole 10:
D-98226 includes TE samples S2-S11, S13-S16, and S19-S20
D-98227 includes TE samples S25-S28 and S30.
D-98228 includes TE samples S35-S41.
D-98229 includes TE samples S45-S51.
D-98230 includes TE samples S61-S66.
D-98231 includes TE samples S71-S82.

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
Core hole 11 (NW¼ NW¼ sec. 27, T. 23 N., R. 94 W.) elev, 6,660 ft								
						30	3½	(No core sent to laboratory.)
TE S1	0.8	0.000	0.001	30	3½	1	¼	(Top of core sent to laboratory.) Siltstone, very fine-grained, tan, unconsolidated.
TE S2	.8	.004	.002	31	3¾		¾	Siltstone, light-gray.
TE S3	1.1	.002	.002	31	4½		2½	Shale, black, carbonaceous; core is broken and mixed coal fragments, possibly from sample below.
TE S4	1.1	.002	.003	31	7		5	Shale, black, and gypsiferous coal; core is badly broken and mixed.
TE S5	1.1	.002	.002	32	0		5	Coal; core is badly broken.
TE S6	1.2	.003	.003	32	5		6	Coal; core is badly broken; components of one thick band of vitrain were noted in the fragments.
TE S7	1.6	.004	.004	32	11		6	Coal, sparsely thin-banded; core is badly broken.
TE S8	2.3	.004	.004	33	5		5¼	Coal, sparsely thin-banded; ½ in of black shale at 33 ft 7½ in excluded from fuel sample.
TE S9	3.7	.008	.009	33	10¼		3¾	Coal, moderately thin- to thick-banded; 1 in of coaly black shale at 34 ft 1 in excluded from fuel sample.
TE S10	2.8	.008	.010	34	2		5	Coal and coaly shale, broken and mixed; excluded from fuel sample.
TE S11	1.7	.003	.003	34	7		2¾	Coal, moderately thin- and thick-banded.
				34	9¾	2	2¼	(Loss in coring interval from 30 ft 3½ in to 36 ft.)
TE S12	.4	.002	.002	36	0		4½	Coal, abundantly thin- and medium-banded.
TE S13	1.3	.003	.003	36	4½		5	Coal, sparsely thin-banded.
TE S14	1.7	.005	.006	36	9½		4½	Coal, sparsely thin-banded; core is badly broken and includes a few ¼-in tan silty nodules.
TE S15	2.7	.009	.006	37	2		6½	Clay, shaly, black, carbonaceous.
TE S16	1.4	.005	.003	37	8½		7	Sandstone, gray, poorly sorted.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections					
Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	In	Ft	
				Core hole 11—Continued				
TE S17	1.0	0.004	0.002	38	3½		5	Sandstone, light-gray, pyritic, poorly sorted.
				38	8½	62	9½	(No core sent to laboratory.)
TE S18	1.7	.005	.004	101	6		2	Shale, medium- and dark-gray, carbonaceous.
TE S19	1.3	.004	.003	101	8		8	Shale, light-gray.
TE S20	2.0	.006	.005	102	4		5	Coal, shaly, 1 in of abundantly medium-banded coal at 102 ft 4 in; 1¼ in of carbonaceous, clayey shale, at 102 ft 5 in.
TE S21	1.6	.005	.004	102	9		8¼	Shale, black, coaly.
TE S22	.8	.002	.001	103	5¼		5	Coal, moderately thin-banded; 2 in of dominantly attrital coal and black shale at 103 ft 5¼ in; ½ in of shale excluded from fuel sample.
TE S23	1.7	.004	.003	103	10¼		3	Coal, dominantly thick- and thin-banded.
TE S24	2.8	.006	.003	104	1¼		5¾	Shale, dark-gray, carbonaceous; clayey below 104 ft 6½ in; excluded from fuel sample.
TE S25	2.0	.006	.003	104	7		5	Shale, black, coaly; core is broken; excluded from fuel sample.
TE S26	2.1	.006	.003	105	0		5½	Coal, shaly; excluded from fuel sample.
TE S27	1.1	.002	.002	105	5½		3½	Coal, dominantly thin- and medium-banded.
TE S28	2.2	<.001	<.001	105	9		3	Coal, moderately medium-banded.
TE S29	2.1	.003	.002	106	0		6	Coal, sparsely thin-banded; 1 in band of vitrain at 106 ft 1¼ in.
TE S30	2.0	.005	.004	106	6		5½	Coal, sparsely thin-banded.
TE S31	2.9	.008	.006	106	11½		4¼	Shale, black, gray-mottled, clayey.
TE S32	1.5	.006	.003	107	3¾		5¼	Shale, medium-gray, carbonaceous.
TE S33	1.9	.003	.003	107	9		5½	Do.
TE S34	2.3	.008	.005	108	2½		4	Shale, black, carbonaceous.
TE S35	2.3	.008	.007	108	6½		8	Coal, shaly, and black shale.
				109	2½		4½	(Loss in coring interval from 106 ft to 109 ft 7 in.)
TE S36	3.2	.012	.007	109	7		6	Shale, dark-gray, carbonaceous.
TE S37	2.6	.009	.006	110	1		4	Shale, black, carbonaceous.
TE S38	2.9	.009	.006	110	5		3½	Shale, black, slightly coaly.
TE S39	3.5	.010	.009	110	8½		5	Coal, shaly.
TE S40	1.8	.006	.004	111	1½		5¾	Shale, black and dark-gray, coaly.
TE S41	1.7	.006	.003	111	7¼		4¼	Shale, medium-gray, carbonaceous, slightly coaly.
TE S42	.9	.004	.002	111	11½		7¾	Shale, light-gray; finely dispersed pyrite.
				112	7¼		2¼	(Loss in coring interval from 109 ft 6 in to 112 ft 9½ in.)
				112	9½	9	6	(No core sent to laboratory.)
TE S43	1.1	.004	.002	122	3½		5¾	Shale, light-gray, slightly coaly.
TE S44	1.5	.005	.002	122	9¼		3¾	Shale, black, carbonaceous; core is broken below 122 ft 11 in.
TE S45	1.7	.006	.004	123	1		6	Shale, black, carbonaceous; 2¼ in of coaly shale at 123 ft 1 in.
TE S46	2.0	.007	.006	123	7		4½	Shale, coaly, and shaly coal.
TE S47	2.0	.005	.004	123	11½		4	Coal, shaly.
TE S48	1.4	.004	.003	124	3½		5½	Coal, impure; 1 in of shaly coal at 124 ft 8½ in.
TE S49	1.5	.004	.003	124	9		4½	Coal, dominantly thin- and medium-banded.
TE S50	1.7	.007	.004	125	1½		5	Coal, shaly, and impure coal.
TE S51	1.5	.004	.003	125	6½		5½	Coal, shaly and impure.
TE S52	1.9	.005	.005	126	0		6	Coal, impure and shaly, dominantly thin-banded.
TE S53	2.1	.007	.004	126	6		5	Shale, black, carbonaceous; ¼-in coaly band at 126 ft 6 in.
TE S54	1.4	.006	.003	126	11		9½	Shale, light-gray; ½ in of coaly shale at base.
TE S55	2.2	.005	.004	127	8½		4½	Coal, impure and shaly.
TE S56	1.3	.004	.003	128	1		4½	Coal, moderately thin- and medium-banded.
TE S57	3.4	.008	.008	128	5½		3¾	Coal, shaly.
TE S58	2.7	.008	.005	128	9¼		4¾	Shale, black, carbonaceous.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample				Core sections				
Sample No.	Radioactivity (PMG)	Equivalent uranium	Uranium	Depth in hole		Length		Description and remarks
		Percent		Ft	In	Ft	In	
				Core hole 11—Continued				
TE S59	3.3	0.008	0.006	129	2		6	Coal, shaly; ½-in band of vitrain at 129 ft 6 in.
TE S60	.4	.003	.002	129	8		7	Coal, and shaly coal; 1¼-in band of vitrain at 129 ft 10¼ in.
TE S61	1.9	.005	.002	130	3		3½	Shale, coaly.
TE S62	2.1	.006	.004	130	6½		5½	Coal, shaly.
-------	-------	-------	-------	131	0		2½	(Loss in coring interval from 126 ft to 131 ft 2½ in.)
TE S63	1.5	.004	.002	131	2½		6	Coal, sparsely thin-banded; 2 in of impure coal at 131 ft 2½ in.
TE S64	2.3	.006	.004	131	8½		3	Coal, impure; core is broken.
TE S65	.9	.003	.002	131	11½		4½	Coal, impure, ¼-in pyrite lens at 132 ft 2⅝ in.
TE S66	.5	.001	.001	132	4		4½	Coal and impure coal; ½-in band of vitrain at 132 ft 6⅛ in.
TE S67	1.3	.004	.003	132	8½		3¾	Coal, sparsely thin-banded.
TE S68	6.2	.016	.018	133	¼		3¼	Shale, coaly.
TE S69	4.4	.010	.009	133	3½		4	Coal, shaly.
TE S70	1.0	.002	.002	133	7½		3	Do.
TE S71	.7	.002	<.001	133	10½		6	Shale, black, carbonaceous.
-------	-------	-------	-------	134	4½		1½	(Loss in coring interval from 131 ft 2½ in to 134 ft 6 in.)
-------	-------	-------	-------	134	6	45	4¾	(No core sent to laboratory.)
TE S72	.9	.003	.001	179	10¾		5¼	Clay, medium- and dark-gray, carbonaceous; 1 in of coaly shale at 180 ft 3 in; core is broken.
TE S73	.3	.001	.001	180	4		3½	Coal, sparsely thin-banded.
TE S74	.8	.002	.002	180	7½		4	Do.
TE S75	.5	.002	.002	180	11½		5	Coal, sparsely thin- and medium-banded.
TE S76	.6	.001	.001	181	4½		4½	Coal, moderately thin- to thick-banded; ¼-in band of fusain at 181 ft 5⅝ in; ¾-in band of vitrain at 181 ft 5⅞ in.
TE S77	0.7	.002	.002	181	9		5	Coal, sparsely thin-banded.
TE S78	2.1	.009	.003	182	2		8	Shale, carbonaceous, black.
TE S79	2.1	.007	.005	182	10		4½	Coal, shaly.
TE S80	1.9	.005	.003	183	2½		2¾	Do.
TE S81	2.0	.006	.005	183	5¼		6½	Coal, dominantly attrital, somewhat impure; ½-in band of vitrain at 183 ft 11⅛ in.
TE S82	2.5	.009	.004	183	11¾		4¼	Shale, black, slightly coaly.
TE S83	2.5	.006	.004	184	4		3½	Shale, black, coaly.
TE S84	1.4	.004	.002	184	7½		3½	Coal, impure.
TE S85	3.7	.008	.005	184	11		2¾	Coal, impure, and black shale.
-------	-------	-------	-------	185	1¾		10¼	(Loss in coring interval from 179 ft 10¾ in to 186 ft.)
TE S86	2.6	.008	.006	186	0		7½	Shale, black, and gray mottled.
TE S87 (top)	-------	-------	-------	186	7½		1½	Shale, coaly.
TE S87 (bottom)	3.2	.006	.006	186	9		3½	Coal, shaly, and sparsely thin-banded; ½-in band of vitrain at 196 ft 11⅛ in.
TE S88	.5	.002	.002	187	½		3½	Coal, dominantly attrital; ½-in band of vitrain at 187 ft 1¾ in.
TE S89	.5	.001	.001	187	4		4½	Coal, dominantly attrital; 1-in band of vitrain at 187 ft 5½ in.
TE S90	3.0	.006	.005	187	8½		4¼	Coal, impure, dominantly attrital; ½-in bands of vitrain at 187 ft 9¼ in and 187 ft 11¾ in.
TE S91	.5	.002	.001	188	¾		5¾	Coal, abundantly thin- to thick-banded.
TE S92	.5	.002	.002	188	6½		5¼	Coal; core is broken into less-than-½-in fragments.
TE S93	1.0	.002	.002	188	11¾		4¼	Coal, dominantly attrital.
TE S94	1.6	.003	.003	189	4		3¾	Do.
-------	-------	-------	-------	189	¾		7¾	(Loss in coring interval from 186 ft to 189 ft 8½ in.)
TE S95	4.1	.012	.008	189	8½		5½	Shale, black, and gray mottled, coaly; excluded from fuel sample.
TE S96	.6	.004	.003	190	2		4	Coal, moderately thin- and medium-banded.
TE S97	1.7	.004	.002	190	6		3	Coal, dominantly attrital.

TABLE 4.—*Lithologic descriptions of coal cores from the Red Desert area, Sweetwater County, Wyo., showing comparison of PMG values, equivalent uranium, and uranium content of coal*—Continued

Sample No.	Radioactivity (PMG)	Equivalent uranium (Percent)	Uranium (Percent)	Depth in hole Ft	Depth in hole In	Length Ft	Length In	Description and remarks
				Core hole 11—Continued				
TE S98	2.3	0.002	0.002	190	9		3¼	Coal, dominantly attrital.
TE S99	4.5	.010	.007	191	¼		5½	Coal, impure.
TE S100	5.1	.012	.010	191	5¾		2½	Shale, black, coaly; excluded from fuel sample.
TE S101	6.7	.010	.012	191	8¼		3½	Coal, sparsely thin-banded.
TE S102	4.7	.016	.011	191	11¾		4¾	Shale, black, gray mottled, coaly.
TE S103	4.4	.014	.009	192	4½		5	Shale, black, carbonaceous.
TE S104	3.1	.011	.009	192	9½		3¾	Shale, black, clayey.
TE S105	.9	.003	.001	193	1¼		4¾	Sandstone, tan, poorly sorted.
	--------	--------	--------	193	6		2½	(Loss in coring interval from 189 ft 8½ in to 193 ft 8½ in.)
	--------	--------	--------	193	8½	-----	-----	(Base of core sent to laboratory.)

Fuel samples (U. S. Bureau of Mines) from core hole 11:
D-98232 includes TE samples S5–S9 and S11–S14.
D-98233 includes TE samples S22–S23 and S27–S30.
D-98234 includes TE samples S56–S70.
D-98235 includes TE samples S73–S77.
D-98236 includes TE samples S87 (bottom)–S94, S96–S99, and S101.

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Tertiary Geology of the Goose Creek District Cassia County, Idaho Box Elder County, Utah And Elko County, Nevada

By WILLIAM J. MAPEL *and* WILLIAM J. HAIL, JR.

URANIUM IN COAL IN THE WESTERN UNITED STATES

GEOLOGICAL SURVEY BULLETIN 1055-H

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TERTIARY GEOLOGY OF THE GOOSE CREEK DISTRICT, CASSIA COUNTY, IDAHO, BOX ELDER COUNTY, UTAH, AND ELKO COUNTY, NEVADA

By William J. Mapel and William J. Hail, Jr.

ABSTRACT

The Goose Creek district is an area of about 260 square miles in the northern and central parts of an intermontane basin in southern Idaho and adjacent parts of Utah and Nevada and is drained by Goose Creek, a large perennial tributary of the Snake River. Tertiary rocks exposed in the district include the Payette(?) formation, of Miocene or Pliocene age, and the overlying Salt Lake formation, of Pliocene age. The Payette(?) formation is at least 900 feet thick and consists mainly of greenish-gray shale and white volcanic ash. The Salt Lake formation is at least 2,300 feet thick and consists largely of volcanic ash and welded rhyolitic tuff. Both formations contain thin beds of carbonaceous shale and lignite, and at various stratigraphic levels there are numerous beds of sandstone and conglomerate derived from the disintegration and erosion of older rocks exposed on adjacent highlands. The Tertiary sedimentary rocks rest unconformably on a large body of Tertiary(?) rhyolite exposed in the mountains bordering the district on the southeast, and on a thick undifferentiated sequence of Carboniferous and older rocks, limestone, quartzite, and shale, exposed in the mountains to the west and northeast. Quaternary deposits of gravel, slope wash, alluvium, and landslide material overlie the older rocks locally.

The Payette(?) and Salt Lake formations are tilted in a general easterly direction, with an average dip of about 3 degrees. Shallow folds and structural terraces modify the eastward tilting, particularly along the eastern margin of the district, where dips in the Tertiary rocks locally are reversed. Normal faults with displacements ranging from a few feet to as much as 900 feet cut the Tertiary sequence at various places. Most of the faults trend northward or northeastward, and some may be traced for several miles.

Lignite has been mined for local use from both the Payette and Salt Lake formations, but most of the lignite has a large content of ash and is of little commercial value. Concentrations of as much as 0.1 percent uranium occur locally in lignite and carbonaceous shale in the lower part of the Salt Lake formation. Most of the uranium-rich beds are on the flanks and in the trough of a shallow syncline in T. 16 S., R. 21 E., Idaho. Other mineral resources include building stone and bentonite.

INTRODUCTION

The Goose Creek district is an area of about 260 square miles in southern Cassia County, Idaho, and adjacent parts of Box Elder

County, Utah, and Elko County, Nevada (fig. 36). Tertiary rocks in the area were mapped during the summer of 1952 by the U. S. Geological Survey on behalf of the Atomic Energy Commission. The work was directed chiefly toward the location of uranium deposits; however, the area was examined for other mineral resources, and some data were gathered on deposits of lignite, building stone, and bentonite.

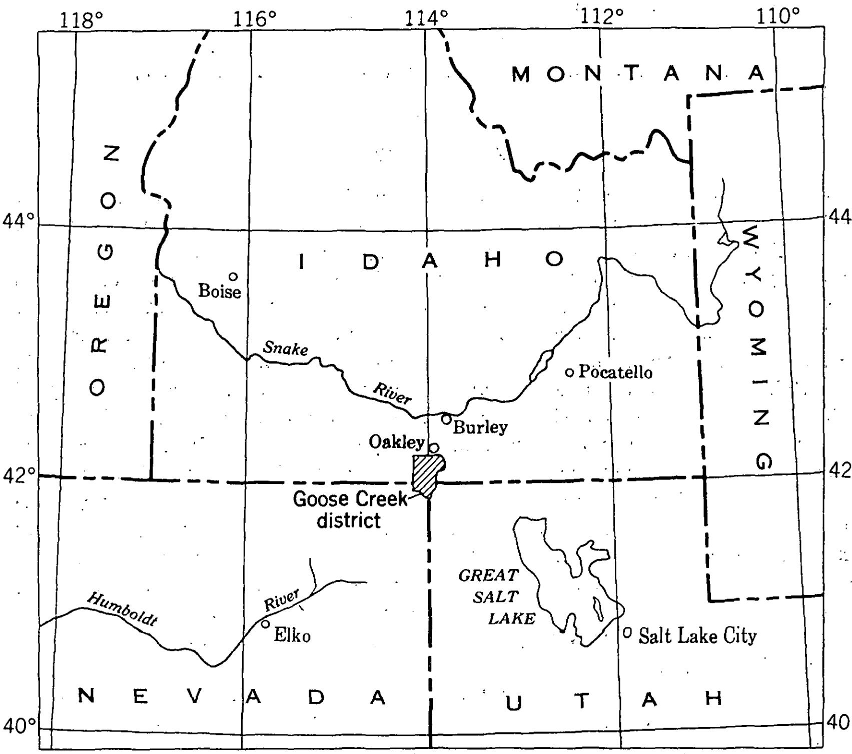


FIGURE 36.—Index map showing the location of the Goose Creek district.

The investigations began in September and October 1951, with a reconnaissance survey of the district by D. C. Duncan, W. J. Hail, Jr., and J. R. Gill. During the following summer, the writers, assisted by J. E. Conkin and J. N. Babcock, mapped the Tertiary rocks of the district on aerial photographs at a scale of about 1:30,000. The fieldwork was followed in August and September of 1953 by the rotary core-drilling of 13 shallow test holes in the central part of the district. Drilling was done by a private company under contract to the Geological Survey, and the drilling program was supervised by M. L. Troyer. Rock and water samples collected during the investigation were analyzed for uranium in the Geological Survey laboratories. J. M. Schopf and R. J. Gray studied the microscopic characteristics of the cores of radioactive lignite and carbonaceous shale from two of the drill holes and the results of their study have been reported separately (Schopf and Gray, 1954).

The base on which the geologic map was compiled was prepared by methods involving a radial plot. Control was established by planetable triangulation tied to U. S. Coast and Geodetic Survey triangulation points and Bureau of Land Management land corners.

PREVIOUS INVESTIGATIONS

Previous geologic investigations in the Goose Creek district include a reconnaissance survey of the lignite beds of the area by C. F. Bowen (1913); a study of the ground-water resources of the Goose Creek drainage basin by A. M. Piper (1923); and an investigation of the geology of the northeastern part of the district as a part of a geologic reconnaissance of eastern Cassia County, Idaho, by A. L. Anderson (1931).

GEOGRAPHY

The Goose Creek district covers the northern and central parts of an elongate northward-trending intermontane basin bordered on the west by an unnamed mountain range, on the southeast and east by the Goose Creek and South Mountains, and on the north by the Snake River Plain.

Steep-sided, even-topped buttes and mesas, and deep, narrow canyons characterize the land surface in the northern and central parts of the district. The surface in the southern part has less relief and in places is gently rolling, although locally it is intricately dissected by gullies and washes. Steep mountain slopes border the district on the east and southwest, but in the northwestern part the rough topography of the basin merges with that of the mountains, with no clear demarcations. Altitudes range from 7,450 feet on Hudson Ridge, in the northwestern corner of the district, to about 4,550 feet at the point where Goose Creek crosses the northern boundary.

Goose Creek, a large perennial tributary of the Snake River, flows northeastward across the area, and is the principal stream. Its chief tributary is Trapper Creek which drains much of the northern part of the district and enters Goose Creek near the northeastern corner. The valleys of both streams are narrow canyons near their confluence, but upstream they became broad and open. Both streams discharge into the Lower Goose Creek reservoir, which occupies the narrowest part of the Goose Creek valley and is about 4 miles long and ½ mile wide. Other perennial streams in the district, all tributary to Goose Creek, include Jay and Trout Creeks, which join Goose Creek from the west, and Cold, Little Pole, Birch, and Pole Creeks which join it from the east. Beaverdam Creek in the west-central part of the district and Hardister Creek in the southern part are the main intermittent streams.

Both the climate and the vegetation in the Goose Creek district are similar to those of other parts of northeastern Nevada and southern Idaho. The mean annual precipitation is about 10½ inches, and the mean temperature at Oakley ranges from about 29° F. in January to 71° F. in July. The vegetation reflects the aridity of the climate: sagebrush grows abundantly; juniper trees, growing singly or in clumps and thickets, are common; aspen and willows are found on high slopes or along the stream courses. Grass is sparse, but it is sufficient to provide grazing for sheep, cattle, and horses, and much of the land is utilized for this purpose. Some hay is grown on irrigated meadow lands in the valleys of Goose and Trapper Creeks, most of it being used for feed within the district.

The district is sparsely settled, having few permanent residents and no towns. Oakley, Idaho, with a population of about 800 is 3 miles north of the district. Burley, Idaho, with a population of about 6,000 is 22 miles north of Oakley and is the county seat of Cassia County.

A branch line of the Oregon Short Line (Union Pacific system) Railroad, and a paved highway connect Oakley and Burley. Graveled roads lead from Oakley up the valleys of Goose and Trapper Creeks. These roads and a network of dirt roads and trails provide access to most parts of the area.

STRATIGRAPHY

The present investigation was devoted primarily to a study of the Tertiary strata of the Goose Creek district. These rocks include the Payette(?) formation of Miocene or Pliocene age, and the overlying Salt Lake formation of Pliocene age. Older rocks were examined only where it was necessary to determine their structural and stratigraphic relations to the Tertiary sequence. They include a massive rhyolite porphyry of Tertiary(?) age, exposed in the mountains bordering the district on the southeast, and an undifferentiated pre-Tertiary sequence of limestone, quartzite, and shale, together with their metamorphic equivalents exposed in the mountains and hills bordering the district on the northeast, south, and west. Younger deposits of Quaternary age consist of alluvium along the present streams, slope wash, landslide material, and gravel deposits on high erosion surfaces.

The thickness and character of the rock formations exposed in the district are summarized in chart 1. Plate 46 shows their distribution.

CHART 1.—*Rocks exposed in the Goose Creek district*

System	Series	Rock type or formation	Character	Thickness (feet)
Quaternary	Recent and Pleistocene(?)	Alluvium and slope wash	Surficial deposits of silt, sand, and gravel on the flood plains of present streams or adjacent to steep mountain slopes.	0–80±
		Gravel deposits on high erosion surfaces	Surficial deposits of stream-worn pebbles and boulders, mainly of rhyolite and quartzite; lenses of sand and silt.	0–15
		—Unconformity—		
Tertiary	Pliocene	Salt Lake formation: Upper part	Interbedded white and grayish-orange volcanic ash, with a few lenticular beds of conglomerate; a thick, persistent bed of welded tuff is at the base.	700±
		Salt Lake formation: Lower part	Mainly white volcanic ash containing a few beds of shale, sandstone, and conglomerate; conspicuous beds of black to dark-reddish-brown welded tuff in the upper half; lenticular beds of uranium-bearing carbonaceous shale and lignite in the lower half.	1550±
	Pliocene - - - Miocene	Payette(?) formation.	Interbedded shale and volcanic ash, with some thin beds of sandstone and conglomerate; a few lenticular beds of carbonaceous shale and lignite.	900±
		—Unconformity—		
Tertiary(?)		Rhyolite	Massive dark-reddish-brown rhyolite porphyry.	
Carboniferous and older systems			Bluish-gray and light-gray cherty limestone; light-gray quartzite, quartz-mica schist, and marble; some dark shale.	

CARBONIFEROUS AND OLDER ROCKS, UNDIFFERENTIATED

Anderson (1934, p. 377) assigns the rocks that crop out in the mountains along the northeastern margin of the district to the Albion Range group of Precambrian age. North of Cold Creek, these rocks consist of well-stratified quartzite containing much muscovite; to the south, between Cold and Little Pole Creeks, the rocks are predominantly light-gray limestone or marble. Light-tan and dark-bluish-gray limestone, containing much dark chert, and some dark-gray to black shale crops out in the hills and mountains on the western side of the district, and in the vicinity of Birch and Hardister Creeks on the southeastern side. Similar rocks in nearby areas have been assigned by Anderson (1931, p. 30–35) to the Brazer limestone of Mississippian age, or to the Wells formation of Pennsylvanian age.

RHYOLITE OF TERTIARY(?) AGE

A thick massive rhyolite of porphyritic texture, much shattered by joints and fractures, crops out in the southeastern part of the mapped area from the vicinity of Birch Creek southward almost to Hardister Creek. Rhyolite is exposed also near the crest of a low hill in the southwestern part of the area between Jay and Trout Creeks. Samples collected from this formation by Piper were studied by E. S. Larsen who gives the following description (Piper, 1923, p. 27):

> These specimens are rather dense red-brown banded tridymite-quartz latites. * * * They carry about 20 percent of phenocrysts as much as 3 millimeters across, most of which are oligoclase feldspar. Quartz in resorbed crystals is abundant, and orthoclase, also resorbed is less abundant. Dark minerals are absent, though they may have been present in small amounts but are now decomposed. Magnetite and zircon are fairly abundant, and apatite is present. The groundmass in one specimen from Pole Creek is mostly a very fine sponge-like intergrowth of feldspar and tridymite with some coarser intergrowths and some unusually large crystals of tridymite in the porous parts. A little quartz is closely associated with the coarse tridymite in the porous parts, and the two look as if they were contemporaneous.

Although the specimens examined by Larsen were identified as quartz latites, Piper (1923) used the field term "rhyolite" for the rocks as a whole and this practice is continued in this report.

The rhyolite probably intrudes Carboniferous and older limestone beds north of Birch Creek, as evidenced by a sill of rhyolite in these older strata in secs. 21 and 28, T. 16 S., R. 22 E., Idaho. Peterson (1942, p. 471–472) described the rhyolite as intrusive into Paleozoic and older rocks in the Ashbrook silver mining district, about 3 miles east of the mapped area in the northwestern part of T. 14 N., R. 17 W., Utah.

The rhyolite is older than Pliocene, as it unconformably underlies sedimentary rocks of Pliocene age. Piper (1923, p. 26) regards it as early Miocene(?) in age, noting that a similar body of rhyolite of probable Miocene age was described by Schrader (1912, p. 35–47) in the Jarbidge mining district, about 50 miles to the west.

SEDIMENTARY ROCKS OF TERTIARY AGE

Sedimentary rocks of Tertiary age exposed in the district consist of a basal series of Miocene or Pliocene age, made up mostly of shale and volcanic ash in about equal amounts, and an overlying predominantly pyroclastic series of Pliocene age made up mostly of volcanic ash and welded rhyolitic tuff. On the basis of lithology, stratigraphic position, and age, the lower sequence is tentatively correlated with the Payette formation as described by Kirkham (1931a, p. 232–234) in the Boise area of southwestern Idaho; and on the basis of lithology and stratigraphic position, the upper pyroclastic sequence is tentatively correlated with the Pliocene Salt Lake formation as described by Mansfield (1920, p. 54–55; 1927, p. 110–112) in and near the Fort Hall Indian Reservation in southeastern Idaho. Anderson (1931, p. 41–44) has pointed out the similarity in lithology and stratigraphic position of the Tertiary rocks of the Goose Creek area to both the Payette and Salt Lake formations. According to Anderson, welded tuffs in the upper part of the Tertiary sequence near Goose Creek are part of an essentially continuous sheet of rhyolitic rocks which overlies the lacustrine and fluviatile sediments of the Payette formation south of Boise in southwestern Idaho, and are interbedded with volcanic ash and clastic rocks in the upper part of the Salt Lake formation near the Fort Hall Indian Reservation and adjacent parts of southeastern Idaho. Kirkham (1931b, p. 580–581) notes the same stratigraphic relations of the Payette and Salt Lake formations, and both writers conclude that the two formations are essentially equivalent. In a more recent paper, Mansfield (1952, p. 46, 59) reported the discovery of two species of plants (*Phragmites* sp. and *Castalia* sp.) in beds of carbonaceous shale associated with welded rhyolitic tuffs near Idaho Falls. F. H. Knowlton, who identified the fossils, considered them to be Pleistocene in age, although his conclusion was not based on positive criteria. If the conclusion is correct, it indicates that the welded tuffs which are interbedded with and overlie the Salt Lake formation in parts of southeastern Idaho may be younger than those in the Goose Creek district and in nearby parts of south-central and southwestern Idaho.

In Cache Valley, eastern Box Elder County, Utah, and the adjacent part of Idaho—about 90 miles east of the Goose Creek district—several writers have described a sequence of as much as 9,000 feet of light-colored tuff, limestone, sandstone, and conglomerate of middle and late Pliocene age called the Salt Lake group and divided by Adamson, Hardy, and Williams (1955) into the Collinston conglomerate, Cache Valley formation, and Mink Creek conglomerate. These rocks apparently are mostly younger than the Salt Lake formation in the Goose Creek district.

On the basis of lithologic similarity and age, the Tertiary rocks of the Goose Creek district might also be correlative with some part of the Humboldt formation, which, as described by Sharp (1939) in the vicinity of Elko and Wells in northeastern Nevada, includes a sequence of fluviatile, lacustrine, and pyroclastic deposits, at least 5,000 feet thick, of Miocene and possibly early Pliocene age. Sharp (p. 150) suggests that the Humboldt formation crops out as far north as Contact, Nev., which is about 40 miles southwest of the Goose Creek district.

The stratigraphic names that have been used for the Tertiary rocks of the Goose Creek district in earlier reports, and the approximate correlation of the Tertiary sequence with some rocks of Miocene and Pliocene age described in other parts of southern Idaho and northeastern Nevada, are summarized by charts 2 and 3. The lithologies of the Payette(?) and Salt Lake formations and the correlation of beds at various places within the district are shown by plate 47.

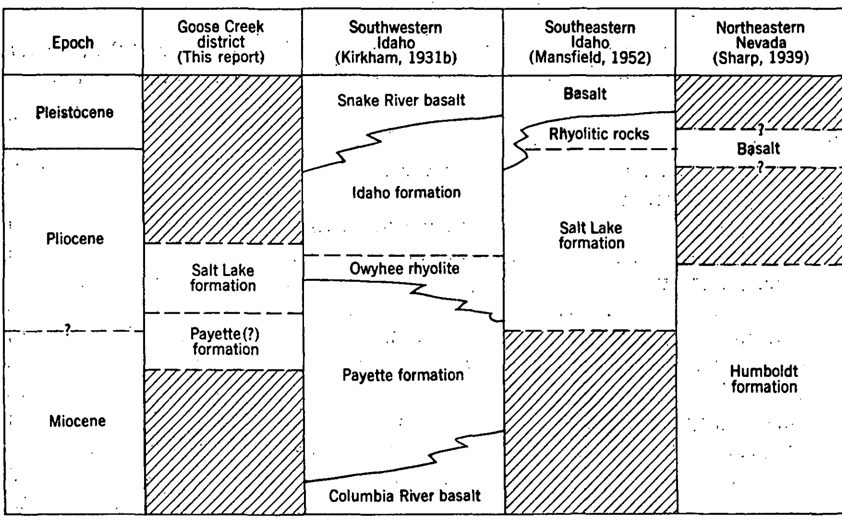
PAYETTE(?) FORMATION

Rocks similar in many respects to the Payette formation crop out in the western part of the Goose Creek district in the valley of Trapper Creek, and in a wide band between the Right Hand Fork of Beaverdam Creek and Jay Creek. These rocks, here designated the Payette(?) formation, consist of interbedded tuffaceous shale and volcanic ash, with lesser amounts of conglomerate, sandstone, and

CHART 2.—*Stratigraphic names used by various writers for the Tertiary rocks exposed in the Goose Creek district.*

<table>
<tr><th>Lithology</th><th colspan="2">Bowen (1913)</th><th colspan="2">Piper (1923)</th><th>Anderson (1931)</th><th colspan="2">This report</th></tr>
<tr><td>Volcanic ash and conglomerate</td><td colspan="2">Not described</td><td colspan="2">Not described</td><td>Not described</td><td rowspan="3">Salt Lake formation</td><td rowspan="2">Upper part</td></tr>
<tr><td>Volcanic ash and welded tuff; some conglomerate</td><td rowspan="3">Tertiary rocks</td><td>Upper division</td><td rowspan="3">Late Miocene rocks</td><td>Upper division</td><td>Quartz latite</td></tr>
<tr><td>Mostly volcanic ash; some shale, sandstone, and conglomerate</td><td rowspan="2">Lower division</td><td rowspan="2">Lower division</td><td rowspan="2">Salt Lake or Payette formation</td><td>Lower part</td></tr>
<tr><td>Mostly shale and volcanic ash; some sandstone and conglomerate</td><td colspan="2">Payette(?) formation</td></tr>
</table>

CHART 3.—*Approximate correlation of some rocks of Tertiary and Quaternary age in southern Idaho and northeastern Nevada, as described by several writers.*



lignite. The thickness of the Payette(?) is not uniform, owing to its deposition on an uneven surface of Carboniferous and older rocks, but it is at least 900 feet thick near Dry Gulch in the west-central part of the mapped area, where all but the basal part was measured. About 200 feet of strata assigned to the Payette(?) formation crops out in the valley of Trapper Creek, but there only the upper part of the formation is exposed. Except for some of the beds of conglomerate, the formation erodes easily and forms gentle slopes and flats.

About 50 percent of the Payette(?) formation is slabby, evenly bedded, light greenish gray and yellowish-gray tuffaceous shale. At some places the shale is diatomaceous; fossil leaves and seeds are abundant in some beds, and the formation contain several lenses and thin beds of brown carbonaceous shale and lignite. Interbedded with the shale and making up most of the rest of the formation are beds of friable light-gray to white volcanic ash which range in thickness from a few inches to more than 100 feet. Beds of sandstone or conglomerate, locally as much as 40 feet thick, occur at various levels in the formation; their resistance to erosion makes them useful key beds for mapping and correlation. The coarse fragments in the beds of conglomerate are subrounded pebbles and cobbles of limestone and chert, commonly 1–4 inches in their longest dimension, derived from the older formations cropping out to the west of the area. Many of the conglomerate beds are lenses that pinch out within a few hundred yards, but a few are more widespread and may be traced for several miles.

The following stratigraphic section (see columnar section 2 of plate 47) shows the character of the Payette(?) formation.

Section of part of the Payette(?) formation exposed near Dry Gulch, center of sec. 10 to NW¼ sec. 13, T. 16 S., R. 20 E., Cassia County, Idaho

	Feet
Salt Lake formation:	
Volcanic ash, light-gray, partly covered	20+
Payette(?) formation:	
Shale, greenish-gray, fissile; contains plant and fish remains	14
Mostly covered; probably volcanic ash	15
Shale, light-gray, fissile, tuffaceous; grades downward to silty light-gray claystone	9
Volcanic ash, light-gray, partly covered	16
Shale, olive-brown, slightly carbonaceous; contains fossil leaves	6
Covered	12
Shale, grayish-green, fissile, tuffaceous	4
Claystone and shale, grayish-green to brown; contains *Equisetum* sp	6
Mostly covered; in part light-gray volcanic ash	32
Shale, greenish-gray, weathers white, fissile, tuffaceous; abundant fish vertebrae	3
Claystone, light-gray, tuffaceous	5
Mostly covered; in part, light-gray volcanic ash	36
Shale, light-gray, fissile, brittle, tuffaceous, abundant *Equisetum* sp	27
Siltstone, brown, carbonaceous	1
Volcanic ash, brownish-gray and light-gray, friable, nonresistant	37
Sandstone, light-gray, fine- to medium-grained, tuffaceous; forms a ledge	3
Siltstone, yellowish-gray, very tuffaceous; contains plant fragments and some interbedded shale	12
Volcanic ash, light-gray, contains lenses and partings of sandstone and siltstone	14
Shale, yellowish-gray, tuffaceous, fissile, slightly carbonaceous; 4-foot bed of light-gray volcanic ash near middle	18
Shale, brown, carbonaceous	1
Sandstone, gray, very fine grained, micaceous, grades upward to gray shale	4
Shale, brown, carbonaceous	4
Shale, grayish-green and brown, tuffaceous, fissile; contains numerous fish bones	12
Sandstone, yellowish-gray, fine- to medium-grained, tuffaceous	8
Shale, brown, carbonaceous; contains a few streaks of dark-brown to black lignite; uppermost 1 foot is silty	5
Claystone, yellowish-gray, tuffaceous; contains a 1-foot bed of brown carbonaceous shale near the base	13
Volcanic ash, light-gray to white, massive; forms a bluff	130
Shale, light grayish-green, tuffaceous, silty in upper part; contains abundant leaf impressions and fish bones	27

Section of part of the Payette(?) formation exposed near Dry Gulch, center of sec. 10 to NW¼ sec. 13, T. 16 S., R. 20 E., Cassia County, Idaho—Continued

	Feet
Payette(?) formation—Continued	
Worthington zone:	
Shale, brown, carbonaceous	3
Sandstone, yellowish-brown, fine-grained, tuffaceous; contains a few partings of brown carbonaceous shale	21
Shale, medium- to dark-brown, carbonaceous	8
Volcanic ash, light-gray	6
Shale, brown, carbonaceous	5
Shale and volcanic ash, in alternating thin to medium beds, light-gray	17
Volcanic ash, light-gray; upper part forms a ledge	35
Covered	27
Shale, light-gray, very tuffaceous; contains a few fish bones and leaf impressions	26
Covered	10
Volcanic ash, light-gray; poorly exposed	5
Shale, brown, carbonaceous; grades downward to gray shale	2
Volcanic ash, light-gray	14
Covered	9
Conglomerate, pebbles of limestone, chert, and shale in a matrix of volcanic ash; forms a ledge	11
Shale, gray and yellowish-gray, very tuffaceous	30
Shale, brown, carbonaceous; contains a few streaks of dark-brown to black lignite	3
Volcanic ash, light-gray, shaly and sandy	24
Siltstone, brown, carbonaceous	4
Volcanic ash, yellowish-gray	3
Conglomerate, pebbles of chert, limestone, silicified wood, and shale in a matrix of tuffaceous sandstone; forms a ledge	16
Volcanic ash, tuffaceous siltstone, and sandstone, interbedded, light-gray; contains a few partings of brown carbonaceous shale	48
Covered	8
Shale, grayish-brown, slightly carbonaceous	6
Sandstone, light yellowish-gray, coarse-grained, tuffaceous	5
Shale, gray, tuffaceous; contains abundant plant fossils	15
Volcanic ash, light-gray	16
Claystone, greenish-gray	6
Total, measured part of the Payette(?) formation	855

Fossils collected from the Payette(?) formation include well-preserved diatoms, leaves and seeds, and some spores and pollen. K. E. Lohman regards the age of the diatoms as early Pliocene, and R. W. Brown regards the age of the leaves and seeds as late Miocene. Spores and pollen that were collected are undiagnostic. The fossils are listed below.

Diatoms collected 5–75 feet stratigraphically below the top of the Payette(?) formation near Trapper Creek in the NE¼ sec. 2, T. 15 S., R. 20 E., Idaho (fossil locality 1, pl. 46); identified by K. E. Lohman:

[Relative abundance: C, common; F, frequent; R, rare]

	Relative abundance
Achnanthes lanceolata Brebisson	R
A. lanceolata var. *elliptica* Cleve	F
A. sp.	R
Amphora commutata Grunow	R
Cocconeis sp.	R
Coscinodiscus cf. *C. subaulacodiscoidalis* Rattray	C
C. sp.	C
Cymbella tumida (Brebisson) Van Heurck	F
Eunotia valida Hustedt	R
Fragilaria construens (Ehrenberg) Grunow	F
F. pinnata Ehrenberg	F
F. sp.	R
Melosira distans (Ehrenberg) Grunow	F
Gyrosigma sp.	R
Melosira distans (Ehrenberg) Kützing	C
M. distans var. *alpigena* Grunow	R
M. distans var. *lineata* (Ehrenberg) Bethge	F
M. granulata (Ehrenberg) Ralfs	C
M. granulata var. *procera* (Ehrenberg) Grunow	F
M. italica (Ehrenberg) Kützing	R
M. sp.	R
Navicula discephala (Ehrenberg) Wm. Smith	R
N. scutelloides Wm. Smith	F
N. subhexagona Hustedt	R
N. sp.	R
Opephora martyi Heribaud	F
Pinnularia sp.	R
Tetracyclus cf. *T. javanicus* Hustedt	R
T. lacustris Ralfs	F
T. cf. *T. pagesi* Hergaud	R
T. rupestris (Brun) Grunow	R

Leaves and seeds collected from the same locality as above (fossil locality 1); identified by R. W. Brown:

Abies laticarpus MacGinitie
Pinus sp.
Picea sp.
Pseudotsuga masoni MacGinitie
Sequoia affinis Lesquereaux
Populus eotremuloides Knowlton
Alnus carpinoides Lesquereaux
Pterocarya? sp.
Zelkova oregoniana (Knowlton) Brown
Quercus browni Brooks
Q. consimilis Newberry
Q. simulata Knowlton
Acer bendirei Lesquereaux
A. glabroides Brown
A. osmonti Knowlton
A. scottiae MacGinitie
Fraxinus idahoensis Brown

Leaves and seeds collected about 450 feet stratigraphically below the top of the Payette(?) formation near the Worthington mine in the SW¼ sec. 23, T. 16 S., R. 20 E., Idaho (fossil locality 2, pl. 46); identified by R. W. Brown:

Pseudotsuga masoni MacGinitie
Alnus carpinoides Lesquereaux
Acer bendirei Lesquereaux
A. scottiae MacGinitie

Commenting on the diatoms, Lohman states (written communication, 1953):

> This assemblage of diatoms was probably deposited in a cool fresh-water lake of moderate depth. It bears a striking resemblance to an assemblage obtained from a lower Pliocene diatomite on the east slope of the Cedar Mountains, Nye County, Nevada. The age of the Cedar Mountain beds was established by a large lower Pliocene vertebrate fauna obtained there by the University of California. *Coscinodiscus* spp. from the Goose Creek district are identical with two of the new species known from the Cedar Mountain beds. The same is true of several of the other unidentified species. Based on comparison with the diatom floras from the Cedar Mountains and elsewhere, I

believe that the shale from the Goose Creek district represented by the sample submitted is early Pliocene in age.

Brown makes the following statement regarding the leaves and seeds (written communication, Jan. 26, 1954):

> The species here identified are individually, but not necessarily collectively, found in the Latah and Payette floras of Washington and Idaho, the Hog Creek flora of western Idaho, the Trout Creek, Sucker Creek, and Mascall floras of central and eastern Oregon. Some of the species have also been found in the Alvord Creek flora of southeastern Oregon, which is said to be early Pliocene in age. Perhaps there is not enough evidence here for drawing a sharp line between late Miocene and early Pliocene, but my inclination, after seeing the stratigraphic relations in the field, is to regard the flora as latest Miocene in age.

SALT LAKE FORMATION

The Salt Lake formation forms the surface of most of the district. It consists largely of friable volcanic ash, with several beds of welded rhyolitic tuff near the middle, and, at various levels, some beds of shale, sandstone, conglomerate, lignite, and limestone. For convenience in showing its distribution, the formation is divided into two parts at the base of the stratigraphically highest persistent bed of welded tuff. The formation is at least 2,300 feet thick, and about 1,200–1,600 feet of the sequence is assigned to the lower part (pl. 48, *A*).

Most of the welded tuff in the Salt Lake formation occurs in four main beds, which range in thickness from less than 10 feet to as much as 250 feet. In general, the beds of welded tuff are thickest in the northern part of the district, where, north of Trapper Creek, they tend to merge. They thin gradually and irregularly southward. They are resistant to erosion and crop out as ledges and steep cliffs in the northern part of the district and as hogbacks in the southern part.

Previous investigators in the Goose Creek district referred to the beds of welded tuff as rhyolite flows. However, the rock is not a crystalline rhyolite, but is composed largely of glass shards and the texture is similar in all respects to the welded rhyolitic tuffs described by Mansfield and Ross (1935) in and near the Fort Hall Indian Reservation. Commonly, the basal part of each of the beds of welded tuff is a layer of black obsidian that ranges in thickness from a few inches to as much as 10 feet. At many places its contact with the underlying beds of volcanic ash is gradational within an interval of 1–6 inches. The obsidian commonly grades upward to a dense, stony, black to dark reddish-brown rock which locally is highly vesicular (pl. 49, *A*). Fragments of feldspar and spherical aggregates of tridymite occur in both rock types.

Ross (*in* Mansfield, 1952, p. 51–52) gives the following description of the composition, texture, and origin of welded tuffs in southeastern

Idaho which probably applies equally well to the welded tuffs of the Goose Creek district:

> Most of the pyroclastic rhyolitic materials show various degrees of welding and distortion of the tuff fragments, due to various degrees of accommodation of the shape of one grain to another while still in a plastic condition. That is, the rhyolitic materials from the Idaho region show a typical eutaxitic texture as described and pictured by Iddings (1909, v. 1, p. 331–333) from the Yellowstone region.
>
> The degree of plasticity of the grains after their fall varied greatly. In many specimens the plasticity was so great that the tuff fragments have become completely welded and are very greatly elongated in one direction. There is, however, no indication of more than slight flowage after fall and welding. In a few specimens there is welding, but only slight accommodation of the shape of one grain to another. In other specimens, the original porosity has been partially eliminated and in many of them it has been almost completely eliminated.
>
> Tuff grains are commonly fragments of broken bubbles and glassy plates; moon-shaped fragments, Y-shapes and occasional hollow spheres are to be observed. * * * The completely collapsed and welded fragments are now in the form of wavy plates or grotesquely distorted forms, but occasionally even these show a typical Y-shaped form. * * *
>
> The completeness of devitrification, the character of the minerals formed (feldspar and tridymite), and the terminated crystals projecting into cavities, are all phenomena indicative of crystallization in the presence of hot gases * * * The strong evidence of a gas-phase control of crystallization and heat adequate to maintain the tuff fragments in a plastic condition during wide dispersion from their volcanic vent suggests comminution and distribution under the influence of a blast of hot gases (nuées ardentes) as described by Lacroix (1904), at Pelée, and by Fenner (1923) for the Valley of Ten Thousand Smokes. However, the eutaxitic tuffs of the Idaho region do not show that heterogeneity that is supposed to characterize nuées ardentes deposits. A large proportion of the fragments are fairly well sorted with only an occasional grain or phenocryst markedly exceeding average size. It, therefore, seems probable that the eutaxitic material of the Idaho region was distributed by blasts of hot gas, but was blown so high and so far from the vent that a very fair degree of sorting occurred. In much of the material that fell under these conditions there was welding of the grains, very commonly a complete fusion together of the grains, and elimination of porosity. Commonly, enough hot gas was present after the fall and welding of the grains to promote devitrification.

Photomicrographs of friable volcanic ash and welded tuff from the Goose Creek district are shown together for comparison on plate 49 *B* and *C*. Chemical analyses of the ash and welded tuff are shown by table 1.

A few thin beds of hard resistant welded tuff in the upper part of the Salt Lake formation are light gray to white. Unlike the welded tuffs described above, the pyroclastic texture of the rock is evident in hand specimens and these beds grade laterally into friable volcanic ash within a few hundred yards.

In most parts of the district, the thick beds of welded tuff maintain relatively uniform stratigraphic positions and so are useful for struc-

TABLE 1.—*Chemical analyses of welded tuff and volcanic ash, Goose Creek district, Cassia County, Idaho*

Location			Description	Laboratory-sample No.	Analysis [a] (percent)																		
Sec.	T.	R.			SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O-	H_2O+	H_2O	TiO_2	CO_2	P_2O_5	Cl	F	S	MnO	BaO
			Salt Lake formation, lower part																				
32	14 S.	20 E.	Welded tuff	B331 [b]	71.24	12.72	2.92	1.09	0.27	2.03	3.16	4.47	0.33	0.18	-----	0.51	0.40	0.09	0.02	0.03	0.01	0.07	0.10
NE¼SE¼ 24	13 S.	21 E.	Volcanic ash	147766 [c]	73.7	10.6	1.1	.64	.14	1.0	.92	5.0	-----	-----	6.8	.18	<.05	.02	-----	-----	-----	.02	-----
Do.			do.	147767 [c]	66.4	14.8	2.5	1.8	1.9	1.1	1.1	6.1	-----	-----	2.9	.62	.06	.12	-----	-----	-----	.04	-----
NW¼NW¼ 25	14 S.	21 E.	do.	B445 [b]	-----	-----	-----	-----	-----	-----	2.16	5.71	.33	4.49	-----	-----	-----	-----	-----	.094	-----	-----	-----
SW¼ 26	14 S.	21 E.	Shards from sample of volcanic ash.	B446 [b]	-----	-----	-----	-----	-----	-----	2.64	6.37	.28	3.31	-----	-----	-----	-----	-----	.146	-----	-----	-----
SW¼ 6	14 S.	21 E.	do.	B447 [b]	-----	-----	-----	-----	-----	-----	1.67	5.74	1.18	4.85	-----	-----	-----	-----	-----	.97	-----	-----	-----
			Payette(?) formation																				
NE¼NW¼ 2	15 S.	20 E.	Volcanic ash	B413 [b]	71.43	11.63	0.84	0.95	0.12	0.65	1.10	6.22	0.39	6.10	-----	0.19	-----	0.01	-----	0.09	0.02	0.03	0.07

[a] Analysts: sample B331, Jean Theobald; samples 147766 and 147767, P. L. D. Elmore, K. E. White, and S. D. Botts; samples B445–B447, L. N. Tarrant and F. H. Neuerburg; sample B413, L. N. Tarrant and E. J. Tomasi.

[b] Sample collected from outcrop by H. A. Powers.

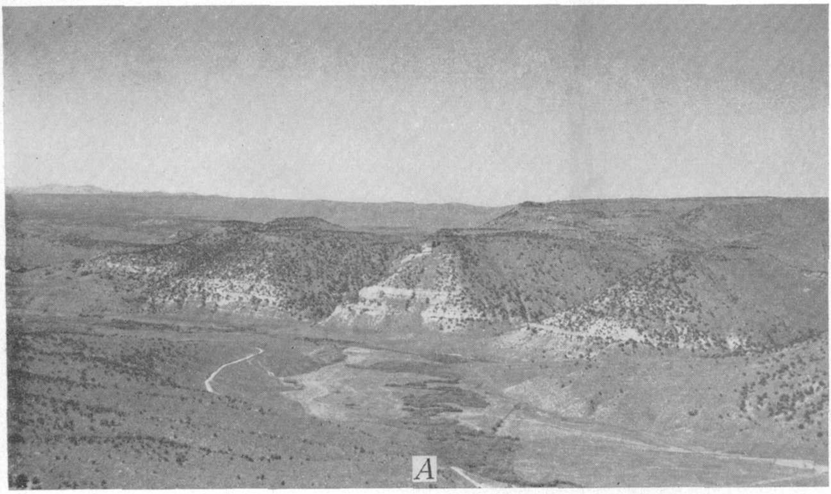
[c] Sample collected from drill cores, hole C 1, by N. M. Denson and J. R. Gill.

tural control. At some places, however, the welded tuff at the base of the upper part of the Salt Lake formation rests on an uneven surface that locally may have a relief of as much as 400 feet in 2 to 3 miles. Thus in secs. 19 and 20, T. 15 S., R. 22 E., and in secs. 13, 14, and 28, T. 15 S., R. 21 E., Idaho, the uppermost bed of welded tuff merges with the bed of tuff normally 200 to 300 feet stratigraphically below it; and at Flatiron Butte, in secs. 33 and 34, T. 16 S., R. 21 E., Idaho, the thickness of the interval between the welded tuff which caps the butte and the next lower bed of tuff exposed on the side of the butte is nearly 400 feet less than its thickness between the equivalent beds about 3 miles to the northwest.

The volcanic ash which, together with welded tuff, makes up a large part of the Salt Lake formation is white to light gray and fairly well stratified in the lower part of the formation, becoming predominantly grayish orange and poorly stratified in the upper part. Some of the beds are thinly laminated, others are massive, and a few are cross-bedded. Fine-grained shards make up most of the beds, but a few contain, in addition, numerous small fragments of spongy white pumice. The ash is friable, and small pieces may be crushed between the fingers; however, some of the beds are fairly resistant to erosion, and locally the ash stands in rounded ledges or in nearly vertical cliffs (pl. 48*A*).

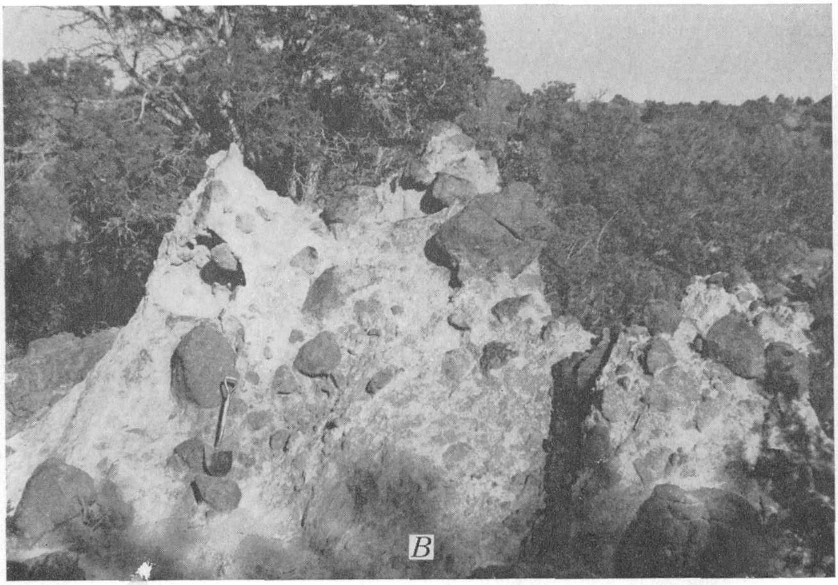
In the vicinity of Birch and Pole Creeks, the darker ash in the upper part of the formation locally contains numerous angular fragments of welded tuff as much as 1 foot in the longest dimension. These fragments are unsorted and are scattered in the ash matrix with only the crudest alinement in beds. Parts of these deposits, including the tuff fragments, may have been eroded from rising fault blocks of the lower part of the Salt Lake formation to the east, carried westward, and reincorporated in the upper part of the formation as mud flows or alluvium. In the SE¼ sec. 31, T. 16 S., R. 22 E., beds of white volcanic ash in the Salt Lake formation contain scattered subrounded boulders of Tertiary(?) rhyolite as much as 3 feet in diameter (pl. 48*B*). Adjacent to this deposit is Tertiary(?) rhyolite separated from the Salt Lake formation by a fault. Movement along this fault during deposition of the Salt Lake formation may have produced a scarp from which the boulders were shed as talus.

Lenticular beds of conglomerate, ranging in thickness from a few inches to 50 feet occur in both the lower and upper parts of the Salt Lake formation. In general, the beds are thickest and most numerous, and their constituent rock fragments are largest, near the mountains bordering the district on the east. Pebbles of quartzite, limestone, and chert make up most of the conglomerate in the lower part of the formation; pebbles and cobbles of rhyolite predominate in conglomerate in the upper part.

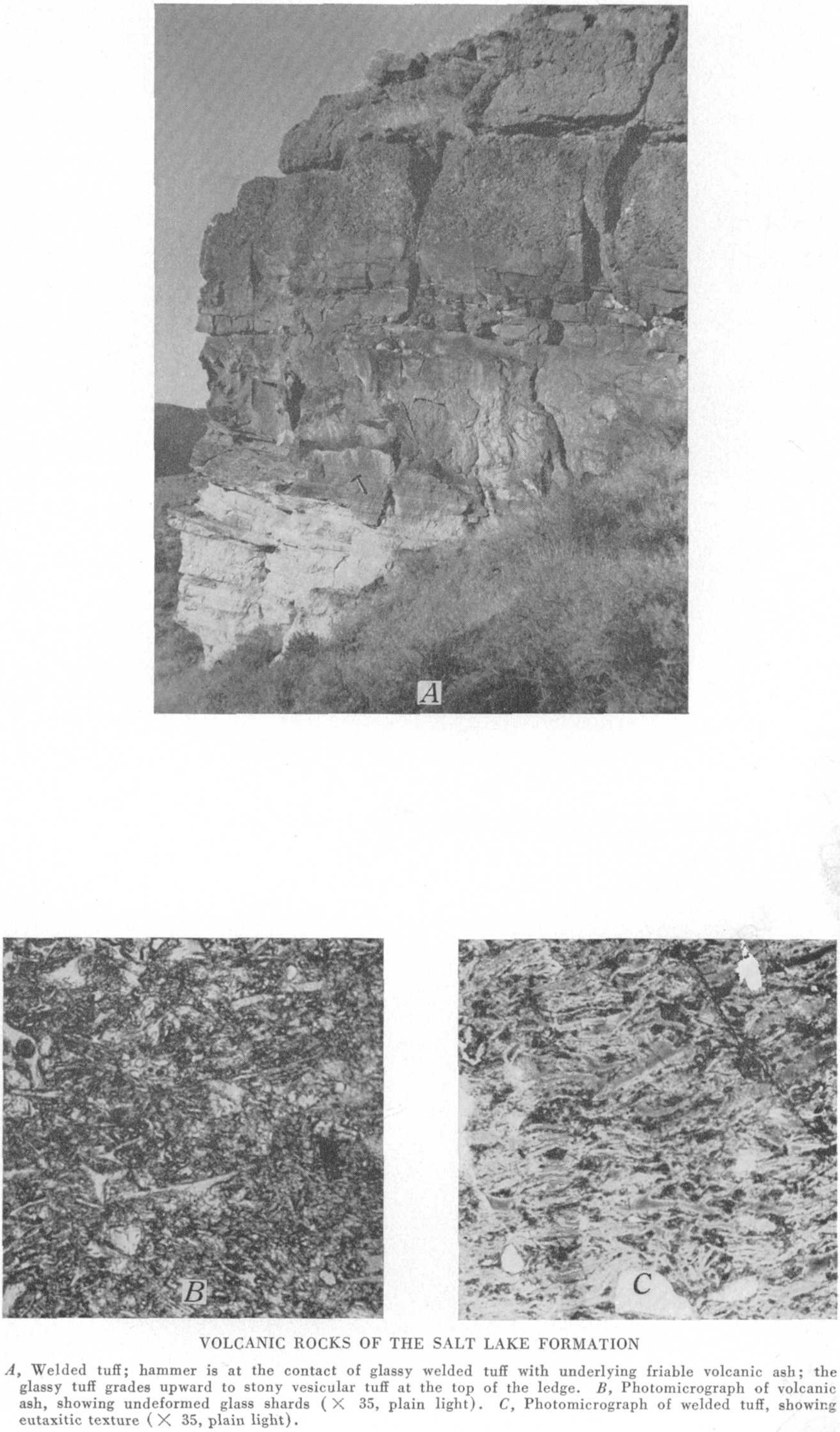


A. LOWER PART OF THE SALT LAKE FORMATION EXPOSED IN THE VALLEY OF GOOSE CREEK, T. 16 S., R. 21 E., IDAHO

Beds of welded tuff cap the high bluffs on the far side of the stream.



B. BOULDERS OF TERTIARY(?) RHYOLITE IN VOLCANIC ASH OF THE SALT LAKE FORMATION, SE¼ SEC. 31, T. 16 S., R. 22 E., IDAHO



VOLCANIC ROCKS OF THE SALT LAKE FORMATION

A, Welded tuff; hammer is at the contact of glassy welded tuff with underlying friable volcanic ash; the glassy tuff grades upward to stony vesicular tuff at the top of the ledge. *B*, Photomicrograph of volcanic ash, showing undeformed glass shards (× 35, plain light). *C*, Photomicrograph of welded tuff, showing eutaxitic texture (× 35, plain light).

Grayish-green shale similar to that which makes up much of the underlying Payette(?) formation occurs also in the Salt Lake formation, particularly in the lower part, in the area south of Beaverdam Creek. Beds of brown carbonaceous shale and lignite also occur in the lower part of the formation at several horizons.

Light-colored argillaceous limestone in beds as much as 3 feet thick crop out locally in the lower part of the formation near Hardister Creek. None of the beds of limestone is persistent for more than a few hundred yards, and limestone is a very minor constituent of the formation.

Bentonite and bentonitic volcanic ash resulting from the devitrification of volcanic glass and its alteration to clay occur in the lower part of the formation, particularly in the central and southern parts of the district. Much of the bentonite and bentonitic volcanic ash have a granular texture, and in hand specimens shardlike outlines are plainly visible, but some of the bentonite is a dense homogeneous clay in which individual grains cannot be distinguished. The bentonite beds range in thickness from a few inches to as much as 20 feet.

The base of the Salt Lake formation in the vicinity of Trapper Creek is a thick sequence of friable volcanic ash which rests on the underlying shale of the Payette(?) formation with a slight angular unconformity. Southward from the Right Hand Fork of Beaverdam Creek, the basal part of the Salt Lake becomes increasingly shaly, and the position of the contact, which here appears conformable, was determined arbitrarily by the correlation of conglomerates. The Salt Lake formation overlaps the Payette(?) formation along the western, southern, and eastern sides of the district, and locally parts of the Salt Lake formation rest directly on Carboniferous and older rocks or on Tertiary(?) rhyolite.

The following stratigraphic sections of the upper part (columnar section 5, pl. 47) and the lower part (columnar section 8, pl. 47) of the Salt Lake formation show its general character.

Composite stratigraphic section of the upper part of the Salt Lake formation west of Pole Creek, SE¼ sec. 26 and NE¼ sec. 35, T. N., R. 19 W., Box Elder County, Utah

	Feet
Top of hill.	
Surficial gravel deposit consisting of pebbles, cobbles, and boulders of rhyolite, chert, and limestone	10
Upper part of the Salt Lake formation (part):	
Volcanic ash, grayish-orange, irregularly bedded; beds of light-gray volcanic ash, each about 3 feet thick, occur 40 feet, 70 feet, and 240 feet above base	280
Conglomerate, pebble-sized fragments of black and light-gray welded tuff in a matrix of grayish-orange volcanic ash; forms a lenticular ledge	4
Partly covered; mostly light-gray volcanic ash grading upward to grayish-orange volcanic ash in the uppermost 20 feet	120

Composite stratigraphic section of the upper part of the Salt Lake formation west of Pole Creek, SE¼ sec. 26 and NE¼ sec. 35, T. 15 N., R. 19 W., Box Elder County, Utah—Continued

	Feet
Upper part of the Salt Lake formation (part)—Continued	
Welded tuff, grayish-white; 2-foot bed of less-resistant grayish-white volcanic ash in middle of the unit; upper and lower parts form irregular, pitted ledges	5
Volcanic ash, light-gray, crossbedded	4
Volcanic ash, grayish-orange; contains angular fragments of white pumice and gray and black welded tuff, the largest of which are 2 inches in maximum dimension	5
Partly covered; mostly friable grayish-white volcanic ash	65
Welded tuff, grayish-white; weathers to a rough, pitted surface; forms a ledge	7
(Section is offset ½ mile north on the base of above unit.)	
Poorly exposed; in part, friable grayish-white volcanic ash	38
Welded tuff, grayish-white; forms a jagged cavernous ledge	6
Covered interval	40
Welded tuff, black, glassy; forms a minor ledge	3
Mostly covered; in part, friable grayish-white volcanic ash	100
Welded tuff, black and dark reddish-brown, stony; forms a conspicuous blocky ledge. The base of this unit is covered and is the base of the upper part of the Salt Lake formation	23
Total measured section, upper part of the Salt Lake formation	710

Composite stratigraphic section of the lower part of the Salt Lake formation near Hardister Creek, sec. 21, T. 14 N., R. 19 W., Box Elder County, Utah, and secs. 29, 30, and 31 (approx.), T. 47 N., R. 70 E., Elko County, Nevada

	Feet
Upper part of the Salt Lake formation (part):	
Welded tuff, dark-gray to black, weathers dark reddish-brown, dense, blocky; forms the crest of a narrow ridge	12
Lower part of the Salt Lake formation:	
Covered interval	65
Volcanic ash, grayish-white, friable, thin- to medium-bedded, in part crossbedded	35
Volcanic ash, grayish-orange and grayish-white	14
Volcanic ash, grayish-white; a few thin beds of grayish-orange volcanic ash in the upper part; in part crossbedded	180
Welded tuff, black, stony to glassy; basal 1 foot grades downward to grayish-white volcanic ash; forms a minor ledge	3
Partly covered; mostly friable grayish-white volcanic ash	50
Limestone, grayish-white, argillaceous, abundantly fossiliferous; forms a ledge	3½
Volcanic ash, grayish-white, friable, thin- to medium-bedded	120
(The part of the section described below is offset ¾ mile south at top of its uppermost unit.)	
Welded tuff, uppermost ½-foot is pink and pumiceous; lower 2 feet is black, stony, and blocky; forms a ledge	2½
Volcanic ash, grayish-white; contains several thin layers composed largely of sand-sized fragments of black welded tuff	5
Welded tuff, black; uppermost 3 feet is stony and slabby, lower 8 feet is glassy and perlitic; forms a prominent ledge	11

Composite stratigraphic section of the lower part of the Salt Lake formation near Hardister Creek, sec. 21, T. 14 N., R. 19 W., Box Elder County, Utah, and secs. 29, 30, and 31 (approx.), T. 47 N., R. 70 E., Elko County, Nevada—Continued

	Feet
Lower part of the Salt Lake formation—Continued	
Volcanic ash, grayish-white, thin- to thick-bedded, some beds are crossbedded	190
Bentonite, light-gray to light yellowish-gray	9
Volcanic ash, grayish-white, friable	20
Covered	50
Volcanic ash, grayish-white, friable	30
Shale, dark greenish-gray, silty and sandy	15
Barrett zone:	
Shale, brown, carbonaceous	½
Shale, greenish-gray; contains a few thin seams of brown carbonaceous shale in the lower part	9
Limestone, light-tan, grading downward to greenish-gray, argillaceous; contains abundant small gastropods; forms a ledge	5
Bentonite, yellow	2
Limestone, light-tan, argillaceous; contains abundant small gastropods	4
Shale and siltstone, interbedded; dark-greenish-gray; contains a few thin beds of yellowish-gray bentonite and 2 thin beds of light-tan argillaceous limestone	65
Sandstone, dark grayish-yellow, fine-grained	4
Partly covered; in part, grayish-green shale, siltstone, and sandstone; shale at the top of the interval contains small gastropods and pelecypods	65
Shale, greenish-gray, fissile, brittle; contains a few leaf impressions	25
Sandstone, light-gray, fine-grained, tuffaceous, crossbedded; forms a ledge	6
Volcanic ash, light-gray; and light yellowish-gray bentonite; thin bedded; contains a few thin beds of grayish-green bentonite	120
Bentonite, light yellowish-gray	8
Covered	5
Total measured section, lower part of the Salt Lake formation	1,120
Carboniferous and older rocks, undifferentiated:	
Limestone, grayish-brown, finely crystalline; contains stringers of gray and brown chert.	

Fossils found in the Salt Lake formation include fresh-water mollusks, a few vertebrate remains, pollen and spores, some unidentified diatoms, and a few poorly preserved leaves and seeds. The mollusks and vertebrate remains indicate a Pliocene age and the formation is classified here as Pliocene, although the spores and pollen suggest that at least part of the formation may be older.

Fragments of vertebrate teeth and bones were collected from the basal part of the Salt Lake formation in sec. 1 (approximate location), T. 46 N., R. 69 E., Nev., on the lower slopes of a pair of gravel-capped buttes about 1½ miles southeast of the Trout Creek ranch (fossil locality 3, pl. 46). The tooth fragments were identified by Jean Hough as parts of the upper molars of the horse *Neohipparion*, probably *Neohipparion occidentale* (Leidy), indicating an early or middle Pliocene age.

Fresh-water mollusks collected from the lower part of the formation were identified by D. W. Taylor as follows:

U. S. G. S. Cenozoic loc. 20942 (fossil locality 4, pl. 46), fossiliferous shale in the upper part of carbonaceous shale zone B (about 160 feet stratigraphically below the Barrett zone), north side of Birch Creek in the SW¼ sec. 25, T. 16 S., R. 21 E., Idaho.[1]

Sphaerium
Valvata referable to *Valvata humeralis* (Say)
Lymnaea albiconica Taylor
Lymnaea cf. *L. megasoma* Say
Planorbidae indet.
Physa

U. S. G. S. Cenozoic loc. 20927 (fossil locality 5, pl. 46), light-tan limestone at the base of the Barrett carbonaceous shale zone, 1 mile southeast of the Goose Creek ranch in sec. 30 (approx.), T. 47 N., R. 70 E., Nevada.

Sphaerium
Lymnaea cf. *L. megasoma* Say

U. S. G. S. Cenozoic loc. 20924 (fossil locality 6, pl. 46), light-gray limestone about 450 feet above the Barrett carbonaceous shale zone in sec. 29 (approx.), T. 47 N., R. 70 E., Nevada.

Sphaerium
Planorbarius? n. sp.

Taylor notes (written communication, 1958) in regard to the collection from locality 20942 that *Lymnaea albiconica*, *Lymnaea* cf. *L. megasoma* Say, the *Valvata*, and the indeterminate planorbid all occur in the Teewinot formation of western Wyoming and southeastern Idaho (Taylor, 1956, p. 123–125), and that the mollusks of that area are dated at two localities by mammals of middle Pliocene age. Taylor also considers the fossils from locality 20927 as middle Pliocene in age although he states that the assemblage is not diagnostic. The fossils from locality 20924 represent a distinctly different type of assemblage, according to Taylor, and he comments:

The two species * * * are clearly similar to very good material from several places in the Rockland Valley area, south of American Falls, Idaho. * * * On the basis of what is known of the late and middle Pliocene of southern Idaho, the collection from loc. 20924 and the Rockland Valley assemblage are more reasonably called late middle Pliocene than early late Pliocene.

Spores and pollen collected from the lower part of the Salt Lake formation were identified by Estella B. Leopold as follows:

Samples D1208–1 and –2, carbonaceous shale from the Barrett carbonaceous shale zone at the Barrett prospect, center of the N½ sec. 5, T. 15 S., R. 21 E., Idaho: pollen of juniper, sedges, poplar, and many unidentified monocots, spores of Polypodiaceae (fern) and remains of *Botrycoccus* (alga).

[1] Fossils from this locality as identified by T. C. Yen were listed in an earlier report (Mapel and Hail, 1956, p. 15–16). Yen's list of species is here modified as a result of a reexamination by D. W. Taylor.

Samples D12028–3 and –4, carbonaceous shale and lignite from the Barrett carbonaceous shale zone at a coal prospect along Coal Banks Creek, SW¼, sec. 34, T. 15 S., R. 21 E., Idaho, contains pollen of *Zelkova* (abundant), *Carya*, *Sarcobatus vermiculatus*, Cyperaceae, *Pinus* (abundant), *Alnus?*, *Abies*, *Potamogeton*, *Betula*, *Sparganium* or *Potamogeton*, Onagraceae (cf. *Ludwigia*), *Ephedra* cf. *viridis*, *E.* cf. *nevadensis*, fern spores, fungal spores.

Miss Leopold notes (written communication, 1958) a close similarity of the assemblage in samples D12028–3 and –4 to material from the Creede formation (Miocene) of southwestern Colorado, especially the abundance of *Zelkova* and *Carya*, the presence of a fir species, and the absence of pollen of the family Compositae. She points out that *Zelkova* and *Carya* are rare or absent in collections of the Miocene-Pliocene Hog Creek flora, Idaho, from the middle Pliocene Teewinot formation, Wyoming, and from middle Pliocene rocks in the Teton region, Wyoming. She states: "The generic composition of this assemblage indicates a Miocene or Pliocene age. The strong representation of the exotic genus *Zelkova* suggests a late Miocene rather than a Pliocene age."

Fossil leaves were collected at several horizons in the lower part of the formation, but those which could be identified (*Equisetum* sp. and *Salix* sp.) do not help in determining the age of the enclosing rocks.

SURFICIAL DEPOSITS OF QUATERNARY AGE

Surficial deposits of Quaternary age include deposits of alluvium, slope wash, landslide material, and gravel on high surfaces.

Alluvial deposits consisting of silt, sand, and gravel floor the valley of Goose Creek in a band as much as half a mile wide. The thickness of these deposits is unknown at most places; however, a core hole drilled near the mouth of Coal Banks Creek went through 80 feet of alluvium at a point not more than 100 feet horizontally from exposures of bedrock on the adjacent valley wall. Near the axis of the valley the alluvium may be thicker. Alluvium also borders a few of the other large streams in the district, but for the most part it occurs in bands that are too narrow to be shown on the geologic map.

A large deposit of slope wash, consisting of soil and rock detritus that conceals the underlying bedrock, covers about 9 square miles in the northeastern corner of the district. Much of the material is bouldery rubble derived from the adjacent slopes of quartzite. Streams have eroded gullies and washes in the deposit at various places, but in general its upper surface is a broadly sloping flat that merges with steeper mountain slopes cut on Carboniferous and older rocks along its upper boundary and with more gentle slopes cut on the Salt Lake formation at its lower boundary.

Three large landslides and two small ones were mapped during the present investigation. The largest landslide covers an area of about

1 square mile near the headwaters of Squaw Creek in the northwestern part of the district; others border Goose Creek in the northeastern, central, and southwestern parts; and one lies at the foot of mountain slopes a few hundred yards south of the Idaho–Nevada boundary in the western part. The displaced material comprising all the landslide masses is from the Salt Lake formation.

Deposits of sand and gravel as much as 15 feet thick cover several high, broad surfaces in the southern part of the district. The surfaces extend from the mountains east of the mapped area toward Goose Creek with a gentle gradient, and near Goose Creek are about 200 feet above the present stream level. Streamworn pebbles, cobbles, and boulders of rhyolite, quartzite, and limestone derived from the mountains to the east make up the coarser fragments in these deposits.

STRUCTURE

The Goose Creek district occupies a topographic and structural basin in the northern part of the Basin and Range province. The Tertiary rocks are faulted, gently folded, and rest unconformably on a complexly folded and faulted basement of Tertiary(?) and pre-Tertiary rocks. Both the Tertiary and older rocks of the district plunge northward beneath relatively undeformed Pliocene and Pleistocene basaltic lava flows of the Snake River plain.

Plate 46 shows the structure of the Salt Lake and Payette(?) formations by means of structure contours drawn at 100-foot intervals on the top of the Barrett carbonaceous shale zone. In general the Tertiary strata have a gentle easterly dip that averages about 3 degrees, but the eastward tilting is modified locally by shallow folds and structural terraces, and the rocks are disrupted at many places by normal faults. The structural relief in the district is at least 3,000 feet, with the structurally highest part west of Ibex Peak in T. 15 S., R. 20 E., Idaho, and the structurally lowest part south of Pole Creek in the northern part of T. 14 N., R. 19 W., Utah.

FOLDS

The main structural feature in the northern part of the district is the Goose Creek syncline, a northerly trending fold, the axis of which coincides roughly with the valley of Goose Creek. Near the upper end of the Goose Creek reservoir, the syncline is a structural basin having a closure of about 200 feet. The welded tuff at the base of the upper part of the Salt Lake formation crops out at the level of Goose Creek in the trough of this fold. The Goose Creek syncline dies out southward against a low anticlinal ridge that extends eastward for about 2 miles in the vicinity of Little Pole Creek. South of this ridge, the Salt Lake formation is folded into a second, broad, poorly defined syncline, the axis of which extends southwestward for about

5 miles, almost to the Idaho–Utah boundary, where it is terminated by a series of northeastward-trending normal faults.

Along Hardister Creek, in the southern part of the district, the welded tuff at the base of the upper part of the Salt Lake formation may be traced around a broad northerly trending syncline and sharply folded anticline that is faulted along its crest. Dips on the steep west flank of the anticline are as much as 50° W.

The Tertiary rocks in the northwestern part of the district are arched into a low anticlinal fold or structural terrace breached by the valley of Trapper Creek. The Payette(?) formation is exposed in a narrow strip near the crest of this fold.

Undulating folds and local flattening or steepening of the general easterly dip are shown by the structure-contour map, plate 46, at various other places in the district.

FAULTS

Many normal faults, some with displacements of several hundred feet, cut the Salt Lake and Payette(?) formations. Most of the larger faults trend northward or northeastward. A few may be traced for several miles.

A normal fault brings the upper part of the Salt Lake formation against Carboniferous and older limestone and quartzite along the eastern side of the district, from Birch Creek northward for at least 10 miles. Because of the slope wash and talus, the fault surface was not observed; however, the upper part of the Salt Lake formation dips eastward into Carboniferous and older rocks at angles ranging from 5° to 46° adjacent to its inferred trace. The Salt Lake formation covers a small area on the upthrown side of the fault in sec. 22, T. 15 S., R. 22 E., where welded tuff at the base of the upper part of the formation rests directly on quartzite. The bed of tuff at this locality is nearly flat lying and is about 300 feet topographically higher than the equivalent bed exposed on the opposite side of the fault half a mile to the west. Vertical displacement along the fault, therefore, may have been as much as 300 feet, after the deposition of the tuff. Some movement and erosion may have occurred along the fault before deposition of the welded tuff, inasmuch as several hundred feet of volcanic ash and other rocks of the lower part of the Salt Lake formation crop out beneath the tuff on the west side of the fault, but are absent east of it.

Near Birch Creek, and extending from Birch Creek southward to Pole Creek, the upper bed of welded tuff of the Salt Lake formation is brought to the surface in a complex series of faulted wedges bounded by northerly or northeasterly trending normal faults. The displacement across the faulted zone is at least 900 feet, down on the east, along Birch Creek in sec. 25, T. 16 S., R. 21 E. Bordering this faulted area on the east and extending from Birch Creek southward to Hardister Creek, the lower and upper parts of the Salt Lake formation are faulted against Tertiary(?) rhyolite along a system of parallel northerly trending high-angle normal faults, downthrown on the west. The displacement of any one of the faults was not determined, but across the fault system the displacement may be several hundred feet.

Several faults cut the Tertiary rocks in the central and western parts of the district. The largest of these, with a displacement of about 500 feet upthrown on the west, is near the junction of Idaho, Utah, and Nevada. The fault trace extends for about 3½ miles with a north-easterly trend in the lower part of the Salt Lake formation. Other faults in the Salt Lake or Payette(?) formations have displacements of less than 250 feet.

STRUCTURAL HISTORY

Sharp (1939, p. 156–158) has proposed that in parts of northeastern Nevada the Miocene basins of deposition originated as a result of downwarping or faulting, and that faulting continued during later Tertiary time. Although folding and faulting in the Goose Creek district may not have been strictly contemporaneous with that noted by Sharp in nearby areas in Nevada, a similar structural history can be postulated as follows: (1) folding or faulting which originated the basin of deposition of the Payette(?) formation, (2) faulting during deposition of the Payette(?) and Salt Lake formations with progressive deepening of the basin and rejuvenation of the adjacent highlands, and (3) renewed faulting and folding after deposition of the Salt Lake formation, perhaps in adjustment to downwarping of the Snake River plains to the north.

MINERAL RESOURCES

LIGNITE

Thin seams and beds of dark-brown to black lignite and beds of brown carbonaceous shale occur in both the Salt Lake and Payette(?) formations. Small prospects and mines have been opened on the lignite beds at various places in the district, and Bowen (1913, p. 258) reports that lignite from one of these mines, the Worthington mine in sec. 23, T. 16 S., R. 20 E., Idaho, was marketed at Oakley before 1911. The other lignite prospects in the district were never worked as commercial mines.

The lignite is dark brown to black when fresh; on weathering, it disintegrates rapidly to brown flakes and scales. It is commonly high in ash and is of doubtful commercial value for fuel. The grade of some of the better lignite and lignitic shale in the district is shown by fuel analyses made by the U. S. Bureau of Mines and given in table 2.

TABLE 2.—*Fuel analyses of lignite and lignitic shale, Goose Creek district*

[Condition of sample: A, as received; B, moisture-free]

U. S. Bureau of Mines sample No.	Location	Condition of sample	Analyses, in percent									Heat value (Btu)
			Proximate			Ultimate						
			Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
12643	Worthington mine, SW¼ sec. 23, T. 16 S., R. 20 E., Idaho; Worthington bed [1]	A	34.5	26.4	21.1	18.0	0.6					5,810
		B		40.3	32.2	27.5	1.0					8,870
E-28432	Drill hole C2, SW¼ sec. 24, T. 16 S., R. 21 E., Idaho; zone B, depth 243.5–247.7 feet	A	33.4	11.8	11.7	43.1	1.0	5.0	16.6	0.3	34.0	2,925
		B		17.7	17.6	64.7	1.5	2.0	24.9	0.5	6.4	4,390
E-37197	Drill hole C2, SW¼ sec. 24, T. 16 S., R. 21 E., Idaho, zone B, depth 260.7–269.8 feet	A	21.6	8.7	8.1	61.6	1.0	3.4	10.6	0.2	23.2	2,050
		B		11.2	10.3	78.5	1.3	1.2	13.5	0.3	5.3	2,620

[1] 4-foot-thick bed of lignite in the mine, 200 feet from the portal (Bowen, 1913, p. 262).

The carbonaceous shale and lignite beds are interbedded with volcanic ash, greenish-gray shale, bentonite, sandstone, and conglomerate in fairly well defined zones, some of which can be traced for tens of miles. Individual beds of lignite and carbonaceous shale, however, are lenticular and may pinch out or be replaced by noncarbonaceous material within a few hundred feet. Carbonaceous zones have been examined at about 100 localities in the district. Detailed sections at 39 of these localities are shown graphically on plate 50.

On both sides of the Coal Banks Creek–Beaverdam Creek divide, beds of lignite in the lower part of the Salt Lake formation have burned underground, and the heat has fused and baked the overlying rocks to conspicuous masses of bright-red clinker.

Two main beds, or zones, and several less persistent lenses of carbonaceous shale and lignite occur in the Payette(?) formation. The Grant zone, here named for its occurrence at the Grant prospect in NW¼ sec. 2, T. 15 S., R. 20 E. (locality 35 [2]), crops out about 125 feet below the top of the formation in the valley of Trapper Creek. The zone contains as many as 6 thin lenticular beds of carbonaceous shale and lignite interbedded with shale, sandstone, and volcanic ash in a stratigraphic interval of as much as 60 feet. The Worthington bed, named by Bowen (1913, p. 257) from the Worthington mine in sec. 23, T. 16 S., R. 20 E. (locality 38), crops out about 500 feet below the top of the formation near South Beaverdam Creek, where it consists of one bed of carbonaceous shale, locally lignitic, 2–5 feet thick. Nearby, in section 11 of this township (locality 37), 3 beds of carbonaceous shale in an interval of 45 feet are mapped as the Worthington zone.

The lower part of the Salt Lake formation contains four main carbonaceous shale zones. Their relative stratigraphic positions and thicknesses are summarized in the generalized section below:

	Thickness (feet)
Top of the lower part of the Salt Lake formation.	
Interval with little or no carbonaceous shale	500
Zone *A*	1–40
Interval with little or no carbonaceous shale	250
Barrett zone	1–80
Interval with little or no carbonaceous shale	160
Zone *B*	1–20
Interval with little or no carbonaceous shale	70
Zone *C*	5–25

Of these four zones, the Barrett zone is the thickest and most persistent. It was named by Bowen (1913, p. 257) from its occurrence at the Barrett prospect in sec. 5, T. 15 S., R. 21 E. (locality 3), where it crops out 30 feet below the lowest bed of welded tuff in the lower part of the Salt Lake formation. The Barrett zone may be traced

[2] Numbers given are the locality numbers shown on plates 46 and 50.

almost continuously from Trapper Creek southward to Hardister Creek, or for almost the length of the mapped area. It is thickest on the sides of the Coal Banks Creek–Beaverdam Creek divide in T. 16 S., R. 21 E., where the zone contains as many as 10 beds of carbonaceous shale and thin stringers of lignite ranging in thickness from less than 1 foot to 10 feet in a stratigraphic interval of 50–80 feet. The beds of lignite in the Barrett zone have been mined at the Barrett prospect, and also near the head of Coal Banks Creek in sec. 34, T. 15 S., R. 21 E. (locality 17).

URANIUM

Most of the Tertiary rocks sampled in the Goose Creek district—including beds of volcanic ash, welded tuff, sandstone, and carbonaceous and noncarbonaceous shale—are slightly radioactive. At some places, however, beds of carbonaceous shale, lignite, or lignite ash in the lower part of the Salt Lake formation contain concentrations of uranium in amounts many times that of the enclosing strata. The thickness and uranium content of some of the more radioactive of these carbonaceous beds, as determined by examination and sampling of outcrops and drill cores, are shown by fig. 37 and pl. 50, and analyses for uranium in some of these beds are given in table 3. No uranium minerals were identified, and the mineralogic nature of the occurrences is unknown.

The Barrett zone contains nearly all known deposits of uranium in the district assaying more than 0.005 percent. The zone is most uraniferous at locality 28, sec. 26, T. 16 S., R. 21 E., Idaho, where the uppermost 1-foot of a bed, at least 8 feet thick, of carbonaceous shale contains 0.12 percent uranium. Beds of carbonaceous shale or lignite in the Barrett zone contain at least 0.01 percent uranium at several other places in the same vicinity. Zone *B*, 160 feet below the Barrett zone, is also radioactive, and where tested by drilling in the SE¼ SW¼ sec. 24, T. 16 S., R. 21 E. (core hole 2), a zone 0.5 foot thick near the top of a bed of lignitic shale 5.5 feet thick contains 0.101 percent uranium.

The principal area in which the Barrett zone and zone *B* are mineralized is a northeasterly trending strip, about 4 miles wide and 6 miles long, near Goose Creek, in T. 16 S., R. 21 E. Isolated concentrations of uranium occur also north of this area in the valley of Trapper Creek, where a carbonaceous bed in the Barrett zone contains 0.045 percent uranium at the Barrett prospect (locality 3), and 0.034 percent uranium about 2½ miles to the southwest at locality 4. As shown by the structure-contour map, pl. 46, the mineralized area in T. 16 S., R. 21 E., is on the flanks and along the trough of a syncline, the axis of which trends northeastward across the southeastern part of the township.

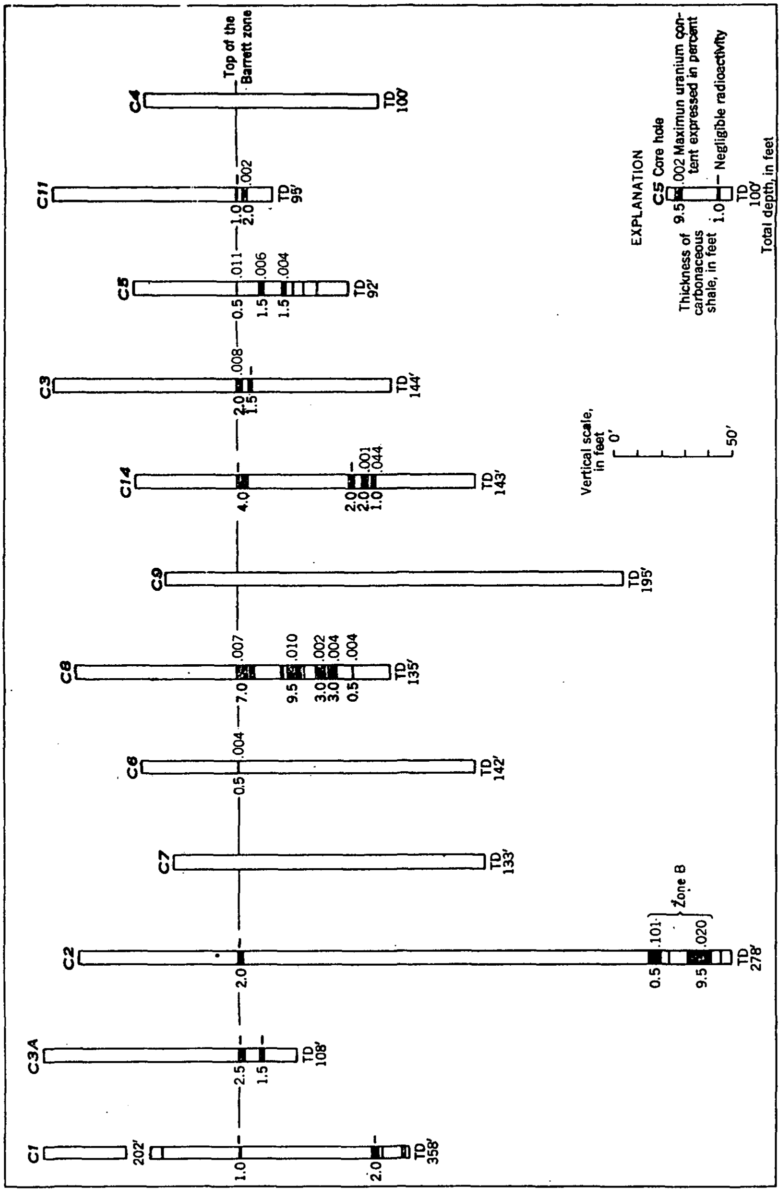


FIGURE 37.—Diagram showing the thickness and maximum uranium content of carbonaceous shale from in core holes, Goose Creek district.

TABLE 3.—*Analyses for uranium in selected samples of carbonaceous shale and lignite, Goose Creek district*

[Analyses by the U. S. Geological Survey]

Locality No. (pls. 46 and 50)	Description	Laboratory sample No.	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	Uranium in ash (percent)
	SALT LAKE FORMATION					
	Barrett zone					
3	4.0-ft bed, top 1.0 ft	68247	0.002			
	8.5-ft bed, top 1.0 ft	68246	.010	0.014	88.7	0.016
	next 1.0 ft	68245	.002		77.8	
	next 0.4 ft	68250	.018	.045	85.2	.060
	next 1.5 ft	68244	.003		84.3	
	next 1.0 ft	68249	.003	.005	86.8	
	next 1.0 ft	68248	.002		54.5	
4	3.0-ft bed	68261	.003			
	8.3-ft bed, top 0.5 ft	52916	.020	.034	76.3	.046
	next 0.4 ft	68260	.004	.005		
8	2.0-ft bed	52903	.005	.004		
	7.5-ft bed, top 0.7 ft	52905	.017	.032	84.4	.034
	next 2.3 ft	52906	.003	.004		
	next 2.6 ft	52907	.002	.003		
	bottom 1.9 ft	52908	.002	.003		
9	1.5-ft bed	68303	.003			
	3.0-ft bed	68304	.006	.011		
	5.0-ft bed	68305	.002			
	2.1-ft bed	68306	.002			
	3.0-ft bed	68307	.002			
	2.8-ft bed	68308	.002			
11	4.0-ft bed, top 0.8 ft	71640A	.002			
	middle 0.8 ft	71640	.002			
	bottom 0.8 ft	71639	.002			
	1.1-ft bed	71638	.002			
	0.5-ft bed	71636	.004			
	13.7-ft bed, top 0.8 ft	71635	.005	.009		
	next 0.8 ft	71634	.008	.009		
	next 0.8 ft	71633	.013	.021	85.8	.024
	next 0.8 ft	71632	.010	.015	83.7	.018
	next 0.8 ft	71631	.004	.007		
	next 1.1 ft	71630	.004	.004		
	next 0.9 ft below 0.9-ft parting of volcanic ash	71629	.002			
	next 0.9 ft	71628	.005	.006		
	next 0.9 ft	71627	.005	.007		
	next 0.9 ft	71626	.005	.005		
	next 1.0 ft	71625	.002			
	next 1.0 ft	71624	.001			
	next 1.0 ft	71623	.002			
	bottom 1.0 ft	71622	.003			
	1.8-ft bed, top 0.9 ft	71621	.002			
	bottom 0.9 ft	71620	.003			
	2.2-ft bed, top 1.1 ft	71619	.003			
	bottom 1.1 ft	71618	.002	.004		
	2.7-ft bed, top 0.9 ft	71617	.002			
	middle 0.9 ft	71616	.002			
	bottom 0.9 ft	71615	.003			
	top 0.8 ft	71615	.002			
12	3.4-ft bed, top 1.4 ft	91247	.001			
	bottom 2.0 ft	91246	.001			
	2.5-ft bed, top 1.0 ft	91245	.003			
	bottom 1.5 ft	91244	.003			
	9.6-ft bed, top 1.5 ft	91243	.005	.005		
	next 1.5 ft	91242	.003			
	next 1.5 ft	91241	.003			
	next 1.5 ft	91240	.005	.006		
	next 1.5 ft	91239	.003			
	9.6-ft bed, bottom 1.5 ft	91238	.003			
	7.2-ft bed, top 1.4 ft	91237	.010	.017	87.4	
	next 1.5 ft	91236	.004	.005	84.4	
	next 1.0 ft	91235	.003			
	next 1.3 ft	91234	.002			
	bottom 2.0 ft	91233	.003			
	1.4-ft bed	91232	.002			
	2.5-ft bed, top 1.2 ft	91231	.002			
	bottom 1.3 ft	91230	.002			

TABLE 3.—*Analyses for uranium in selected samples of carbonaceous shale and lignite, Goose Creek district*—Continued

Locality No. (pls. 46 and 50)	Description	Laboratory sample No.	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	Uranium in ash (percent)
	SALT LAKE FORMATION—continued					
	Barrett zone—Continued					
12	2.6-ft bed, top 1.3 ft	91229	0.002	0.002		
	bottom 1.3 ft	91228	.004	.004		
14	4.3-ft bed, top 1.5 ft	68351	.001			
	bottom 2.8 ft	68350	.005	.006		
	1.6-ft bed	68349	.002		83.8	
	1.3-ft bed	68347	.003			
	3.0-ft bed, top 1.0 ft	68346	.008	.010		
	middle 1.0 ft	68345	.015	.018		
	bottom 1.0 ft	68344	.006	.006		
	3.2-ft bed, top 1.6 ft	68343	.003			
	bottom 1.6 ft	68342	.003			
	1.7-ft bed	68341	.004	.003		
	0.9-ft bed	68340	.004	.005		
	1.4-ft bed	68339	.004	.006		
	1.0-ft bed	68338	.004	.002		
	2.6-ft bed	68337	.004	.003		
17	1.7-ft bed	68285	.010	.021	67.8	0.031
	5.2-ft bed, top 1.2 ft	68284	.001	.004	46.9	.008
	next 1.0 ft	68283	.001		34.4	
	next 1.0 ft	68282	.001		42.4	
	next 1.0 ft	68281	.001		37.5	
	bottom 1.0 ft	68280	.001		38.9	
18	2.3-ft bed, top 1.0 ft	91563	.002			
	2.3-ft bed, bottom 1.3 ft	91562	.001			
	1.3-ft bed	91561	.001			
	1.8-ft bed	91560	.002			
	3.0-ft bed, top 0.6 ft	91558	.005	.007		
	next 1.2 ft	91557	.003			
	bottom 1.2 ft	91556	.003			
	1.7-ft bed, top 1.0 ft	91555	.002	.003		
	bottom 0.7 ft	91554	.008	.012		
	2.6-ft bed, top 1.3 ft	91553	.002			
	bottom 1.3 ft	91552	.002			
20	1.6-ft bed	91209	.013	.016		
	1.1-ft bed	91207	.003			
	1.0-ft bed	91208	.001			
23	4.4-ft bed, top 1.1 ft	91614	.015	.015		
	next 1.1 ft	91613	.008	.008		
	next 1.1 ft	91612	.006	.006		
	bottom 1.1 ft	91611	.004	.004		
	1.1-ft bed, top 0.7 ft	91610	.005	.005		
	bottom 0.4 ft	91609	.006	.005		
26	1.5-ft bed, top 0.5 ft	91594	.010	.009		
	bottom 1.0 ft	91593	.014	.014		
	0.4-ft bed	91592	.008	.009		
	0.6-ft bed	91591	.010	.012		
	0.3-ft bed	91590	.003			
	1.7-ft bed, top 0.7 ft	91589	.003			
	bottom 1.0 ft	91588	.010	.012		
27	1.0-ft bed	71590	.002			
	1.9-ft bed, top 0.9 ft	71589	.012	.009		
	bottom 1.0 ft	71588	.010	.008		
	0.7-ft bed	71587	.013	.014		
	1.0-ft bed	71586	.022	.026		
	2.8-ft bed, top 1.0 ft	71585	.007	.003		
	bottom 1.8 ft	71584	.011	.006		
	2.0-ft bed	71583	.009	.005		
28	8.0-ft bed, top 1.0 ft	54278	.097	.12	84.2	.14
	next 1.0 ft	54279	.062	.081	87.0	.094
	next 1.0 ft	54280	.040	.047	89.7	.053
	next 1.0 ft	54281	.019	.019	94.9	.020
	next 1.0 ft	54282	.015	.016	94.8	.017
	next 1.0 ft	54283	.019	.016	93.8	.017
	next 1.0 ft	54284	.024	.020	93.5	.021
	bottom 1.0 ft	54285	.020	.017	94.1	.018

TABLE 3.—*Analyses for uranium in selected samples of carbonaceous shale and lignite, Goose Creek district*—Continued

Locality No. (pls. 46 and 50)	Description	Laboratory sample No.	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	Uranium in ash (percent)
	SALT LAKE FORMATION—continued					
	Barrett zone—Continued					
29	7.8-ft bed, top 1.3 ft	71612	0.003			
	next 1.3 ft	71611	.008	0.007		
	next 1.3 ft	71610	.008	.004		
	next 1.2 ft	71609	.005	.003		
	next 1.2 ft	71608	.004	.002		
	bottom 1.5 ft	71607	.005	.001		
	2.0-ft bed, top 1.0 ft	71605	.006	.004		
	bottom 1.0 ft	71604	.008	.006		
	3.3-ft bed, top 1.1 ft	71603	.021	.035		
	middle 1.1 ft	71602	.017	.023		
	bottom 1.1 ft	71601	.013	.013		
C5	0.7-ft bed	115802	.011	.011		
	1.4-ft bed, top 1.0 ft	115803	.008	.005		
	bottom 1.4 ft	115804	.005	.006		
	1.7-ft bed, top 1.0 ft	115805	.006	.004		
	bottom 0.7 ft	115806	.003	002		
	0.7-ft bed	115807	.004	.002		
	0.3-ft bed	115808	.004	.002		
	0.3-ft bed	115809	.004	.002		
C8	6.7-ft bed, top 1.0 ft	115814	.005	.004		
	next 1.8 ft	115815	.007	.004		
	next 1.4 ft	115816	.007	.007		
	next 1.2 ft	115817	.004	.003		
	bottom 0.8 ft	115818	.004	.003		
	1.2-ft bed, top 0.6 ft	115819	.009	.009		
	bottom 0.6 ft	115820	.009	.010		
	5.7-ft bed, top 1.2 ft	115821	.005	.004		
	next 1.2 ft	115822	.003	.001		
	next 1.2 ft	115823	.003	.002		
	next 0.8 ft	115824	.003	.002		
	next 0.4 ft	115825	.008	.009		
	bottom 0.3 ft	115826	.002			
	2.8-ft bed, top 1.1 ft	115827	.002			
	bottom 1.1 ft	115828	.003	.002		
	2.9-ft bed, top 0.7 ft	115829	.003	.002		
	next 1.3 ft	115830	.002			
	bottom 0.9 ft	115831	.005	.004		
	0.5-ft bed	115832	.005	.004		
C14	2.5-ft bed, bottom 0.6 foot	115833	.003	.001		
	0.7-ft bed	115834	.038	.044		
	Zone B					
C2	5.5-ft bed, top 0.4 ft	120773	0.053	0.050	84.2	0.059
	next 0.4 ft	120774	.026	.022	70.1	.031
	next 0.5 ft	120775	.076	.101	59.7	.170
	next 0.4 ft	120776	.057	.055	47.7	.116
	next 0.6 ft	120777	.088	.085	67.4	.126
	next 0.4 ft	120778	.041	.053	62.1	.082
	next 0.4 ft	120779	.018	.033	57.3	.057
	next 0.5 ft	120780	.028	.028	63.1	.044
	next 0.5 ft	120781	.022	.036	73.3	.050
	next 0.5 ft	120782	.020	.035	71.2	.048
	next 0.5 ft	120783	.012	.018	51.4	.039
	bottom 0.4 ft	120784	.010	.014	60.1	.025
	9.1-ft bed, top 0.4 ft	120791	.021	.022	65.2	.033
	next 0.6 ft	120792	.014	.019	78.3	.025
	next 0.6 ft	120793	.010	.013	88.8	.014
	next 0.4 ft	120794	.007	.010	80.5	.012
	next 1.2 ft	120795	.004	.002	91.4	.002
	next 1.0 ft	120796	.008	.007	78.2	.009
	1.2 ft in lower part	120797	.010	.014	72.8	.019
	next 0.2 ft	120798	.007	.006	85.4	.006
	next 1.4 ft	120799	.020	.017	57.1	.030
	bottom 0.4 ft	120800	.006	.009	61.0	.014

TABLE 3.—*Analyses for uranium in selected samples of carbonaceous shale and lignite, Goose Creek district*—Continued

Locality No. (pls. 46 and 50)	Description	Laboratory sample No.	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	Uranium in ash (percent)
	PAYETTE (?) FORMATION					
	Worthington zone					
38	2.7-ft bed, top 1.2 ft	68316	0.001		20.0	
	bottom 1.5 ft	68317	.001		29.3	0.007

The vertical distribution of uranium in the carbonaceous beds is irregular. In the thicker and more mineralized beds (3 feet or more in thickness and containing 0.01 percent or more uranium), the uranium content is generally greatest in the upper part of the bed and decreases progressively downward (see sections at localities 3, 8, 11, 12, 23, 28, and *C* 2, pl. 47). Thinner and less mineralized beds show no regular pattern of vertical distribution.

The uranium content of the carbonaceous beds is very irregular at different places along the same bed, and in different beds in the same zone. For this reason, and because the beds themselves are lenticular, no individual uranium-rich beds could be traced continuously for more than a few hundred feet.

Tertiary(?) rhyolite exposed in the southeastern part of the district was sampled north of Birch Creek in the SW¼ sec. 32, T. 16 N., R. 22 E., Idaho, and near Pole Creek in the NW¼ sec. 18, T. 14 N., R. 18 W., Utah, where it contains 0.007 and 0.006 percent uranium, respectively. Samples of volcanic ash from the Salt Lake formation contain 0.001 percent or less uranium, but equivalent uranium in the same samples ranges from 0.001 to 0.005 percent. Dark shale and limestone of Carboniferous age have negligible radioactivity where tested at various places along the margins of the district.

Analyses of noncarbonaceous rocks in the district are given in table 4.

TABLE 4.—*Analyses for uranium in samples of miscellaneous rock types, Goose Creek district*

[Analyses by the U. S. Geological Survey]

Location				Description	Laboratory-sample No.	Equivalent uranium (percent)	Uranium (percent)
State	Sec.	T.	R.				
				Salt Lake formation, upper part			
Utah	35	15 N.	19 W.	Grayish-orange volcanic ash, upper 2 ft of 5-ft bed	D-76310	0.002	0.0003
				Light-gray volcanic ash, grab sample	D-76311	.003	.0002
				Grayish-white volcanic ash, 2-ft bed	D-76312	.002	.0001
				Grayish-orange volcanic ash, 2-ft bed	D-76313	.002	.0001
				Grayish-orange volcanic ash, 2-ft bed	D-76314	.003	.0003

TABLE 4.—*Analyses for uranium in samples of miscellaneous rock types, Goose Creek district*—Continued

Location				Description	Laboratory-sample No.	Equivalent uranium (percent)	Uranium (percent)
State	Sec.	T.	R.				
Salt Lake formation, lower part							
Idaho	1	15 S.	20 E.	Light-gray volcanic ash, grab sample	54767	0.001	
	5	15 S.	20 E.	do	54772	.003	
	25	15 S.	20 E.	Clinker, bottom 1-ft of 7.9-ft bed	68318	.004	
	5	15 S.	21 E.	Light-gray volcanic ash, grab sample	54768	.005	
	6	15 S.	21 E.	Glassy welded tuff, grab sample	54766	.004	
				Grayish-yellow bentonite, 1.1-ft bed	100250	.002	
	12	16 S.	20 E.	Yellow opal, grab sample	D-70178	.001	0.0004
	22	16 S.	21 E.	Light-gray volcanic ash, middle of 19-ft bed	87776	.002	
	23	16 S.	21 E.	Light-gray volcanic ash, top 1-ft of 12-ft bed	87767	.003	
	26	16 S.	21 E.	Yellowish-gray bentonite, bottom 1-ft of 6-ft bed	71612A	.003	
Utah	21	14 N.	19 W.	Grayish-white volcanic ash, grab sample	D-76316	.005	.0002
	33	15 N.	19 W.	Light-gray volcanic ash, bottom 1-ft of 2.3-ft bed	100352	.002	
				Light-gray volcanic ash, top 1-ft of 2.3-ft bed	100353	.001	.0001
Nevada		47 N.	70 E.	Grayish-white volcanic ash, grab sample	D-76315	.003	.0003
				do	D-76317	.004	.0002
				Black welded tuff, grab sample	D-76318	.004	.0005
				Grayish-white volcanic ash, 2-ft bed	D-76319	.003	.0001
				Bentonitic volcanic ash, grab sample	D-76320	.003	.0001
				Grayish-white volcanic ash, grab sample	D-76321	.004	.0006
				Yellowish-gray bentonite, grab sample	D-76322	.002	.0013
Rhyolite of Tertiary(?) age							
Idaho	32	16 S.	22 E.	Light-gray rhyolite, grab sample	87790	0.005	0.007
Utah	18	14 S.	18 W.	Reddish-brown rhyolite, grab sample	D-85547	.003	.006
Carboniferous and older rocks							
Idaho	9	15 S.	20 E.	Gray limestone, grab sample	D-70176	0.001	0.0003
	15	15 S.	20 E.	do	D-70177	.001	.0001
Nevada		47 N.	69 E.	Dark-gray shale, grab sample	D-76326	.002	.0004
				Gray limestone, grab sample	D-76327	.001	.0001

The potential low-grade resources of uranium in the district total about 100 short tons in beds at least 1 foot thick containing at least 0.010 percent uranium. Estimates are listed on table 5, and the areas for which estimates were calculated are shown on figure 38. A weight of 1,100 short tons of carbonaceous shale per acre-foot, used in calculations for the Barrett zone, was based on an average specific gravity of 0.83 for 6 samples from outcrops. A weight of 2,700 short tons of carbonaceous shale and lignite per acre-foot, used in calculations for zone *B*, was based on an average specific gravity of 2.0 for 2 samples from drill holes.

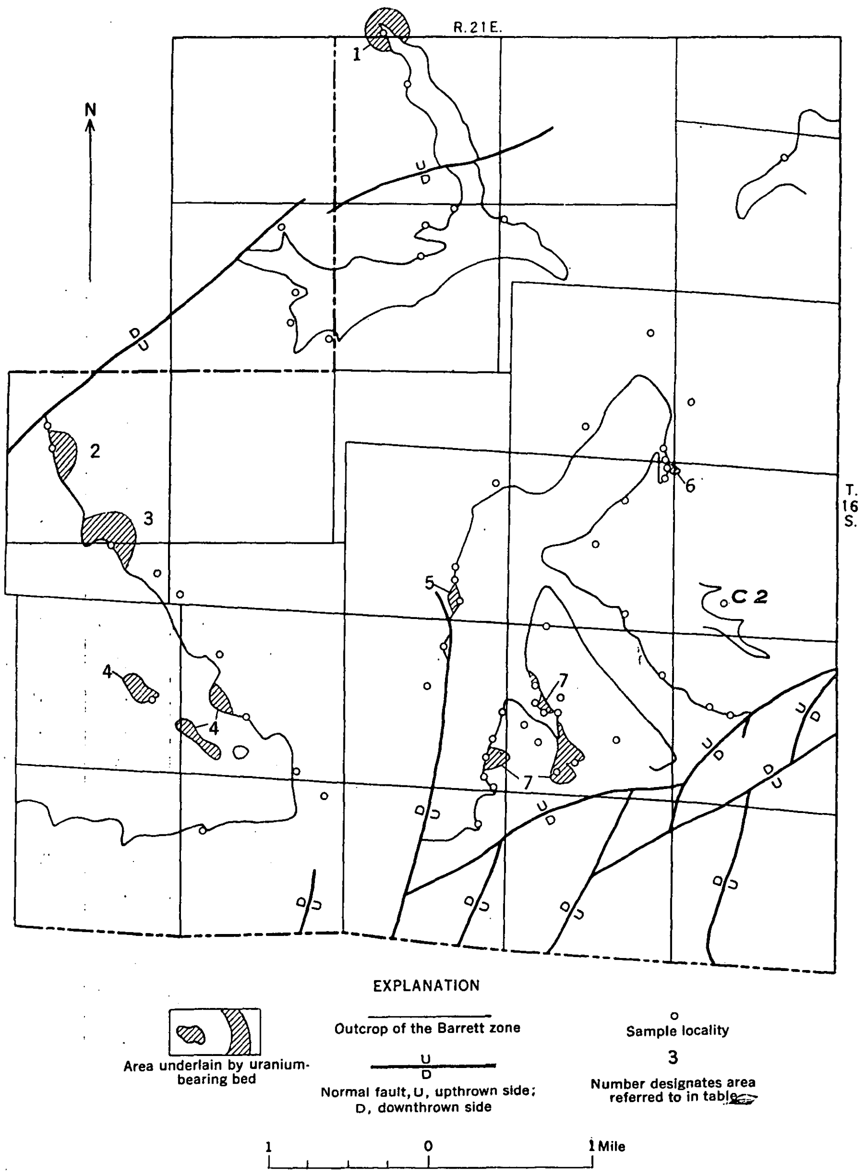


FIGURE 38.—Map of part of T. 16 S., R. 21 E., Idaho, showing areas that may be underlain by carbonaceous shale in beds at least 1 foot thick containing at least 0.01 percent uranium.

Several lines of evidence support a hypothesis that uranium now concentrated in the beds of carbonaceous shale and lignite was derived by ground water from volcanic ash in the Salt Lake formation. The excess of equivalent uranium in samples of volcanic ash from the Salt Lake formation suggests that significant amounts of uranium have been removed from the ash and either carried away or

TABLE 5.—*Potential resources of uranium in beds of carbonaceous shale and lignite at least 1 foot thick containing at least 0.01 percent uranium, Goose Creek district*

Locality (reference nos. on fig. 38)	Area (acres)	Thickness of bed [a] (feet)	Uranium [a] (percent)	Tonnage	
				Carbonaceous shale and lignite	Uranium content
SALT LAKE FORMATION					
Barrett zone					
1	25	1.7	0.022	47,000	10
2	20	1.0	.024	22,000	5
3	40	3.0	.011	130,000	14
4	25	6.1	.010	170,000	17
5	10	2.5	.013	27,000	4
6	3	1.6	.013	5,300	1
7	44	2.3	.015	110,000	17
Sec. 5, T. 15 S., R. 21 E., Idaho	14	1.5	.024	24,000	6
Secs. 12 and 13, T. 15 S., R. 20 E., Idaho	66	1.0	.020	73,000	15
Total or average[b]	247	2.2	.015	610,000	89
Zone B					
Vicinity of core hole 2, sec. 24, T. 16 S., R. 21 E., Idaho	1	10.3	0.031	28,000	9

[a] Weighted average.
[b] Rounded.

redeposited in other beds. The affinity of uranium for carbonaceous material is well known and Moore (1954) has shown that lignite and carbonaceous shale extract large percentages of uranium from dilute cold-water solutions. Inasmuch as ground water tends to percolate downward, or to travel laterally on top of impervious beds of shale, beds of shale in synclines would seem favorably located for exposure to large volumes of moving water carrying uranium. The principal mineralized area in the district is on the flanks and in the trough of a syncline. Moreover, the thicker mineralized beds tend to be richest in uranium at the top of the bed suggesting that the uranium was introduced from above, as might be expected if the downward movement of uranium-bearing solutions was deflected by the shale.

The availability of uranium to ground water would probably depend partly on the degree of devitrification and weathering of glass shards comprising the ash. Most of the ash in the district appears relatively fresh and unweathered, but at some places the ash is almost completely devitrified and altered to bentonite. Commonly the beds of bentonite are associated with beds of uranium-rich carbonaceous shale.

Table 6 gives the uranium content, in parts per billion, of water from streams and springs at 18 localities in the district. Content ranges from less than 2 parts per billion (3 samples) to 5 parts per billion (3 samples). In comparison, Rona (1943, p. 137–138) reports that sea water contains about 0.7 parts uranium per billion, and water from the Mississippi, Hudson, and St. Lawrence Rivers contains about 0.04 parts per billion. The analyses suggest that more than average amounts of uranium are being carried by the present surface and ground waters of the district, although the data are too scant to indicate that any one formation is a principal contributor of uranium to the water.

TABLE 6.—*Analyses for uranium (in parts per billion) in samples of water, Goose Creek district*

[Analyses by the U. S. Geological Survey]

Location			Description	Laboratory sample No.	pH [a]	Uranium (ppb)
Sec.	T.	R.				
			Cassia County, Idaho			
SW¼ 17	14 S.	22 E.	Main canal leading from the Lower Goose Creek reservoir.	D-76199	6	2
SW¼ 27	14 S.	22 E.	Hot spring in quartzite of Carboniferous or older age.	D-72767	7	(b)
SE¼ 29	15 S.	22 E.	Spring at fault contact between limestone of Carboniferous or older age and the Salt Lake formation.	D-76196	6	3
SW¼ 14	15 S.	21 E.	Spring in the Salt Lake formation	D-76193	6	(b)
SW¼ 34	15 S.	21 E.	Water dripping from the roof of an adit in the Barrett carbonaceous zone, Salt Lake formation.	58073	--------	4
SW¼ 34	16 S.	21 E.	Little Pole Creek near its mouth; stream heads in Carboniferous and older rocks and flows for 3 miles across the Salt Lake formation above the place where the sample was collected.	D-76195	6	4
NW¼ 14	16 S.	21 E.	Spring in the Salt Lake formation	D-76200	6	2
SW¼ 23	16 S.	21 E.	Birch Creek near its mouth; stream flows across Tertiary(?) rhyolite and the Salt Lake formation for at least 6 miles above the place where the sample was collected.	D-72766	6–7	4
SE¼ 25	16 S.	21 E.	Spring in the Salt Lake formation	D-76205	6	3
SE¼ 31	16 S.	22 E.	Birch Creek about 3½ miles from its mouth; stream flows across Tertiary(?) rhyolite and the upper part of the Salt Lake formation above the place where the sample was collected.	D-72765	6	3
SW¼ 35	16 S.	21 E.	Spring in the Salt Lake formation	D-76202	6	3
NE¼ 33	16 S.	21 E.	Beaverdam Creek near its mouth; stream heads in Carboniferous and older rocks and flows across the Payette(?) and Salt Lake formations for at least 6 miles above the place where the sample was collected.	D-72768	6	5
SW¼ 13	16 S.	20 E.	Beaverdam Creek about 5 miles from its mouth; stream heads in Carboniferous and older rocks and flows across the Payette(?) formation above the place where the sample was collected.	D-76194	6	3
SE¼ 9	16 S.	20 E.	Spring in the Payette (?)formation	D-76193	6	(b)
			Elko County, Nev.			
NE. part	47 N.	69 E.	Spring in the Payette(?) formation	D-76198	6	2
SE. part	47 N.	69 E.	Goose Creek	D-76197	6	2
			Box Elder County, Utah			
SE¼ 32	15 N.	18 W.	Spring in Tertiary(?) rhyolite	D-76204	6	5
NW¼ 13	14 N.	19 W.	Spring near fault contact between the Salt Lake formation and Tertiary(?) rhyolite.	D-76203	6	5

[a] pH determined with pH-indicator paper in the field.
[b] Less than 2 ppb.

BUILDING STONE

Large amounts of rock suitable for building stone are available in the district. Blocks cut from beds of dark reddish-brown welded tuff or from the lighter colored volcanic ash of the Salt Lake formation are used successfully for the outside walls of schools, churches, stores, and houses in many of the towns in the region. In Oakley, the exteriors of two-story buildings made with blocks of welded tuff and volcanic ash show no signs of deterioration after many years of service. Anderson (1931, p. 141–150) describes in detail the use and physical properties of these materials as building stones.

Small amounts of Precambrian quartzite and marble, similar to that found in the mountains that border the district on the northeast, have been quarried and used locally for foundations and trim.

BENTONITE

Bentonite occurs in the lower part of the Salt Lake formation in relatively pure beds which range in thickness from a few inches to as much as 20 feet. The lateral extent of individual beds was not determined, but some of them may be traced for several hundred yards. Commonly the bentonite is white, grayish white, or light grayish yellow. Small lumps of the rock placed in water swell to about twice their original volume. Much bentonite is associated with beds of carbonaceous shale and sandstone in the central part of the district in T. 16 S., R. 21 E., Idaho, and other beds crop out in the southern part in Utah and Nevada. None of the bentonite has been mined commercially, although a small prospect has been opened on a bed in the NW¼ sec. 26, T. 14 N., R. 19 W., Utah.

The bentonite was formed by the devitrification and alteration of volcanic ash to the clay mineral montmorillonite. Much of the bentonite retains the texture of the ash with great perfection. Some of the bentonite, however, is a dense homogeneous rock in which pyroclastic textures are largely destroyed. Such deposits may have resulted from partial devitrification and reworking of the ash before burial with consequent obliteration of much of the texture of the original material.

A. J. Gude analyzed by X-ray diffraction two samples of bentonite collected in the southern part of the district: one sample was from a bed about 20 feet thick a mile southeast of the junction of Goose and Hardister Creeks, T. 47 N., R. 70 E., Nev., and the other was from a bentonite prospect in a bed at least 10 feet thick in the NW¼ sec. 26, T. 14 N., R. 19 W., Utah. Both samples consisted almost entirely of montmorillonite. The first sample contained, in addition, minor amounts of quartz; the second contained almost no quartz but was contaminated with small amounts of some unidentified mica mineral or minerals.

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Geology and Uranium Deposits in Carbonaceous Rocks of the Fall Creek Area, Bonneville County, Idaho

By JAMES D. VINE

URANIUM IN COAL IN THE WESTERN UNITED STATES

GEOLOGICAL SURVEY BULLETIN 1055-I

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[Plates are in box]

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GEOLOGY AND URANIUM DEPOSITS IN CARBONACEOUS ROCKS OF THE FALL CREEK AREA, BONNEVILLE COUNTY, IDAHO

By James D. Vine

ABSTRACT

Uranium occurs in carbonaceous rocks of the Bear River formation, of Early Cretaceous age, in the Fall Creek area, Bonneville County, Idaho. The principal deposit is at the Fall Creek coal prospect in sec. 4, T. 1 S., R. 42 E., where impure coal contains an average of about 0.02 percent uranium. Geologic mapping and sampling have demonstrated that the zone of uranium-bearing rocks is widespread in the area and is repeated in outcrop several times, owing to folding and faulting of the enclosing strata, although exposures suitable for sampling and analysis are few. Analytic data suggests a possible geochemical relation between uranium, germanium, and molybdenum. Four general hypotheses are advanced for the origin of uranium in carbonaceous rocks, but comparison of the deposits with other occurrences of uranium-bearing carbonaceous rocks suggests that an epigenetic hypothesis of deposition by downward percolating meteoric water seems best able to explain the occurrence of uranium in the Fall Creek area. Core drilling was inconclusive in demonstrating the areal extent of the radioactive units. Most of the holes did not reach the uranium-bearing strata, because the area is one of structural complexity, with faulting, thinning of incompetent strata, and increasingly steep dips at depth.

About 6½ million tons of coaly shale, carbonaceous shale, and carbonaceous limestone with an average grade of about 0.02 percent uranium is believed to be in the area. This estimate is based on the average thickness and grade of uranium-bearing strata exposed in the Fall Creek coal prospect, by drill-hole data, and by the inferred extent of these strata over an area of slightly more than 400 acres.

INTRODUCTION

In the course of reconnaissance for uranium-bearing coal and carbonaceous materials during the 1951 field season George W. Moore and the author made many radioactivity measurements in coal mines in Idaho, Colorado, and Utah, especially where coal was associated with silicic volcanic rocks because this association was suggested as a favorable one for the occurrence of uranium in the lignites of western South Dakota by Denson, Bachman, and Zeller (see chapter B, this bulletin). Several deposits were found in which the uranium content was too small to be of interest. However, investigations in the Fall Creek area, where Mansfield (1920) had reported several coal prospects closely associated with volcanic rocks, resulted in the discovery of a significant concentration of uranium.

Field work was carried on during July and August 1952 to determine the areal extent, structural setting, and nature of the occurrence of uranium in the Fall Creek area. Core drilling to determine the thickness and grade of the uranium-bearing zone was done during June, July, and August 1953.

ACKNOWLEDGMENTS

The field investigations were greatly facilitated by the use of an advance copy of a geologic map of the Irwin and part of the Hell Creek quadrangles prepared by Louis S. Gardner of the U. S. Geological Survey. The author is indebted to George W. Moore who assisted in the reconnaissance in 1951, Robert F. Flege, Jr., who assisted with the geologic mapping during the 1952 field season, and Max L. Troyer, who supervised the drilling program. All analytical work was performed in U. S. Geological Survey laboratories.

LOCATION AND ACCESSIBILITY

The uranium-bearing strata of the Fall Creek area are on the west flank of the Caribou Mountains in Bonneville County, Idaho, in Tps. 1 N. and 1 S., R. 42 E. (fig. 39). The area is about 16 miles southwest of Swan Valley, Idaho, and is easily accessible in good weather. The principal exposure is in the NE¼ sec. 4, T. 1 S., R. 42 E., at an abandoned, inclined shaft dug for coal, adjacent to the Fall Creek road in the Caribou National Forest. This shaft, referred to in this report as the Fall Creek coal prospect, may be reached as follows: drive 3 miles northwest on U. S. Highway 26 from the town of Swan Valley and cross the bridge that spans the Snake River. At the west side of the bridge turn left onto a graveled road and proceed about a mile along the Snake River to the junction of the Fall Creek road. Turn right and travel about 12 miles up the Fall Creek Road. The entrance to the Fall Creek coal prospect is marked by a timbered entry on the south side of the road about a mile beyond the Fall Creek Ranger Station (pl. 51).

TOPOGRAPHY AND WATER SUPPLY

The U. S. Geological Survey topographic maps of the Hell Creek and Irwin quadrangles show altitudes in the Fall Creek area that

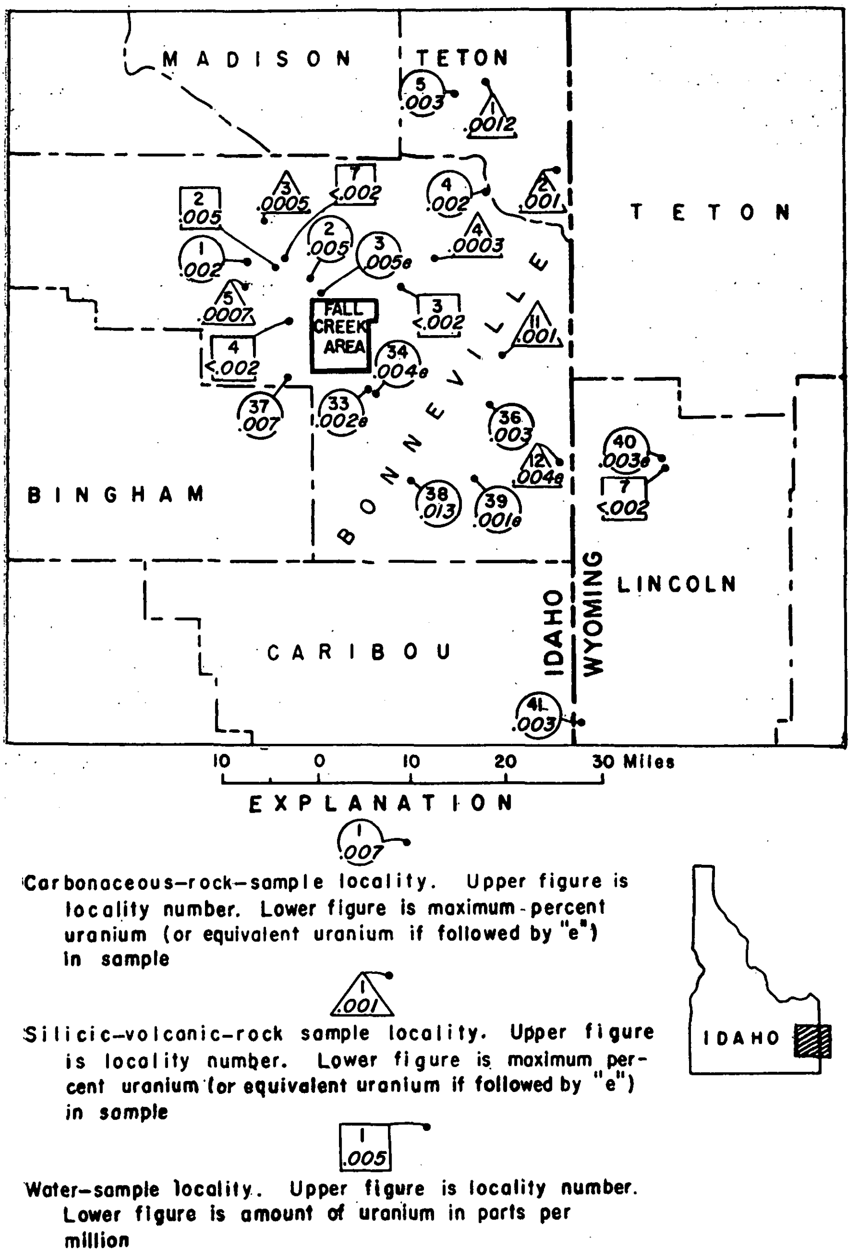

FIGURE 39.—Index map of southeastern Idaho, showing location of the Fall Creek area, Bonneville County, and adjacent areas in which samples were collected.

range from about 5,600 feet, in the valley of Fall Creek, to 7,600 feet, along the drainage divide between Fall Creek and Pritchard Creek in the northern part of the area. Fall Creek, flowing northeast to the Snake River, drains most of the area, although Hell Creek, which flows northwestward into the Snake River, drains the southwestern part of the area (pl. 51). Fall, Pritchard, and Hell Creeks and many of their tributaries are permanent streams.

LAND OWNERSHIP

Except for a tier of sections along its west side, most of the area mapped lies within the boundary of the Caribou National Forest. Several small tracts of privately owned land, however, lie within the National Forest. These tracts are shown on the U. S. Department of Agriculture map of the Caribou National Forest, dated 1949.

GEOLOGY

SEDIMENTARY ROCKS

Strata of Mesozoic and Paleozoic age are present in the Caribou Mountains, but only Cretaceous and Jurassic rocks crop out in the area mapped; therefore, only the rocks of these systems are described. A summary of the sedimentary rocks exposed in the area is shown in the chart. The following descriptions are adapted from Kirkham (1924, p. 20–29), with important modifications in the descriptions of the Tygee and Wayan formations in order to include Louis S. Gardner's usage (oral communication, 1952) of the Bear River formation.

Sedimentary rocks exposed in the Fall Creek area[1]

		Formation	Thickness (feet)	Description
Upper Cretaceous		Wayan formation	3,000–4,000 (estimate)	Shale, red and purple, and sandstone, gray, medium- to coarse-grained, crossbedded, friable; sandstone beds form prominent ledges in the softer shales.
				——— Unconformity ———
Lower Cretaceous		Bear River formation	300–500	Siltstone, dark-gray, carbonaceous, ferruginous; and brown, thin-bedded sandstone in lower two-thirds; overlain in upper third by brown to gray medium-grained quartzite or sandstone that is very resistant to weathering. Uranium-bearing coaly shale and carbonaceous limestone occur near the top of the formation.
Lower Cretaceous	Gannett group	Tygee sandstone	285–300	Shale, red, interbedded with gray to brown, fine-grained sandstone; some sandstone is gray, medium grained, crossbedded and friable; the sandstone beds form ledges in the shales.
Lower Cretaceous	Gannett group	Draney limestone	175–300	Limestone, gray, fine- to coarse-grained; weathers very light gray; fossiliferous at top.
Lower Cretaceous	Gannett group	Bechler redbeds	225–300	Shale, red, weathers to a red soil.
Lower Cretaceous	Gannett group	Peterson limestone	50–100	Limestone, fine-grained, dark gray; weathers very light gray.
Lower Cretaceous	Gannett group	Ephraim conglomerate	360–400	Conglomerate and sandstone, reddish-gray, coarse-grained, gritty; some reddish-gray shale and purplish-gray limestone.
Upper Jurassic		Stump sandstone	220–300	Sandstone, gray to greenish-gray, fine-grained and shaly; some sandstone is massive and coarse grained.
Upper Jurassic		Preuss sandstone	425–500	Shale, red and green with green "salt and pepper" sandstone and thin beds of limestone.
				——— Minor unconformity ———
Middle Jurassic		Twin Creek limestone	970–1,200	Limestone, gray, impure; weathers yellowish-gray, forms small splintery fragments.
Lower Jurassic		Nugget sandstone	1,000	Quartzite and sandstone, red to pink or white, very resistant; weathers into large blocks which form extensive talus slopes.

[1] Modified from Kirkham (1924) and unpublished data of L. S. Gardner (oral communication, 1952).

JURASSIC SYSTEM

Nugget sandstone.—The base of the Nugget sandstone is not exposed in the mapped area, but the formation is probably about 1,000 feet thick. It consists of fine-grained, white to pink or red sandstone and quartzite, generally thin-bedded, though locally crossbedded. The entire formation is highly resistant and weathers to blocks which cover extensive talus slopes.

Twin Creek limestone.—Lying with apparent conformity on the Nugget sandstone, the Twin Creek limestone forms a unit 970 to 1,200 feet thick that is easily recognizable by its lithology. The Twin Creek consists chiefly of gray, impure limestone that weathers into yellowish-gray splintery fragments or flakes of characteristic appearance. The formation forms rounded, gentle slopes with sparse vegetation.

Preuss sandstone.—The Preuss sandstone is probably about 425 feet thick and separated from the Twin Creek limestone by a minor unconformity. The Preuss consists of interbedded shale, sandstone, and limestone ranging in color from red and green to brown and gray. The difficulty in distinguishing this formation from the overlying Stump sandstone and Ephraim conglomerate made it necessary to map all three formations as a single unit.

Stump sandstone.—No distinctive lithologic contact separates the Stump sandstone from the underlying Preuss sandstone. The Stump is probably about 220 feet thick and consists chiefly of fine- to coarse-grained gray sandstone, which is commonly ripple marked and weathers to yellowish or brownish gray.

CRETACEOUS SYSTEM

Gannett group.—Five formations totaling 1,100 to 1,400 feet of strata at the base of the Cretaceous make up the Gannett group. They are, from oldest to youngest, the Ephraim conglomerate, Peterson limestone, Bechler redbeds, Draney limestone, and Tygee sandstone. A striking cyclic repetition of units of similar lithology is represented by the Peterson and Draney limestones, each of which is overlain by the red shale and sandstone, Bechler redbeds or Tygee sandstone.

Ephraim conglomerate.—Conformably overlying the Stump sandstone and forming the basal unit of the Gannett group is the Ephraim conglomerate, at least 360 feet thick. The Ephraim consists of interbedded red to gray sandstone, conglomerate, reddish limestone, and reddish shale. The difficulty in distinguishing the Ephraim from the underlying Stump and Preuss sandstones made it necessary to map all three formations as a single unit.

Peterson limestone.—Lying conformably on the Ephraim conglomerate, the Peterson limestone is about 50 to 100 feet thick and forms prominent ledges. The Peterson consists of gray massive fine-grained limestone, which weathers into characteristic whitish outcrops. The formation makes an excellent horizon marker.

Bechler redbeds.—The Bechler redbeds lie conformably over the Peterson limestone and are at least 225 feet thick. The Bechler consists of red shale, which weathers into a red soil and forms a valley or saddle between the underlying and overlying limestone formations.

Draney limestone.—Conformably overlying the Bechler redbeds is the Draney limestone, about 175 feet thick. The weathered appearance of the Draney limestone is very similar to that of the Peterson limestone and where not seen in continuous sequence is sometimes indistinguishable from the Peterson limestone. The Draney consists chiefly of gray massive fine-grained limestone, with coarse-grained fossiliferous dark-colored limestone at the top. The limestone weathers into whitish outcrops that stand out as ridges between the enclosing red shale and sandstone.

Tygee sandstone.—Lying with apparent conformity on the underlying Draney limestone is the Tygee sandstone, 285 feet thick where measured on Skyline Ridge. The formation consists of interbedded red shale and gray to brown sandstone. The sandstone is commonly medium grained, crossbedded, and friable, resembling sandstone in the Wayan.

The following section of the Tygee sandstone was measured on Skyline Ridge in sec. 27, T. 1 S., R. 42 E. The strata in this section are overturned and dip 85° to the northeast. The intense deformation may have caused the formation to be thinner here than in a normal section. The limits of the formation differ greatly from the limits described by Kirkham (1924, p. 26–28) who included beds in the Tygee that are here called the Bear River formation. Apparently Kirkham measured his section east of the Fall Creek Ranger Station, where faulting has duplicated the strata.

Section of the Tygee sandstone, sec. 27, T. 1 S., R. 42 E., Bonneville County, Idaho

[The dip is about 85° NE., beds are overturned]

Bear River formation: shale and siltstone, dark-gray, ferruginous (not measured).

Tygee sandstone:

Unit	Thickness ft	in
1. Covered, red soil	6	0
2. Sandstone, fine-grained, dark-gray to brown, hard	1	8
3. Covered, red soil	18	0
4. Sandstone, fine-grained, gray, hard	2	0
5. Covered, red soil	10	6
6. Sandstone, fine-grained, gray, hard, calcareous		10
7. Covered, red soil, probably red shale	52	0
8. Covered, dark soil, sandstone float	24	0
9. Sandstone, fine- to medium-grained, gray, crossbedded, friable, calcareous; similar to sandstone in the Wayan formation	26	0
10. Covered, red soil, probably red shale	54	0
11. Sandstone, reddish-brown, calcareous	2	0
12. Covered, reddish-brown soil	35	0
13. Sandstone, fine-grained, gray, numerous black grains, calcareous	2	0
14. Covered, reddish-gray soil and a thin ledge of gray siltstone	15	0
15. Sandstone, fine-grained, gray, massive, calcareous	2	0
16. Covered, reddish-gray soil	6	0
17. Sandstone, fine-grained, gray, massive, calcareous	2	0
18. Covered, light-gray soil	15	0
19. Sandstone, fine-grained, brown, thin-bedded, calcareous	1	0
20. Covered, light-gray soil, limestone float	10	0
Total, Tygee sandstone	285	0

Draney limestone: Limestone, dark bluish-gray, fossiliferous (not measured).

Bear River formation.—The Bear River formation, lying with apparent conformity on the Tygee sandstone, is about 300 to 500 feet thick. The upper and lower contacts of the formation, as described herein, follow the usage of Louis S. Gardner (oral communication, 1952). The lower two-thirds of the formation consists of dark-gray, ferruginous, carbonaceous shale and siltstone interbedded with thin beds of dark-brown sandstone. The upper third of the formation consists of a prominent ledge of medium-grained gray to brown quartzite or sandstone 75 feet thick, overlain by black shale, thin beds of fine-grained brown sandstone, coaly shale, and black fossiliferous granular limestone probably of brackish-water origin. The limestone and coaly shale are the uranium-bearing strata in the Fall Creek area. The Bear River formation does not contain any of the beds of the red or green shale that are so characteristic of nearly all the other Jurassic and Cretaceous clastic sedimentary rocks in this area. The thick ledge-forming quartzite or sandstone in the upper third of the formation is the principal marker bed in this part of the section. The dark somber color of soils derived from the formation as a whole is fairly characteristic and helps to identify the formation where exposures are poor. The Bear River formation is generally poorly exposed and the outcrops are commonly complicated by faulting or folding, so that no complete section of the formation was measured. The following section of the lower part of the formation was measured near the divide between Blacktail, Porcupine, and Pritchard Creeks.

Section of the lower part of the Bear River formation in sec. 22, T. 1 N., R. 42 E., Bonneville County, Idaho

[The strata here dips 40°–45° NE]

Bear River formation (the upper part of the formation is not exposed):

Unit	*Thickness (feet)*
1. Quartzite, fine-grained, brown, thin-bedded to massive, noncalcareous	22
2. Covered, quartzite float	35
3. Sandstone, fine-grained, gray, thin-bedded to massive, calcareous; weathers brown	5
4. Covered, dark-gray soil covered with small chips of dark-gray to brown siltstone float	169
5. Sandstone, fine-grained, quartzitic, dark-brown, ferruginous	2
6. Covered, dark-gray soil covered with small chips of dark-gray to brown siltstone float	67
Total, lower part of Bear River formation	300

Tygee sandstone: covered, red soil (not measured).

A section of the upper part of the Bear River formation and part of the lower Wayan formation is described later in the text under the heading Fall Creek coal prospect.

Wayan formation.—An unconformity probably separates the Wayan formation from the underlying Bear River, though proof of its existence in this area depends primarily on the variation in the interval between the massive ledge of quartzite in the Bear River and the first appearance of red shale above the quartzite. The variation in the interval may also be dependent on primary depositional differences and unequal deformation at the time of folding. The formation is estimated to be at least 3,000–4,000 feet thick where involved in a series of folds in Fall Creek basin, but the top of the formation is not exposed. No attempt was made to measure a stratigraphic section of the Wayan formation, but various exposures of it consist chiefly of red and purple shale interbedded with medium- to coarse-grained, gray, crossbedded, friable sandstone in beds up to 20–30 feet thick. The sandstone beds commonly form prominent ledges in slopes developed on the otherwise nonresistant strata. A characteristic of the sandstone beds is crossbedding; this feature is very useful in determining the sequence of strata and therefore the structure, particularly in areas where folds are overturned.

IGNEOUS ROCKS

Tertiary volcanic flows and tuffs lie unconformably on the folded and faulted strata of Mesozoic and Paleozoic age in the Caribou Mountains. Several hills within the mapped area are capped by remnants of volcanic rocks. These remnants occur at different altitudes. Large remnants in the northern part of the area, in secs. 20, 29, and 30, T. 1 N., R. 42 E., lie at altitudes ranging from 7,000 to 7,600 feet; whereas, similar remnants in the southwestern part of the area, in secs. 29, 30, and 31, T. 1 S., R. 42 E., lie at about 6,600 to 6,700 feet. This difference in altitude would seem to indicate at least 1,000 feet of topographic relief at the time the volcanic rocks were deposited and may indicate that the original thickness of tuffs and flows was much greater than is represented in any of the present remnants. Ross and Forrester (1947) assign the tuffs and flows to the oldest of a series of three volcanic groups recognized in southeastern Idaho. This oldest group consists of Miocene and Pliocene silicic volcanic rocks (beds of welded tuff and flows resembling rhyolitic lava) associated with the Snake River basalt. In the Fall Creek area this group of volcanic rocks is made up of hard, dense, gray and tan to red, felsite porphyry containing small feldspar phenocrysts. Black and gray obsidian rocks with microlites and spherulites are also present.

STRUCTURAL SETTING

The Caribou Mountains in southeastern Idaho are at the northern end of a system of parallel mountain ranges that form an arcuate belt along the Idaho-Wyoming border. The Caribou Mountains are characterized by complex structural features that trend northwest and ultimately plunge beneath the lavas of the Snake River Plain, which surrounds the northern end of the range. Closely spaced, parallel folds, overturned at many places and broken by faults, are the principal structural features of the range.

Cross section A–A′ (pl. 51) shows the principal structural features in the area mapped. Folds in the southwestern part of the area are overturned to the northeast, whereas, folds in the northeastern part of the area are overturned towards the southwest. The Fall Creek coal prospect is located on the flank of a nearly symmetrical anticline between the two areas of overturning. Both longitudinal and transverse faults are superimposed on the pattern on the folds. Most of the longitudinal faults are normal faults, but the faults along Skyline Ridge and the next ridge to the southwest are thrust faults. In sec. 12, T. 1 S., R. 42 E., a longitudinal normal fault is offset by a transverse normal fault. At this place the relation between two types of faulting can be clearly determined. A northeast-trending joint pattern at right angles to the folding is suggested in the Fall Creek basin by the trellislike drainage pattern so characteristic of the area.

Folding in the area ranges in magnitude from minor drag folds to folds involving thousands of feet of strata in which the horizontal distance from the axis of one fold is several miles from the axis of an adjacent fold.

STRUCTURE AND EXTENT OF THE BEAR RIVER FORMATION

The Bear River formation is exposed along the flanks of most of the synclines and anticlines in the area mapped and also in many of the surrounding areas. The prominent synclinal trough at the northeastern corner of the area mapped (pl. 51) is divided into two synclines by a small faulted anticline. The Bear River formation occurs along the flanks of both the major and the minor folds, but exposures of the coal-bearing zone are very poor. Along the overturned southwest flank of the major anticlinal structure east of the Fall Creek Ranger Station the Bear River formation is duplicated by faulting. Exposures of the coal-bearing zone are poor, and the zone itself is thin, apparently owing to stretching which was a part of the intense deformation. A faulted anticline broken by transverse faults to form a horstlike structure brings the Bear River formation to the surface at the Fall Creek coal prospect. Elsewhere along the strike of the same anticlinal feature the zone of radioactive rocks is not exposed.

The Fall Creek basin is a broad area of gentle relief eroded from folded strata in the Wayan formation. Between the Fall Creek coal prospect and Skyline Ridge, an anticline overturned to the northeast has exposed strata older than the Wayan formation. However, the northeast flank of this anticline is so steep, the strata so thin, and the exposures so poor that the radioactive zone could not be found. The southwest flank of the anticline, however, has a relatively gentle dip and the coal-bearing zone appears to be quite similar to that at the Fall Creek coal prospect, though the exposures are poor. Southwest of this overturned anticline is a thrust sheet that parallels the crest of Skyline Ridge. A belt of very complex structure including recumbent folds and imbricate thrust sheets occurs between Skyline

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Ridge and Hell Creek. Within this belt of complex structure the Bear River formation is repeated at least three times, but the exposures of the coal-bearing zone are very poor. The intense deformation has probably caused the thinning of incompetent strata including the coal-bearing strata.

A relatively gentle syncline and anticline occupy the southwest corner of the area mapped, but soil and vegetation cover the coal-bearing zone and no outcrops could be found. An area near the heads of Camp, Haskin, Trap, and Beaver Creeks, in the south-central part of the mapped area, is one of complex and indeterminate structure. Soil cover, heavy vegetation, and hillwash mask the exposures. Locally, outcrops of the Bear River formation were recognized, but the structural setting is poorly understood.

URANIUM-BEARING ROCKS

GENERAL DISTRIBUTION

Uranium in coal and carbonaceous rocks was discovered in September 1951 at the entrance to the Fall Creek coal prospect, sec. 4, T. 1 S., R. 42 E. (pl. 51). Most of the uranium-bearing rocks are restricted to a single stratigraphic zone in the upper part of the Bear River formation, which is present throughout much of the northern part of the Caribou Mountains. Limestone pebble conglomerates containing about 0.01 percent uranium were also found locally in the Wayan formation. One of these yielded a fossil-bone fragment that contains 0.17 percent uranium (locality 16, table 3). The Phosphoria formation of Permian age also contains uranium, but a study of this formation in the Caribou Mountains was not included in this investigation.

The exposure of uranium-bearing strata in the Fall Creek coal prospect (locality 13, pl. 51) is discussed in the next section. Elsewhere exposures of the uranium-bearing strata are rare. Trenches (localities 9, 10, 11 and 12, pl. 51 and table 3) were dug to expose these strata at intervals along the strike northwest of the coal prospect for nearly half a mile. Together these five exposures supply the best information available on the lithology and uranium content of the uranium-bearing strata. Exposures elsewhere serve chiefly to demonstrate the widespread distribution of the uranium-bearing strata. The locations of the exposures discussed below are shown on figure 39. Roadcuts have exposed uraniferous strata at locality 36 (sec. 18, T. 2 S., R. 45 E.) and locality 38 (sec. 23, T. 3 S., R. 43 E.), both outside the area mapped and about 17 to 18 miles from the Fall Creek coal prospect. A select grab sample of coal from the dump of the Croley coal prospect, locality 37 (sec. 27, T. 1 S., R. 41 E.), contains 0.007 percent uranium in the coal and 0.03 percent uranium in the ash. The mine itself is not accessible and so the thickness and nature of the strata are not known. Carbonaceous shale on the dump of an abandoned coal prospect in sec. 5, T. 32 N., R. 119 W., near Auburn, Wyo., 47 miles to the southeast (fig. 39, locality 41) contains 0.0035 percent uranium in the sample and 0.0053 percent uranium in the ash. Elsewhere a slight radioactivity was detected in material on the dumps of abandoned coal prospects, including the Brinson prospect, locality 1 (sec. 34, T. 2 N., R. 40 E.), the Pine Creek Pass prospect, locality 4 (sec. 25, T. 3 N., R. 44 E.), which is 21 miles distant, and at a mine in the Bear River formation about 12 miles west of Driggs (locality 5). However, the radioactivity measured in these areas indicated no more than 0.003 percent equivalent uranium. At several other localities radioactivity was detected in rocks exposed by trenches, auger holes, or from limestone float, but fresh samples of the zone of coaly shale were not obtainable and the analyses of these samples can serve only in a qualitative way to show the general distribution of uranium (fig. 39, pl. 51, and table 3).

FALL CREEK COAL PROSPECT

The Fall Creek coal prospect is an inclined shaft that extends about 83 feet down the dip of a bed of coaly shale in the Bear River formation. The shaft was sunk about 1922 by J. H. Smith of Rigby, Idaho, who reports that he mined down the dip of the bed for a distance of about 98 feet and ceased operations when he reached water. A firm limestone roof and good timbering have helped to keep the shaft open, though the floor is covered with rubble and the lowest 15 feet are filled with rubble. Plate 52 is a diagrammatic longitudinal section of the shaft showing the distribution of uranium in the samples.

The prospect lies on the northeast flank of a faulted anticline (pl. 51). The beds here dip 33° northeast and strike northwest. A fault system transverse to the general strike has uplifted the Bear River formation for about half a mile along the axis of the anticline. The inclined shaft has been driven in a zone of incompetent strata which have been sheared by differential movement and are characterized by drag folds.

Uranium in measurable amounts at the Fall Creek coal prospect is confined to a stratigraphic zone of brackish or fresh-water organic-rich strata—units 16 through 21 in the stratigraphic section as described below and represented graphically in figure 40.

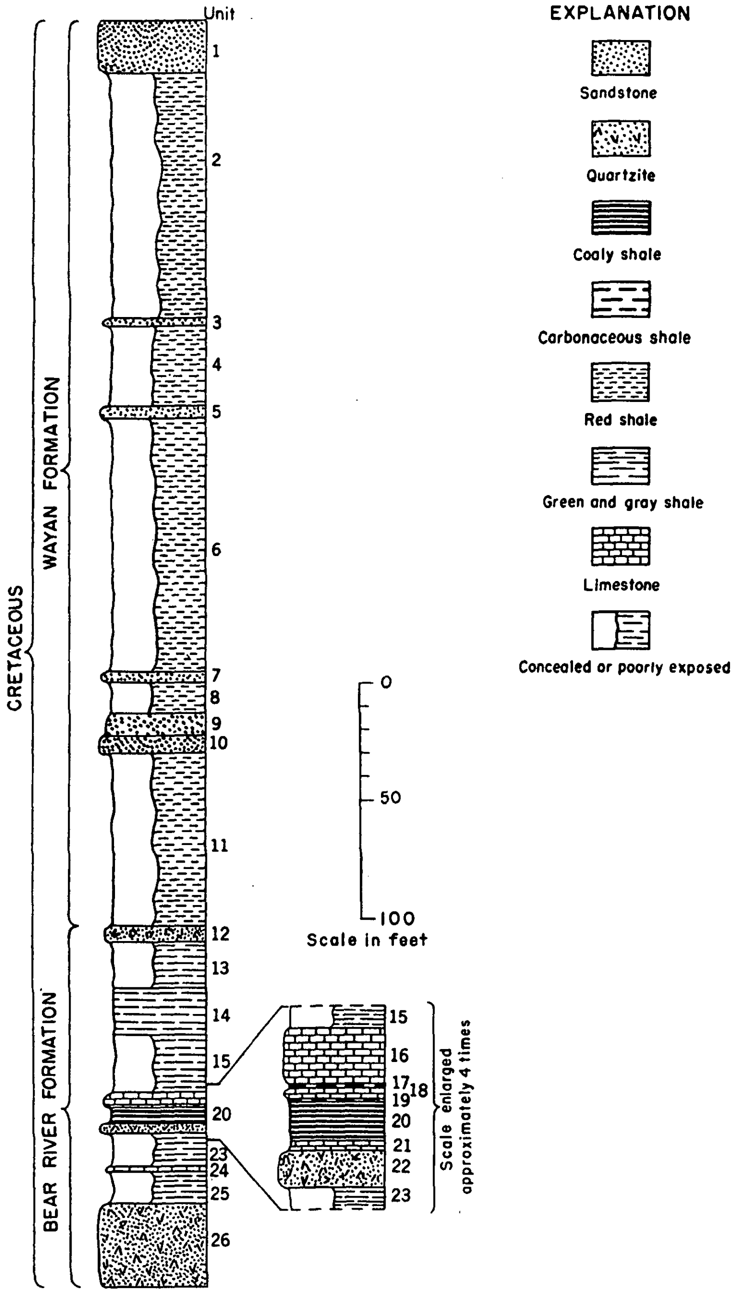

FIGURE 40.—Stratigraphic section of the upper part of the Bear River formation and the lower part of the Wayan formation, as measured at the Fall Creek coal prospect.

Stratigraphic section of the upper part of the Bear River formation and the lower part of the Wayan formation, measured at the Fall Creek coal prospect in sec. 4, T. 1 S., R. 42 E., Bonneville County, Idaho

[The dip here is about 30°–35° to the northeast]

Wayan formation:

Upper part (not measured).

Lower part:

Unit	Thickness ft	Thickness in
1. Sandstone, light-gray, medium-grained, thin- to thick-bedded, crossbedded; forms prominent ledge	23	0
2. Covered; probably contains red shale; forms slope	106	0
3. Sandstone, bulish-gray, fine- to medium-grained	2	0
4. Covered; probably contains red shale; forms slope	34	0
5. Sandstone, bluish-gray, fine-grained	5	0
6. Covered; probably contains red shale; forms slope	108	0
7. Sandstone, greenish-gray, fine-grained	4	0
8. Covered; probably contains red shale; forms slope	13	0
9. Sandstone, light-gray, fine- to medium-grained, forms ledge locally	10	0
10. Sandstone, light-gray, fine- to medium-grained, crossbedded, thin-bedded, slightly friable; forms ledge; the lower 6–8 inches contain a siltstone-pebble conglomerate	6	0
11. Covered, reddish soil; probably contains red shale, forms slope	75	0
Total, lower part of Wayan formation (measured)	386	0

Bear River formation:

Unit	Thickness ft	Thickness in
12. Quartzite, greenish-gray, fine-grained to dense	6	0
13. Covered; probably contains green nonfissile shale	20	0
14. Shale, greenish- to purplish-gray, not fissile; forms slope	20	0
15. Covered by road fill; probably contains green nonfissile shale	25	0
16. Limestone, carbonaceous, gray to black, weathers gray, dense to finely crystalline; contains fossil fragments, including smooth gastropod shells, uraniferous	4	6
17. Shale, carbonaceous, dark greenish gray, uraniferous	0	4
18. Limestone, carbonaceous, dark-gray to black, weathers gray; contains fossil fragments; fresh fragments give off fetid odor; uraniferous	1	3
19. Shale gouge, carbonaceous, contains lenses of clay, coal, and limestone; uraniferous	0	6
20. Coaly shale and thin lenses of coal, clay, and limestone; sheared. This unit contains the highest percent of uranium	4	0
21. Shale, carbonaceous; carbonaceous limestone and uraniferous coal	1	0
22. Quartzite, greenish-gray to brown, fine-grained; forms ledge	4	0

Stratigraphic section of the upper part of the Bear River formation and the lower part of the Wayan formation, measured at the Fall Creek coal prospect in sec. 4, T. 1 S., R. 42 E., Bonneville County, Idaho—Continued

Bear River formation—Continued

Unit	*Thickness ft*	*in*
23. Mostly covered slope-forming unit; probably gray to black, fissile shale	15	0
24. Limestone, impure, dark-brown, weathers brown, dense to finely crystalline; fresh fragments give off a fetid odor; contains fossil fragments including smooth gastropod shells	0	8
25. Mostly covered, slope-forming unit; probably contains gray to black fissile shale	15	0
26. Quartzite, greenish-gray to brown, fine-grained; cross-bedded in part; forms massive ledge, the most prominent marker bed in this part of the section. The lower part of the Bear River formation is not exposed	35	0
Total, Bear River formation exposed (measured)	152	5

Units 16, 17, and 18 in the above section are considered as a relatively resistant limestone zone with a thin shale parting. The limestone ranges from a gray, fine-grained limestone that is not uraniferous to a black, medium- to coarse-grained limestone rich in carbonaceous material, macerated fossil fragments, and some gastropod and pelecypod shells. This type of organic-rich limestone is commonly, though not invariably, uranium bearing throughout a widespread area. The roof of the Fall Creek coal prospect is formed by the base of this limestone. It has a wavy lower surface and contains cavernous joints which may have been enlarged by groundwater circulation. A group of incompetent strata underlying the limestone has been sheared by differential movement and is characterized by shear structure rather than bedding features.

Unit 19 in the stratigraphic section at the Fall Creek prospect is a gouge zone of variable thickness and lithology in which the shear structure is roughly parallel to the bedding of the overlying limestone units. This unit is composed of varying proportions of carbonaceous shale, carbonaceous and calcareous clay gouge, thin limestone lenses, and thin lenses of coal. A sample of black vitreous coal from a 2-inch-thick lens was insoluble in carbon disulfide. Pyrite occurs in the lenses of coal. The unit ranges in thickness from 4 inches to 2 feet and contains an average of about 0.02 percent uranium.

Unit 20, the most highly uraniferous unit of the group, consists of sheared coaly shale with thin lenses of coal, clay, and limestone; it is approximately 4 feet thick. Unit 20 is characterized by drag folds in which lenses of yellow and gray clay, coal, and limestone have been dragged into the sheared coaly shale. Gypsum, calcite, and jarosite commonly occur as secondary encrustations on fractures, joints, and shear planes. A bulk sample of unit 20 was collected about 35 feet from the entrance to the inclined shaft for proximate and ultimate analysis by the U. S. Bureau of Mines. The results are shown in table 1, together with the analysis of a sample collected in 1923 from the same or a nearby prospect. The ash content of this bulk sample is too great for commercial use of the material as fuel. However, sufficient carbonaceous matter is present to make the material comparable to coal. The ratio of carbon to hydrogen is similar to that of subbituminous coal, but the ratio of volatile matter to fixed carbon is higher than for most coals except certain unusual varieties such as cannel coal. This high proportion of volatile matter indicates that this unit may originally have been more similar to canneloid shale than to a true coal. The top foot of unit 20 contains an average of about 0.04 percent uranium and a maximum of about 0.13 percent uranium. The basal 3 feet contain an average of about 0.01 percent uranium.

Underlying the coaly shale of unit 20 is unit 21, which, like unit 19, consists of carbonaceous shale, with lenses of limestone, clay, and jet-black coal. The shear planes in this unit are wavy but roughly parallel the bedding. The unit ranges in thickness from about 6 inches to 2 feet; the base is poorly exposed. The uranium content of this unit is relatively small and averages slightly less than 0.006 percent.

TABLE 1.—*Proximate and ultimate analyses of coaly-shale samples from the Fall Creek coal prospect, Bonneville County, Idaho*

[Analyses by the U. S. Bureau of Mines. Form of analysis: A, as received; B, air dried; C, moisture-free; D, moisture- and ash-free]

Sample		Analyses, in percent									Fusibility (° F)		
		Proximate				Ultimate							
Laboratory No.	Form of analysis	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Initial deformation temperature	Softening temperature	Fluid temperature
D-78075 [1]	A	2.9	25.4	16.6	55.1	2.7	28.8	0.5	9.9	3.0	2,170	2,300	2,530
	B	2.9	25.4	16.5	55.2	2.7	28.9	.5	9.7	3.0			
	C	------	26.1	17.1	56.8	2.4	29.7	.5	7.5	3.1			
	D	------	60.4	39.6	------	5.6	68.7	1.2	17.3	7.2			
94887 [2]	A	4.6	20.7	7.7	67.5	2.5	19.2	.3	7.2	3.3	2,180	2,340	2,390
	C	------	21.2	8.0	70.8	2.0	20.1	.3	3.4	3.4			
	D	------	72.4	27.6	------	7.0	68.7	1.0	11.6	11.7			

[1] Analyzed January 2, 1952.
[2] Analyzed September 24, 1923. From Cooper and others (1947, p. 38).

The average percent ash of samples from the Fall Creek coal prospect (exclusive of the limestone in the roof of the shaft) is greater than 50 percent. A sample of jet-black vitreous coal (sample 2, table 3, pl. 52) from a small lens contained 17.3 percent ash, the least of all the samples collected. This and other samples relatively low in ash contained considerably more uranium than most samples with higher ash contents. At localities 9 (pl. 51) and 37 (fig. 39), grab samples VI–371 and VI–1140 from abandoned prospect dumps had relatively low ash contents of 37 and 21.7 percent and uranium contents of 0.08 and 0.007 percent respectively (table 3).

DISTRIBUTION OF URANIUM AND OTHER ELEMENTS

Carbonaceous rocks are a complex mixture of organic and inorganic compounds and characteristically contain a large suite of minor elements in trace quantities. The ash of coal that has burned represents a concentration of those constituents which are noncombustible and nonvolatile, though not necessarily in the same form as in the unburned coal. The elements present in the ash include at least two and probably three distinct suites, according to their mode of origin (Katchenkov, 1952). The extraneous ash is generally the most abundant and includes several of the common rock-forming elements which were carried into the coal swamp as constituents of sand and clay prior to burial. The extraneous ash probably includes such elements as silicon, aluminum, calcium, iron, magnesium, and possibly, sodium, potassium, manganese, and titanium, most of which are likely to be abundant in those carbonaceous rocks having a high ash content. The intrinsic ash consists of those elements that were part of the mineral constituents in the plant bodies from which the coal was formed. These elements generally include several of the common metals, such as barium, strontium, lead, nickel, zinc, and cobalt—present commonly only in trace amounts, plus many minor metals such as boron, beryllium, scandium, gallium, germanium, lanthanum, niobium, yttrium, molybdenum, and silver—also present only in trace amounts. Several additional elements including sulfur and phosphorus are common constituents of raw coal, but may or may not be present in the ash depending on the original form of the element present in coal. Elements not normally abundant in plant tissues or common rock minerals are sometimes found in considerable abundance in coal ash. Germanium is one such element, and it has been pointed out by Haught[1] that such an accumulation is difficult to explain except as the result of secondary enrichment. Thus, secondary enrichment may produce a third possible distinct suite of

[1] Haught, O. L., 1954, On the occurrence and distribution of rare elements in coal: Paper read at meeting of the Appalachian Geol. Soc., Charleston, W. Va., April 5, 1954.

elements in carbonaceous rocks. Any specific element may be introduced by any one or a combination of the three methods.

Until recently uranium was not considered to be important as a trace element in coaly rocks because it is normally present only in extremely small amounts, probably in the range of 0.000X percent or less. It is now known, however, that the ash of coal may contain as much as 1 percent uranium (Bachman and others, chapter J, this bulletin). The nature of the occurrence of uranium in coaly matter is not clearly understood. Investigations by Tolmachev (1943) suggest that uranium may be associated with carbonaceous material in the form of an adsorbed ion held by the platy structure of the carbon molecules. Ion-exchange studies by Breger and Deul (1955) suggest that uranium may occur as a metallo-organic compound in lignite from South Dakota. Autoradiographic studies by E. F. Koppe and others (written communication, 1954) suggest that uranium or one of its radioactive daughter products is concentrated in an unidentified crystalline material that forms the pore filling of fossil cell lumens in coal. No uranium minerals have been recognized in the carbonaceous material of the Fall Creek area, though an autoradiograph made by exposing ortho-type film for three weeks to a cut section of coal, sample 2 (table 3), shows numerous point sources of radiation in a clouded background and indicates a concentration of radioactive material in microscopic units within a mass of less intensely disseminated radioactive substance.

Semiquantitative spectographic analyses were obtained on a select group of ashed carbonaceous rock samples from the Fall Creek area. The analyses of samples in table 8 are arranged by lithologic types, as follows: coal, less than 50 percent ash; coaly shale, 50–80 percent ash; carbonaceous shale, more than 80 percent ash; and limestone, in which the ash content is not significant. Within each group the samples are arranged by locality, and where possible in order of decreasing percent uranium in the ash. This results in the list having, in general, an order of decreasing percent uranium in the ash. In other words, the percent uranium in the ash shows a general inverse proportion to the percent ash in the sample.

The essential rock-forming elements are listed at the left in table 8 and the accessory elements are grouped to the right according to chemical affinities. Most of the elements occur in what may be considered normal quantity (Goldschmidt, 1937, p. 669), but there are several which deviate from the normal. Uranium, of course, has a range of approximately 50 to one, and even the sample with the least uranium probably contains on the order of 10 times that normally found in rocks of this type. Molybdenum and germanium correlate remarkably well with the uranium (fig. 41), for the samples which are high in uranium also contain one or two orders of magnitude times the

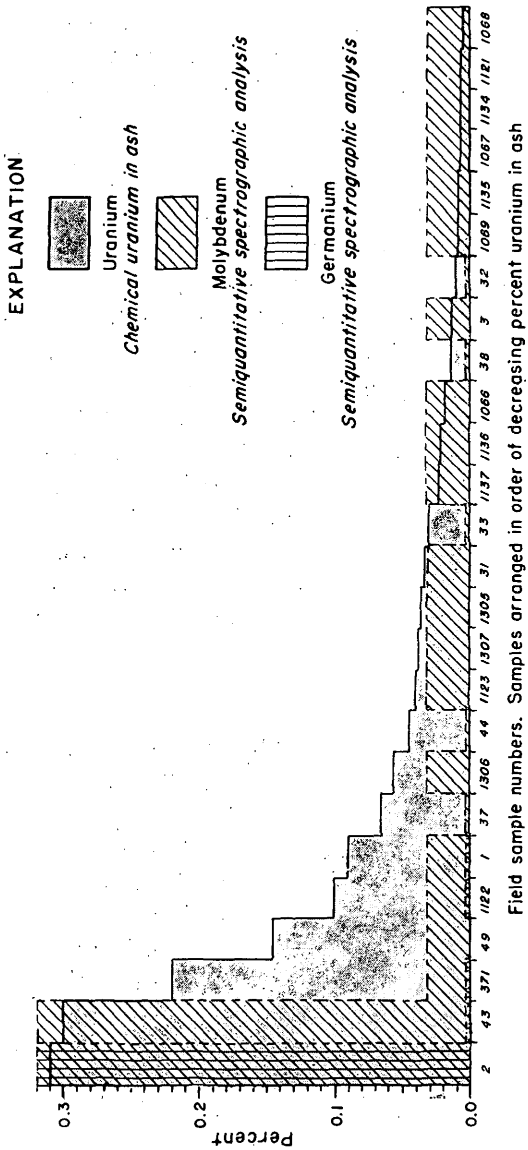

FIGURE 41.—Comparison of uranium, molybdenum, and germanium content in the ash of coal.

normal quantity of molybdenum and germanium, although the germanium and molybdenum contents are not consistently proportional to the uranium content. This correlation of the three elements, which is apparent in the samples with the greatest amount of uranium and less apparent in the samples with less uranium, suggests a geochemical relation and possibly a common origin. Several elements, including beryllium, zinc, gallium, yttrium, and lead, appear to be less abundant in the Fall Creek material than in average coal though the significance of this fact is not apparent.

Uranium in the carbonaceous rocks of the Fall Creek area occurs most abundantly in the units that contain the most carbonaceous material (pl. 52). These units include coal, coaly shale, carbonaceous shale, and black carbonaceous limestone, in a general decreasing order of uranium content. However, even within each unit the uranium content is far from uniform. This is perhaps best shown within the unit of sheared coaly shale, because of the greater number of samples collected. The percent of uranium within this unit at the Fall Creek coal prospect ranges from 0.004 (sample 16) to 0.131 (sample 43). In general, the uranium content is small near the weathered surface exposure and increases to a maximum at about 60 feet down the dip of the bed. The weighted-average content of uranium in samples from this unit at the entrance to the inclined shaft is 0.015 percent uranium, whereas the weighted average for the same unit 60 feet from the entrance is 0.043 percent uranium. There is also a pronounced vertical pattern to the distribution of uranium. The top 1 foot of this coaly shale unit contains an average of about 0.044 percent uranium, in contrast to only about 0.008 percent uranium contained in the basal 1 foot of the unit.

ORIGIN OF URANIUM DEPOSITS

Four general hypotheses for the origin of uranium in coal and carbonaceous materials warrant consideration. These may be classed according to the time and manner of emplacement of the contained uranium, as follows:

1. Syngenetic: simultaneous emplacement of the uranium with the sedimentary material in which it occurs by concentration in living plant tissues.
2. Diagenetic: emplacement of the uranium after the deposition of the sediment but before the consolidation or deep burial of the sedimentary material by concentration in decaying plant remains.
3. Epigenetic: emplacement of the uranium long after the consolidation or deep burial of the sedimentary material:
   (a) By invasion of carbonaceous rocks with uranium-bearing hydrothermal solutions and removal of uranium from solution by reaction with the organic material.

(b) By migration through carbonaceous rocks of uranium-bearing meteoric waters under the force of gravity and removal of the uranium from solution by reaction with the organic material.

For each hypothesis there is general agreement that the organic material in some way causes concentration of the uranium derived from a source that is relatively dilute. It is not known whether the organic material concentrates uranium by reduction, ionic adsorption, chemical combination with the organic constituents, or by other related processes.

It should be possible to deduce the origin of the uranium from the size and shape of the deposit, the distribution of uranium within it, and the type of gangue minerals which characterize the deposit. A syngenetic or diagenetic origin should result in a blanket deposit showing no structural control and being relatively uniform and widespread, similar to those in the uraniferous black Chattanooga shale of Devonian and Mississippian age or the black shales and phosphorite of the Phosphoria formation of Permian age. Hydrothermal solutions should be expected to form small local deposits of uranium concentrated near veins or fissures through which the solutions rose and uranium minerals should be associated with gangue minerals and altered wall rock characteristic of hydrothermal mineralization. On the other hand, deposits of epigenetic origin formed by migrating meteoric waters may be large or small, depending on (1) the size of the area and the content of uranium available from the source; (2) the factors that influence the flow of groundwater from the source to the host rock: regional structure, local structure, and the permeability of the rocks; and (3) the organic content of the host rock. They should contain the type of gangue minerals which are deposited by meteoric waters.

Although hydrothermal gold deposits have been found on Caribou Mountain, an igneous intrusion more than 20 miles away, there is no evidence of hydrothermal activity near the Fall Creek coal prospect. The radioactivity of the Bear River formation throughout a widespread area is somewhat suggestive of a syngenetic or diagenetic origin of the uranium accumulations. However, the uranium content of samples from this widespread area is far from being uniform, and some of the samples from the Fall Creek coal prospect contain several times more uranium than that normally found in the Chattanooga shale or Phosphoria formation, which have been mentioned as examples of deposits of syngenetic origin. Also, there is an apparent relation between the grade of the deposit and structure. The top of the zone of sheared coaly shale has the largest content of uranium, and there is an apparent increase in the percent of uranium below prominent cavernous joints and fissures in the overlying bed of limestone. Where vertical strata were examined and sampled (localities 1 and 39) they were found to contain less uranium than elsewhere. These factors are difficult to explain by a syngenetic or diagenetic origin and are suggestive of an epigenetic origin of the uranium in which the mineralizing solutions were introduced from above. More data are necessary before the structural control of the deposit can be established with certainty.

A definite structural control has been demonstrated in other areas of uraniferous coals and lignites where additional field relationships can be observed that indicate an epigenetic origin by migrating meteoric waters. These areas include those of the uranium-bearing lignite in western North and South Dakota (chapter B), the La Ventana area in Sandoval County, N. Mex. (chapter J), the Red Desert area of Wyoming (chapter G), and the Goose Creek area of southern Idaho (chapter H). From the limited evidence available at the Fall Creek coal prospect and from comparison with other deposits of uraniferous coal and lignite, the epigenetic origin of the uranium from migrating meteoric water seems most plausible in the Fall Creek area.

There still remains the problem of the ultimate source of the uranium which is transported to the deposit by meteoric water. In the Dakota areas of uraniferous lignite the ultimate source is thought to be the tuffaceous sandstones of the White River group of Oligocene age and the Arikaree formation of Miocene age which directly overlie the uraniferous lignite, and in the La Ventana area, New Mexico, the ultimate source is believed to be the Bandelier rhyolite tuff of Smith (1938) of Quaternary age. In the Goose Creek area, Idaho, the source is believed to be the rhyolitic tuffs of the Salt Lake formation of Pliocene age which are interbedded with the lignite. In each example the ultimate source is believed to be a rock of volcanic origin, either a tuffaceous sandstone or a volcanic tuff containing uranium in a highly disseminated form.

A similar potential source for the uranium was present in the Fall Creek area, when the entire area was covered by the silicic volcanic rocks of Miocene or Pliocene age of which only a few small remnants remain, as shown on the geologic map (pl. 51). Samples of these rocks contain 0.002–0.004 percent equivalent uranium and about 0.0012 percent uranium.

Analyses of spring waters issuing from source rocks have helped to demonstrate the leaching action of ground water in other areas. Some spring waters from the White River group in South Dakota and Wyoming contain 40 or more parts per billion of uranium. This compares with considerably less than 1 part per billion for most waters from nontuffaceous rocks that have been tested. No springs could be found in the Fall Creek area issuing directly from the silicic volcanic rocks, but water from a spring at the Fall Creek Ranger

Station, which is near the trough of a syncline, part of which is overlain by silicic volcanic rocks contained 8 parts uranium per billion.

The origin of the uranium is of considerable economic importance because the approach to be used in physical exploration depends on the interpretation of the size and shape of the occurrence, which in turn is related to the mode of origin. If the uranium is of epigenetic origin, then exploration for ore-grade material should be conducted in areas structurally favorable for the concentration and flow of ground water solutions, such as along synclinal troughs. On the other hand, if it is of syngenetic or diagenetic origin, then the deposit should be relatively uniform over a large area and exploration should be conducted in areas most easily mined.

CORE-DRILLING PROGRAM

DRILLING OPERATIONS

Core drilling in the Fall Creek area, Bonneville County, Idaho, was conducted to obtain information about the subsurface areal extent, thickness, and grade of unweathered uranium-bearing carbonaceous rocks. It was hoped that information might also be obtained on the relation between uranium content and the structural position of the uraniferous strata. Drilling was done for the Geological Survey under contract by a private company.

Six core holes were drilled at three different structural settings (fig. 42) to obtain information on the reserves of uranium in three blocks, as follows:

1. Core holes 1 and 2 were drilled on the northeast limb of an anticline in the northern part of sec. 4, T. 1 S., R. 42 E.
3. Core holes 3, 3A, and 4 were drilled on the southwest limb of an anticline near the center of the same section.
2. Core hole 5 was drilled on the southwest limb of an anticline at the northeast corner of sec. 8, T. 1 S., R. 42 E.

All holes were planned to test the same sheared stratigraphic zone exposed in the Fall Creek coal prospect.

DESCRIPTION OF CORE HOLES

The six core holes have a combined total footage of 1,618 feet (figs. 42 and 43). The average hole depth was 270 feet, the deepest being 472 and the shallowest, 55 feet.

Core recovery of rocks other than the coaly shale was good, but core recovery of the coaly shale was poor. The structure of the area was much more complex than anticipated, and only one hole reached the uranium-bearing carbonaceous rocks. The other holes did not reach them owing to faulting and to increasing dip of the strata at depth.

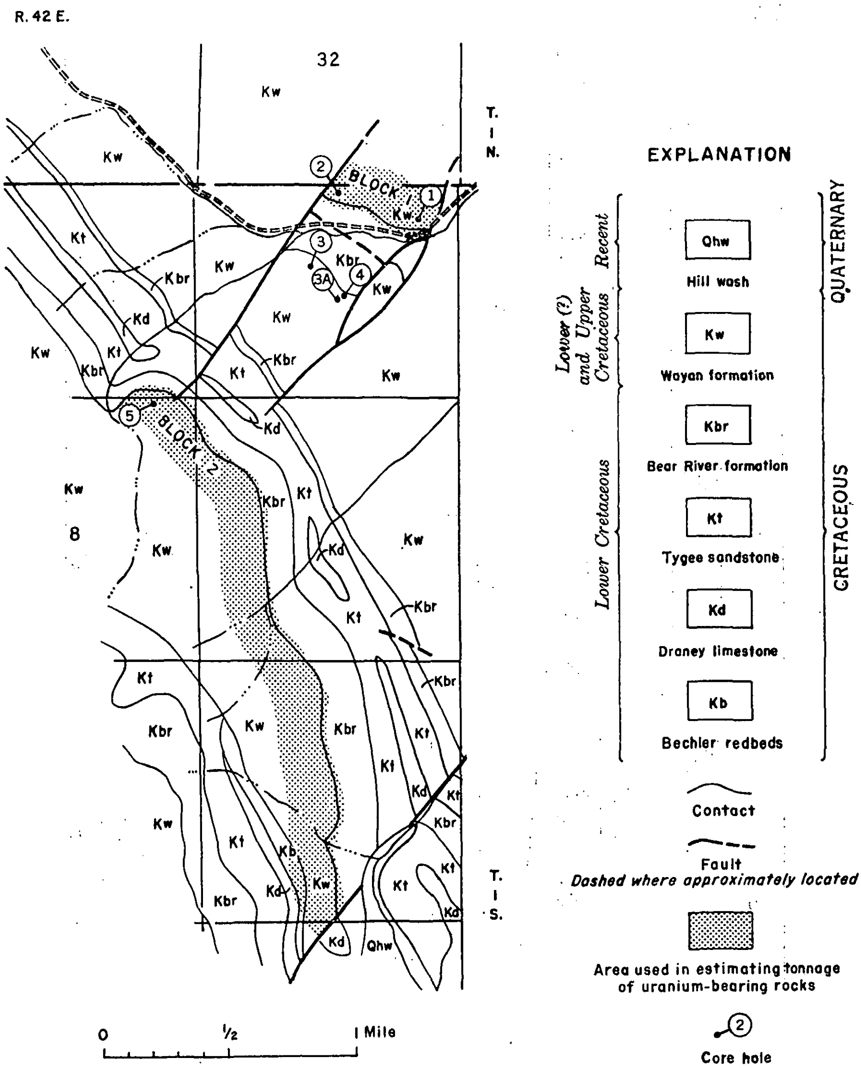

FIGURE 42.—Sketch map of part of Fall Creek area, Bonneville County, Idaho, showing location of core holes and areas underlain by uranium-bearing rock.

Core hole 1 was drilled to a depth of 293 feet from a location about 300 feet northeast and 60 feet higher than the exposure of uranium-bearing rocks at the Fall Creek coal prospect. A zone of uraniferous limestone and carbonaceous shale is present in the interval penetrated from 264–270.9 feet. Analyses of 8 samples, VI–1300 to VI–1307 (table 6), from this zone ranged from 0.003 to 0.036 percent uranium in the sample. The highest grade sample, VI–1306, with 70.0 percent ash, contained 0.056 percent uranium in the ash. This is the only hole in which the anticipated thickness of uranium-bearing rock was found.

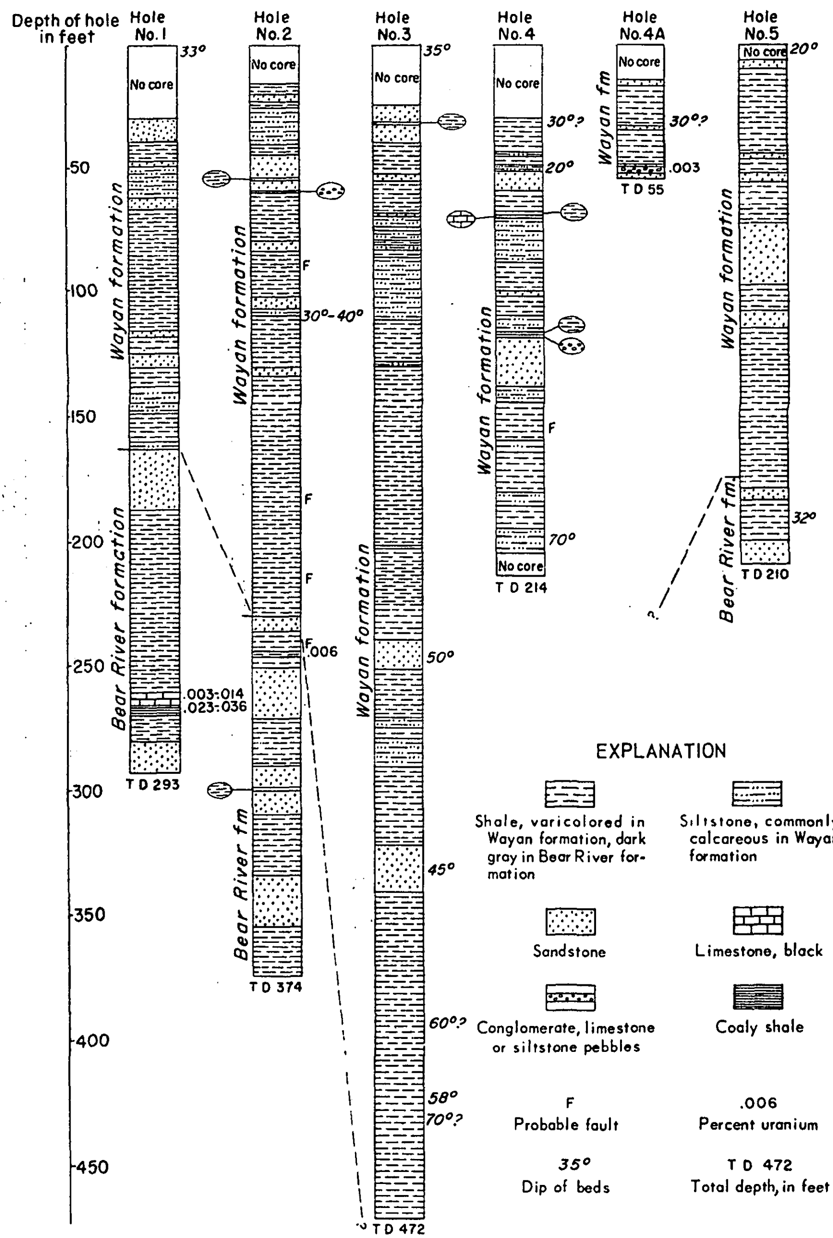

FIGURE 43.—Stratigraphic sections of cores from Fall Creek area, Idaho.

Core hole 2 was drilled to a depth of 374 feet from a point about 350 feet northeast and 100 feet higher than the outcrop of uraniferous rock sampled at locality 9 (pl. 51). If the surface dip of about 35° had been maintained at depth, the uranium-bearing zone should have been reached at about 345 feet. However, a thin zone of dark-gray carbonaceous shale from core-hole depths of 246 to 248 feet analyzed 0.006 percent equivalent uranium (sample VI–1308). Below this zone the core more nearly resembles the carbonaceous, ferruginous siltstone present in the lower two-thirds of the Bear River formation. Therefore, if the thin zone from 246 to 248 feet represents the uranium-bearing zone exposed at the Fall Creek coal prospect, it has apparently been squeezed and deformed because of its proximity to a fault.

Core hole 3 was drilled to a depth of 472 feet from a point about 430 feet southwest and at the same altitude as the outcrop of radioactive soil and limestone sampled at locality 14. Here too, if the surface dip of about 35° had been maintained, the uranium-bearing zone should have been reached at a depth of about 295 feet. However, the dip of the rocks, as shown from the core, gradually increased to as much as 70°, and the red shale characteristic of the Wayan formation was present at the bottom of the hole. No reliable estimate can be made as to the depth required to reach the uraniferous zone in the Bear River formation at this locality.

Core hole 4 was drilled to a depth of 214 feet at a point 140 feet south and level with the outcrop of radioactive soil and limestone near carbonaceous-rock-sample locality 15. Dip readings at the surface in this area range from 20° to 45°, so the uranium-bearing zone should have been reached at a depth between 50 and 135 feet. Radioactive rock was present at a depth of 53–54 feet, but no core was recovered and below this interval no other radioactivity was detected in the wall rock of red shale characteristic of the Wayan formation. Strata in the core from the bottom of the hole had dips of 70°.

Core hole 4 A was drilled at a point offset about 3 feet from core hole 4 to a depth of 55 feet to obtain a sample of core from the radioactive rock for which no core was obtained in core hole 4. At a depth of 51.5–52 feet a uranium-bearing limestone-pebble conglomerate was cored that is similar to beds of limestone-pebble conglomerate observed in outcrops of the Wayan formation.

Core hole 5 was drilled to a depth of 210 feet at a location about 330 feet south and 42 feet below the outcrop of limestone in radioactive soil that is half a mile northwest of carbonaceous-rock-sample locality 24. Dips at the surface near the hole range from 20° to 22°, so the uranium-bearing zone should have been reached at a depth between 75 and 90 feet. However, dips as much as 32° were measured on the core. The bottom of the hole was in the Bear River formation, probably within 50 feet of the objective.

TONNAGE OF URANIUM-BEARING ROCK

Carbonacous rocks containing 0.01 to 0.04 percent uranium are believed to underlie parts of two areas in secs. 4, 5, 8, 9, and 16, T. 1 S.,

R. 42 E., and sec. 32, T. 1 N., R. 42 E., Bonneville County, Idaho. These areas are shown in two blocks on figure 42. The blocks were determined by assuming that the uranium-bearing strata extend 1000 feet down dip from the known outcrop. Block 1, on the northeast, as shown in figure 42, contains 57 acres and was sampled at the Fall Creek coal prospect, at core hole 1 and at surface sample localities 9, 10, 11, and 12. Because of the small number and variable quality of the samples from this block, the estimate of amount of uranium-bearing rock in block 1 is considered to be subject to large error. However, because core hole 2, at the northwest end of the block, did not reach the anticipated thickness of uranium-bearing strata, the size of block 1 for the purpose of estimating tonnage of uranium-bearing rock was arbitrarily reduced to 50 acres. Block 2, on the southwest, as shown on figure 42, is 356 acres in size and was sampled at the surface at sample localities 24, 27, and 28. Core hole 5 at the northwest end of block 2 did not reach the uranium-bearing strata, but the existence of a block having uranium-bearing rock is not invalidated. However, because of the inadequacy of the surface samples to provide a means of evaluating the thickness and grade of the uranium-bearing strata the estimates of tonnage for block 2 is considerably less reliable than that for block 1.

Because of the excellent exposure and number of samples collected in the Fall Creek coal prospect, these data alone were considered in estimating the average thickness and grade of the various units used in calculating tonnage for both blocks 1 and 2. The estimates are in error to whatever extent the average thickness and grade throughout blocks 1 and 2 differ from that in the Fall Creek coal prospect.

For these reasons, it is estimated there are about 6½ million tons of rock containing about 0.02 percent uranium underlying about 400 acres of the Fall Creek area, as shown in table 2.

TABLE 2.—*Tonnage estimate of uranium-bearing carbonaceous rock, Fall Creek area, Bonneville County, Idaho*

[Block 1 lies on the northeast flank of the anticline north of the Fall Creek coal prospect. Block 2 lies in an outcrop band midway between the Fall Creek coal prospect and Skyline Ridge]

Rock type	Thickness (feet)	Tons per acre-foot	Uranium (percent)	Block 1 (50 acres)	Block 2 (356 acres)
				Tonnage	
Limestone	1.5	3,600	0.02	270,000	1,920,000
Carbonaceous shale	1.5	2,600	.024	195,000	1,390,000
Coaly shale (top)	1.5	1,750	.045	87,500	623,000
Coaly shale (base)	3.6	1,750	.011	262,500	1,870,000
Total				815,000	5,803,000
Grand total					6,618,000

TABLE 3.—*Analyses of sedimentary rocks in the Fall Creek and adjacent areas, Idaho and Wyoming*

All samples are carbonaceous rocks from the Bear River formation except for samples from locality 16 (Wayan formation) and from localities 23 and 35 (Draney limestone). All localities are in Bonneville County, Idaho, except localities 40 and 41, which are in Lincoln County, Wyo. Description of sample: the following arbitrary limits of ash content were used: coal, less than 50 percent; coaly shale, 50–80 percent; carbonaceous shale, more than 80 percent. Uranium: most samples containing less than 0.004 percent equivalent uranium were not analyzed for uranium.

[Analysts: Maryse Delevaux, Harry Levine, Audry Pietsch, Joseph Budinsky, R. Dufour, W. P. Tucker, Carmen R. Hoy, S. Lundine, B. A. McCall, S. Furman, U.S. Geological Survey.]

Sample					Analyses, in percent			
						Uranium—		
Field No.	Laboratory No.	Type	Material	Thickness (in.)	Equivalent uranium	In sample	In ash of sample	Ash in sample
LOCALITY 1, BRINSON COAL PROSPECT, SEC. 34, T. 2 N., R. 40 E. (FIG. 39)								
VI-1170	95499	Grab	Coaly shale		0.001			70.1
1171	D74343	do	do		.003	0.0015	0.0012	74.65
1172	D74324	do	Limestone		.003	.0019		
LOCALITY 2, SEC. 2, T. 1 N., R. 41 E. (FIG. 39)								
VI-1045	87722	Grab	Limestone		0.006	0.005	0.008	59.6
1046	87723	do	Black clay soil		.002			81.6
LOCALITY 3, SEC. 13, T. 1 N., R. 41 E. (FIG. 39)								
VI-1044	87721	Grab	Limestone		0.003			61.7
LOCALITY 4, PINE CREEK PASS PROSPECT, SEC. 25, T. 3 N., R. 44 E. (FIG. 39)								
VI-1093	90198	Grab	Coaly shale		0.003			63.5
1094	90199	do	Coaly limestone		.001			58.5
1095	90200	do	Limestone		.001			
1149	95484	do	Selected coal		.002	0.002	0.003	50.0
LOCALITY 5, HORSESHOE DISTRICT, SEC. 32, T. 5 N., R. 44 E. (FIG. 39)								
VI-1153	95486	Grab	Coal on dump		0.003	0.003	0.009	36.2
1154	95487	do	Fossils in coal		<.001			79.0
LOCALITY 6, SEC. 16, T. 1 N., R. 42 E. (PL. 51)								
VI-1043	87720	Grab	Black clay soil		0.004			84.4
1166	95495	Auger	do	8	.004	0.005	0.006	84.4
1167	95496	do	do	8	.004	.003	.004	85.7
1168	95497	do	do	4	.003			86.7
1169	95498	Channel	Limestone	2	.003			80.8
LOCALITY 7, SEC. 25, T. 1 N., R. 42 E. (PL. 51)								
VI-1042	87719	Grab	Limestone		0.004			59.4

TABLE 3.—*Analyses of sedimentary rocks in the Fall Creek and adjacent areas, Idaho and Wyoming*—Continued.

Sample					Analyses, in percent			
						Uranium—		
Field No.	Laboratory No.	Type	Material	Thickness (in.)	Equivalent uranium	In sample	In ash of sample	Ash in sample
LOCALITY 8, SEC. 36, T. 1 N., R. 41 E. (PL. 51)								
VI-1080	90185	Grab	Limestone		<0.001			
LOCALITY 9, SEC. 4, T. 1 S., R. 42 E. (PL. 51)								
VI-371	66858	Grab	Selected coal on dump		0.066	0.08	0.22	37.0
372	66859	do	Coaly soil		.021	.016	.028	58.1
373	66860	do	Black clay soil		.002			
LOCALITY 10, SEC. 4, T. 1 S., R. 42 E. (PL. 51)								
VI-1036	87713	Channel	Limestone	18	0.013	0.010	0.017	61.5
1033	87710	do	Coaly shale	9	.008	.006	.009	70.2
1034	87711	do	do	9	.011	.011	.014	75.1
1035	87712	do	do	17	.010	.008	.011	71.2
LOCALITY 11, SEC. 4, T. 1 S., R. 42 E. (PL. 51)								
VI-1138	90223	Grab	Limestone		0.008	0.007		
1134	90219	Channel	Carbonaceous clay	6	.008	.006	0.007	83.6
1135	90220	do	do	6	.013	.007	.009	83.3
1136	90221	do	Coaly shale	6	.017	.015	.021	69.8
1137	90222	do	do	6	.021	.015	.023	66.8
LOCALITY 12, SEC. 4, T. 1 S., R. 42 E. (PL. 51)								
VI-1133	90218	Grab	Limestone		0.013	0.012		
1132	90217	do	Coaly shale		.009	.006	0.008	74.4
LOCALITY 13, FALL CREEK COAL PROSPECT, SEC. 4, T. 1 S., R. 42 E. (PLS. 51 AND 52)								
Samples collected at entry of inclined shaft								
4	66874	Channel	Carbonaceous shale	3	0.002	0.001		
5	66873	do	Carbonaceous limestone	15	.027	.024		
6	66861	do	Carbonaceous shale, coal, and limestone.	2	.019	.015	0.018	84.8
7	66862	do	Sheared coaly shale	15	.011	.011	.014	78.8
8	66863	do	do	15	.013	.023	.025	74.6
9	66864	do	do	15	.009	.013	.016	77.5
10	66865	do	Carbonaceous limestone	6	.007	.007		
11	66866	do	Carbonaceous shale	6	.004	.003		
Samples collected 10 feet from entry								
12	66867	Channel	Coaly shale	4	0.021	0.022	0.029	77.5
13	66868	do	Sheared coaly shale	12	.011	.012	.018	69.4
14	66869	do	do	12	.017	.020	.027	71.5
15	66870	do	do	12	.009	.016	.022	73.0
16	66871	do	do	12	.005	.004	.006	72.6
17	66872	do	Coaly shale	12	.004	.005	.007	72.8

TABLE 3.—*Analyses of sedimentary rocks in the Fall Creek and adjacent areas, Idaho and Wyoming*—Continued

Sample					Analyses, in percent			
						Uranium—		
Field No.	Laboratory No.	Type	Material	Thickness (in.)	Equivalent uranium	In sample	In ash of sample	Ash in sample
LOCALITY 13, FALL CREEK COAL PROSPECT—continued								
Samples collected 20 feet from entry								
18	66875	Channel	Carbonaceous limestone and shale.	6	0.012	0.013		
19	66876	do	Sheared coaly shale	12	.035	.040	0.066	61.3
20	66877	do	do	12	.006	.008	.011	71.8
21	66878	do	do	12	.009	.011	.015	73.4
22	66879	do	Coaly shale	12	.005	.005	.007	77.9
23	66880	do	Carbonaceous limestone and shale.	12	.004	.006	.008	69.3
Samples collected 30 feet from entry								
24	66881	Channel	Carbonaceous shale	12	0.024	0.028		
25	66882	do	Sheared coaly shale	16	.008	.010	0.014	72.0
26	66883	do	do	16	.006	.008	.011	68.3
27	66884	do	do	16	.007	.010	.014	69.7
28	66885	do	Sheared coaly shale, carbonaceous shale, and limestone.	15	.007	.007	.009	74.4
Samples collected 40 feet from entry								
29	66886	Channel	Carbonaceous shale	6	0.026	0.032		
30	66887	do	Carbonaceous limestone, shale, and coal.	10	.028	.031	0.044	70.8
31	66888	do	Sheared coaly shale	16	.021	.024	.033	72.3
32	66889	do	do	16	.006	.007	.010	74.6
33	66890	do	do	16	.018	.021	.030	71.4
34	66891	do	Carbonaceous shale, limestone, and coal.	16	.005	.007	.009	78.2
Samples collected 50 feet from entry								
35	66892	Channel	Carbonaceous shale and limestone.	12	0.026	0.030		
36	66893	do	Carbonaceous limestone, shale, and coal.	8	.025	.027		
37	66894	do	Sheared coaly shale	15	.033	.040	0.066	60.4
38	66895	do	do	15	.007	.009	.013	66.0
39	66896	do	do	15	.005	.007	.010	70.8
40	67239	do	Carbonaceous shale and coal.	12	.006	.006	.008	70.8
Samples collected 60 feet from entry								
41	67240	Channel	Carbonaceous shale	8	0.016	0.020		
42	67241	do	Carbonaceous limestone and shale.	15	.018	.022		
43	67242	do	Sheared coal	15	.096	.131	0.300	43.7
44	67243	do	Sheared coaly shale	15	.025	.029	.044	66.2
45	67244	do	do	15	.006	.008	.010	75.9
46	67245	do	do	15	.007	.007	.009	77.4
Samples collected 75 feet from entry								
47	67246	Channel	Carbonaceous shale and limestone.	4	0.003	0.003		
48	67247	do	Carbonaceous limestone	17	.010	.011		
49	67248	do	Sheared coaly shale	13	.064	.089	0.145	58.4
50	67249	do	do	13	.007	.006	.009	64.9
51	67250	do	do	13	.008	.009	.012	72.4

TABLE 3.—*Analyses of sedimentary rocks in the Fall Creek and adjacent areas, Idaho and Wyoming*—Continued

Sample					Analyses, in percent			
Field No.	Laboratory No.	Type	Material	Thickness (in.)	Equivalent uranium	Uranium— In sample	Uranium— In ash of sample	Ash in sample
LOCALITY 13, FALL CREEK COAL PROSPECT—continued								
Samples typical of the lithologic units represented in and near the Fall Creek coal prospect								
1	52040	Grab	Sheared coal		0.064	0.040	0.090	43.9
2	52041	do	Vitreous coal		.10	.053	.31	17.3
3	52042	Channel	Sheared coaly shale	48	.020	.010	.013	77.5
VI-1121	90206	do	Carbonaceous shale from unit 19.	10	.008	.006	.007	87.4
1122	90207	do	Sheared coaly shale from unit 20.	12	.048	.054	.100	51.9
1123	90208	do	Coaly shale, from unit 19	6	.033	.028	.040	70.0
1124	90209	do	Carbonaceous limestone from unit 19.	2	.003			62.7
1125	90210	do	Quartzitic sandstone from unit 22.	4	.001			
1126	90211	do	Carbonaceous limestone from unit 16.	12	.001			
1127	90212	do	Carbonaceous limestone from unit 24.	8	<.001			
1128	90213	Grab	Carbonaceous shale from unit 25.		.002			89.9
1129	90214	do	Black soil on line of strike with strata in mine.		.005	.004	.006	74.6
1130	90215	do	Carbonaceous limestone float near mine.		.004			
LOCALITY 14, SEC. 4, T. 1 S., R. 42 E. (PL. 51)								
VI-1120	90205	Grab	Limestone		<0.001			
LOCALITY 15, SEC. 4, T. 1 S., R. 42 E. (PL. 51)								
VI-1131	90216	Grab	Limestone		<0.001			
LOCALITY 16, SEC. 3, T. 1 S., R. 42 E. (PL. 51)								
VI-1031	87708	Grab	Fossil bone (Wayan formation).		0.16	0.17	0.21	82.3
LOCALITY 17, SEC. 33, T. 1 N., R. 42 E. (PL. 51)								
VI-1075	90180	Grab	Limestone		0.001			
LOCALITY 18, SEC. 33, T. 1 N., R. 42 E. (PL. 51)								
VI-1074	90179	Grab	Limestone		0.001			
1071	88112	Auger	Gray clay soil	10	.004			91.5
1072	90117A	do	do	16	.001			88.1
1073	90118	do	do	16	.002			86.2
LOCALITY 19, SEC. 34, T. 1 N., R. 42 E. (PL. 51)								
VI-1041	87718	Grab	Black clay soil		0.004			85.3
LOCALITY 20, SEC. 34, T. 1 N., R. 42 E. (PL. 51)								
VI-1032	87709	Grab	Limestone		0.006	0.004	0.007	61.1

TABLE 3.—*Analyses of sedimentary rocks in the Fall Creek and adjacent areas, Idaho and Wyoming*—Continued

Sample					Analyses, in percent			
Field No.	Laboratory No.	Type	Material	Thickness (in.)	Equivalent uranium	Uranium— In sample	Uranium— In ash of sample	Ash in sample
LOCALITY 21, SEC. 34, T. 1 N., R. 42 E. (PL. 51)								
VI-1040	87717	Grab	Sandy clay soil		0.001			92.3
LOCALITY 22, SEC. 2, T. 1 S., R. 42 E. (PL. 51)								
VI-1038	87715	Channel	Black clay soil	6	0.007	0.004	0.005	86.4
1039	87716	do	do	6	.007	.006	.007	86.6
LOCALITY 23, SEC. 7, T. 1 S., R. 42 E. (PL. 51)								
VI-1087	90192	Grab	Limestone (Draney limestone).		<0.001			
LOCALITY 24, SEC. 9, T. 1 S., R. 42 E. (PL. 51)								
VI-1047	87724	Grab	Limestone		0.003			61.9
1048	88089	do	Black clay soil		.012	0.011	0.013	84.6
1052	88093	do	do		.010	.008	.010	83.2
1049	88090	Auger	do	7	.006	.004	.005	84.0
1050	88091	do	do	14	.005	.003	.004	85.4
1051	88092	do	do	28	.003			86.3
LOCALITY 25, SEC. 12, T. 1 S., R. 42 E. (PL. 51)								
VI-1099	90204	Grab	Limestone		<0.001			
LOCALITY 26, SEC. 7, T. 1 S., R. 43 E. (PL. 51)								
VI-1098	90203	Grab	Limestone		<0.001			
LOCALITY 27, SEC. 16, T. 1 S., R. 42 E. (PL. 51)								
VI-1053	88094	Grab	Limestone		0.003			
1055	88096	Auger	Black clay soil	17	.004			85.6
1056	88097	do	do	17	.012	0.009	0.010	85.6
1057	88098	do	do	18	.006	.004	.005	88.5
LOCALITY 28, SEC. 16, T. 1 S., R. 42 E. (PL. 51)								
VI-1088	90193	Grab	Limestone		0.005	0.004		
LOCALITY 29, SEC. 22, T. 1 S., R. 42 E. (PL. 51)								
VI-1092	90197	Grab	Limestone		0.004			
1091	90196	do	Black clay soil		.003			

TABLE 3.—*Analyses of sedimentary rocks in the Fall Creek and adjacent areas, Idaho and Wyoming*—Continued.

Sample					Analyses, in percent			
Field No.	Laboratory No.	Type	Material	Thickness (in.)	Equivalent uranium	Uranium— In sample	Uranium— In ash of sample	Ash in sample
LOCALITY 30, SEC. 27, T. 1 S., R. 42 E. (PL. 51)								
VI-1089	90194	Grab	Limestone		0.006	0.004		
1142	95478	Auger	Brown clay soil	9	.002			85.4
1143	95479	do	do	9	.004	.003	0.003	88.4
1144	95480	do	do	9	.003			84.7
1145	95481	do	do	9	.003			87.3
1146	95482	do	do	9	.003			88.0
1147	95483	do	do	9	.003			88.1
LOCALITY 31, SEC. 23, T. 1 S., R. 42 E. (PL. 51)								
VI-1090	90195	Grab	Limestone		0.002			
LOCALITY 32, SEC. 25, T. 1 S., R. 42 E. (PL. 51)								
VI-1054	88095	Grab	Limestone		0.004			
LOCALITY 33, SEC. 1, T. 2 S., R. 42 E. (FIG. 39)								
VI-1058	88099	Grab	Black soil		0.002			87.7
LOCALITY 34, SEC. 6, T. 2 S., R. 43 E. (FIG. 39)								
VI-1060	88101	Grab	Limestone		0.004			
1059	88100	Channel	Black clay soil	18	.003			83.4
1061	88102	Auger	do	8	.002			80.6
1062	88013	do	do	8	.002			80.7
1063	88014	do	Gray clay soil	8	.003			82.7
1064	88015	do	Sandy clay soil	8	.002			90.0
LOCALITY 35, SEC. 17, T. 2 S., R. 43 E. (FIG. 39)								
VI-1065	88016	Grab	Limestone (Draney limestone).		<0.001			
LOCALITY 36, SEC. 18, T. 2 S., R. 45 E. (FIG. 39)								
VI-1174	D74326	Channel	Limestone	24	0.002	0.0011		
1173	D74325	do	Coaly shale	12	.004	.0033	0.0042	77.53
LOCALITY 37, CROLEY COAL PROSPECT, SEC. 27, T. 1 S., R. 41 E. (FIG. 39)								
VI-1140	95476	Grab	Selected coal on dump		0.005	0.007	0.030	21.7
1141	95477	do	Average material on coal dump.		.003	.002	.004	48.6
LOCALITY 38, SEC. 23, T. 3 S., R. 43 E. (FIG. 39)								
VI-1066	88107	Channel	Coaly shale	9	0.011	0.013	0.019	69.9
1067	88108	do	Carbonaceous clay	9	.006	.006	.007	81.6
1068	88109	do	do	9	.005	.005	.006	83.1
1069	88110	do	do	9	.006	.007	.009	79.9

TABLE 3.—*Analyses of sedimentary rocks in the Fall Creek and adjacent areas, Idaho and Wyoming*—Continued

Sample					Analyses, in percent			
Field No.	Laboratory No.	Type	Material	Thickness (in.)	Equivalent uranium	Uranium— In sample	Uranium— In ash of sample	Ash in sample
LOCALITY 39, SEC. 24, T. 3 S., R. 44 E. (FIG. 39)								
VI-1070	88111	Channel	Carbonaceous shale	12	0.001			82.4
LOCALITY 40, SEC. 4, T. 37 N., R. 117 W. (FIG. 39)								
VW-1082	90187	Grab	Limestone		0.003			
1083	90188	Channel	Black shale	12	.001			91.9
1084	90189	do	Conglomerate	14	<.001			85.7
LOCALITY 41, AUBURN COAL PROSPECT, SEC. 5, T. 32 N., R. 119 W. (FIG. 39)								
VW-1190	D74342	Grab	Carbonaceous shale		0.004	0.0035	0.0053	88.01

TABLE 4.—*Analyses of silicic volcanic rocks, Fall Creek and adjacent areas, Idaho*

[Analyses by W. Niles, W. Montjoy, R. Dufour and S. Furman, U. S. Geological Survey]

Locality — No. and map	Sec.	T.	R.	Field No.	Laboratory No	Rock type	Equivalent uranium (percent)	Uranium in sample (percent)
1 (fig. 39)	25	5 N.	44 E.	VI-367	66854	Vesicular lava	0.004	
				368a	D84780	Tuff	.004	0.0012
2 (fig. 39)	19	3 N.	46 E.	1096	D84787	Rhyolite	.004	.0010
3 (fig. 39)	1	2 N.	40 E.	1151	D73712	Tuff	.002	.0005
4 (fig 39)	25	2 N.	43 E.	1148	D73711	Pumiceous loess	.001	.0003
5 (fig. 39)	11	1 N.	40 E.	366a	D84779	Rhyolitic tuff	.003	.0007
6 (pl. 51)	21	1 N.	42 E.	1030	D84785	Obsidian	.004	.0012
7 (pl. 51)	30	1 N.	42 E.	1037	87714	Rhyolitic tuff	.004	
8 (pl. 51)	29	1 N.	42 E.	370a	D84782	do	.004	.0010
9 (pl. 51)	8	1 S.	42 E.	1081	D84786	do	.004	.0012
10 (pl. 51)	29	1 S.	42 E.	1139	90224	do	.004	
11 (fig. 39)	16	1 S.	45 E.	369a	D84781	Tuffaceous sand	.004	.0010
12 (fig. 39)	16	3 S.	46 E.	1085	90190	Tuffaceous sand	.004	
				1086	90191	Tuff	.001	

TABLE 5.—*Analyses of natural waters, Fall Creek and adjacent areas, Idaho and Wyoming*

[Analyses by W. Niles and W. Montjoy, U. S. Geological Survey]

Locality: No. and map	Locality: Sec.	Locality: T.	Locality: R.	Field No.	Laboratory No.	Uranium (ppm)	Description
1 (fig. 39)	32	2 N.	41 E.	VI-1105	D73708	<0.002	Spring at base of silicic volcanic rocks.
2 (fig. 39)	31	2 N.	41 E.	1104	D73707	.005	Spring in Wayan formation just below contact with silicic volcanic rocks.
3 (fig. 39)	8	1 N.	43 E.	1106	D73709	<.002	Mineral spring on Fall Creek.
4 (fig. 39)	28	1 N.	41 E.	1103	D73706	<.002	Spring in Wayan formation just below contact with silicic volcanic rocks.
5 (pl. 51)	32	1 N.	42 E.	1101	D73704	.003	Spring in Wayan formation about 500 feet below contact with silicic volcanic rocks.
6 (pl. 51)	33	1 N.	42 E.	1102	D73705	.008	Spring at Fall Creek Ranger Station along a synclinal axis in the Wayan formation. A remnant of silicic volcanic rocks overlies the synclinal axis about 1½ miles to the northwest.
7 (fig. 39)	4	37 N. (Wyoming)	117 W.	1100	D73703	<.002	Water from the Snake River.

TABLE 6.—*Analyses of core samples from Fall Creek area, Idaho*

[Analyses by Alice Padgett and B. A. McCall, U. S. Geological Survey]

Sample: Field No.	Sample: Laboratory No.	Sample: Rock type	Sample: Thickness (feet)	Depth of interval sampled (feet)	Analyses, in percent: Equivalent uranium	Uranium— In sample	Uranium— In ash of sample	Ash in sample
Core hole 1								
VI-1300	113580	Limestone	0.6	261.9–262.5	0.003	0.003		
1301	113581	do	1.0	262.5–263.5	.003	.004		
1302	113582	do	1.0	263.5–264.5	.003	.003		
1303	113583	do	1.0	264.5–265.5	.007	.007		
1304	113584	do	1.0	265.5–266.5	.013	.014		
1305	113585	Coaly shale	1.2	[1] 266.5–267.7	.020	.028	0.036	77.1
1306	113586	do	.5	269.0–269.5	.025	.039	.056	70.0
1307	113587	do	1.0	269.5–270.5	.023	.028	.039	69.0
Core hole 2								
VI-1308	113588	Carbonaceous shale	0.9	246.3–247.2	0.006			
Core hole 4A								
MI-1004	115800	Conglomerate	0.5	51.5–52.0	0.004	0.003		
1005	115801	do	.5	52.0–52.5	.004	.003		

[1] No core recovered, interval at 267.7–269.0 feet.

TABLE 7.—*Standard sensitivities for the elements determined by the semiquantitative spectrographic method in the U. S. Geological Survey Laboratory, May 1952*

Elements	Percent	Elements	Percent	Elements	Percent
Ag	0.0001	Ge	0.0005	Sc	0.001
Al	.001	K	1.0	Si	.001
B	.005	La	.005	Sr	.0005
Ba	.0001	Mg	.005	Ti	.001
Be	.0001	Mo	.001	U	.05
Ca	.001	Mn	.001	V	.001
Co	.0005	Na	.01	Y	.001
Cr	.0005	Nb	.1	Yb	.0001
Cu	.0001	Ni	.01	Zn	.05
Fe	.001	P		Zr	.001
Ga	.001	Pb			

TABLE 8.—*Semiquantitative spectrographic analyses for other elements in the ash, and chemical analyses for uranium and ash of selected carbonaceous rock samples, Fall Creek area, Bonneville County, Idaho*

[Analysts: Mona Frank, C. L. Waring, R. G. Havens, and Audry Smith, U. S. Geological Survey]

Range of semiquantitative spectrographic analyses: A, more than 10 percent; B, 1–10 percent; C, 0.1–1 percent; D, 0.01–0.1 percent; E, 0.001–0.01 percent; F, 0.0001–0.001 percent. Elements looked for but not found: Au, As, Bi, Cd, Ce, Dy, Er, Gd, Hf, Hg, In, Ir, Li, Nd, Os, Pd, Pt, Re, Rh, Ru, Sb, Sm, Sn, Ta, Te, Th, Tl, and W. Laboratory number, type, description, and thickness of samples listed here can be found in tables 3 and 4 with the exception of several that are explained in footnotes. See table 7 for standard sensitivities determined by the semiquantitative spectrographic method.

Field No.	Semiquantitative spectrographic analyses, in percentage ranges																																Chemical analyses, in percent	
	Si	Al	Ca	Fe	Mg	Na	K	P	Mn	Cu	Ag	Be	Sr	Ba	Zn	B	Sc	Y	La	Yb	Ga	Ti	Zr	Ge	Pb	V	Nb	Cr	Mo	U	Co	Ni	Uranium in ash	Ash in sample
COAL SAMPLES																																		
Locality 13, sec. 4, T. 1 S., R. 42 E.																																		
2	B	B	A	B	B	C	----	----	D	D	----	E	D	D	----	D	F	E	----	E	E	D	D	C	----	D	----	D	C	C	D	D	0.310	17.3
43	A	A	B	B	B	C	----	----	D	D	F	F	D	D	----	D	E	E	----	F	E	C	D	E	E	D	----	D	C	C	D	D	.300	43.7
1	A	A	B	B	B	C	----	C	D	D	----	F	D	D	----	D	F	E	D	F	E	C	D	E	----	D	----	D	D	C	D	D	.090	43.9
1122A [1]	A	A	B	B	B	B	B	----	C	D	----	F	D	C	----	E	E	E	----	----	E	B	D	E	E	D	E	D	C	C	E	C	--------	48.7
Locality 9, sec. 4, T. 1 S., R. 42 E.																																		
371	B	B	A	B	B	C	----	----	D	E	----	F	D	D	----	----	F	E	----	F	E	D	E	E	E	E	----	E	D	C	D	D	0.220	37.0

See footnotes at end of table.

TABLE 8.—*Semiquantitative spectrographic analyses for other elements in the ash, and chemical analyses for uranium and ash of selected carbonaceous rock samples, Fall Creek area, Bonneville County, Idaho*—Continued

Field No.	Semiquantitative spectrographic analyses, in percentage ranges																														Chemical analyses, in percent	
	Si	Al	Ca	Fe	Mg	Na	K	P	Mn	Cu	Ag	Be	Sr	Ba	Zn	B	Sc	Y	La	Yb	Ga	Ti	Zr	Ge	Pb	V	Nb	Cr	Mo	U	Co	Ni	Uranium in ash	Ash in sample
COALY-SHALE SAMPLES																																	
Locality 13, sec. 4, T. 1 S., R. 42 E.																																	
1122	A	A	B	B	C	C	----	----	D	D	----	F	D	D	----	D	E	E	----	F	E	C	D	E	E	E	----	D	D	----	D	D	0.100	51.9
49	A	A	B	B	B	C	----	----	D	E	----	F	D	D	----	D	E	E	----	F	E	C	D	----	E	D	----	D	D	C	D	D	.145	58.4
37	A	B	B	B	B	D	----	----	D	E	----	F	D	D	----	----	F	E	----	F	E	D	E	----	E	E	----	E	E	----	E	E	.066	60.4
44	A	B	B	B	B	C	----	----	D	D	----	----	D	D	----	----	----	----	----	F	E	D	E	----	E	----	----	E	E	----	----	E	.044	66.2
38	A	A	B	A	B	D	----	----	D	D	----	F	D	D	----	D	E	----	----	F	E	C	E	----	E	E	----	D	E	----	E	E	.013	66.0
1123	A	A	B	B	C	C	----	----	D	E	----	----	D	D	----	D	F	E	----	F	E	D	E	----	E	E	----	D	D	----	D	D	0.040	70.0
33	A	A	B	B	B	D	----	----	D	E	----	F	D	D	----	----	F	E	----	F	E	D	E	----	E	E	----	E	E	----	----	E	.030	71.4
31	A	A	A	B	B	D	----	----	D	E	F	F	D	D	----	C	E	E	----	F	E	C	E	----	E	E	----	D	D	----	E	D	.033	72.3
32	A	A	B	B	B	D	----	----	D	D	----	F	E	E	----	----	F	----	----	F	E	C	E	----	E	E	----	E	E	----	D	D	.010	74.6
3	A	A	B	B	B	C	----	----	D	E	----	F	D	D	----	D	E	E	----	F	E	C	E	----	E	E	----	D	D	----	D	D	.013	77.5
Core hole 1, sec. 4, T. 1 S., R. 42 E.																																	
1307	A	A	B	B	C	C	----	C	D	E	----	F	D	D	----	D	E	E	----	F	E	C	E	----	E	E	----	D	D	----	D	D	0.039	69.0
1306	A	A	B	B	C	C	----	----	D	E	----	F	D	D	----	D	E	E	----	F	E	C	E	----	E	E	----	D	D	----	D	D	.056	70.0
1305	A	A	B	B	B	C	----	C	D	E	----	F	D	D	----	D	E	E	----	F	E	C	E	----	D	E	----	D	D	----	D	D	.036	77.1
Locality 11, sec. 4, T. 1 S., R. 42 E.																																	
1137	A	A	B	B	C	D	----	----	D	D	----	F	D	E	----	D	E	E	----	F	E	C	E	----	E	E	----	D	D	----	E	D	0.023	66.8
1136	A	A	A	B	C	D	----	----	D	E	----	F	D	C	----	D	----	E	----	F	E	D	E	----	E	E	----	D	D	----	D	D	.021	69.8
Locality 38, sec. 23, T. 3 S., R. 43 E.																																	
1066	A	A	B	B	C	D	----	----	E	E	----	F	E	C	----	D	E	E	----	F	E	C	D	----	E	D	----	----	D	----	E	D	0.019	69.9
1069	A	A	B	B	C	D	----	----	D	D	----	F	E	D	----	D	E	E	----	F	E	C	D	----	E	D	----	D	D	----	E	D	.009	79.9

CARBONACEOUS-SHALE SAMPLES

Locality 38, sec. 23, T. 3 S., R. 43 E.

1067	A	A	B	B	C	D	...	...	D	D	...	F	E	C	D	D	E	E	...	F	E	C	D	...	E	E	...	D	D	...	D	D	0.007	81.6
1068	A	A	B	B	C	D	...	...	D	D	...	F	D	C	D	D	E	E	...	F	E	C	D	...	E	D	...	D	D	...	D	D	.006	83.1
Locality 11, sec. 4, T. 1 S., R. 42 E.																																		
1135	A	A	B	B	B	C	...	...	...	E	...	F	D	C	...	D	E	E	...	F	E	C	E	...	E	E	...	D	D	...	E	D	0.009	83.3
1134	A	A	B	B	B	C	...	...	...	E	...	F	D	C	...	D	E	...	...	F	E	C	E	...	E	E	...	D	D	...	E	D	.007	83.6
Locality 13, sec. 4, T. 1 S., R. 42 E.																																		
1121	A	A	B	B	C	C	...	...	D	E	...	F	D	D	...	D	E	E	...	F	E	C	D	...	E	E	...	D	D	...	D	D	0.007	87.4
1123A[2]	A	B	A	B	B	C	C	...	C	E	...	...	D	D	...	E	F	E	...	F	E	C	D	...	E	E	...	E	E	...	F	E	...	87.6
LIMESTONE SAMPLES																																		
Locality 11, sec. 4, T. 1 S., R. 42 E.																																		
1138	B	B	A	C	C	D	...	...	C	E	F	...	D	D	...	...	...	...	...	...	...	E	...	...	...	...	...	E	...	...	...	...	[3]0.007	...
Locality 13, sec. 4, T. 1 S., R. 42 E.																																		
1124	B	B	A	B	C	D	...	...	D	E	...	...	D	D	...	...	...	...	...	...	...	D	...	...	...	E	...	E	...	...	...	D	[3]0.003	62.7
1124A[4]	B	C	A	B	C	D	...	...	C	E	...	...	...	D	...	...	...	...	...	...	...	D	...	...	...	E	...	E	E	...	...	E	...	93.3
1124B[4]	A	B	A	B	B	C	C	...	C	E	...	...	D	C	...	...	E	E	...	F	E	B	E	...	E	E	...	E	E	...	F	E	...	89.4
1124C[4]	C	D	A	C	D	...	...	...	B	F	...	F	D	E	...	...	...	...	...	...	...	B	D	E	...	D	D	E	E	...	...	...	...	...

[1] Laboratory No. 82815. This sample is a grab sample nearly equivalent to VI-1122.

[2] Laboratory No. 82816. This sample is a grab sample nearly equivalent to VI-1123.

[3] Estimate.

[4] Samples designated 1124A, 1124B, and 1124C, laboratory Nos. 82817, 82818, and 82819, respectively, are grab samples nearly equivalent to VI-1124, except that 1124A was seelcted for being highly calcareous, 1124B for being highly argillaceous, and 1124C for being highly carbonaceous.

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Uranium-Bearing Coal and Carbonaceous Shale in the La Ventana Mesa Area, Sandoval County New Mexico

By GEORGE O. BACHMAN, JAMES D. VINE, CHARLES B. READ, *and* GEORGE W. MOORE

URANIUM IN COAL IN THE WESTERN UNITED STATES

GEOLOGICAL SURVEY BULLETIN 1055-J

CONTENTS

ILLUSTRATIONS

[Plates 53, 55, and 57 are in box]]

TABLES

URANIUM-BEARING COAL AND CARBONACEOUS SHALE IN THE LA VENTANA MESA AREA, SANDOVAL COUNTY, NEW MEXICO

By George O. Bachman, James D. Vine, Charles B. Read, and George W. Moore

ABSTRACT

Uranium-bearing coal, carbonaceous shale, and carbonaceous sandstone of Late Cretaceous age occur on and adjacent to La Ventana Mesa, Sandoval County, N. Mex. The uranium is present in three lenticular beds forming a mineralized zone several feet thick at the base of the La Ventana tongue of the Cliff House sandstone. An epigenetic origin for the uranium from groundwater solutions that ultimately derived the uranium from the Pleistocene Bandelier rhyolite tuff of Smith (1938) is suggested. The content of uranium in the coal is as much as 0.62 percent and in the coal ash is as much as 1.34 percent. It is estimated that 132,000 tons of coal and carbonaceous shale containing an average of 0.10 percent uranium are present on La Ventana Mesa.

INTRODUCTION

PURPOSE AND SCOPE OF THE REPORT

Uranium in coal, carbonaceous shale, and carbonaceous sandstone was discovered on La Ventana Mesa, Sandoval County, N. Mex., during the summer of 1951. The area has since been carefully mapped, 125 samples have been collected and analyzed for uranium, and it is now possible to describe and evaluate the deposits in some detail. This report describes the occurrances and discusses the possible source of uranium and its deposition in coal.

GEOGRAPHY

La Ventana Mesa is 1 mile east of La Ventana, N. Mex., on State Route 44, between Cuba and San Ysidro, and about 65 miles northwest of Albuquerque, N. Mex. (pl. 53). It is 151 miles by primary road from Durango, Colo., and approximately 115 miles from Grants, N. Mex.

La Ventana Mesa culminates in a north and a south butte, located in secs. 28, 29, 32, 33, and 34, T. 19 N., R. 1 W., on the west side of the

Nacimiento Mountains. The north butte ranges in altitude from 7,200 to 7,400 feet above sea level, and the south butte, from 7,400 to 8,000 feet. As the highway adjacent to La Ventana is about 6,000 feet above sea level, the topographic relief of the area is approximately 2,000 feet. The surface of the mesa is a relatively broad area of gentle relief (pl. 54).

The climate of the area is semiarid and the lowest areas are only sparsely vegetated. Juniper forests grow in the intermediate uplands and forests of yellow pine in the mountains. The entire area is drained by the Rio Puerco, which has an intermittent flow. Potable water is available at Cuba, about 12 miles to the north, and at Warm Springs, about 12 miles south of the mesa.

FIELDWORK

Fieldwork was done during the summer and fall of 1951. One hundred and eight samples for analysis were collected from 70 localities along the outcrop of the uranium-bearing zone around the periphery of the two buttes, and 17 samples were collected from 7 localities in the hogback area to the east and the area west of the mesa, many at natural exposures, others at localities where excavation was necessary. Geologic mapping was done on aerial photographs at a scale of about 1: 36,000 and, where greater detail was needed, on enlargements at a scale of about 1: 9,600. The geologic data were transferred to a topographic map at a scale of 1: 12,000 that was compiled from aerial photographs with vertical and horizontal control established by plane table mapping.

PREVIOUS INVESTIGATIONS

The area described herein has been studied and mapped previously in connection with investigations of the water resources (Renick, 1931); the coal resources (Dane, 1936); and the potential oil and gas resources (Wood and Northrop, 1946, fig. 1).

GENERAL GEOLOGY

STRUCTURAL SETTING

The most prominent topographic and geologic feature in the area is the Nacimiento Mountains, a high mountainous area of Precambrian rocks, which is 2 to 3 miles east of La Ventana Mesa (pl. 53). The west flank of the Nacimiento Mountains is characterized by hogbacks of steeply dipping Paleozoic and Mesozoic strata. Beneath La Ventana Mesa, however, the rocks dip gently towards the San Juan Basin to the west. The mesa lies along the axis of a broad syncline, plunging gently to the northwest (pl. 53) and called the La Ventana syncline in this report.

STRATIGRAPHY

The sequence of sedimentary strata exposed in the area is shown in the following chart (adapted from Dane, 1936, p. 92–108; and Beaumont, Dane, and Sears, 1956).

System	Geologic units		Thickness (feet)
Cretaceous	Lewis shale		80–1,600
	Mesaverde group	La Ventana tongue of Cliff House sandstone	60–80
		Allison member and Cleary coal member of Menefee formation	640
		Point Lookout sandstone	100
	Mancos shale		2,000
	Dakota sandstone		200
Jurassic and older rocks.	Morrison and older formations.		

Of these, the strata of importance for the purpose of this report are those of the Mesaverde group and the Dakota sandstone. Following the revised nomenclature of Beaumont, Dane, and Sears (1956), the Mesaverde group is divisible into three units, in ascending order: the Point Lookout sandstone, the Menefee formation, and the La Ventana tongue of the Cliff House sandstone. The Point Lookout sandstone, 100 feet or more in thickness, consists chiefly of pale-yellow to brown sandstone interbedded with one or more thin beds of carbonaceous shale or coal. It is difficult to distinguish the Cleary coal member and the Allison member of the Menefee formation (Beaumont, Dane, and Sears, 1956) in this area and they are not differentiated on the geologic map. The Menefee consists of about 640 feet of lenticular sandstone, clay, carbonaceous shale, and many coal beds. The geologic map of the La Ventana area (pl. 55) shows a contact drawn on the top of a locally prominent sandstone about 250 feet below the base of the La Ventana tongue of the Cliff House sandstone. This contact divides the Menefee into two parts, which in this report are referred to as the upper and lower parts of the Menefee formation. The La Ventana tongue consists of about 60–80 feet of light-yellow to brown, cliff-forming sandstone which contains shark's teeth and is of marine origin. It forms the resistant caprock at the top of La Ventana Mesa (pl. 56).

URANIUM DEPOSITS

Uranium occurs in coal, carbonaceous shale, and carbonaceous sandstone in the La Ventana area. The principal deposit is just below the La Ventana tongue of the Cliff House sandstone on La Ventana Mesa. Minor deposits are present in the Point Lookout sandstone and the Dakota sandstone in the hogback area east of La Ventana Mesa, and at the base of the La Ventana tongue in the area west of La Ventana Mesa.

LA VENTANA MESA

Uranium occurs erratically within a zone several feet thick immediately below the base of the cliff-forming La Ventana tongue of the Cliff House sandstone near the top of La Ventana Mesa (pls. 55 and 57). The uranium-bearing zone of strata includes three beds: an upper bed, 6 inches to 6 feet thick, of friable gray sandstone containing fragments of carbonaceous debris, silt, and shale (fig. 44 and pl. 58*A*); a middle bed, 2 inches to 4 feet thick, of coal and impure coal; and a lower bed, as much as 10 feet thick, of carbonaceous shale. The upper bed, friable sandstone, contains as much as 0.065 percent uranium; the middle bed, coal and impure coal, contains as much as 0.62 percent uranium and with as much as 1.34 percent uranium in the ash; and the upper part of the lower bed, carbonaceous shale, as much as 0.062 percent uranium. These three beds are somewhat lenticular and not always distinct. Locally, the upper bed interfingers with the overlying more indurated La Ventana tongue. Both the middle and upper beds pinch out to the southeast and are absent on the southeastern part of the south butte. The uranium-bearing zone varies greatly even in relatively short horizontal distances. At locality 59, shown in detail in figure 44, the uranium content of the impure-coal bed ranges from 0.005 to 0.3 percent within less than 50 feet. Elsewhere, exposures are inadequate to determine the variability in such detail. There is also considerable variation vertically. The greatest concentration of uranium is confined to the stratigraphically highest bed of coal or carbonaceous material, which is the middle bed, of impure coal, at the base of the La Ventana tongue on La Ventana Mesa. Stratigraphically lower coal beds are essentially barren of uranium as is shown by a sample collected from an abandoned coal mine, locality 71 (pl. 55), near the base of La Ventana Mesa. Locally, within the uranium-bearing impure-coal bed the uranium content is in inverse ratio to the ash content of the coal. For example, in an exposure of 3 feet of coal at locality 4 (pl. 59), the uppermost foot of impure coal has an ash content of 59 percent and contains 0.065 percent uranium; the middle foot of coal has an ash content of 39 percent and contains 0.16 percent uranium; whereas the lowest foot of coal and bone has an ash content of 50 percent and contains 0.08 percent uranium.

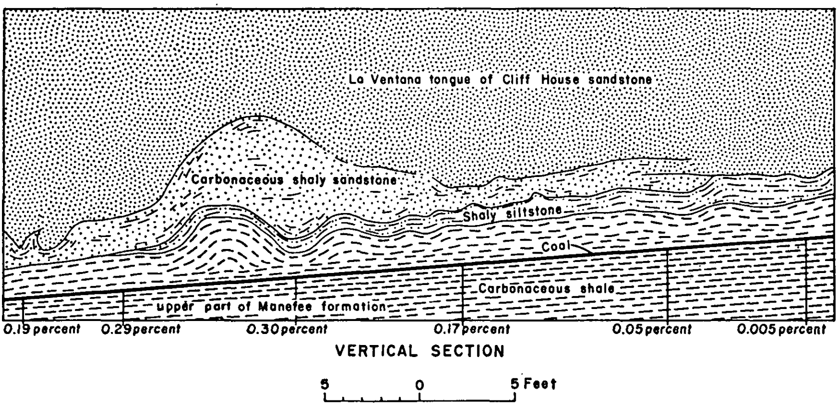


FIGURE 44.—Variation of uranium content in a coal bed below a minor structure.

Areas of greater than average uranium content are present on both the north and south buttes. The largest of such areas is on the southwest and west sides of the north butte. The next largest area is on the westernmost tip of the south butte, and several small localities, though east of the westernmost tip of the south butte, that are on the narrow segment of the butte that extends west from its main area. The area on the west side of the north butte represents the most favorable area for production of uranium, for the west end of the north butte is underlain by 1–4 feet of mineralized coal, whereas the maximum thickness of mineralized coal on the south butte is only 6 inches and the average is only about 3 inches.

HOGBACK AREA EAST OF LA VENTANA MESA

In the hogback area, uranium-bearing shale beds occur in the Dakota sandstone at San Miguel Mine Canyon (locality 76 pl. 53) and Arroyo Dedos Gordos (locality 78). According to Renick (1931, p. 35–36), the Dakota sandstone at San Miguel Mine Canyon is approximately 188 feet thick and is divisible into three units, two of

Sandstone, fine- to medium-grained; carbonaceous material

	ft	in
Mancos shale (not measured).		
Dakota sandstone:		
Sandstone, fine-to medium-grained; carbonaceous material (wood fragments) disseminated throughout; contains streaks of carbonaceous sandstone; massive at base, medium- to thin-bedded at top	64	8
Carbonaceous shale, sandy shale and shaly carbonaceous sandstone; most concealed	67	6
Sandstone, massive; thin layers of grit, conglomerate coal, carbonaceous sandstone, and shale	56	0
Total	188	2
Morrison formation (not measured).		

A 6-inch bed of carbonaceous shale in the upper part of the lower sandstone unit at San Miguel Mine Canyon contains 0.02 percent uranium. Uranium is also present in less persistent lenses of carbonaceous material in this part of the unit. One associated small lens of impure coal contains 0.088 percent uranium, and 0.10 percent uranium is present in the ash. Interbedded sandstone that contains fragments of carbon contains 0.004 percent uranium.

In Arroyo Dedos Gordos, about 5½ miles south of San Miguel Mine Canyon, the section of the Dakota sandstone is similar in character to the section just described. A bed of radioactive carbonaceous shale 18 inches thick occurs near the base of the middle unit. The equivalent-uranium content of the carbonaceous shale is 0.007 percent but the uranium content is only 0.002 percent. The Dakota sandstone has been examined in the other water gap canyons in the hogbacks between San Miguel Mine Canyon and Arroyo Dedos Gordos, but no radioactivity has been detected. This suggests that the uranium deposits in the Dakota sandstone east of La Ventana Mesa are not continuous, but future prospecting in the Dakota sandstone should not be discouraged because, at present, the data are inadequate to permit appraisal of the possibilities of this outcrop belt.

Three uranium-bearing zones, each about 1 foot in thickness and consisting of carbonaceous shale, are present east of La Ventana Mesa in a hogback formed by the Point Lookout sandstone (locality 77). These zones have an average uranium content of about 0.05 percent and each underlies a bed of permeable sandstone.

AREA WEST OF LA VENTANA MESA

West of New Mexico State Route 44 the La Ventana tongue of the Cliff House sandstone forms a prominent escarpment for several miles north and south of La Ventana. The strata in this escarpment have been examined at many localities, but the uranium content is negligible. Several samples were collected from coal and natural coal ash which occurs at the base of the La Ventana tongue north and northwest of La Ventana. The location of these samples is shown on plate 53. The greatest uranium content is 0.009 percent, which occurs in a natural coal ash at locality 74, north of La Ventana. The other samples average about 0.003 percent uranium.

STRUCTURAL CONTROL

The two largest deposits of uranium-bearing material on La Ventana Mesa are near the axis of the La Ventana syncline (pl. 53). This suggests that movement of uranium-bearing solutions may have been concentrated along the axis of the syncline.

The relationship of structural features to concentrations of uranium suggests they have played an important part in localizing mineralization. Three types of minor structural features on La Ventana Mesa that show close relationships with the uranium deposits are:

1. Tent-shaped thickening of beds in the upper part of the unit of the undifferentiated Menefee formation below the La Ventana tongue of the Cliff House sandstone (fig. 44 and pl. 58*A*).
2. Minor synclines in the uranium-bearing zone (pl. 58*B*).
3. Joints in the La Ventana tongue directly above the uranium-bearing zone.

Tent-shaped thickening of beds in the uranium-bearing zone is common. These structures are probably the result of plastic deformation and are caused by the overload of the more competent La Ventana tongue. The tent-shaped beds are best exposed on the south butte, where they are usually associated with prominent joints in the overlying La Ventana tongue and with the greatest concentrations of uranium. In a similar structural feature (fig. 44) the carbonaceous sandstone that overlies the coal thickens from an average of about 1 foot to about 6 feet. The uranium content of the coal increases correspondingly from 0.005 percent to 0.3 percent along a 50-foot exposure. The mechanism for the structural control is not known, but it appears that minor structures have controlled the movement of the mineralizing solutions.

The second type of structural feature is due to a lens of indurated sand above the coal, which has caused the uranium-bearing zone to be compressed into a minor syncline (pl. 58*B*). The greatest concentration of uranium is in the trough of the syncline.

The third type of minor structural feature that seems to have influenced mineralization is the joint system commonly present in the La Ventana tongue of the Cliff House sandstone. For example, at locality 8 (pl. 55) a joint contains a deposit of uranium-bearing opal. The uranium content of the coal bed downdip from the intersection of the joint with the coal bed averages 0.3 percent; updip from the joint it averages 0.047 percent uranium. This relationship suggests that the uranium-bearing solutions which deposited the siliceous material in the joint entered the coal bed along the joint and percolated downdip from it. On the other hand, the La Ventana tongue has such a high permeability that joints, although possibly important in localizing mineralization at some places, may be insignificant in others.

The configuration of the base of the La Ventana tongue may be a significant factor in concentrating or localizing the uranium, but at present, data are inadequate to evaluate its importance.

STRATIGRAPHIC CONTROL

Two stratigraphic features appear to be important in the concentration of uranium in La Ventana area. All major concentrations of uranium observed are in, or adjacent to, beds of carbonaceous sediments or porous sandstone.

The physical and chemical conditions which account for the concentration of uranium in carbonaceous material are poorly understood. Likewise, little is known of the nature of the uranium compounds that occur in carbonaceous material. However, the association of uranium with fossil wood in carnotite deposits has long been established (Boutwell, 1904, p. 200). The occurrence of uranium in lignite, coal, and similar carbonaceous sediments has been reported in widespread areas.

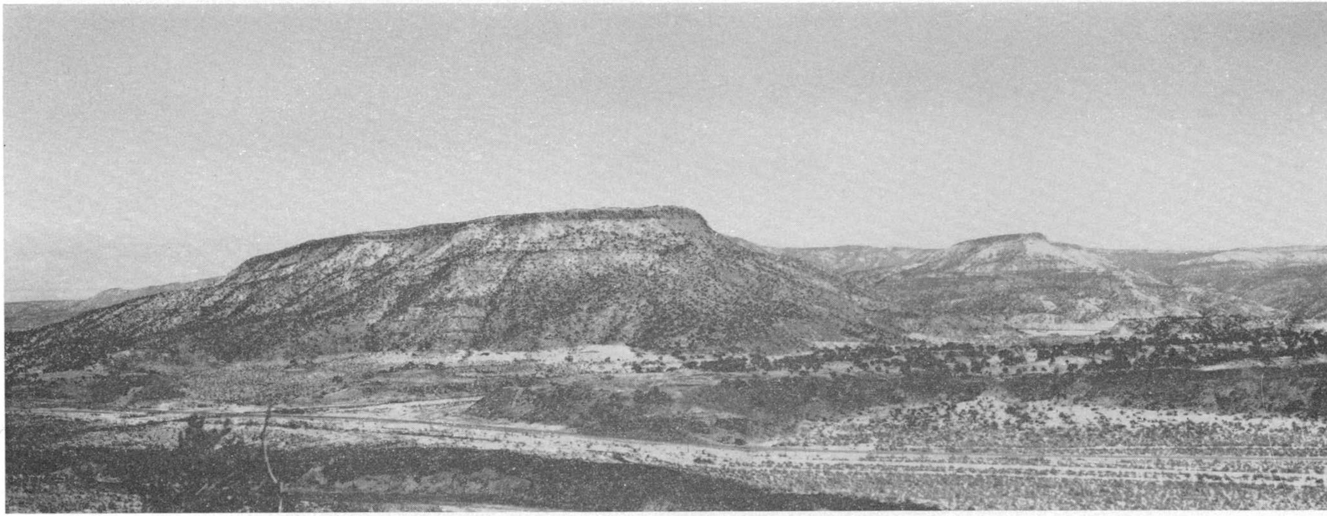
Though no uranium minerals are visible in coal from La Ventana Mesa, J. W. Gruner (oral communication) has reported the presence of coffinite, a uranium silicate of undetermined chemical composition.

Adsorption of uranium by carbonaceous material is the most plausible explanation known by the writers for the association of uranium with carbon as found in nature. Tolmachev (1943) demonstrated in the laboratory that activated charcoal and carbonaceous shale remove uranium from a uranyl nitrate solution. Experiments performed by G. W. Moore (1954) demonstrate that coal also will remove uranium from solution.

The writers made autoradiographs of both polished sections and thin sections of the uranium-bearing coal in an attempt to determine the nature of the mineralization. Autoradiographs of polished sections of the coal demonstrate that the most intense radioactivity is associated with fractures and joints in the coal. Less intense radioactivity is found in certain layers parallel with the bedding planes. These layers, which are faintly visible bands on the polished sections, are brown and may represent clay or shale partings stained brown by humic colloids. The radioactivity associated with these bands could be due to greater adsorbency of the material but is probably due to greater permeability along the band. A faint gray fog on the film over the entire area covered by the coal specimen indicates mild radioactivity uniformly distributed throughout the specimen. Autoradiographs of thin sections of the coal examined under high magnification demonstrate that most of the radioactivity is from opaque constituents in the coal.

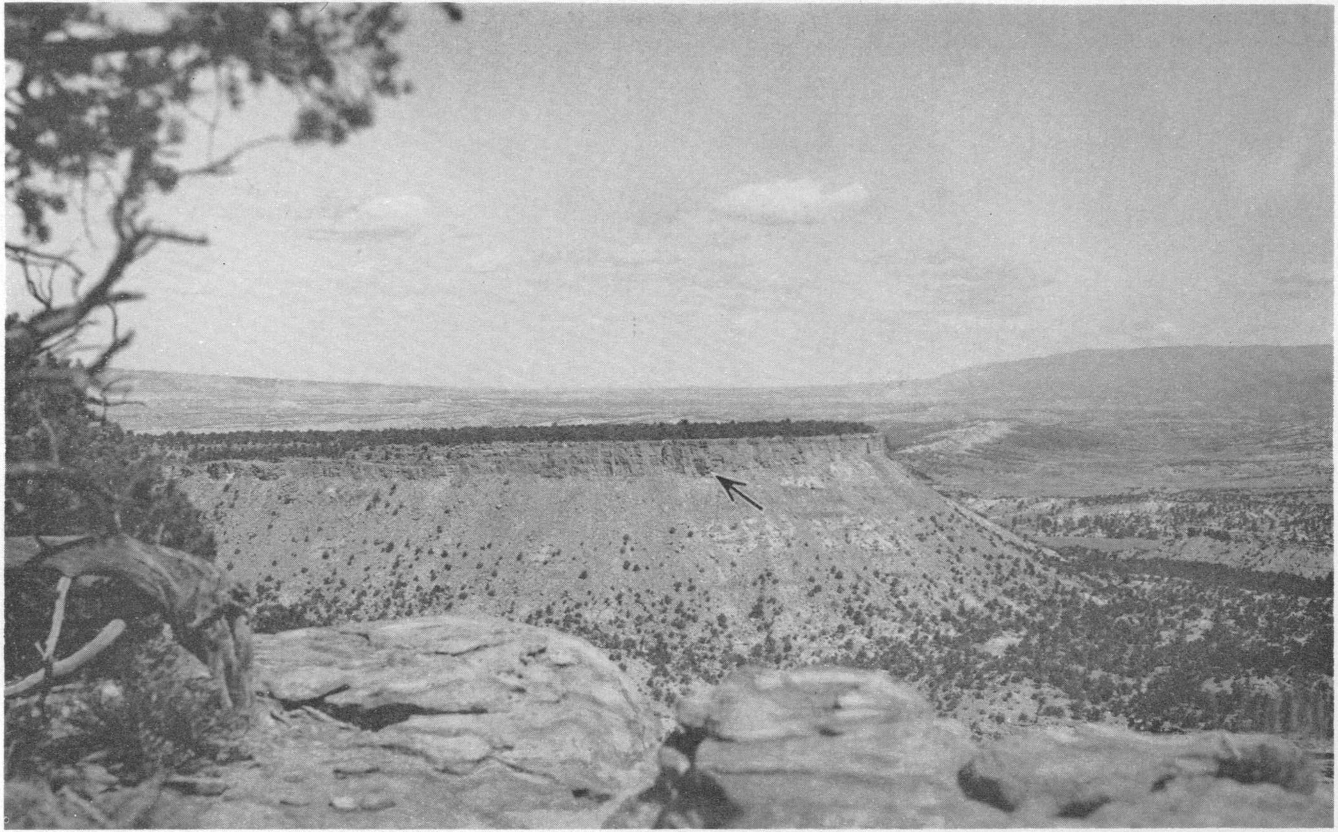
These studies indicate that the uranium is in close association with carbonaceous material, that uranium-bearing solutions entered the coal along fractures and joints in the coal, and that certain constituents of the coal are better adsorbents of uranium than others.

The close association of the uranium deposits in the La Ventana area with beds of permeable sandstone suggests that the sandstone beds have served as aquifers through which uranium-bearing solutions have migrated. This is especially evident for uranium-bearing beds in the hogback area east of La Ventana Mesa, where carbonaceous shale and sandstone are in contact with permeable sandstone



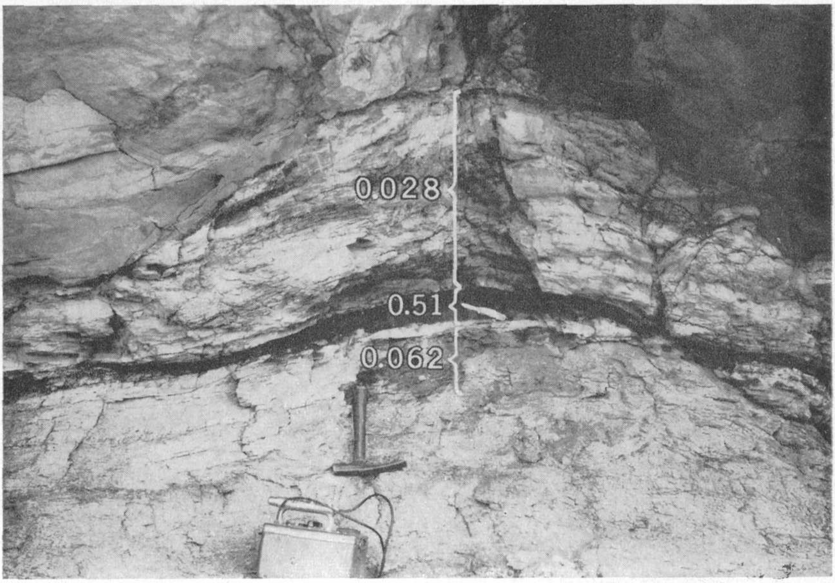
LA VENTANA MESA, SANDOVAL COUNTY, NEW MEXICO

View is east across the Río Puerco, showing the north butte, on the left, and the south butte, on the right. State Route 44 in foreground.

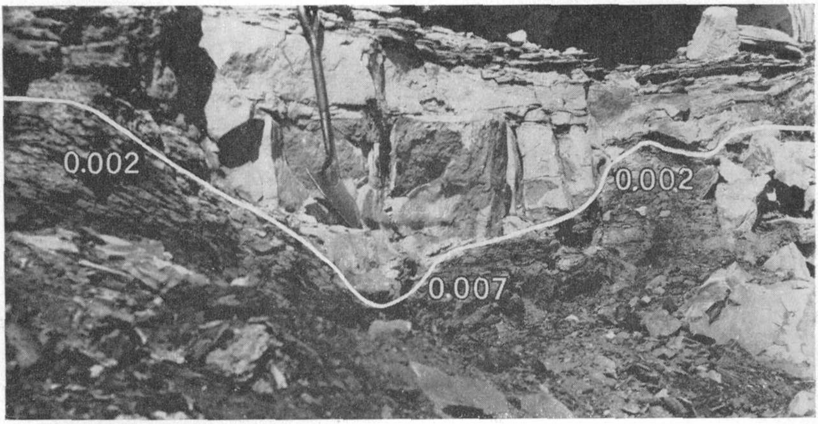


NORTH BUTTE OF LA VENTANA MESA VIEWED FROM THE SOUTH BUTTE

Arrow indicates the coal bed of the uranium-bearing zone directly below the cliff-forming La Ventana tongue of the Cliff House sandstone.

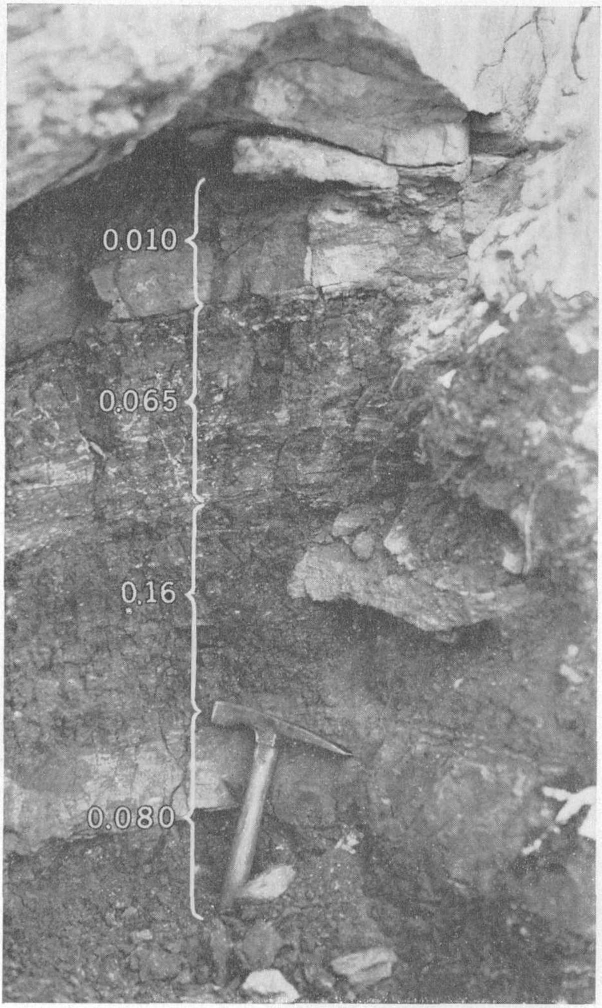


A. *Tent-shaped thickening of beds at* locality 46 on south butte of La Ventana Mesa, showing content of uranium in percent.



B. Effect of minor syncline in coal below a sandstone body at the base of the La Ventana tongue of the Cliff House sandstone. Value of equivalent uranium, *in percent, indicates more intense* mineralization in trough of syncline than on flanks.

URANIUM-BEARING ZONE ON LA VENTANA MESA, SHOWING MINOR STRUCTURES ASSOCIATED WITH URANIUM IN COAL



THE WEATHERED OUTCROP OF A 3-FOOT BED OF URANIUM-BEARING COAL AT LOCALITY 4. THE URANIUM CONTENT IS INDICATED IN PERCENT.

beds of the Dakota sandstone and the Point Lookout sandstone. On La Ventana Mesa the uranium-bearing zone is directly overlain by the La Ventana tongue of the Cliff House sandstone, in which permeability has been increased by numerous joints. The coal bed of this zone is the only coal bed that is uranium bearing, though many coal beds are present at lower stratigraphic horizons.

ORIGIN

At the present time any hypothesis of the origin of the uranium at La Ventana Mesa is unproved because direct evidence is lacking. The possibility that the uranium could have been introduced into the carbonaceous rocks by thermal, or juvenile, solutions has been considered because slightly radioactive ground water is present within the Jemez Mountain region. At Warm Springs, 15 miles south of La Ventana, slightly radioactive travertine is being deposited around a well from which warm water flows. However, the Quaternary travertine deposits in the SW¼ sec. 32, T. 19 N., R. 1 W., in the vicinity of a fault, were checked radiometrically but were found to be non-radioactive. Likewise, strata in the vicinity of the fault, as well as numerous coal beds in the stratigraphic sequence below the uranium-bearing coal beds at La Ventana Mesa were examined without finding additional radioactivity. The absence of abnormal radioactivity in rocks at places where juvenile waters would be expected to travel normally and the absence of radioactivity in rocks directly below the uranium-bearing coal suggests that uranium has not been carried upward into the rocks by such waters. There is very strong evidence that there has been lateral transportation of uranium within the mineralized areas, but there is little evidence to indicate that these mineralized areas are closely associated with fault systems.

Therefore the writers believe that the uranium deposits at La Ventana Mesa are of epigenetic origin and were derived from groundwater solutions and that a source of the uranium was the Bandelier rhyolite tuff of Smith (1938) of Pleistocene age. The Bandelier rhyolite tuff is widespread on the Jemez volcanic plateau to the east of the Nacimiento Mountains. It contains an average of 0.003 percent uranium and a variation of 0.003 to 0.006 percent equivalent uranium. This concentration of uranium, by itself, is probably of little significance; but the great quantity of disseminated uranium represented by the Bandelier is worthy of consideration.

The Bandelier rhyolite tuff was deposited on a surface of considerable relief and it is conceivable that the tuff formerly extended across the area of the Nacimiento Mountains into the La Ventana Mesa area. However, a careful search has been made in the La Ventana area for erosional remnants of the Bandelier but at present none have been discovered. This fact causes the epigenetic hypothesis of origin to be speculative. The process of release of uranium from volcanic tuff and concentration of the uranium in carbonaceous material is discussed by Denson, Bachman, and Zeller in chapter B.

TONNAGE AND GRADE OF THE DEPOSITS

A total of 125 samples was collected from the La Ventana area and analyzed in the laboratory for uranium content. A detailed list of the results of sampling is given in table 1. Local variations in both thickness and uranium content of the mineralized zone make calculations of tonnage and grade difficult. Isopach maps were prepared of areas where the zone contains 0.1 percent uranium in the mesa area. The thickness at each locality was determined by combining material having more than 0.1 percent uranium with that having less than 0.1 percent until the average equals 0.1 percent uranium. On the basis of geometric constructions derived from relative spacing of sample stations and of geologic inference as to the continuity of the uranium-bearing zone behind the outcrop, the writers estimate that two major mineralized areas contain about 132,000 tons of material containing an average of 0.10 percent uranium. These estimates are summarized in table 2.

Many parts of the La Ventana area appear to have lower grade uranium-bearing material, containing between 0.01 and 0.10 percent uranium. In addition to those of the north and south buttes of the mesa, deposits are in the Dakota sandstone and the Point Lookout sandstone in the hogback area to the east of La Ventana. A summary of tonnage and grade of these low grade resources is given in table 3.

TABLE 1.—*Analyses of samples from the La Ventana Mesa area, New Mexico*

Locality No.	Sample			Analyses, in percent			
	Field No.	Thickness (inches)	Material	Equivalent uranium	Uranium: In sample	Uranium: In ash	Ash
			La Ventana Mesa (pl. 55)				
1	VNM-467	8	Carbonaceous shale	0.028	0.038		
	468	6	Impure coal	.060	.077	0.130	59.3
	469	7	do	.11	.11	.195	55.8
2	470	9	do	.11	.045	.075	59.7
3	471	12	do	.027	.017	.028	61.3
	472	12	do	.040	.025	.042	58.4
4	473	6	Friable sandstone	.012	.010		
	474	12	Impure coal	.083	.065	.110	58.7
	475	12	Coal	.13	.16	.42	38.8
	476	12	Coal and bone	.061	.080	.16	49.7
5	477	3	Carbonaceous shale and jarosite.	.17	.18		
	478	3	Coal	.46	.62	1.34	46.0
	479	6	do	.34	.46	1.24	36.8
6	480	6	Impure coal	.064	.10	.19	53.1

TABLE 1.—*Analyses of samples from the La Ventana Mesa area, New Mexico*—Con.

Locality No.	Sample			Analyses, in percent			
	Field No.	Thickness (inches)	Material	Equivalent uranium	Uranium		Ash
					In sample	In ash	
La Ventana Mesa (pl. 55)—Continued							
7	481	9	Carbonaceous sandstone	0.063	0.065		
	482	5	Impure coal	.20	.30	0.50	58.7
	483	5	do	.13	.16		
8	458		Opal vein above coal	.003	.003		
9	484	7	Impure coal	.051	.047	.085	55.7
10	485	3–6	do	.070	.081	.155	52.0
11	486	12	do	.075	.097	.177	54.9
12	487	12	Coal	.033	.043	.154	28.0
13	488	12	Impure coal	.034	.034	.050	68.3
14	489	12	Coal	.008	.009	.039	23.0
15	490	6	do	.19	.27	1.07	24.8
	491	12	do	.032	.051	.305	16.6
	492	3	Carbonaceous shale	.030	.008		
16	493	12	Coal	.005	.010	.064	15.5
17	494	12	Coal and carbonaceous shale	.006	.005		
18	495	6	Impure coal	.041	.014	.020	68.4
19	496	8	do	.031	.035	.065	54.6
20	497	6	do	.014	.014	.023	62.5
21	498	5	do	.010	.006	.009	64.2
22	453	6	Coal	.014	.015	.038	39.7
23	452	15	do	.008	.012	.042	28.7
24	451	12	Impure coal	.006	.006	.011	55.8
25	450	10	Coal	.012	.017	.046	37.0
26	449	12	Impure coal	.005	.004	.007	60.3
27	454	10	Coal	.009	.013	.028	45.4
28	455	6	Impure coal	<.001			60.8
29	456	12	do	.002			
30	457	12	Coal	.009	.008	.018	41.7
31	459	3–6	do	.024	.029	.058	49.9
32	460	12	Impure coal	.025	.018	.032	57.5
33	461	12±	Coal breccia	.021	.018	.037	48.4
34	463	12±	Impure coal	.039	.031	.060	51.6
35	462	12±	Coal breccia	.051	.042	.112	37.5
36	464	12	Coal	.020	.038	.084	45.0
37	465	12	do	.031	.059	.176	33.7
38	466	12	Impure coal	.057	.091	.152	59.7
39	BNM-92	3–6	do	.084	.075	.12	62.9
40	72	11	Friable sandstone	.012	.015		
	73	5	Impure coal	.10	.078	.12	64.9
	74	6	Carbonaceous shale	.030	.033		
41	68	8	Friable sandstone	.014	.006		
	69	7	Impure coal	.066	.040		
	70	5	Carbonaceous shale	.019	.013		
	71	5	do	.019	.022		
42	75	19	Friable sandstone	.036	.030		
	76	8	Coal and carbonaceous shale	.087	.088		
	77	14	Carbonaceous shale	.046	.060		
43	78	11	Carbonaceous sandstone	.057	.058		
	79	7	Impure coal	.14	.21	.27	77.7
	80	21	Carbonaceous shale	.016	.019		
43A	81	4	Impure coal	.17	.24	.34	71.2
44	84	9½	Carbonaceous sandstone	.039	.046		
44	82	3½	Impure coal	.30	.42	.74	56.3
45	85	12	Carbonaceous sandstone	.018	.021		
	86	3½	Coal	.24	.34	.70	48.0
	87	6	Carbonaceous shale	.014	.013		
46	88	20	Carbonaceous sandstone	.032	.028		
	89	2½	Impure coal	.32	.51	.84	61.1
	90	7	Carbonaceous shale	.046	.062		
47	91	13	Carbonaceous sandstone	.017	.019		
48	VNM-499	1	Impure coal	.006	.003	.004	81.0
49	500	2½	do	.029	.021	.028	76.4
50	501	2½	do	.011	.007	.009	80.4
51	502	2½	do	.006	.004	.005	82.4
52	503	1	do	.004	.002	.002	76.4
53	424	2½	do	.015	.010		
54	425	3	do	.074	.082	.136	60.5
55	426	10	Carbonaceous shale	.028	.022	.025	89.3
	427	3	Impure coal	.11	.044	.060	73.9
	428	12	Carbonaceous shale	.013	.009	.010	87.3
56	429	6	Impure coal	.017	.011		
57	430	3½	do	.061	.10	.17	59.7
58	431	3½	do	.028	.028		
59A	432	2	do	.18	.19	.30	62.3
59B	433	2	do	.18	.29	.48	60.7

TABLE 1.—*Analyses of samples from the La Ventana Mesa area, New Mexico*—Con.

Locality No.	Sample			Analyses, in percent			
	Field No.	Thickness (inches)	Material	Equivalent uranium	Uranium		Ash
					In sample	In ash	
La Ventana Mesa (pl. 55)—Continued							
59C	438	12	Carbonaceous sandstone	0.014	0.013		
	434	2	Impure coal	.21	.30	0.48	61.1
	439	12	Carbonaceous shale	.027	.036		
59D	435	2	Impure coal	.096	.17	.30	56.3
59E	436	2	Coal	.034	.05	.11	45.2
59F	437	2	do	.013	.005	.014	38.9
60	442	12	Carbonaceous shale	.004	*.002		
61	443	12	do	.005	.003		
62	444	12	do	.006	.002		
63	445	12	do	.004	*.001		
64	446	18	Carbonaceous shale	.002	*.001		
65	447	6	do	.003	*.001		
66	448	4	do	.003			
67	423	6	do	.003			
68	422	4	do	.001	*.001		
69	441	6	do	.007	.003		
70	440	6	do	.007	.005		
71	504	12	Coal	.002	.001	.003	27.7
Area west of La Ventana Mesa and Hogback area (pl. 53)							
72	BNM-43	0.3	Bony coal	0.001	0.002	0.013	15.5
73	45	24	Some bone	.001	.002	.012	13.8
74	44	0.4	Natural coal-ash and clinker	.006	.009		
75	47	Upper 12 of 24.	Coal	.003	.004	.019	22.2
	46	Lower 12 of 24.	do	.001	.001	.005	12.2
76 [a]	60	Uppermost 2 of 6.	Carbonaceous shale in Dakota sandstone.	.028	.028		
				.029			
	61	Middle 2 of 6.	Carbonaceous shale	.028	.016		
				.027	.014		
				.023			
	62	Lowest 2 of 6.	do	.025	.012		
				.027	.014		
				.027			
				.029			
	63	6	do	.030	.018		
				.030	.020		
				.030			
				.034			
	64		Roof rock, carbonaceous sandstone in Dakota sandstone.	.009	.004		
				.009	.004		
				.012			
	65		Pocket of bony impure coal, sandy streamer.	.074	.088	.10	87.8
				.071			
77	97		Sandy carbonaceous shale, Point Lookout sandstone.	.013	.012		
	98		Carbonaceous shale, coaly, Point Lookout sandstone.	.021	.031		
					.036		
	99		Sandy carbonaceous shale, Point Lookout sandstone.	.021	.019		
	100		Carbonaceous shale, coaly, Point Lookout sandstone.	.065	.120		
					.120		
	101		Carbonaceous shale, Point Lookout sandstone.	.054	.066		
					.066		
					.060		
78 [b]	66		Carbonaceous shale in the Dakota sandstone.	.006	.002		
				.007			
				.006			

[a] San Miguel Canyon.
[b] Arroyo Dedos Gordos.

TABLE 2.—*Tonnage of uranium-bearing coal and carbonaceous shale at least 1 foot thick and containing at least 0.10 percent uranium, La Ventana Mesa*

Area	Location in area	Thickness (feet)	Ash	Uranium content In coal (percent)	Uranium content In ash (percent)	Tonnage Coal (short tons)	Tonnage Ash (short tons)
North butte	NE¼NE¼ sec. 32, and SE¼ sec. 29, T. 19 N., R. 1 W.	1-3	50	0.10	0.20	120,000	60,000
Do	Locality 15 (pl. 55)	1.5	20	.12	.56	1,000+	200+
South butte	N½SE¼ and S½ of NE¼ sec. 33, T. 19 N., R. 1 W.	1-1.5	88	.10	.11	12,000	10,000

TABLE 3.—*Estimates of tonnage and grade of uranium-bearing rocks at least 1 foot thick and containing 0.01–0.10 percent uranium*

Locality	Geologic occurrence	Thickness (feet)	Uranium (percent)	Tonnage of uranium-bearing rocks (short tons)
La Ventana Mesa:				
North butte	Uranium-bearing zone at base of La Ventana tongue of Cliff House sandstone.	1-1.5	0.04	336,000
South butte	do	1-1.5	.02	57,000
Hogback area	Point Lookout sandstone	1	.05	13,000
Do	Dakota sandstone	1	.02	8,000
Total tonnage				414,000

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