Uranium-Bearing Lignite and Its Relation to the White River and Arikaree Formations in Northwestern South Dakota and Adjacent States

By N. M. Denson, G. O. Bachman, and H. D. Zeller

Trace Elements Investigations Report 467

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By N. M. Denson, G. O. Bachman, and H. 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 the overlying Ludlow, Tongue River, and Sentinel Butte members of the Fort Union formation of Paleocene age. Uranium analyses of 275 surface and auger samples and about 1,000 core samples show that many of the lignite beds contain 0.005 to 0.02 percent uranium with concentrations of 0.05 to 0.10 percent uranium in the lignite ash. Analytical data indicate that the region contains an aggregate of at least 47,500,000 tons of lignite with an average grade of slightly more than 0.008 percent containing 3,900 tons of uranium. Almost a fifth of the estimated reserves are adapted to strip mining and are in beds averaging about 4 feet in thickness. Uranium concentrations of this magnitude in lignite indicate that these deposits upon the development of proper utilization techniques and processes may be an important future source of uranium. Recent discoveries of ore-grade deposits of autunite-bearing lignite and secondary uranium minerals in carbonaceous sandstone at Cave Hills and Slim Buttes indicate that northwestern South Dakota and

adjacent areas may contain important reserves of uranium ore.

The stratigraphic units containing the uraniferous lignite beds have a combined thickness of about 1,500 feet and are unconformably overlapped by 300 feet or more of tuffaceous sandstone and bentonitic claystone of the White River and Arikaree formations of Oligocene and Miocene age. The stratigraphically highest lignite beds in the local sequence have the greatest concentration of uranium, and the uranium content 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 rock overlying the mineralized lignite beds seem to be reflected in the intensity of uranium mineralization. Most of the known uranium-bearing lignite deposits in the region are closely overlain by the White River and Arikaree formations. Field evidence indicates that the uranium in the lignite is independent of the age of the formation in which the lignite occurs and that the uranium has been concentrated by downward and laterally moving ground water from the overlying mildly radioactive, tuffaceous rocks. The White River and Arikaree formations have about 12 times more uranium than the average sedimentary rock. The uranium content of spring water from these formations is 30 times as great or greater than that of normal ground water. Field relations suggest that the uranium is of secondary origin and has been introduced subsequent to the accumulation and marked regional warping of the lignite beds and associated rocks.

During the transportation of the uranium-bearing volcanic materials from their place of origin to the site of deposition in South Dakota, the uranium is believed to have been held as a finely disseminated constituent in volcanic ash. Subsequent release or displacement of the uranium is thought to have resulted from weathering and chemical breakdown, thus freeing and allowing the transportation of the uranium, probably in ionic form, to the lignite by downward and laterally moving groundwaters. Carbonaceous material in the path of these uranium-bearing waters is believed to have acted as a receptor that extracted the uranium as a result of an ion exchange mechanism or by the formation of organo-metallic compounds.

Geologic factors that seem most significant in controlling the distribution and concentration of uranium in Dakota lignites are as follows: 1) stratigraphic proximity of the lignite to the base of the White River formation; 2) permeability of the rocks overlying the lignites; 3) adsorptive properties and porosities of the lignitic constituents; 4) present and past position of the groundwater table; and 5) the amount of uranium in the original White River and Arikaree sediments.

Individual maps showing the extent, thickness, and variations in mineral content of the important deposits in the Table Mountain, Cave Hills, Slim Buttes, Lodgepole, and Medicine Pole areas are included. Conditions controlling the concentration of uranium are described and their application as guides to finding additional reserves by the presently held concepts are explained and illustrated.

INTRODUCTION

The study of radioactive lignite in northwestern South Dakota and adjacent areas was undertaken as part of a program of exploration for radioactive materials by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. The purpose of the study was to evaluate the economic possibilities of radioactive lignites and to determine the geologic factors controlling the accumulation of uranium in lignite. Field work began June 25 and was completed October 22, 1950. Geiger-Mueller counters and a portable scaler guided the field work and sampling program. A jeep-powered auger was employed to obtain samples of unweathered radioactive lignite (fig. 25). Estimates of potential underground and strippable reserves were submitted upon the completion of the field work in 1950 (Denson, Bachman, and Zeller, 1950) and were revised and briefly described by Zeller (1952 and 1953), Denson and others (1952, p. 13-19), and Gill (1954b) upon the completion of the core-drilling programs conducted during the summers of 1951-53.

During the 1950 field investigations, 275 samples were collected for laboratory analysis. Radiometric and chemical determinations for uranium in these samples were made by the U. S. Geological Survey laboratories at Denver, Colo. and Washington, D. C. Chemical and semiquantitative spectrographic analyses for other minor elements and petrologic examinations of a few samples also were made in these laboratories.

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, where its application made possible the discovery of other occurrences of uranium-bearing carbonaceous materials (Denson, 1950; Denson, and others, 1952).

Geography

The lignite field of northwestern South Dakota and adjacent areas consists of about 5,000 square miles near the eastern margin of the Great Plains province, north of the Black Hills (fig. 1). The region is a rolling prairie, interrupted by small areas of badlands, or by buttes and ridges that are rugged and precipitous. The more prominent buttes are the Cave Hills and the Slim Buttes near the center of the area, and the Short and Long Pine Hills near the southwest corner of the area. These buttes standing 300 to 500 feet above the surrounding country support a growth of yellow pine. Rock strata are well exposed in the cliffs around 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 adjoin the rivers, whereas, away from the streams, 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 field ranges from 2,100 feet above sea level along

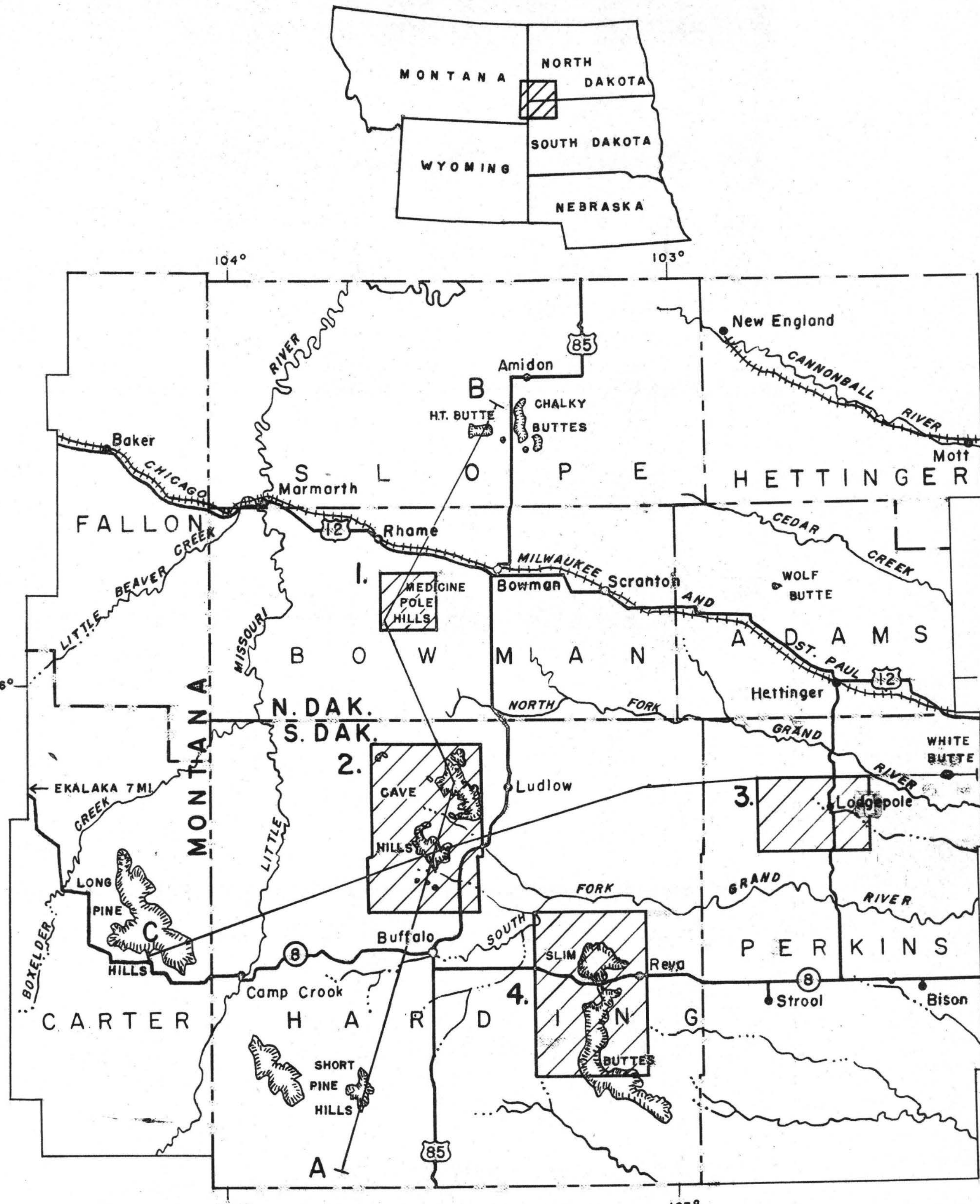

FIGURE I.— INDEX MAP SHOWING LOCATIONS OF RADIOACTIVE LIGNITE DEPOSITS DESCRIBED IN THIS REPORT.

(1.) MEDICINE POLE HILLS, (2) CAVE HILLS, (3.) LODGEPOLE AREA, (4) SLIM BUTTES
A-B AND C-D ARE LINES OF CROSS SECTION.

10 0 10 20 30 40 MILES

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. Numerous county roads and prairie trails, in addition to State and Federal highways, make most places in the region 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

The writers acknowledge the helpful suggestions and advice given in the field by C. H. Dane, W. G. Pierce, and V. E. McKelvey. To D. G. Wyant and E. P. Beroni, the writers express appreciation for analytical data and for an advance copy of their uncompleted report on the uranium-bearing lignites in North Dakota and eastern Montana (Wyant and Beroni, 1950). W. E. Benson likewise contributed to the investigation by permitting the authors the use of his unpublished map showing the areal distribution of late Tertiary formations in western North Dakota (Benson, 1951). R. W. Brown visited the party in the early stages of the investigation and gave valuable assistance in the field identifying

Plate I—BLOCK DIAGRAM OF NORTHWESTERN SOUTH DAKOTA AND ADJACENT AREAS SHOWING RELATIONSHIP OF RADIOACTIVE LIGNITE DEPOSITS TO REGIONAL GEOLOGIC SETTING

1950

plant collections and establishing the age relationships of the rock units mapped. Special thanks are due W. E. Benson and D. G. Wyant for their helpful assistance during the early stages of the field work, and to Howard A. Powers for his study and interpretation of 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. A generalized columnar section (fig. 2), adapted from Winchester and others (1916) and Hares (1928) shows the average thicknesses, characteristics, and relations of the various formations and the stratigraphic position of the principal coal beds.

Radioactive lignite occurs 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 lignite-bearing formations aggregate 1,500 feet or more in thickness and consist predominantly of fluviatile deposits of sombre-colored, soft, sandy, clay shale and massive, thick-bedded, tan, and buff-gray sandstone. Overlapping the lignite-bearing sequence with marked regional unconformity are 300 feet or more of ash-gray, mildly radioactive tuffaceous sandstone and bentonitic clay of the White River and Arikaree formations of Oligocene and Miocene age.

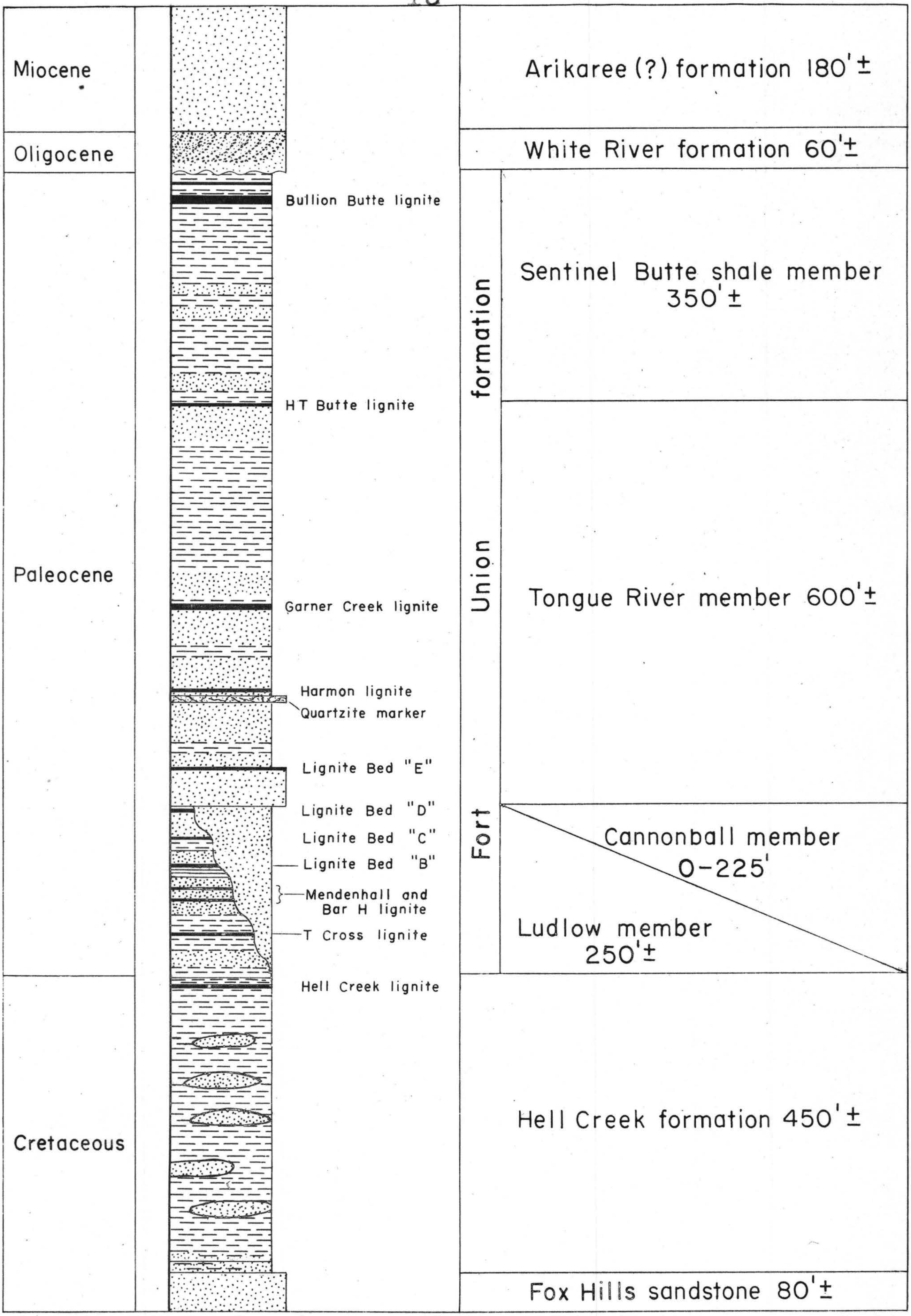

Figure 2.— GENERALIZED COLUMNAR SECTION SHOWING STRATIGRAPHIC POSITION OF PRINCIPAL COAL BEDS IN NORTHWESTERN SOUTH DAKOTA AND ADJACENT AREAS.

Erosional remnants of these formations now unconformably capping many of the high buttes and escarpments indicate that these formations once extended over most if not all of the lignite-bearing rocks in western South Dakota and adjacent parts of North Dakota and Montana. (See plate 1.)

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

Cretaceous system

Hell Creek formation

The Hell Creek formation is the oldest stratigraphic unit in a 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 south and west of Slim Buttes, Cave Hills, and Table Mountain and to the north along the east flank of the Cedar Creek anticline in southwest Bowman County.

The Hell Creek ranges from 300 to 575 feet in thickness and consists of fresh and possibly 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 or 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, cross bedded, and seemingly orderless. 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 predominant colors are gray, buff, olive green, and chocolate. The rocks of the Hell Creek formation are distinguishable at a distance from the overlying prevailingly yellow sandy strata of the Ludlow by their uniformly dark, sombre hues. 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 economically important lignite beds. Such lignite as occurs is usually in lenticular beds of small areal extent in the upper 100 feet of the formation. Radioactive lignite was found at only two places in the formation in northwestern South Dakota: 1) in the E 1/2 sec. 13, T. 17 N., R. 3 E.; 2) and near the CSL sec. 17, T. 19 N., R. 3 E. There the beds are thin, and the occurrence of uranium-bearing carbonaceous materials is only of academic interest.

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 lower 300 feet of the formation referred to as the Ludlow member intertongues to the east with non-lignite bearing strata of marine origin assigned to the Cannonball member. Overlying the Ludlow and Cannonball members with apparent conformity is the Tongue River member in turn overlain by the Sentinel Butte shale. 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, 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 covering of the 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. The greater proportion of the rock is loosely consolidated and easily disintegrated.

At its type locality the member consists of 300 to 350 feet of interbedded sandstone, shale, and lignite 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. 4). 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 separation 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 separated. At most places, however, the lower limit of the Ludlow is drawn where predominantly sombre-colored shale of the Hell Creek is succeeded by prominent yellow sandy strata in the Ludlow member of the Fort Union formation. The point of change in many places is marked 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 worked to supply a large part of the fuel for local residents. Significant deposits of uranium-bearing lignite occur in the Ludlow in the Bar H and Mendenhall areas along the west-central and northeastern parts of Slim Buttes (fig. 18), and in the 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., and in the North Cave Hills, Harding County, S. Dak., but the deposits are not considered of economic importance.

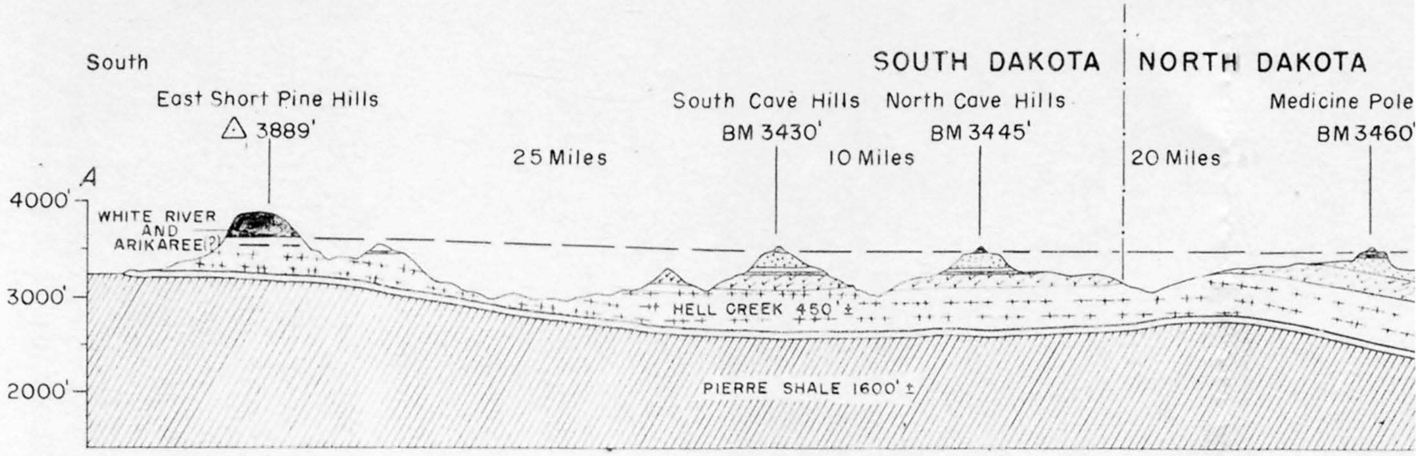

FIGURE 3.– CROSS SECTION FROM SHORT PINE HILLS IN HARDING COUNTY, SOUT
BOWMAN COUNTY, NORTH DAKOTA, SHOWING INTERRELATION OF RADIOAC
WHITE RIVER FORMATION

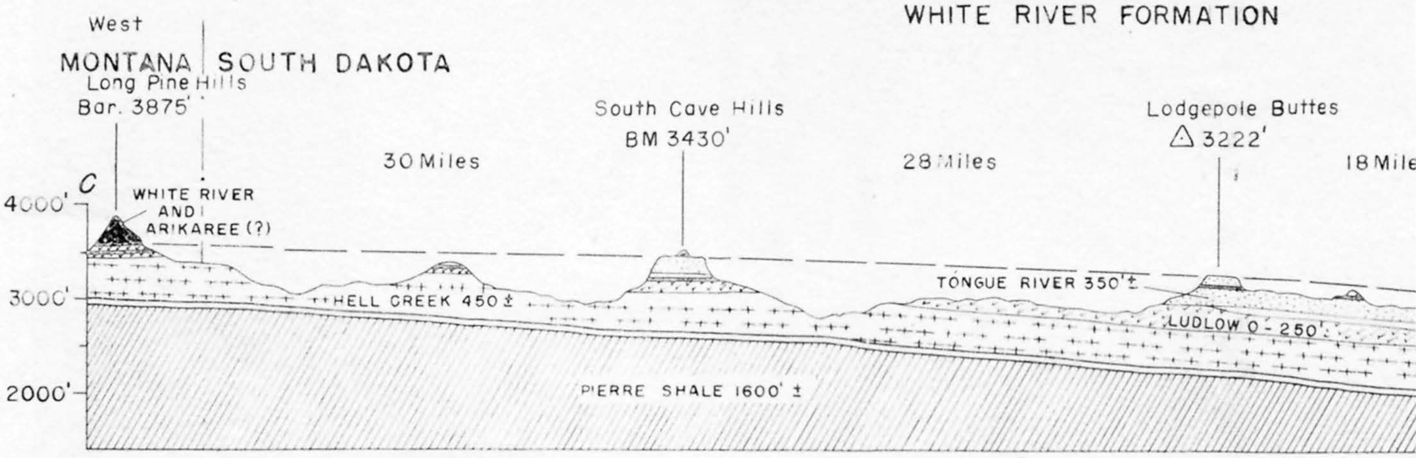

FIGURE 4.– CROSS SECTION FROM LONG PINE HILLS IN CARTER COUNTY, M
IN PERKINS COUNTY, SOUTH DAKOTA, SHOWING INTERRELATION
TO BASE OF WHITE RIVER FORMATION

LEGEND — — — — Projected position of base of White River formation
Position of radioactive lignite. Lignites lower in strati
and are not shown

10 5 0 10 20 MILES

Horizontal scale in miles

Cannonball member.--The Cannonball member of the Fort Union formation is named for exposures along the Cannonball River in Grant County (Tps. 132 S., 133 N., R. 88 W.), about 50 miles northeast of the area here described. The member consists of sediments deposited in 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., after the deposition of the rocks of continental origin in the underlying Ludlow member. 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. The Cannonball has not been recognized west of R. 8 E. in the vicinity of Anarchist 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. Since 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 removed by erosion from most of northwestern South Dakota and 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 are the surface rocks 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 parts have 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. To the north, in the Marmarth field where these rocks are overlain by the Sentinel Butte shale, Hares (1928, p. 47-48) describes a total of 600 feet of Tongue River. The rocks are light gray, tan, buff, and white in color and are chiefly sandstone. For the most part the sandstone is fine grained and evenly thin bedded, though quite massive in places. The sandstone commonly resists erosion and stands out in vertical walls, to which is due the mesa-like character of the Cave Hills and Table Mountain. The Tongue River rocks are lighter colored, contain a larger percentage of sandstone, and have thicker and more persistent beds of lignite than the underlying Ludlow member. The individual strata are also more persistent and regular.

On the southwest side of the North Cave Hills stratigraphically about 170 feet above the base of the Tongue River, a 2-foot bed of quartzite, the lowest such bed in the Fort Union formations, 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 derived from this horizon and from horizons higher in the stratigraphic section are scattered over the surface of much of the region. 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 beds form the caprock on the prominent buttes east of the North Cave Hills. The bed of quartzite is present in the Tepee Buttes, Anarchist (Mud) Butte, and on the Johnson outlier in the Lodgepole area. (See fig. 17.) It normally occurs 10 to 20 feet below a widespread and persistent bed of lignite, referred to in this report as the Harmon lignite. In western Perkins County the quartzite may be within 100 feet of the base of the Tongue River member; however, since the Tongue River rests on the Cannonball member, 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 at Anarchist Butte in SW 1/4, 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 shale member.--The Sentinel Butte shale 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 as belts around the higher buttes in the adjoining area to the north in Bowman County, N. Dak. There, it is unconformably overlain by a massive sandstone of probable Oligocene age. The Sentinel Butte member is about 350 feet thick and is lithologically very similar to the Hell Creek formation of late Cretaceous age. The Sentinel Butte member is composed chiefly of siltstone, clay shale, and thin beds of lignite. Sombre shades of gray and brown predominate, but the upper part of the unit, directly underlying the White River sandstone, is characteristically oxidized to a yellow or light tan.

Radioactive lignite beds occur in the Sentinel Butte shale at HT Butte near the central part of Slope County (fig. 3), but the beds of lignite are thin and of little commercial importance.

White River formation (Oligocene)

The White River formation crops out prominently in the Slim Buttes and Short Pine Hills in Harding County, and in the adjoining area to the west in the Long Pine Hills, Carter County, Mont. Numerous isolated hills in Perkins and Bowman Counties have thin remnants of White River rocks capping them. The formation 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 shale on HT Butte. The amount of erosion beneath this unconformity is at least 1,200 feet (figs. 3 and 4).

The White River formation is 40 to 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 grits. Locally these units exhibit slump structures (Gill and Moore, 1954a, p. 17), and are commonly overlain by massive nearly horizontal cliff-forming sandstones of the Arikaree formation. (See fig. 21.) The lower 25 feet or more of the White River formation, 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 debris in the White River formation consists of pebbles of pink porphyry in the basal clastic phases of the formation and in the succeeding finer-grained clastics. A persistent 10 to 40-foot bed of dark-gray bentonitic clay occurs in the upper part of the formation. Its 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 of two water samples from the White River formation in the Slim Buttes area, Harding County, S. Dak., made by the U. S. Geological

Survey's Water ResourcesDivision, Quality of Water Branch, Lincoln, Nebr. (Aberdeen, and others, 1952, p. 35) are given below. Uranium analyses are included for comparison.

	Colonel Spring, West flank of Slim Buttes, (Mendenhall area) Custer Natl. Forest, SE 1/4 sec. 1, T. 17 N., R. 7 E., Harding County, S. Dak.	West Spring, West flank of Slim Buttes (Bar H area), Custer Natl. Forest, NE 1/4 sec. 26, T. 19 N., R. 7 E., Harding County, S. Dak.
	Parts per million	
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 (Ci)	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	0.030* to 0.036**	0.030* to 0.045**

* Uranium determinations made by the U. S. Geological Survey Trace Elements Laboratory, Washington, D. C.

** Uranium determinations made by Oak Ridge National Laboratory, Oak Ridge, Tennessee

Gill and Moore (1954a) report that the average uranium content of water from 26 springs in the White River and Arikaree formations in the Slim Buttes area is 41 parts per billion.

Volcanic material forms an appreciable part of the White River formation in other areas (Wanless, 1922; Wood, 1949). Various workers have noted that volcanic material in the White River rocks ranges in quantity from none or very little to the bulk of the formation. Wood (1949, p. 88) summarizes the volcanic nature of the White River formation 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 lower Oligocene age (Chadronian) from the White River sandstone capping Medicine Pole Hills in secs. 1, 2, and 12, T. 130 N., R. 104 W., Bowman County, N. Dak. (fig. 15), were identified by Dr. 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) reports Oligocene fossils from the White River formation at many localities in the Slim Buttes and Short Pine Hills in northwestern South Dakota.

Arikaree formation (Miocene)

The rocks referred to as 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 fossil beaver collected in Carter County, Mont., Wood (1945, p. 5) interpreted that the rocks assigned to the Arikaree in this area are of upper rather than middle Miocene age. The rocks, however, are lithologically more closely related to the Arikaree formation than to the upper Miocene 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. (See fig. 21.) A distinctive zone, 20 to 30 feet thick, composed largely of concretions with concentric and stalactitic 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. (See fig. 23.) The Arikaree rests disconformably on the White River formation in the Slim Buttes and Short Pine Hills in Harding County, S. Dak., and the Long Pine Hills in Carter County, Mont. A 2- to 3-foot bed of conglomerate, composed of very fine-grained tuffaceous sandstone pebbles as much as 3 inches in diameter, occurs at many places directly above the 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 a rhyolitic tuff by E. S. Larsen, Jr. of the U. S. Geological Survey (Winchester and others, 1916, p. 34-35). The Arikaree and White River formations are remarkably uniform in lithologic characteristics over large areas in western North and South Dakota, Nebraska, and eastern Wyoming. Their general areal distribution, compiled from Federal and State Survey maps, is shown on figure 5.

Three hand specimens from the tuffaceous Arikaree formation in the Slim Buttes area (ZD-33, 50, and 41) and thin sections of two of these (ZD-33 and 40) were studied by Howard A. Powers of the U. S. Geological Survey.

FIG. 5.--GENERALIZED MAP SHOWING AREAL DISTRIBUTION OF OLIGOCENE WHITE RIVER AND MIOCENE ARIKAREE FORMATIONS

Field data

ZD-33	From concretionary zone near base of Arikaree formation, SE 1/4 sec. 36, T. 18 N., R. 7 E.
ZD-40	From depth of 120 feet in core hole 16A, near base of Arikaree formation, NE 1/4, sec. 12, T. 17 N., R. 7 E. (same horizon as ZD-33).
ZD-41	From depth of 53 feet in core hole 17, near top of Arikaree formation, SW 1/4 sec. 6, T. 17 N., R. 8 E. (Zeller, 1952, fig. 3).

Mr. Powers reports the following (personal 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 .05 and .15 mm., and 60 percent matrix; the other two samples contain about 60 percent of fragments ranging in diameter from .02 to .25 mm. with the greatest number between .05 and .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, $1.464 \pm .003$ 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 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 a zone near the base of the Arikaree formation is shown in figure 6. Semiquantitative spectrographic and chemical determinations on core samples of the Arikaree and White River formations in the Slim Buttes area, Harding County, S. Dak., are listed below:

Field number	Hole number (Zeller, 1952, fig. 3)	Thickness of sample	Depth in hole	Formation	Rock type (tufface ous)
ZD-41	17	8"	53'	Arikaree	Quartzitic siltstone
ZD-40	16A	7"	120'	Arikaree	Siltstone
ZD-39	16A	6"	137'	White River	Bentonitic clay
ZD-37	16A	8"	173'	White River	Calcareous grit
ZD-38	16	9"	242'	White River	Pink clay
ZD-36	19	8"	240'	White River	Green clay

Semiquantitative spectrographic analyses of core samples of White River and Arikaree, Slim Buttes.

A=over 10%; B=1-10%; C=0.1-1.0%; D=0.01-0.1%; E=0.001-0.01%; F=0.0001-0.001%.

ZD sample number	Laboratory number	Si	Al	Fe	Mg	Ca	Na	K	Ba	Sr	Mn	Ti	B	Cu	Mo	V	Cr	Ni	Pb	Co	Sc	Zr	Ga	Y	Sn	Be	La	Percent eU	Chemical determinations: Percent U	Chemical determinations: Percent F
41	62912	A	B	B	C	B	B	B	D	D	D	C	-	E	-	E	E	E	F	F	F	D	F	E	-	-	-	.002	.001	.008
40	62911	A	B	B	C	B	B	B	C	D	D	C	E	E	-	E	E	F	F	F	F	D	F	E	-	-	E	.002	.001	.005
39	62910	A	B	B	B	C	C	B	D	D	D	C	E	E	F	E	E	E	F	F	E	E	F	-	F	-	-	.001	.001	.002
37	62908	A	B	B	C	C	B	B	D	D	D	C	-	E	E	E	E	E	F	-	-	E	F	E	-	-	E	.001	.001	.008
38	62909	A	B	B	B	C	C	B	D	D	D	C	E	E	-	D	E	E	E	F	E	E	F	E	E	F	E	.003	.001	.008
36	62907	A	B	B	B	C	B	C	D	D	D	C	E	E	-	E	E	E	E	F	F	D	F	E	-	-	-	.001	.001	.009

Searched for but not found - P, Ag, As, Au, Bi, Cd, Ce, Ge, In, Ir, Hf, Hg, Li, Nb, Nd, Os, Pd, Pt, Re, Rh, Ru, Sb, Sm, Ta, Te, Th, Tl, U, W, Zn.

Analyses by Paul R. Barnett

Minimum amounts of elements detectable with semiquantitative spectrographic methods are indicated below.
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	- 0.001	Ga	- 0.001	Nd	- 0.01	Sm	- 0.01
As	- 0.1	Gd	- 0.05	Ni	- 0.0005	Sn	- 0.001
Au	- 0.005	Ge	- 0.0005	Os	- 0.005	Sr	- 0.0005
B	- 0.005	Hf	- 0.1	P	- 0.5	Ta	- 0.05
Ba	- 0.0001	Hg	- 1.0	Pb	- 0.001	Te	- 0.5
Be	- 0.0001	In	- 0.001	Pd	- 0.0005	Th	- 0.05
Bi	- 0.001	Ir	- 0.005	Pr	- 0.005	Ti	- 0.001
Ca	- 0.001	K	- 1.0(0.005)*	Pt	- 0.005	Tl	- 0.05
Cd	- 0.005	La	- 0.005	Rb	- - (0.01)*	U	- 0.05
Ce	- 0.05	Li	- 0.01(0.0001)*	Re	- 0.005	V	- 0.001
Co	- 0.0005	Mg	- 0.005	Rh	- 0.005	W	- 0.01
Cr	- 0.0005	Mo	- 0.001	Ru	- 0.005	Y	- 0.001
Cs	- 1.0(0.05)*	Mn	- 0.0005	Sb	- 0.05	Zn	- 0.05
Cu	- 0.0001	Na	- 0.05(0.001)*	Sc	- 0.001	Zr	- 0.001

* A second exposure is required for the high sensitivity listed.

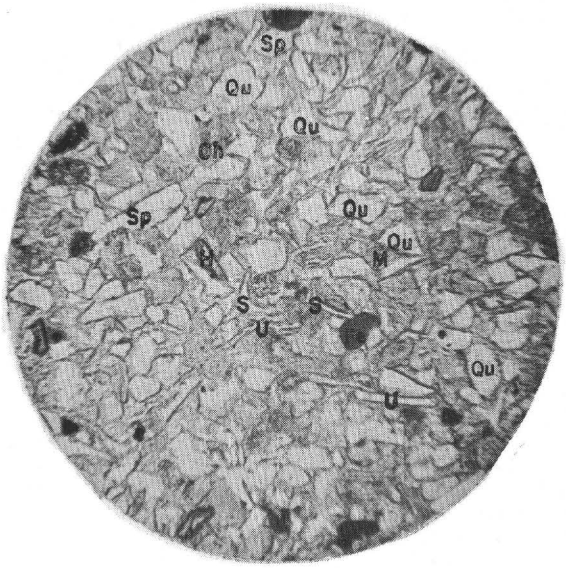

Figure 6.--Photomicrograph of a thin section of Arikaree sandstone. Enlarged 50 diameters. U = high index (greater than 1.60) isotropic, rather brownish colored, scaly-shaped secondary mineral; M = matrix of isotropic secondary material, index less than 1.48, clear in transmitted and white in reflected light; Qu = quartz; Sp = andesine; Ch = chalcedony; H = hornblende, both brown and green; Fe = opaque iron oxide; S = shard. A common fibrous secondary mineral of low index (less than 1.48) and low birefringence is not identifiable in the photo. Rounded grains of microcline also not recognizable. (Identifications by Howard A. Powers).

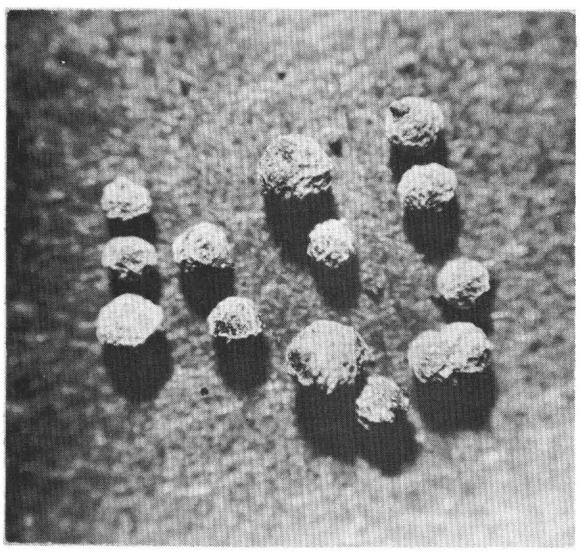

Figure 7.--Photomicrograph of a group of analcite ($NaAlSi_2O_6 \cdot H_2O$) rosettes isolated from uranium-bearing lignite, South Cave Hills, Harding County, South Dakota. Enlarged 10 diameters.

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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 to 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 seemed to be related to the occurrence of radioactive lignites these Quaternary rocks 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. 1). In general, the strike of the rocks is northwest and the regional dip is 10 to 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 passes 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 deformed about equally. The younger White River and Arikaree formations and Quaternary terrace gravels 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 Slim Buttes. At numerous places, however, landsliding of Recent and Miocene (?) ages produces effects similar to faulting as well as folding.

URANIUM-BEARING LIGNITE

Mode of occurrence of the uranium

Megascopically visible uranium minerals have been only recently discovered in lignite and carbonaceous sandstones in the Cave Hills and Slim Buttes areas of northwestern South Dakota (Gill, 1954c). There the uranium minerals autunite and metatyuyamunite, impregnate fractures and joints in thin impure lignite beds and in the enclosing sandstones.

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. According to the presently held concepts, however, the uranium is thought to occur as a disseminated constituent of carbonaceous material. Petrographic and mineralogic studies by the Battelle Memorial Institute (Ewing, and others, 1950), the U. S. Geological Survey (Schopf and Gray, 1954; Breger and Deul, 1952), and Pennsylvania State College (Bates, and others, 1952) of lignites from North and South Dakota demonstrated that the uranium, although not present as a distinct mineral, was 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. Semi-quantitative spectrographic analyses of the ash from radioactive lignite cores from South Dakota (Zeller, 1952, p. 25) show that most chemical elements are uniformly distributed through a vertical section of lignite. Uranium and molybdenum were 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 relationship between their distribution and that of uranium is less obvious.

Lignite from South Dakota has been shown to be a good extractor of uranium from solution (Moore, 1954). Non-radioactive lignite from 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 absorptive 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 in the writers' opinions an abundance of field evidence favors the third of three opposing concepts. The three concepts are referred to here as the 1) diagenetic, 2) syngenetic, and 3) epigenetic hypotheses of origin.

As the result of work in 1948 and 1949 Wyant and Beroni (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."

Beroni and Bauer, as the result of more detailed work in 1949, reiterated these two hypotheses (1952, p. 35), 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 Page (in Lovering, 1950) that the second, or "syngenetic origin", was more probable.

The 1950 work of the writers (Denson, Bachman, Zeller, 1950) led to the proposal of a third hypothesis: the uranium is epigenetic in origin, having been extracted by the lignite subsequent to coalification from ground water bringing uranium from overlying tuffaceous source rocks by downward percolating or by lateral movement along aquifers near the lignite beds. The uranium ion is believed to have been held as a finely-disseminated constituent in volcanic ash and other glassy extrusive equivalents. Subsequent release or displacement of the uranium may have been accomplished by weathering and ultimate divitrification 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 an ion exchange mechanism or by the formation of organo-metallic compounds (Breger and Deul, 1952).

Subsequent field work including extensive core drilling in the Dakotas has elaborated and confirmed this hypothesis now termed the "ash leach" or volcanic ash theory (Thomas, 1954; Hager, 1954; Miller and Gill, 1954). The mechanism proposed has been applied in other areas as an exploration guide 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 mechanism, as has Griggs (1954) in New Mexico and Gruner (1954) in the Colorado Plateau and other areas. Koeberlin in 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 (Gill and Moore, 1954b; Gill, 1954c) offer additional confirmatory evidence for the theory. The origin of the uranium seems important because reconnaissance for additional occurrences will be successful chiefly to the extent that it is guided by applicable concepts of origin.

Observations supporting a syngenetic theory of origin

The following observations were summarized by Beroni and Bauer (1952, p. 35-40):

1) Uranium-bearing lignites are confined to a limited stratigraphic zone and were therefore formed by a mechanism which operated

only during that time.

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 White River unconformity 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 formation which could make it a source bed for the radioactive materials in the lignite.

Observations supporting an epigenetic theory of origin

There are many lines of field evidence which support the theory that the uranium in the Dakota lignites was secondarily derived by ground water leaching of the volcanic materials in the White River and Arikaree formations, of which the following 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 mineralized beds over vast 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. (See pl. 1.) Since lignite beds of successively younger age are mineralized adjacent to the unconformity it seems logical to assume that the 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 listed by formation and stratigraphic proximity to base of the White River formation (or Arikaree) is shown below.

Location of radioactive deposit	Formation in which deposit occurs	Age	Stratigraphic proximity of deposits to base of White River or Arikaree fm.
1. Slim Buttes, S. Dak.	Ludlow mbr., Ft. Union fm.	Paleocene	5 to 40 feet
2. South Cave Hills, S. Dak.	do.	do.	120 to 160 feet
3. North Cave Hills, S. Dak.	do.	do.	10 to 150 feet
4. Table Mtn., S. Dak.	do.	do.	*150 to 160 feet
5. Long Pine Hills, Mont.	do.	do.	75 to 150 feet
6. Ekalaka Hills, Mont.	do.	do.	10 to 85 feet
7. Lodgepole area, S. Dak.	Tongue River mbr., Ft. Union fm.	do.	*25 to 75 feet
8. Med. Pole Hills, S. Dak.	do.	do.	25 to 60 feet
9. HT Butte, N. Dak.	Sentinel Butte mbr., Ft. Union fm.	do.	70 to 80 feet
10. Chalky Buttes, N. Dak.	do.	do.	10 to 80 feet
11. Bullion Butte, N. Dak.	do.	do.	30 to 90 feet
12. Sentinel Butte, N. Dak.	do.	do.	40 to 140 feet

* Indicates projected position of base of the White River formation in areas where White River has been removed by erosion.

In addition to the Paleocene deposits listed above, thin beds of uranium-bearing lignite occur in the Hell Creek formation of Late Cretaceous age in 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. Both of these occurrences are within 10 to 20 feet of the base of the White River formation.

If the uranium in the lignite is syngenetic it is difficult to explain the reason for the occurrence of radioactive lignites 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. Many of them have been sampled or tested radiometrically, but all are radiometrically inert. Much of this 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 in determining the factors controlling its accumulation.

2) Most highly radioactive lignites occur highest in stratigraphic section.

Within a series of nearly flat-lying carbonaceous beds the stratigraphically and topographically higher beds, in general, are more radioactive. The uranium content of succeeding lower beds decreases to the vanishing point. This suggests that the uranium probably was deposited from an overlying source. This relationship is noted at a majority of the localities where a sufficient number of samples has been collected in each stratigraphic section. Locality 84 (figs. 18, 19, and 24) at the Mendenhall mine in Slim Buttes is an excellent example. There the uppermost lignite in the stratigraphic section contains 0.030 percent uranium. The second lowest bed of lignite contains 0.010 percent uranium, while the third lowest bed contains 0.005 percent uranium in its upper half and only 0.002 percent uranium in its lower half. The fourth lowest bed of lignite sampled at this locality contained only 0.002 percent uranium. Beds lower in the stratigraphic section in this area were tested radiometrically but did not show appreciable radioactivity. Numerous localities which show this relationship may be cited as, for example, localities 82, 88, 92, 96, and 97 (fig.19) in the Slim Buttes; locality 9 (fig. 13) at Table Mountain; localities 36, 38, 39, 40, 44, 45, and 46 (fig. 13) in the North Cave Hills; and localities 66 and 68 (fig. 11) in the South Cave Hills. Departures from this relationship may be explained by 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 (fig. 13) at Table Mountain the stratigraphically highest lignite contains only 0.003 percent uranium; whereas the second highest lignite contains 0.036 percent uranium. The highest 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 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. Notable exceptions to this generalization also occur at localities 52 and 63 (fig. 11) 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 within a mineralized lignite bed 3 feet or more in thickness is higher at the top and diminishes progressively downward. This suggests that the uranium was introduced from an overlying source. The following examples show the top preferential distribution of uranium characteristic of thick radioactive lignites in the Dakotas.

Core hole No. 14, Perkins Co., S. Dak. 7'9" lignite cored (After Zeller, 1952, fig. 8)		Surface Section No. 30, Slope Co., N. Dak. 7' lignite exposed (After Moore et al., 1954, figs. 7 and 11)		1/ Auger hole no. 86, Harding Co., S. Dak. 12' lignite cuttings (Fig. 19, this report.)	
	U in lignite (percent)		U in lignite (percent)		U in lignite (percent)
Top	0.036	Top	0.022	upper 2'	0.010
	.028		.013	next 2'	.006
	.021		.010	next 5'	.003
	.013		.006	lower 3'	.002
	.008		.004		
	.002		.001		
	.001	Base	.005		
	-				
	-				
	-				
	-				
Base	-				

Sample interval 6 inches (Core hole No. 14)

Sample interval 12 inches (Surface Section No. 30)

1/ Contamination of lignite cuttings with wall rocks makes these analyses 25 to 45 percent below their true values.

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

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(1952 p. 23), 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:

a) Near top of Sentinel Butte shale, north side of Sentinel Butte, SE 1/4, sec. 6, T. 39 N., R. 104 W., Golden Valley County, N. Dak.

	Percent ash	Percent U in ash	Percent U in sample	Percent eU
Upper 6"	50.5	.002	.001	.001
Lower 6"	41.7	.030	.012	.009

12" Total thickness of bed

b) Near top of Ludlow member of Fort Union formation, east side of Table Mountain, SE 1/4, sec. 5, T. 22 N., R. 4 E., Harding County, S. Dak. (locality no. 9, fig. 10).

	Percent ash	Percent U in ash	Percent U in sample	Percent eU
Upper 1"	38.1	.004	.001	.003
Next 9"	22.8	.035	.008	.008
Lower 9"	28.6	.078	.022	.017

19" Total thickness of bed

The order of magnitude and normal pattern of distribution of uranium in the Dakota lignites are shown on figure 8. Due to contamination of

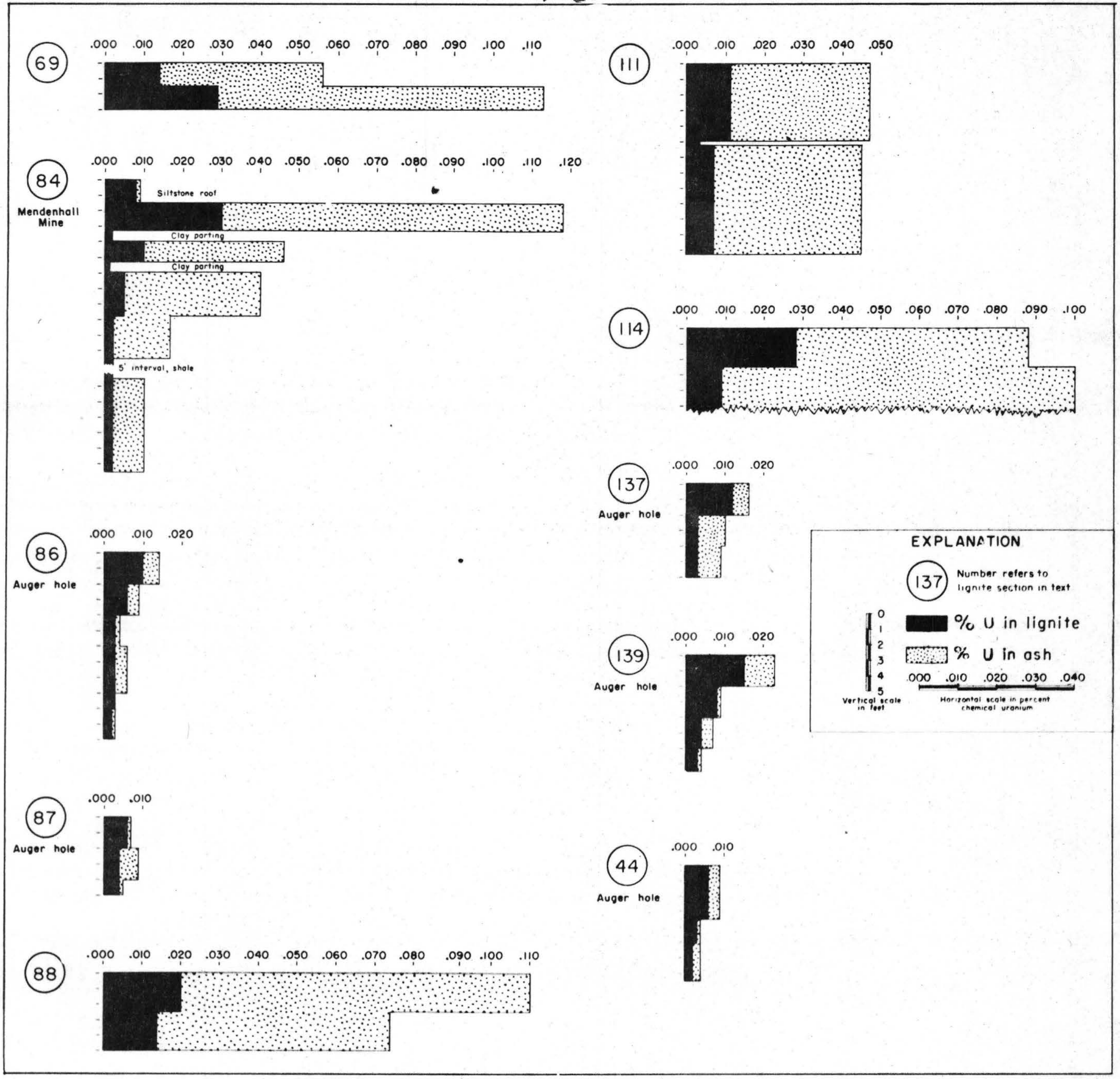


DIAGRAM SHOWING PATTERN OF DISTRIBUTION AND ORDER OF MAGNITUDE OF URANIUM CONCENTRATIONS IN LIGNITE AND LIGNITE ASH, HARDING AND PERKINS COUNTIES, SOUTH DAKOTA

FIGURE 8

lignite cuttings with the wall rock, the uranium analyses shown for the auger holes in figure 8 are approximately 25 to 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 mineralized bed is directly overlain by a permeable sandstone, it is more highly mineralized than where the same bed is overlain by clay or shale. An excellent example of the effect the permeability of the roof rock has on the intensity of mineralization of a lignite bed is shown by data gathered at localities 111 and 112 (fig. 19) in the northeast corner of Slim Buttes. At locality 111, the Bar H lignite bed is directly overlain by 30 feet or more of coarse-grained permeable sandstone which grades laterally in 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 bed is about 5 feet thick and contains 0.011 percent uranium or more; the lower bench is about 7 feet thick and contains 0.007 percent uranium. At the Bar H Mine (locality 112) where the same lignite is directly overlain by 25 feet or more of impervious clay shale, the uranium content of the upper bench is 0.001 percent and the lower bench is radiometrically inert.

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

The radioactivity of the White River-Arikaree source beds unconformably overlying the uranium-bearing lignites on Slim Buttes was measured in four drill holes with a scaler equipped with a thyroid tube and a 400-foot coaxial cable (Zeller, 1952, p. 30, and fig. 11). Logs obtained by this method showed radioactivity above background throughout most of the holes.

Chemical analyses of representative samples from the White River and Arikaree formations 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 and Ponsford, 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 formation at several widely separated localities in South Dakota (Gill and Moore, 1954a; Moore and Levish, 1954) suggest that these volcanic materials may be source beds of uranium.

6) Water analyses show high uranium contents for spring water now issuing from the White River and Arikaree formations indicating that uranium as well as other elements are being leached today from these volcanic materials.

Gill and Moore (1954a) have shown that spring water issuing from the White River and Arikaree formations in the Slim Buttes area, Harding County, S. Dak., contains 10 to 30 times more uranium than water from the Fort Union and Hell Creek formations. Chemical analyses show that the water from the White River formation also contains significant concentrations of vanadium. The average uranium content of water from 26 springs in the White River and Arikaree formations 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 lower in areas remote 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 Daniels (1953) writes:

> "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 processes today, it is logical to assume that similar processes could have operated in the past to leach the uranium out of these or similar rocks, transport it along aquifers in the underlying strata, and deposit it in favorable host materials. Favorable host materials in addition to the lignite underlying the White River and Arikaree formations would include carbonaceous sandstones which Beroni and Bauer (1952, p. 40) predicted would be favorable for the localization of secondary uranium minerals if the tuffaceous rocks in the White River formation were a significant source of uranium. A recent discovery of a 3.2 foot bed of uranium-bearing carbonaceous sandstone 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 Slim Buttes (Gill and Moore, 1954b) 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 present as a common accessory impurity (Ewing and others, 1950; Beroni and Bauer, 1952; Gill, 1954a). The mineral occurs finely disseminated as minute white particles or rosettes 0.5 to 1 mm. in diameter (see fig. 7) or 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 brief note.

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

In a report on the occurrence of uranium in coal Davidson and Ponsford (1953, p. 8) conclude as follows:

> "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 seems reasonable to conclude that most of the uranium in the Dakota lignite has been secondarily derived from tuffaceous materials in the non-lignite bearing formations of Oligocene and Miocene age.

Conditions controlling concentration of uranium

The distribution of uranium in the Dakota lignite is controlled by a combination of factors, none of which has absolute control but all of which are potentially complementary. The conditions listed below are believed to be of primary significance. (See fig. 9.)

1) Stratigraphic proximity of lignite to base of the Oligocene White River formation, or to the projected position of its base in areas where the White River has been removed by erosion. Lignite underlying the pre-Oligocene surface by

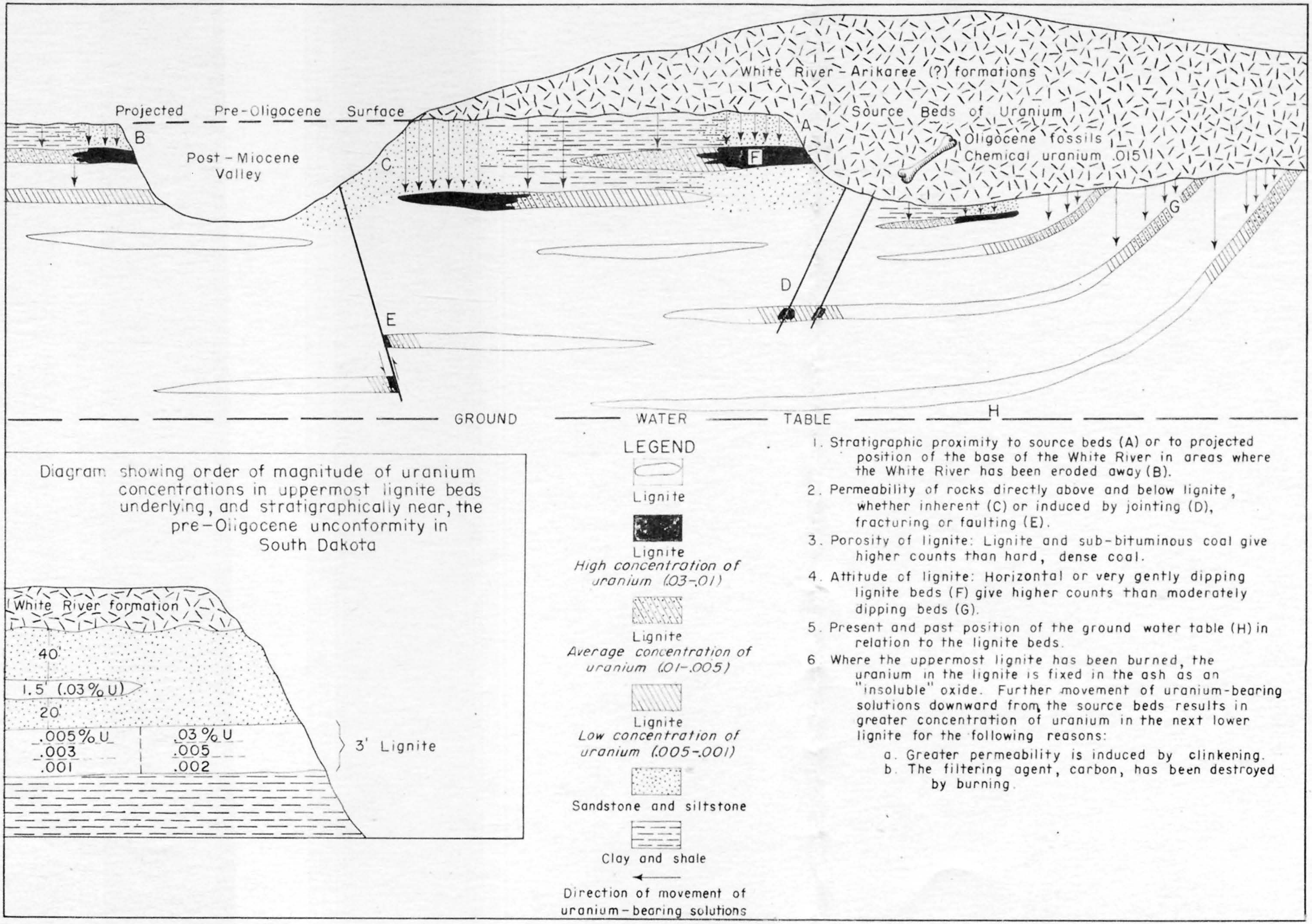


FIGURE 9--DIAGRAM ILLUSTRATING AUTHORS' INTERPRETATION OF CONDITIONS WHICH CONTROL THE URANIUM CONTENT OF LIGNITE.

150 feet or more is inactive. This observation is in general accordance with the work of Wyant and Beroni (1950, p. 7) who report that radioactive lignite in North Dakota appears to be limited from 40 to 140 feet below the White River formation.

2) Permeability of the rocks overlying the lignite, whether the permeability is inherent as in sandstones or induced by jointing, fracturing, or faulting. Highest concentrations of uranium are present in lignite directly overlain by sandstone. The same lignite overlain by beds of shale or clay contains little or no uranium. Lignite adjacent to joints in general shows higher concentrations of uranium than that away 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, hard, impervious semi-bituminous coal and anthracite. Furthermore, that the amount of uranium extracted from solution may be directly proportional to the presence of certain specific lignitic constituents.

4) Present and past position of the ground water table in relation to lignite and their effects on active ground water circulation.

5) Amount of uranium originally present in the White River and Arikaree sediments and the nature and degree of its dissemination and distribution. Studies of drill cores by Farrington Daniels of the University of Wisconsin (personal communication) 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.

Description of radioactive deposits

South Cave Hills

The South Cave Hills are a conspicuous mesa-like feature 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. (See fig. 10.) The mesa rises several hundred feet above the surrounding country in almost impassable cliffs. Several flat-topped ridges separated by deep box canyons extend beyond the main area of the mesa. Below the cap rock of the mesa, a steep talus slope of large blocks of slumped sandstone makes the area almost inaccessible. Directly to the south of South Cave Hills, 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 the lignite. Their brick-red colors are very distinctive and can be seen for many miles. The top of the South Cave Hills mesa is accessible by a few cattle trails and by a narrow secondary Forest Service road at the northwest corner of the mesa.

The lower part of the mesa and the surrounding country consists of soft sandstones and shales of the Ludlow member of the Fort Union formation, but the cap rock of the prominent buttes (McKensie and Rattlesnake Buttes) and of the main area of the 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 thin, discontinuous lignite bed in the lower part of this sandstone is called Bed "E". A remnant of the White River formation, 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 was apparently close to the present position of the mesa top. At most places the beds are essentially horizontal and dip uniformly at about 40 feet per mile to the northeast.

The important radioactive lignite in the South Cave Hills occurs in the upper 50 feet or less of the Ludlow member of the Fort Union formation and is referred to in this report as Bed "D" (see figs. 11 and 12). The bed has a maximum observed 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 lignite or carbonaceous zone, 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 makes it only of local importance. The occurrence of autunite-bearing lignite at this horizon in the North Cave Hills (Gill, 1954c) and the close stratigraphic proximity of Bed "E" to the base of the overlying White River formation makes it not unlikely, however, that significant deposits of secondary uranium minerals may be found at this horizon 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 nonradioactive and were not mapped or studied in detail.

The three areas in the South Cave Hills underlain by significant deposits of radioactive lignite, 3 feet or more in thickness, are listed here in the order of their apparent importance. 1) SW 1/4 sec. 28 and NW 1/4 sec. 33, T. 21 N., R. 5 E. (locations 57 to 61); 2) NE 1/4 sec. 5, T. 20 N., R. 5 E. (location 63); and 3) S 1/2 sec. 13, T. 21 N., R. 4 E. and SW 1/4 sec. 18 and SW 1/4 sec. 16, T. 21 N., R. 5 E. (locations 55 and 56). These areas, with a combined total of about 600 acres, are

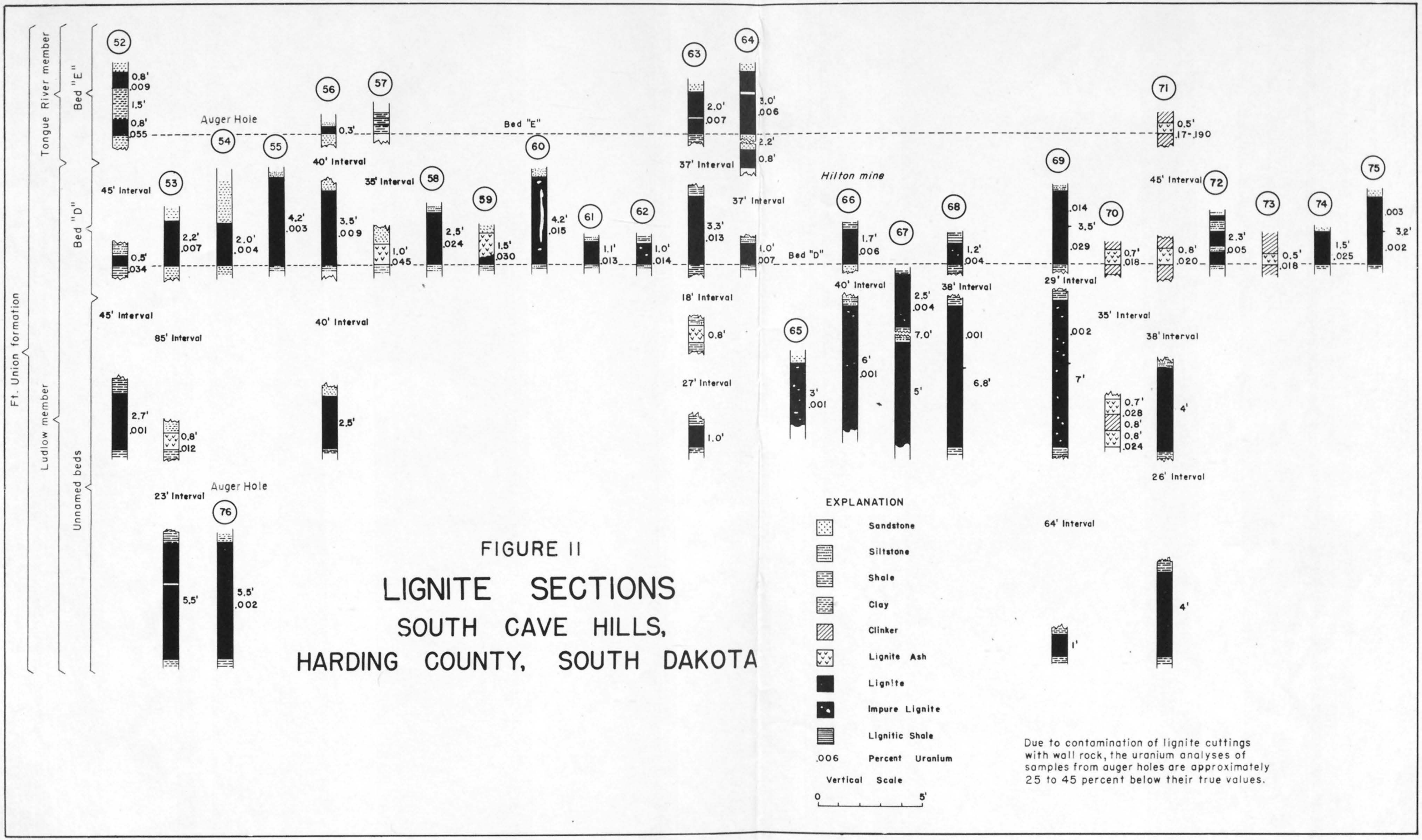


FIGURE II

LIGNITE SECTIONS

SOUTH CAVE HILLS, HARDING COUNTY, SOUTH DAKOTA

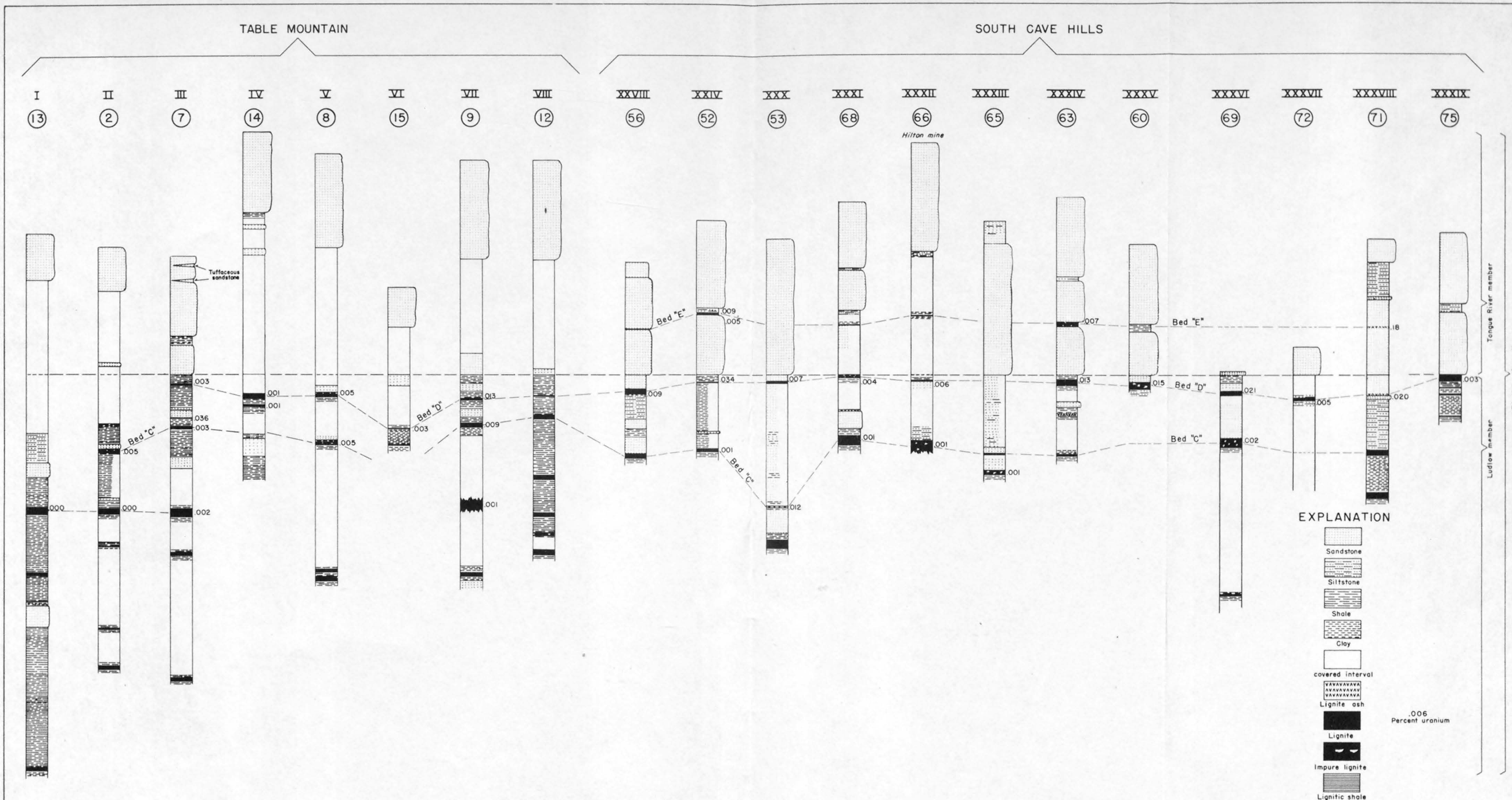


FIGURE 12--COLUMNAR SECTIONS SHOWING STRATIGRAPHIC RELATIONSHIPS OF RADIOACTIVE LIGNITES IN TABLE MOUNTAIN AND SOUTH CAVE HILLS AREAS, HARDING COUNTY, SOUTH DAKOTA

estimated to contain 3,060,000 tons of radioactive lignite. A small area of about 50 acres at McKensie Butte in SE 1/4 sec. 20, T. 20 N., R. 5 E. may also contain an additional 255,000 tons of uranium-bearing lignite. (See fig. 10, location 69.) 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 the widely spaced localities sampled make a closer estimate of the potentialities of the area impossible without trenching or drill-core data.

There are no strippable reserves in the South Cave Hills. Because of the thickness and character of the overburden, all the lignite reserves will require development by underground mining. Bowman, N. Dak., the nearest railroad shipping point, is 25 to 30 miles to the north along U. S. Highway 85.

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. (See fig. 10, and pl. 1.) They are very similar topographically and structurally to the South Cave Hills and are separated from them by about 4 miles of low rolling country in which is the valley of Bull Creek. From a distance the North Cave Hills have the appearance of a single mesa rising 300 to 400 feet above the surrounding country, but in reality the hills are a series of narrow flat-topped ridges separated by narrow canyon-like gullies. The hills are capped by about 200 feet of thick-bedded sandstone which in most places forms sheer cliffs. The contact between the Tongue River and the underlying Ludlow member is placed at the base of the sandstone that forms the rim rock of the Hills. Two small remnants of White River conglomerate overlie the Tongue River in secs. 21 and 28, T. 22 N., R. 5 E., but throughout the remainder of the area the White River formation has been removed by erosion. In some parts of the North Cave Hills two distinct cliffs are formed by two sandstone units belonging to the Tongue River member (Winchester and others, 1916, p. 27). These sandstone units are separated by 40 to 125 feet of light-gray friable sandstone and whitish-gray clay. A thin bed of carbonaceous shale or clayey lignite rests on the basal massive sandstone. This lignite, which is also present at some places in the sandstone cap rock in the South Cave Hills, is referred to as Bed "E". (See fig. 14.) The basal sandstone ledge in the North Cave Hills is from 75 to 100 feet thick and is gray to buff in color. The upper sandstone is commonly pink in color, cross bedded, and at some places contains clay pellets and rounded pebbles of sandstone. A two-foot bed of quartzite, described on page 23, occurs on top of the massive sandstone cap rock. (See fig. 14, 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 are essentially horizontal and, in general, dip about 25 feet per mile to the southeast (Winchester and others, 1916, p. 73).

Only two lignites of minable thickness, Beds "B" and "C", are mildly radioactive in the North Cave Hills area. (See fig. 13.) These beds occur

LIGNITE SECTIONS

LUDLOW MEMBER OF FT. UNION FORMATION
TABLE MOUNTAIN AND NORTH CAVE HILLS,
HARDING COUNTY, SOUTH DAKOTA

FIGURE 13

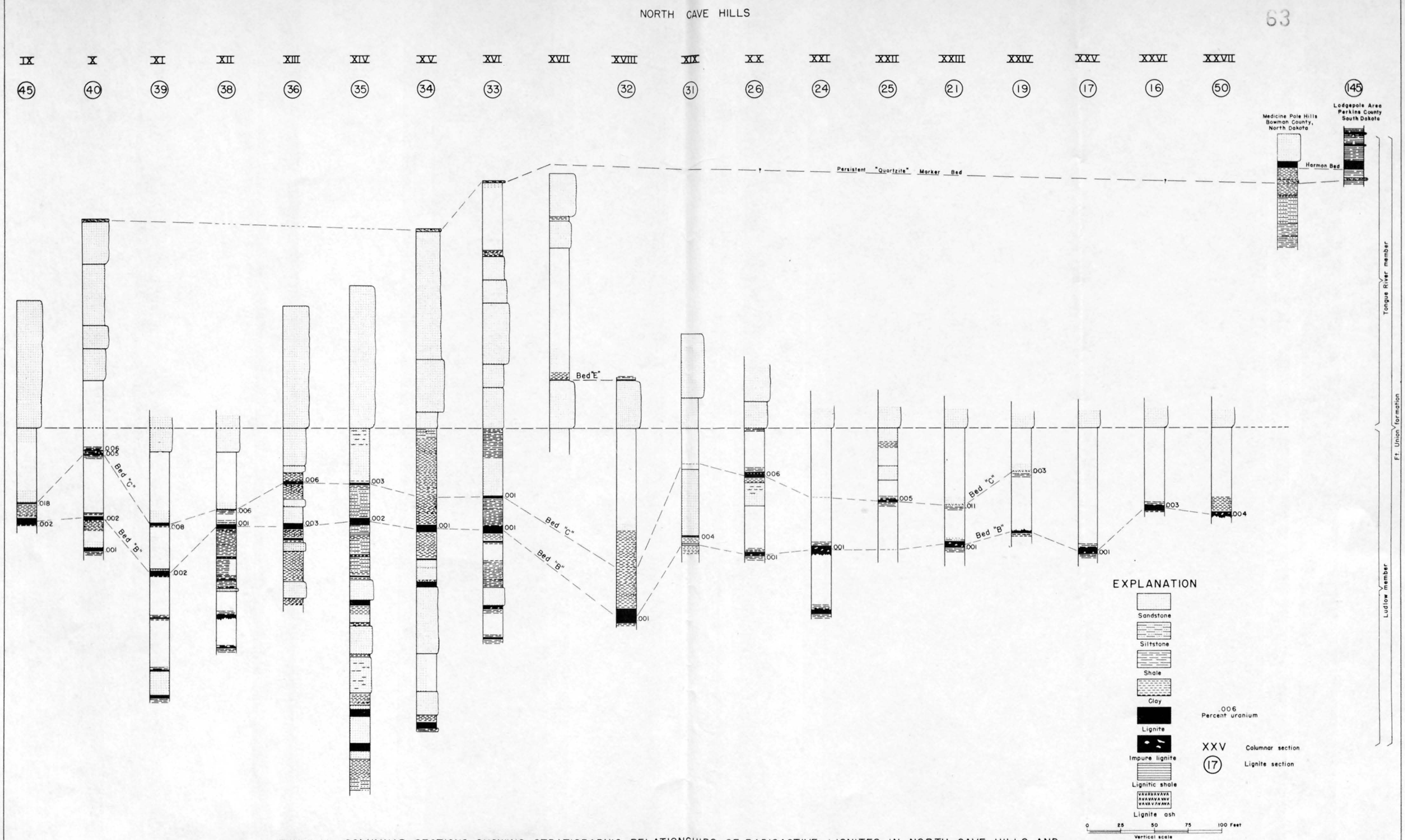


FIGURE 14--COLUMNAR SECTIONS SHOWING STRATIGRAPHIC RELATIONSHIPS OF RADIOACTIVE LIGNITES IN NORTH CAVE HILLS AND ADJACENT AREAS, HARDING COUNTY, SOUTH DAKOTA

in the upper 100 feet of the Ludlow member of the Fort Union formation. Lack of exposures and their marked variability in thickness and quality makes an exact correlation of the lignites in many places doubtful. The evidence from the 36 localities sampled indicates that there are few if any places where the mineral content of these beds is such that underground mining could be recommended. An area of about 15 acres near the center of sec. 19, T. 22 N., R. 5 E., may be favorable for stripping. There Bed "B" is 5 to 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 170,000 tons of radioactive lignite. (See fig. 10, locations 47, 48, and 49.) 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. In this area the bed ranges from 6 inches to two 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. (Gill, 1954c.) The reason for the low uranium content of the lignite in other parts of the North Cave Hills is not known but may be attributed to the presence of 40 to 75 feet of impervious shale directly overlying the stratigraphically highest lignites (Beds "B" and "C"). These shales may have prevented downward moving uranium-bearing ground water from reaching the lignite. The much higher concentration of uranium in the South Cave Hills may be due to the fact that Bed "D", a stratigraphically higher bed absent in the North Cave Hills, occurs throughout the South Cave Hills and at most places is directly overlain by massive porous sandstone which could have served as an aquifer in carrying uranium-bearing water to 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. (See fig. 10.) 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 over a foot in thickness but are quite conspicuous by their color and indentation which they form in the cliff. The regional eastward dip at Table Mountain and vicinity is about 50 feet to the mile.

The radioactive lignites at Table Mountain are in the upper 40 feet of the Ludlow member. They occur in two beds referred to as Beds "D" and "C", which average about 2 and 2.5 feet, respectively. (See figs. 12 and 13.) The lack of exposures and the prevalence of slumping along the steep sides of the butte make their identification and correlation at many places very difficult. The important minable reserves of radioactive lignite are in Bed "C" which is thicker and less variable in thickness than Bed "D". The average mineral content of Bed "C", however, is not as high as that of Bed "D". This is probably due to the fact that Bed "C" is overlain at most places by Bed "D" as well as relatively impervious shale. The lignites stratigraphically below Bed "C" show little or no radioactivity. (See fig. 12.) From 17 measured sections and as many analyses it is estimated that there are at least 1,700,000 tons of radioactive lignite underlying Table Mountain (secs. 5, 6, 7, and 8, T. 22 N., R. 4 E.). These reserves underlie about 500 acres in beds averaging about 30 inches in thickness. The character and thickness of the overburden will require that the lignite be recovered by underground mining.

Medicine Pole Hills

The Medicine Pole Hills were mapped and described in detail by Hares (1928, p. 95, 98). They are on a hilly divide separating the little Missouri and Grand River drainages in the southwestern part of the Marmouth lignite field, Bowman County, N. Dak. (See pl. 1.) The hills are capped by a thin veneer of the Oligocene (Chadronian) White River formation (C. L. Gazin, personal communication). Thin beds of well-indurated sandstone and quartzite in the Paleocene Tongue River formation, which unconformably underlies the White River, form resistant ledges that outline the hills. The hills are nearly flat-topped and are easily accessible by dirt road leading half a mile east from the main north-south graveled road to Rhame, N. Dak. The nearest railroad shipping point is at Rhame, 8 miles to the north.

The important radioactive lignites in the Medicine Pole Hills are the Harmon lignite and its associated "rider". These beds are overlain by 60 to 70 feet or less of soft poorly-indurated sandstone and shale. The easy accessibility of the area, the soft character of the overburden, and the fact that strip mining methods can be applied to the deposits, make the area attractive for exploitation. The Harmon lignite is in the Tongue

River member of the Fort Union formation and averages about 4.5 feet in thickness. At some places 10 to 20 feet above it a "rider" bed is present which varies from a few to as much as 30 inches in thickness. These beds underlie about 360 acres in parts of secs. 1 and 2, T. 130 N., R. 104 W., and SW 1/4 sec. 35, T. 131 N., R. 104 W., and are estimated to contain about 2,204,000 tons of radioactive lignite. (See figs. 15 and 16.) Analysis of the lignite core from the Harmon bed (Zeller, 1952, p. 23 and 54) shows on an air dried basis an average of about 26 to 33 percent fixed carbon, 11 to 17 percent ash, 0.5 to 3.0 percent sulfur, and a heating value of 7,680 B.T.U.'s.

Hares (1928, p. 97) estimates that there are 4,480,000 tons of lignite in the Harmon bed which underlies the low hills 3 miles to the northeast of Medicine Pole Butte, but significant amounts of uranium were not found in samples from lignite surface exposures and auger drilling. See figs. 15 and 16.) There the Harmon bed is 20 feet or more thick and throughout most of the area is overlain by less than 60 to 75 feet of soft sandstone and shale. Although the mineral ization of the Harmon lignite at the four sampled localities (Nos. 129 to 132) is too low to be of commercial significance, there is a likely possibility that there are places in the area where conditions for mineralization were much more favorable than those examined. The inadequacy of the present exposures will make necessary additional trenching and drilling before the area's potentialities can be fully appraised.

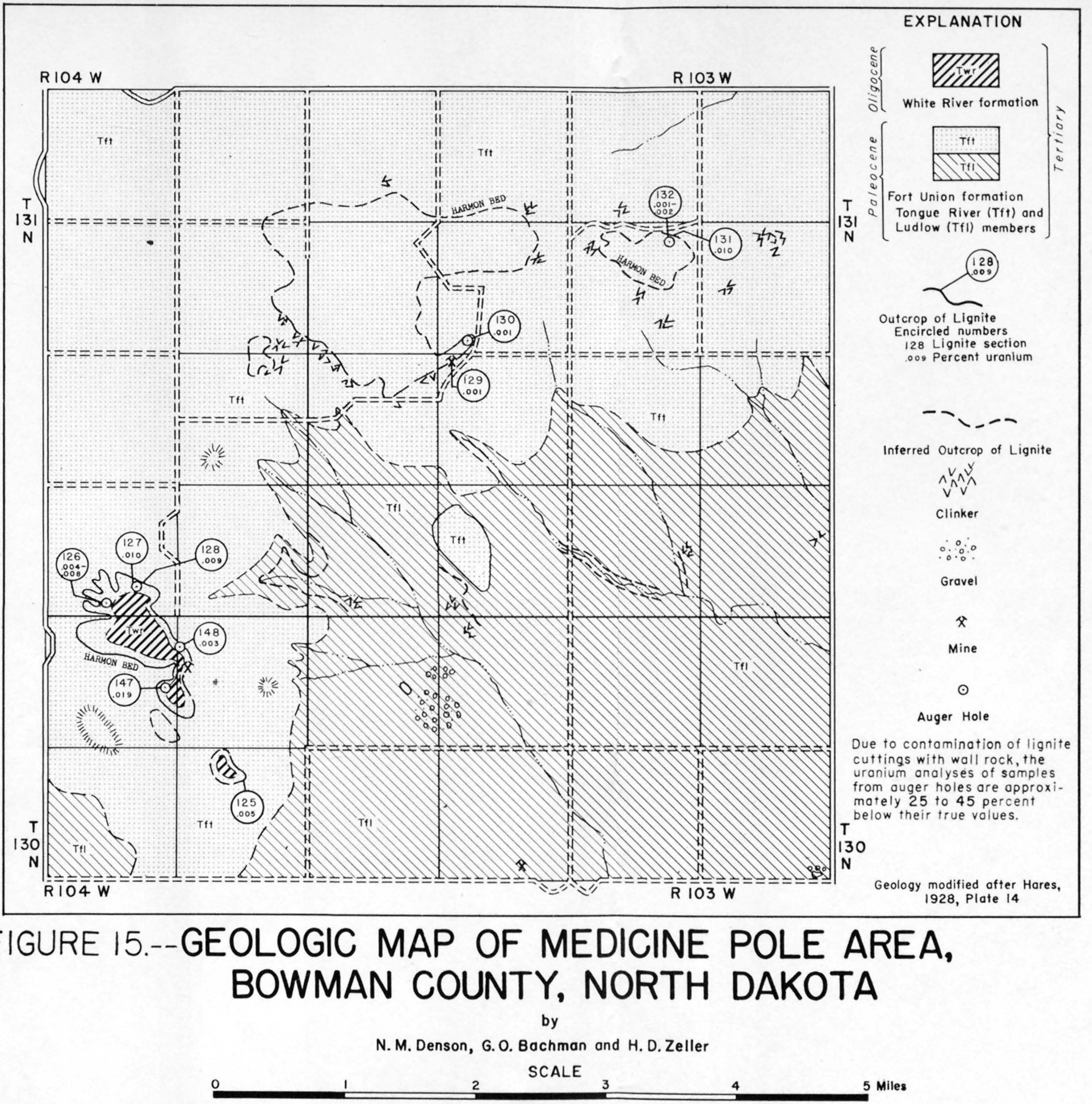


FIGURE 15.--GEOLOGIC MAP OF MEDICINE POLE AREA, BOWMAN COUNTY, NORTH DAKOTA

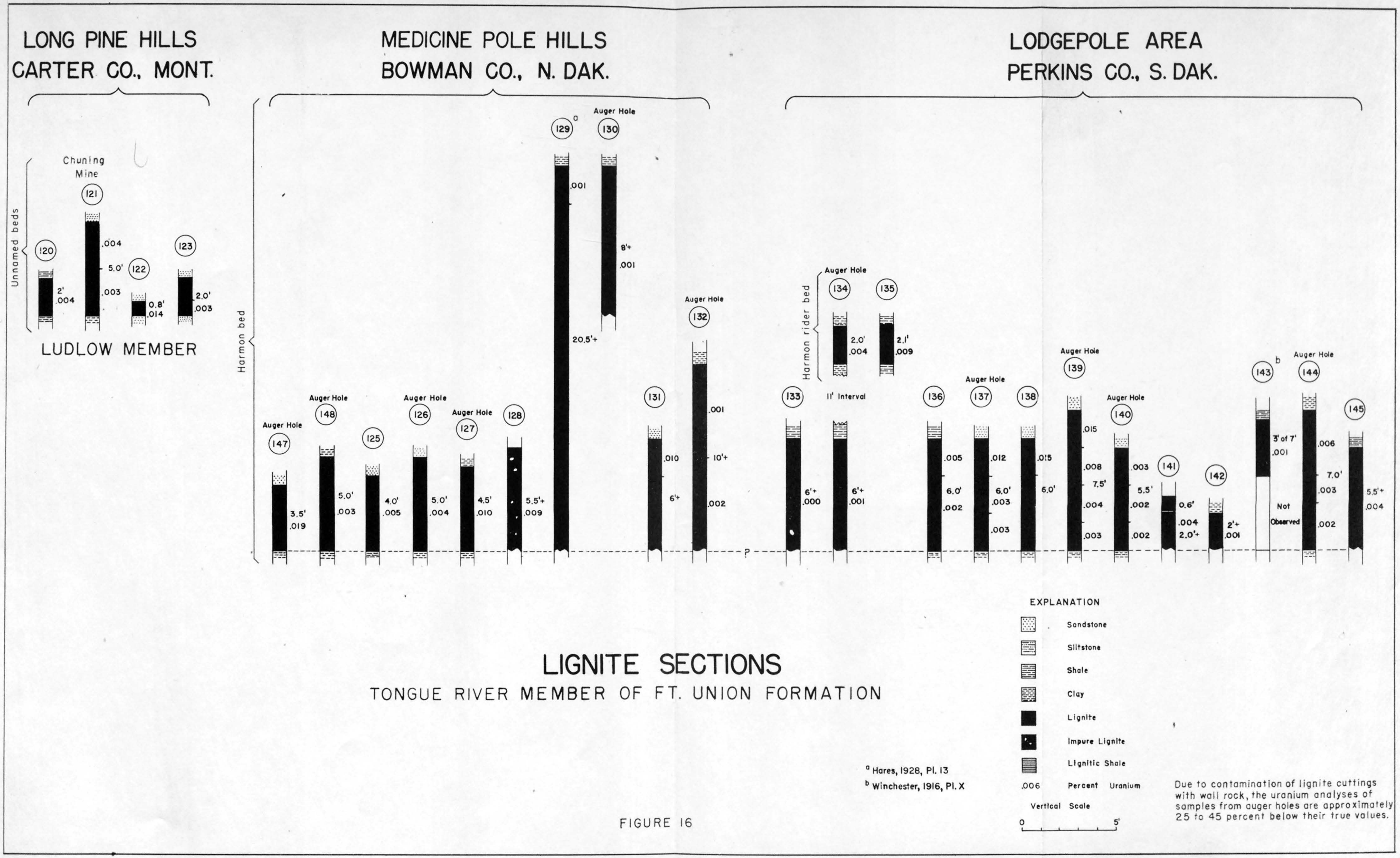
by

N. M. Denson, G. O. Bachman and H. D. Zeller

SCALE

0 1 2 3 4 5 Miles

1954



LIGNITE SECTIONS

TONGUE RIVER MEMBER OF FT. UNION FORMATION

FIGURE 16

Lodgepole area

The Lodgepole area is on 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. (See figs. 1 and 17.) The area is readily accessible by 17 miles of graveled road extending north from State Highway 8 about 9 miles west of Bison. Hettinger, N. Dak., 17 miles to the north, is the nearest railroad shipping point. A low grassy butte about 2 miles south of Lodgepole Post Office is the main topographic feature in the area. A similar butte, referred to in this report as the Johnson outlier, is 5 miles to the west. The lignites underlying these buttes were mapped and described by Winchester and others (1916, p. 138, 142).

The radioactive lignite in these areas is about 150 feet above the base of the Tongue River member of the Paleocene Fort Union formation, which has a regional dip of about 24 feet per mile to the northeast. The dominant lithologies of the Tongue River are soft, gray to pink sandstone and siltstone, with interbedded gray shale and lignite. The main coal bed averages 6 feet or more in thickness and is believed to be the Harmon bed. It is commonly associated with a "rider" bed, 10 to 15 feet stratigraphically higher, which averages from a few inches to 6 feet in thickness in short distances along the outcrop. The bed in the Johnson outlier may be either the Harmon bed or its "rider".

The lignite beds in the Logepole area are only locally radioactive, probably because of the variation in lithologic character and permeability of the overlying rocks. Data from 5 auger and 6 core holes indicate that there are at least 120 acres underlain by approximately 660,000 tons of strippable radioactive lignite in beds 3 to 6 feet thick. These deposits lie principally in the SW 1/4 sec. 19, T. 21 N., R. 12 E., and in S 1/2 sec. 9, T. 21 N., R. 11 E. (fig. 17). Analyses of the lignite core (Zeller, 1952, p. 21, 53, and 54) show on an air dried basis an average of about 25 percent fixed carbon, 18 percent ash, 2 percent sulfur, and a heating value of 6,170 B.T.U.'s.

The Harmon lignite, a mile northeast of the Lodgepole Post Office, underlies approximately 1,000 acres and is reported by Winchester and others (1916, plate 10) to average 6 feet or more in thickness. There, however, the overburden directly above the lignite is a thick impervious clay shale. In this area the Harmon lignite is essentially nonradioactive and at the two localities sampled contains only a trace of uranium in its upper 2 feet. (See locations 142 and 143, fig. 17.)

Slim Buttes

Slim Buttes is a timber-covered, steep sided mesa a half to 5 miles in width and 20 miles in length in southwestern Harding County, S. Dak. (figs. 1, 18, and 19). The mesa is composed chiefly of massive, chalky gray, tuffaceous sandstone in the Arikaree formation that in places forms sheer cliffs 200 feet or more in height. Slumped rocks that recent erosion has dissected into nearly impassable badlands are present at many places around the mesa (fig. 20). Slumping and landslides have so greatly

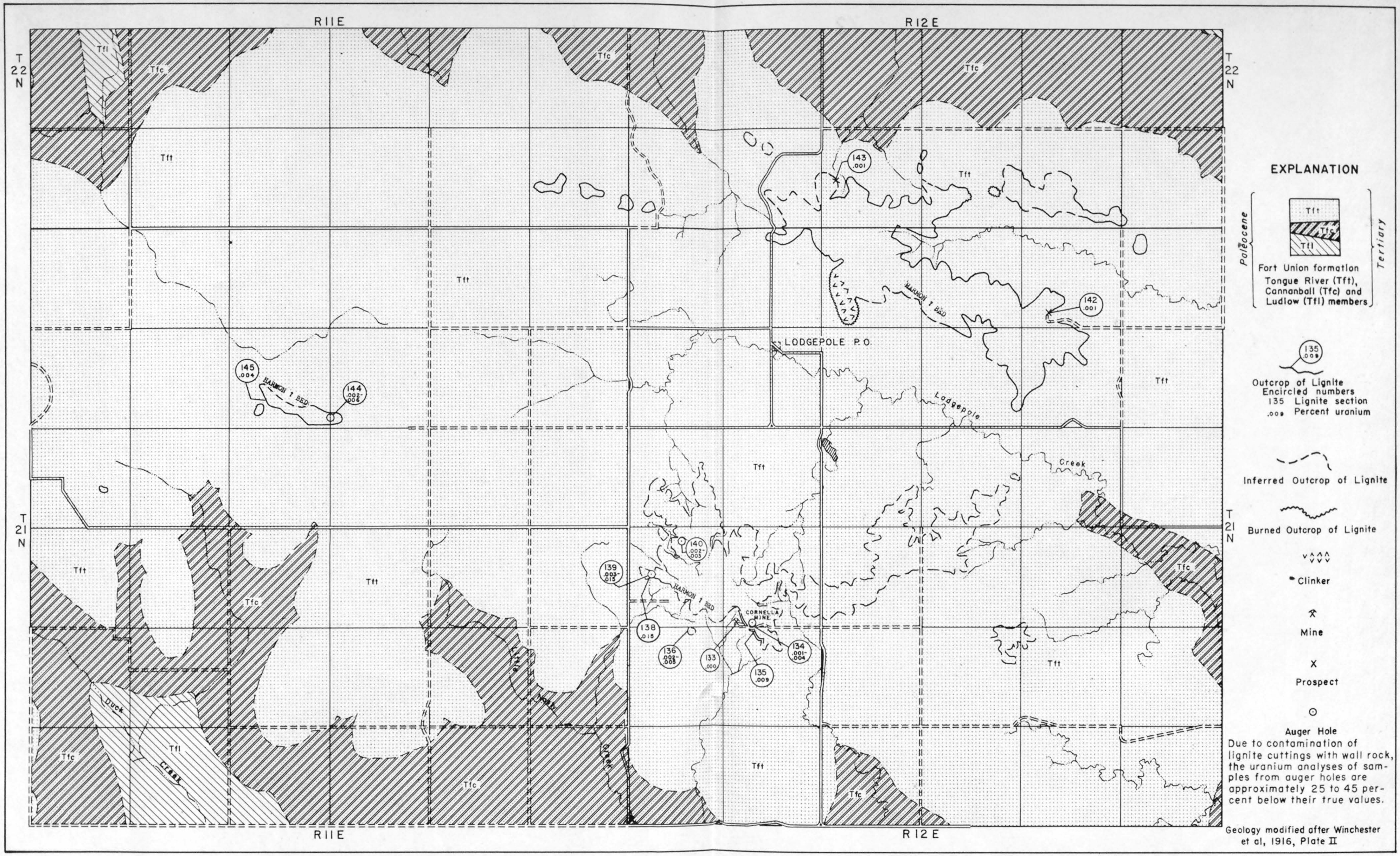


FIGURE 17.--GEOLOGIC MAP OF LODGEPOLE AREA, PERKINS COUNTY, SOUTH DAKOTA

by

N. M. Denson, G. O. Bachman and H. D. Zeller

SCALE

0 1 2 3 4 5 Miles

1954

disturbed and covered the lignite-bearing rocks about 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 rugged nature of the surface in their vicinity is such that few stock ranches are located so as to take advantage of the excellent water. Water tanks have been erected at many of these springs by the U. S. Forest Service. 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 the margin of the butte. 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 six miles of Forest Service road extending northeastward from State Highway 8, 2 miles west of Reva.

The oldest rocks exposed in the Slim Buttes area are at its southern margin where the White River and Arikaree formations unconformably overlie the Hell Creek formation of Upper Cretaceous age. To the north the pre-Oligocene unconformity transgresses 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. (See fig. 18.) The lignite-bearing rocks dip northeastward at about 20 feet or less per mile.

The lignite-bearing rocks are relatively undisturbed except at the north end of the Buttes, where the rocks are broken by a pre-White River fault (fig. 18) 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. Drag produced by the relative downward movement along its south side is quite noticeable. The nearly horizontal beds of the White River formation overlie the steeply dipping lignite-bearing rocks of the Ludlow (fig. 22), but lignite-bearing rocks are essentially horizontal 500 feet away from the fault. 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 faulting and pre-Arikaree landsliding were not differentiated.

The two areas in the Slim Buttes where core and surface data are adequate to estimate reserves are along the west central part of the Buttes in the vicinity of the Mendenhall mine, locations 83 to 96 (figs. 18, 23, and 24) and in the Bar H area at the northeast tip of the Buttes, locations 110 to 118. The radioactive beds in these areas average 6 to 12 feet in thickness (fig. 19) and are of excellent quality lignite. An average of 13 Bureau of Mines analyses of lignite core from the Mendenhall area shows the radioactive bed to contain on an air dried basis approximately 38 percent fixed carbon, 13 percent ash, 1.7 percent sulfur, and a heating value of about 8,420 B.T.U.'s (Zeller 1952). The amount of mineralization varies

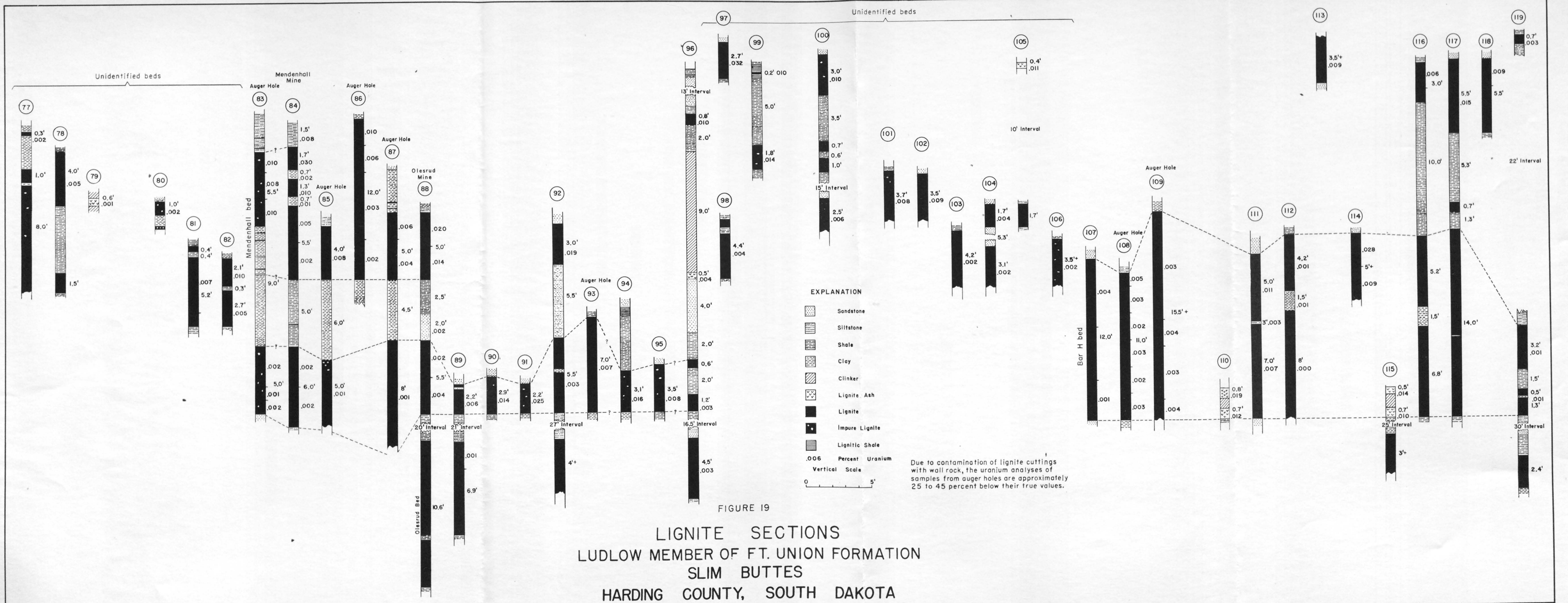


FIGURE 19

LIGNITE SECTIONS
LUDLOW MEMBER OF FT. UNION FORMATION
SLIM BUTTES
HARDING COUNTY, SOUTH DAKOTA

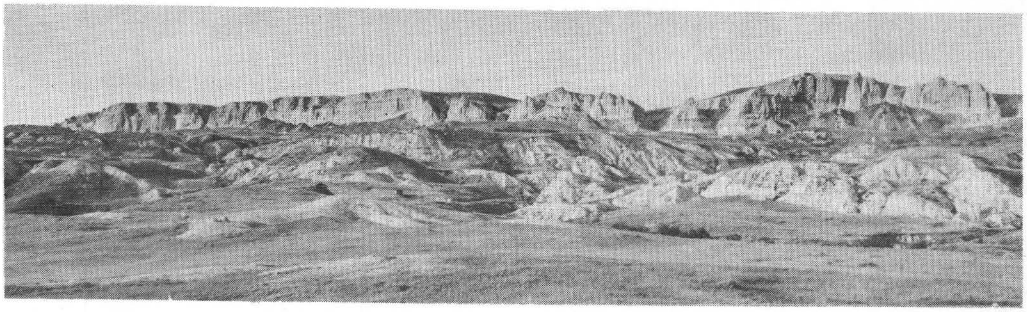


Figure 20.--West face of Slim Buttes T. 16 N., R. 7 E., showing badland topography formed by landslides and slumping in White River and Arikaree formations.

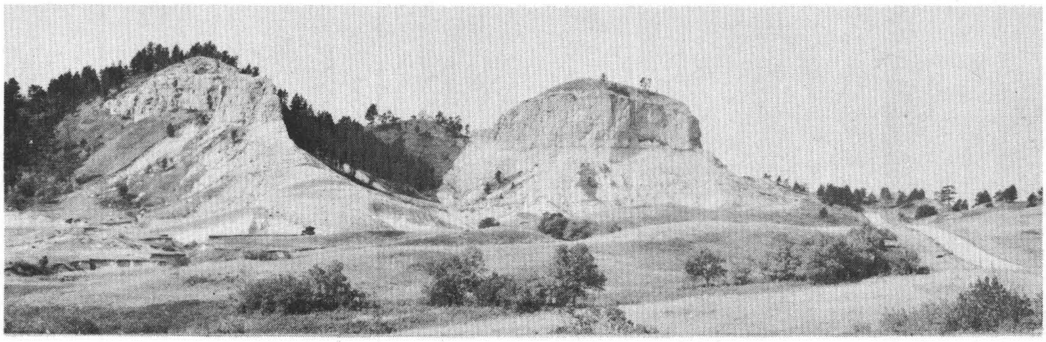


Figure 21.--Cliff-forming, tuffaceous sandstone of Arikaree formation unconformably overlying bentonitic clay and siltstone of White River formation at Reva Gap, SW$\frac{1}{4}$ sec. 8, T. 18 N., R. 8 E., Harding County, South Dakota.

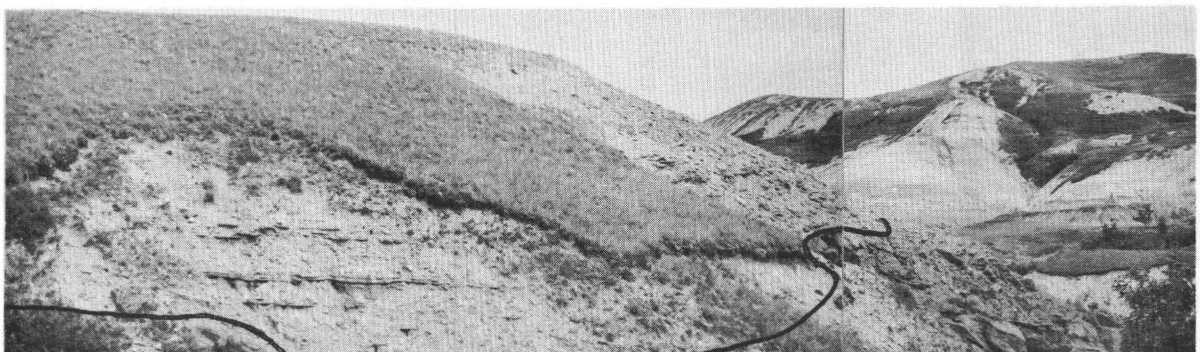


Figure 22.--Angular unconformity between White River and Fort Union formations in Bar H area, NE$\frac{1}{4}$ sec. 33, T. 19 N., R. 8 E., Harding County, South Dakota.

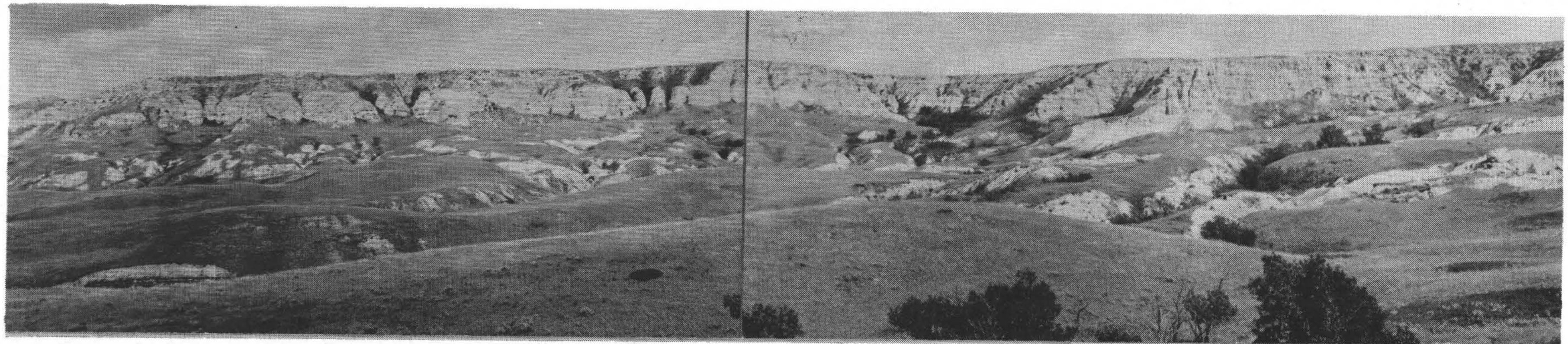
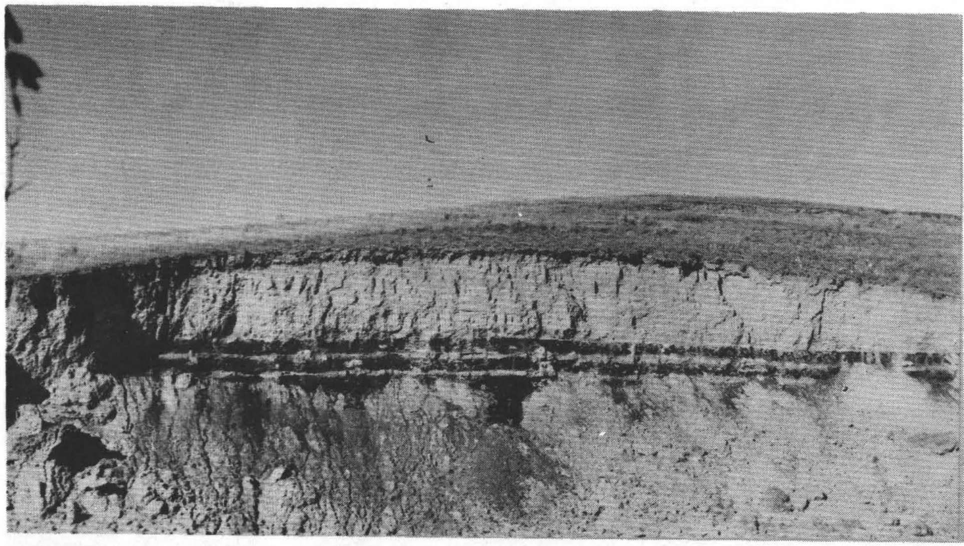


Figure 23.--Radioactive lignite in Fort Union formation unconformably overlain by White River-Arikaree source beds of uranium T. 17 N., R. 7 E., Harding County, South Dakota. Mendenhall strip mine in left foreground (see fig. 24 below).



		% U
18"	Silt	.008
18"	Lig.	.030
8"	Clay	
16"	Lig.	.010
8"	Clay	
33"	Lig.	.005
33"	Lig.	.002

Figure 24.--Mendenhall strip mine, NW¼ SE¼ sec. 1, T. 17 N., R. 7 E. Harding County, South Dakota. Three-foot shovel in center foreground rests on base of lignite averaging 8 feet in thickness. Analyses listed in margin show uranium content of lignite and siltstone roof.

Figure 25.--Jeep-powered auger used in S. Dak. by the Geological Survey to obtain unweathered samples of radioactive lignite.

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from place to place and appears to be most closely controlled by the stratigraphic proximity of the lignite bed to the base of the White River formation and to the permeability of the rocks directly overlying the bed.

The occurrences at widely separated locations 79, 81, 101, 107, and 108 (fig. 18) indicate that radioactive lignites 5 feet or more in thickness probably underlie most of the 60 odd square miles of White River and Arikaree terrane capping Slim Buttes. However, in computing the reserves of radioactive lignite the surface and core data were considered adequate for only a total of about 7 square miles. On the basis of the surface and core hole data, it is estimated that there are at least 5,250,000 tons of strippable lignite in beds 5 feet or more in thickness in the Mendenhall area and a combined total of 33,250,000 tons of lignite in the Mendenhall and the Bar H areas which will require underground mining. Potential reserves of radioactive lignite underlying all of Slim Buttes are estimated to be in the neighborhood of 340,000,000 tons.

Long Pine Hills

The Long Pine Hills are a high mesa, 2 to 5 miles in width and 14 miles long north and south in the eastern part of Carter County, Mont. Throughout the length of the mesa, chalky gray sandstones and bentonitic clays of the Arikaree and White River formations unconformably overlie the lignite-bearing Ludlow member of the Fort Union formation. 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 in thickness occur at few places around the mesa and are generally overlain by 100 feet or more of impervious shale. A 7-day 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 NE 1/4 sec. 21, T. 3 S., R. 62 E., a lignite 5 feet in thickness occurs 150 feet below the base of the White River formation (Bauer, 1924, plate 23, locality 287). The impure character of the bed and its low uranium content (see fig. 16, locality 121) makes the occurrence only of academic interest. The lignite at the Chuning mine thins to the west and in the NW 1/4 sec. 19, T. 3 S., R. 62 E. (Bauer's locality 291) ranges from 6 inches to 2 feet in thickness. The lignite is only mildly radioactive. (See fig. 16, locality 120.) The same bed, or one in the NE 1/4 sec. 20, T. 1 S., R. 61 E., at about the same stratigraphic horizon at the northern tip of the mesa, contains a significant amount of uranium but is 1 foot or less in thickness at most places and is of no commercial importance (locality 122, fig. 16).

The thin, lenticular character and poor quality of the stratigraphically highest lignite, the thickness of generally impervious materials between it and the overlying source beds, and the low mineral content of the five most radioactive samples collected during the reconnaissance examination make it seem unlikely that radioactive lignites of commercial importance will be discovered in the region of the Long Pine Hills. The massive coarse-grained sandstones directly underlying the pre-Oligocene unconformity in the Long Pine Hills, however, may at some places act as a favorable host rock for the localization of secondary uranium minerals. The discovery of secondary uranium minerals in sandstones underlying the White River formation at Reva Gap in Slim Buttes make the possibility of a similar discovery in the Long Pine Hills not unlikely.

RESERVES

General statement

Available data from northwestern South Dakota and adjacent areas indicate that the region contains an aggregate of at least 47,500,000 tons of lignite containing 3,900 tons of uranium. Almost a fifth of the estimated reserves are adapted to strip mining and are in beds averaging 4 feet in thickness. Analyses of about 275 channel and auger samples in addition to 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 in the ash thus is at least five times and generally seven to ten times that of the lignite. Proximate and ultimate analysis show a low sulfur content (2 percent or less) and heating values on an air dried basis of about 8,200 B.T.U.'s (Zeller, 1952).

The radioactive deposits in the Slim Buttes area of Harding County, S.Dak., are perhaps the most promising of those examined in the

Dakotas. The lignites underlying Slim Buttes average ten feet or more in thickness and are favorably related to the position of the base of the overlying White River formation to permit wide-spread mineralization by groundwater.

Approximately 850 feet of core drilling in 8 shallow holes along the northeast side of Slim Buttes under contract No. Igs 12521 was completed late in July, 1952 (Zeller, 1953). The core drilling conducted in the Slim Buttes area under this contract in 1951 and 1952 and by the U. S. Bureau of Mines in 1952 and 1953 (Gill, 1954b), is not considered adequate to appraise the area's potentialities. For example, radioactive lignite probably underlies about 60 square miles in the Slim Buttes area, but only the reserves underlying about 7 square miles, where data from both drilling core and surface sections were available, are included in the estimates. From the incomplete data at hand it is possible that Slim Buttes may be underlain by 340,000,000 tons of radioactive lignite in beds averaging 5 feet or more in thickness and containing at least 24,000 tons of uranium. A total of 15 to 20 core holes, 375 to 400 feet deep, at an estimated cost to the government of $25,000 to $35,000 would provide a more complete and accurate appraisal of the area's potentialities. Large underground reserves of nonradioactive lignite at most places underlie the uppermost mineralized bed in the Slim Buttes area. Large additional strippable and underground reserves of nonradioactive lignite also are available 7 to 9 miles north of 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 region in the icinity of Slim Buttes, therefore, seems particularly well adapted for providing large tonnages of lignite for lignite-consuming industrial installations of major size.

In addition to the estimates of uranium-bearing reserves listed herein for northwestern South Dakota and adjacent areas, Moore, and others (1954) report an inferred estimate of about 5,000,000 tons of radioactive lignite (average grade 0.007 percent) underlying about 1,200 acres at Sentinel Butte in Golden Valley County, N. Dak., and about 4,200,000 tons (average grade 0.007 percent) underlying 500 acres at Bullion Butte in Billings County, N. Dak. The radioactive beds in these areas average from 2.5 to 4.5 feet in thickness. Bullion and Sentinel Buttes are in the southwest corner of North Dakota 38 and 52 miles north of the Medicine Pole Hills. The thickness and character of the White River formation which caps these Buttes will require that the lignite be recovered by underground mining.

In Slope County, N. Dak., about 5 miles north of Bowman, Moore and others estimate a reserve total of about 17,950,000 tons of uranium-bearing lignite underlying about 5,200 acres in the vicinity of Chalky Buttes. There 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 recovery by methods of underground mining. Approximately 600 acres are overlain by 30 feet or less of overburden and underlain by uranium-bearing lignite 2.0 feet or more in thickness (average grade 0.016 percent) which are suitable for stripping.

In the Ekalaka Hills, Carter County, Mont., Gill (1954a) estimates a total reserve of 16,500,000 tons of mildly radioactive lignite (average grade 0.005 percent) which 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.

Summary of inferred reserves of uranium-bearing lignite in northwestern South Dakota and adjacent areas

Strippable reserves

Location	Area (acres)	Thickness (feet)	Grade (percent U)	Lignite 1/ (short tons)	Uranium 2/ (short tons)	Core holes
Mendenhall area, in parts of secs. 1 and 12, 17 N., 7 E.; sec. 36, 18 N., 7 E., and secs. 5, 6, and 8, 17 N., 8 E.	600	5.0	0.009	5,250,000	470	14
Johnson Outlier, S 1/2 sec. 9, and SW 1/4 SW 1/4 sec. 10, 21 N., 11 E., Perkins County	90	Upper	0.010	472,000	45	2
Lodgepole area, C of W 1/2 sec. 19, 21 N., 12 E., Perkins County	30	4.0	0.010	210,000	20	4
*North Cave Hills, C sec. 19, 22 N., 5 E., Harding County	20	5.0	0.005	175,000	10	0
Medicine Pole Hills, in parts of secs. 1 and 2, 130 N., 104 W., and SE 1/4 sec. 35, 131 N., 104 W., Bowman County	360 40	4.5 3.0	0.006 0.013	2,835,000 210,000	170 25	5
			Subtotal	9,152,000	740	

1/ Tonnage estimates based on 1,750 tons of lignite per acre foot - net result rounded to nearest 1,000 tons.

2/ Figures rounded to nearest 5 tons.

* Reserve data for the mineralized "E" Bed in parts of secs. 22, 26, and 27, T. 22 N., R. 5 E., in the North Cave Hills are not available but will be included in a subsequent report.

Summary of inferred reserves of uranium-bearing lignite in northwestern South Dakota and adjacent areas--Continued

Underground mining reserves

Location	Area (acres)	Thickness (feet)	Grade (percent U)	Lignite 1/ (short tons)	Uranium 2/ (short tons)	Core holes
Bar H area, in parts of secs. 20, 21, 28, 29, and 33, 19 N., 8 E., Harding County	600	upper 5.0 of 12.9	0.010	5,250,000	525	1
Mendenhall area, in parts of secs. 1 and 12, 17 N., 7 E., secs. 5, 6, 7, and 8, 17 N., 8 E., and secs. 31 and 32, 18 N., 8 E., Harding County	3,200	upper 5.0 of 8.0	0.008	28,000,000	2,240	28
South Cave Hills, in SW 1/4 sec. 28 and NW 1/4 sec. 33, 21 N., 5 E., NE 1/4 sec. 5, 20 N., 5 E., S 1/2 sec. 13, 21 N., 4 E., Harding County	600	3.0	0.009	3,150,000	285	0
McKensie Butte, in SE 1/4 sec. 20, 20 N., 5 E., Harding County	50	3.0	0.01	262,000	25	0
Table Mt., in parts of secs. 5, 6, 7 and 8, 22 N., 4 E., Harding County	500	2.0	0.008	1,750,000	140	0
Subtotal				38,412,000	3,215	
Grand total strippable and underground				47,564,000	3,955	

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APPENDIX

Summary of analytical data on surface samples and auger cuttings of radioactive lignites from northwestern South Dakota and adjacent areas. Data supplied by U. S. Geological Survey Trace Elements Laboratories, Washington, D. C. and Denver, Colorado: J. C. Rabbitt and Lewis F. Rader in charge.

Chemical analyses by: F. Cuttitta, A. Dufour, E. Mallory, J. J. McGee, W. P. Tucker, Jr., and H. W. Worthing.

Radiometric analyses by: C. Cox, B. A. McCall, J. N. Rosholt, and J. J. Warr, Jr.

Locations 1 to 15, Table Mountain and adjacent outliers, Harding County, South Dakota. (See fig. 13.)

Locality number	Laboratory number	Thickness of sampled interval (feet)	Ash (percent)	Uranium in ash (percent)	Uranium in sample (percent)	Equivalent uranium (percent)	Location
1	42469	2.3	23.6	0.028	0.005	0.004	NW NW 7-22N-4E
2	42458	2.6	34.6	.017	.005	.006	Do.
	42461	3.8	16.1	.002	.000	.000	Do.
3	42459	2.6	26.4	.090	.020	.016	Do.
4	42460	2.9	57.3	.026	.012	.014	NW SE 7-22N-4E
7	42465	1.3	45.0	.006	.003	.002	NE SE 7-22N-4E
	42467	0.3	63.2	.067	.036	.021	Do.
	42468	2.1	28.7	.012	.003	.002	Do.
	42462	4.8	33.5	.005	.002	.001	Do.
8	42466	1.6	45.4	.010	.005	.004	NE NE 8-22N-4E
	42933	3.0	26.8		.005	.005	Do.
9	42455	1.7	30.9	.046	.013	.014	NW SE 5-22N-4E
	42457	2.8	17.0	.062	.009	.008	Do.
	42463	3.0	44.1	.001	.001	.000	Do.
	42470	2.3	29.7	.003	.001	.000	Do.
10	42454	1.7	32.4	.038	.015	.012	Do.
11	43901	2.2			.004	.004	Do.
13	42936	5.0	22.1		.000	.001	NW SE 6-22N-4E
14	42934	2.2	29.1		.001	.001	CSL 17-22N-4E
	42935	0.7	59.6		.001	.002	Do.
15	42937	0.5	53.5		.003	.004	SE SW 9-22N-4E

Locations 16 to 51, North Cave Hills, Harding County, South Dakota. (See fig. 13.)

Locality number	Laboratory number	Thickness of sampled interval (feet)	Ash (percent)	Uranium in ash (percent)	Uranium in sample (percent)	Equivalent uranium (percent)	Location
16	43148	3.2	25.77	0.012	0.003	0.004	CEL SE 4-22N-5E
17	43150	3.9	27.16	.003	.001	.001	CWL NE 9-22N-5E
19	43151	0.5	95.63	.003	.003	.007	SW NW 10-22N-5E
21	43153	0.5	95.40	.016	.011	.006	SW SE 10-22N-5E
	43152	4.8	29.49	.005	.001	.001	Do.
22*	45024	2.0	76.9	.002	.002	.002	Do.
	45025	2.0	65.66	.002	.002	.002	Do.
23	43154	5.2	22.14	.002	.001	.001	SW SW 11-22N-5E
24	43155	5.0	42.27	.005	.001	.000	SW NW 11-22N-5E
25	44254	1.9			.005	.005	NW SE 2-22N-5E
26	43659	4.5			.001	.000	NW SW 14-22N-5E
	43660	4.0	42.65	.015	.006	.004	Do.
27*	45023	3.0	69.54	.008	.005	.006	Do.
28	43658	1.8	35.49	.025	.007	.006	SE NW 26-22N-5E
29*	45022	1.0	82.08	.002	.002	.004	Do.
30	47864	2.0	27.42	.011	.003	.003	CEL SE 27-22N-5E

Note: At locations 5, 6, 12, 18, and 20, lignite is nonradioactive and was not sampled.

* Auger hole. Due to contamination of wall rock with lignite cuttings, uranium analyses are 25 to 45 percent below their true values.

Locations 16 to 51, North Cave Hills, Harding County, South Dakota. (See fig. 13.)--Continued

Locality number	Laboratory number	Thickness of sampled interval (feet)	Ash (percent)	Uranium in ash (percent)	Uranium in sample (percent)	Equivalent uranium (percent)	Location
31	43898	1.6			0.004	0.004	SW SW 35-22N-5E
32*	43903	10.0	53.43	0.001	.001	.001	SE SE 36-22N-5E
33	43900	2.2			.001	.001	SW SE 12-21N-5E
	43899	5.8			.001	.000	Do.
34	45110	4.8			.001	.000	NE NW 13-21N-5E
35	46222	1.3			.003	.002	SW SE 11-21N-5E
	46221	5.0			.002	.001	Do.
36	43654	2.1	42.23	.018	.006	.007	SW NW 10-21N-5E
	43653	4.6			.003	.002	SW NE 10-21N-5E
37	43657	1.1	38.82	.025	.004	.004	SE NW 34-22N-5E
38	43656	0.8	37.21	.019	.006	.006	NE SE 33-22N-5E
	43655	3.6			.001	.001	Do.
39	43652	1.7	42.71	.023	.008	.006	EL SW NW 33-22N-5E
	43651	3.3			.003	.002	Do.
40	44264	0.5			.006	.007	SE SE 29-22N-5E
	44263	0.3			.005	.004	Do.
	44262	2.0			.002	.003	Do.
	44261	1.9			.001	.001	Do.
41	44260	1.8			.002	.002	NE SW 29-22N-5E
42	44258	1.6			.000	.000	SW NE 30-22N-5E
	44259	5.4			.000	.000	Do.
43	44267	1.2			.003	.005	NW NE 25-22N-4E
44	43649	3.6	19.96	.028	.005	.003	SE NE 24-22N-4E
	43650	1.1	27.13	.043	.010	.014	Do.
45	44269	1.0			.018	.021	NW SW 19-22N-5E
	44268	4.3			.002	.002	Do.
46*	45026	1.25	73.94	.008	.006	.004	Do.
	45027	1.25	62.84	.007	.005	.007	Do.
	45028	2.25	61.2	.003	.003	.003	Do.
	45029	2.25	65.28	.003	.003	.004	Do.
47*	45039	1.0	69.14	.006	.004	.005	NW SE 19-22N-5E
	45040	5.0	46.26	.005	.003	.004	Do.
48*	45396	1.0	71.86	-	.002	.004	Do.
	45030	1.0	52.81	.005	.003	.003	Do.
	45031	1.0	54.33	.006	.003	.002	Do.
	45032	1.0	54.59	.004	.003	.002	Do.
	45033	1.0	52.68	.007	.003	.002	Do.
	45034	1.0	54.94	.005	.003	.003	Do.
	45035	1.0	58.42	.004	.003	.002	Do.
	45036	1.0	42.61	.004	.002	.002	Do.
	45037	1.0	45.0	.005	.003	.003	Do.
	45038	1.0	55.73	.006	.003	.002	Do.
49*	45397	2.5	40.80		.005	.006	SW NE 19-22N-5E
	45041	4.0	32.85	.006	.003	.001	Do.
	45042	1.5	70.63	.003	.003	.003	Do.
50	44256	2.0			.004	.004	SW SW 9-22N-5E
51	44255	4.5			.002	.001	SE SE 8-22N-5E

* Auger hole. Due to contamination of wall rock with lignite cuttings, uranium analyses are 25 to 45 percent below their true values.

Locations 52 to 76, South Cave Hills and adjacent outliers, Harding County, South Dakota. (See fig. 11.)

Locality number	Laboratory number	Thickness of sampled interval (feet)	Ash (percent)	Uranium in ash (percent)	Uranium in sample (percent)	Equivalent uranium (percent)	Location
52	43668	0.8	34.32	0.025	0.009	0.006	SW NE 23-21N-4E
	43667	0.8	68.39	.084	.055	.041	Do.
	43666	0.5	36.63	.093	.034	.025	Do.
	43669	2.7			.001	.000	Do.
53	43664	2.2	48.5	.013	.007	.028	SE SW 23-21N-4E
	43663	0.8	69.39	.020	.012	.017	Do.
54*	45097	2.0	93.88	.004	.004	.005	Do.
55	43894	4.2			.003	.003	SW SW 13-21N-4E
56	44716	3.5	21.93		.009	.007	C SW 18-21N-5E
57	44717	1.0	82.20		.045	.042	NW SW 28-21N-5E
58	47866	2.5	22.12	.108	.024	.020	NW NW 33-21N-5E
59	44719	1.5	70.13		.030	.029	CSL 28-21N-5E
60	44718	4.2	29.33		.015	.014	CSL 28-21N-5E
61	43670	1.1	51.18	.021	.013	.006	Do.
62	43889	1.0	39.59	.039	.014	.011	SE NW 9-20N-5E
63	43888	2.0	49.8	.013	.007	.006	SW NE 5-20N-5E
	43887	3.3	40.42	.031	.013	.008	Do.
64	43890	3.0	38.8	.014	.006	.006	NE NE 6-20N-5E
	43891	1.0	30.15	.021	.007	.003	Do.
65	44715	3.0	42.13		.001	.001	NE SE 6-20N-5E
66	43893	1.7	60.01	.011	.006	.011	NW SE 6-20N-5E
	43892	6.0			.001	.001	Do.
67	43673	2.5			.004	.003	C NE 36-21N-4E
68	43671	1.2			.004	.004	SE NE 35-21N-4E
	43672	3.0			.001	.000	Do.
69	47934	1.75	25.17	.056	.014	.015	NE SW 20-20N-5E
	47933	1.75	25.07	.116	.029	.016	Do.
	47932	3.0			.002	.003	Do.
70	47937	0.7	83.61	.020	.018	.023	NE NE 19-20N-5E
	47936	0.7	94.87	.035	.028	.038	Do.
	47935	0.8	87.62	.031	.024	.020	Do.
71	47925	0.5	85.74	.22	.19	.14	SW SE 30-20N-5E
	47927	0.8	88.94	.022	.020	.018	Do.
72	47926	2.3			.005	.003	SE SW 13-20N-4E
73	47930	0.5	94.93	.019	.018	.017	NE NE 21-20N-4E
74	47931	1.5	54.93	.046	.025	.018	CSL 21-20N-4E
75	47928	1.6			.002	.003	NE NE 28-20N-4E
	47929	1.6			.003	.001	Do.

* Auger hole. Due to contamination of wall rock with lignite cuttings, uranium analyses are 25 to 45 percent below their true values.

Locations 77 to 119, Slim Buttes, Harding County, South Dakota. (See fig. 19.)

Locality number	Laboratory number	Thickness of sampled interval (feet)	Ash (percent)	Uranium in ash (percent)	Uranium in sample (percent)	Equivalent uranium (percent)	Location
77	45052	0.3			0.002	0.000	SW NW 1-16N-7E
78	45050	4.0			.002	.005	NE NW 34-17N-7E
79	45051	0.6			.001	.002	NE SW 35-17N-7E
80	47851	1.0	43.79		.002	.003	NW SE 8-17N-8E
81	47852	4.9	17.85	0.039	.007	.009	SW SE 8-17N-8E
82	47853	2.1	34.30	.029	.010	.009	SE NE 5-17N-8E
	47854	2.7	29.47	.017	.005	.005	Do.
83*	45064	1.5	76.19	.011	.010	.010	SE SW 1-17N-7E
	45065	2.0	82.5	.009	.008	.009	Do.
	45066	2.0	80.3	.010	.010	.008	Do.
	45067	3.0	69.74	.003	.002	.003	Do.
	45069	1.0	33.21	.003	.002	.001	Do.
	45070	1.0	48.07	.003	.002	.003	Do.
84	45368	1.5	86.53		.008	.010	NW SE 1-17N-7E
	45367	1.75	25.53		.030	.031	Do.
	45366	0.7	85.80		.002	.003	Do.
	45365	1.3	21.93		.010	.008	Do.
	45364	0.7	82.0		.001	.002	Do.
	45362	2.75	12.20		.005	.004	Do.
	45055	2.75			.002	.002	Do.
	45054	3.0			.002	.001	Do.
	45053	3.0			.002	.002	Do.
85	45063	4.0	64.56	.011	.008	.005	NE SW 1-17N-7E
	45049	4.0	40.84	.002	.001	.002	Do.
86*	45061	2.0	78.15	.014	.010	.010	SW NE 1-17N-7E
	45062	2.0	63.61	.009	.006	.006	Do.
	45044	5.0	56.94	.006	.003	.004	Do.
	45045	3.0	50.60	.003	.002	.001	Do.
87*	45072	2.0	55.51	.007	.006	.005	SW SE 36-18N-7E
	45073	3.0	38.45	.009	.004	.003	Do.
	45076	8.0	22.18	.002	.001	.000	Do.
88	45104	2.5	20.39	.011	.020	.012	NW SE 36-18N-7E
	45103	2.5	20.26	.074	.014	.009	Do.
	45102	2.0			.002	.002	Do.
	45101	2.75			.002	.001	Do.
	45100	2.75			.004	.003	Do.
89	46206	2.2	34.84	.017	.006	.004	Do.
	46205	2.0			.001	.001	Do.
90	46204	2.9	40.34	.042	.014	.012	Do.
91	46207	2.2	37.15	.075	.025	.017	SW NE 36-18N-7E
92	45106	3.0	33.09	.058	.019	.015	Do.
	45105	5.5			.003	.004	Do.
93*	45080	7.0	58.5	.009	.007	.005	Do.
94	47843	3.1	22.67	.075	.016	.017	SW SE 25-18N-7E

* Auger hole. Due to contamination of wall rock with lignite cuttings, uranium analyses are 25 to 45 percent below their true values.

Locations 77 to 119, Slim Buttes, Harding County, South Dakota. (See fig. 19.)--Continued

Locality number	Laboratory number	Thickness of sampled interval (feet)	Ash (percent)	Uranium in ash (percent)	Uranium in sample (percent)	Equivalent uranium (percent)	Location
95	47844	3.5	25.63	0.039	0.008	0.010	NW SW 25-18N-7E
96	46212	0.8	27.13	.043	.010	.007	Do.
	46210	0.5			.004	.005	Do.
	46209	1.2			.003	.002	Do.
	46208	4.5			.003	.003	Do.
97	46213	2.7	33.99	.110	.032	.026	Do.
98	46211	4.4			.004	.002	Do.
99	47848	0.2	8.24	.121	.010	.009	NE SE 24-18N-7E
	47847	1.8	26.20	.053	.014	.014	Do.
100	47849	3.0	19.87	.050	.010	.009	SE SW 20-18N-8E
	47850	2.5	17.61	.034	.006	.006	Do.
101	47855	3.7	25.05	.020	.008	.005	NW SW 28-18N-8E
102	47856	3.5	35.80	.025	.009	.007	SW SW 29-18N-8E
103	47857	4.2	17.93	.011	.002	.002	SE SE 8-18N-8E
104	47859	1.7	28.07	.014	.004	.004	NE NE 17-18N-8E
	47858	3.1	12.55		.002	.003	Do.
105	47860	0.4	80.13	.014	.011	.012	Do.
106	43895	3.5			.002	.003	NE SE 1-18N-7E
107	43896	5.0			.004	.003	Do.
	43897	3.0			.001	.001	Do.
108*	47943	1.0			.005	.002	SW SW 8-18N-8E
	47944	2.0			.003	.002	Do.
	47945	2.0			.002	.001	Do.
	47946	2.0			.003	.002	Do.
	47947	2.0			.002	.001	Do.
	47948	2.0			.003	.001	Do.
109*	47949	8.0			.003	.002	SE NW 8-18N-8E
	47953	2.0			.004	.003	Do.
	47954	4.0			.003	.002	Do.
	47956	1.5			.004	.002	Do.
110	42930	0.8	93.3		.019	.019	NW NE 33-19N-8E
	42931	0.7	29.1		.012	.013	Do.
111	42729	5.0	23.7	.059	.011	.011	Do.
	42730	0.25	94.5	.002	.003	.003	Do.
	42731	7.0	15.7	.064	.007	.019	Do.
112	42928	4.2	17.0		.001	.000	NW SW 27-19N-8E
	42927	1.5	92.9		.001	.002	Do.
	42926	8.0	14.6		.000	.000	Do.
113	42929	3.5	36.1		.009	.007	CSL 28-19N-8E
114	46196	2.5	28.32	.088	.028	.013	C E-1/2 28-19N-8E
	46195	2.5	9.89	.010	.009	.007	Do.
115	46198	0.5	97.80	.012	.014	.019	Do.
	46197	0.70	97.07	.010	.010	.011	Do.
116	46199	2.0	22.54	.038	.006	.007	SW NE 28-19N-8E
117	46200	5.5	19.70	.085	.015	.011	SW SE 20-19N-8E
118	46201	2.0	18.12	.053	.009	.007	SE SE 20-19N-8E
119	42923	0.7	36.5		.003	.005	SW 20-21N-8E
	42924	3.2	19.4		.001	.001	Do.
	42925	2.2	18.0		.001	.001	Do.

Locations 120 to 123, Long Pine Hills, Carter County, Montana. (See fig. 16.)

Locality number	Laboratory number	Thickness of sampled interval (feet)	Ash (percent)	Uranium in ash (percent)	Uranium in sample (percent)	Equivalent uranium (percent)	Location
120	42472	2.0	70.6	0.006	0.004	0.004	NW NW 19-3S-62E
121	46215	2.5			.004	.005	SW NE 21-3S-62E
	46214	2.5			.003	.005	Do.
122	46216	0.8	33.62	.043	.014	.008	NE NE 20-1S-61E
123	46217	0.8			.003	.002	SW SW 13-1N-58E
Locations 125 to 132, 147, and 148, Medicine Pole Hills, Bowman County, North Dakota. (See fig. 16.)							
125	42474	4.0	45.1	0.015	0.005	0.005	NE NW 12-130N-104W
126*	45390	5.0	61.33		.004	.005	SE SW 35-131N-104W
127*	45393	4.5	64.0		.010	.008	NW SE 35-131N-104W
128	45398	5.5	17.33		.009	.007	Do.
129	45056	2.0			.001	.001	NW NW 29-131N-103W
130*	45394	8.0	55.46		.001	.002	SW SW 20-131N-103W
131	45369	2.0	34.26		.010	.008	NE NE 21-131N-103W
132*	45395	5.0	59.60		.001	.002	Do.
	45060	5.0	54.20	.002	.002	.003	Do.
147*	45391	3.5	58.40		.019	.019	NE SE 2-130N-104W
148*	45392	5.0	60.66		.003	.003	SW NW 1-130N-104W
Locations 133 to 145, Lodgepole area, Perkins County, South Dakota. (See fig. 16.)							
133	42473	6.0	21.3	0.001	0.000	0.000	SW SW 20-21N-12E
134	45091	2.0	76.94	.005	.004	.004	SL SE SW 20-21N-12E
	45092	6.0	38.48	.001	.001	.000	Do.
135	45109	2.1	29.95	.035	.009	.007	Do.
136	43902	2.0	29.12	.016	.005	.004	Do.
	43156	4.0	19.89	.008	.002	.001	NW NE 30-21N-12E
137*	45081	2.0	64.17	.016	.012	.008	SW NW 19-21N-12E
	45082	2.0	57.13	.005	.003	.002	Do.
	45083	2.0	40.43	.004	.003	.001	Do.
138	45107	2.0	54.28	.028	.015	.010	Do.
139*	45084	2.0	61.99	.023	.015	.015	Do.
	45085	2.0	66.20	.009	.008	.006	Do.
	45086	2.0	47.31	.007	.004	.002	Do.
	45087	1.5	48.10	.004	.003	.002	Do.
140*	45088	2.0	56.53	.004	.003	.002	NW NE 19-21N-12E
	45089	2.0	21.9	.003	.002	.001	Do.
	45090	1.5	54.41	.002	.002	.002	Do.
141	45108	2.6			.004	.003	NE NW 19-21N-12E
142	47958	2.0			.001		SW SW 2-21N-12E
143	43157	3.0	23.41	.003	.001	.001	NW SW 33-22N-12E
144*	45093	3.5	64.75	.009	.006	.006	CEL SESE 9-21N-[illegible]E
	45094	1.5	53.05	.004	.003	.003	Do.
	45095	2.5	52.53	.004	.002	.002	Do.
145	44272	5.5			.004	.003	NE SW 9-21N-11E

* Auger hole. Due to contamination of wall rock with lignite cuttings, uranium analyses are 25 to 45 percent below their true values.

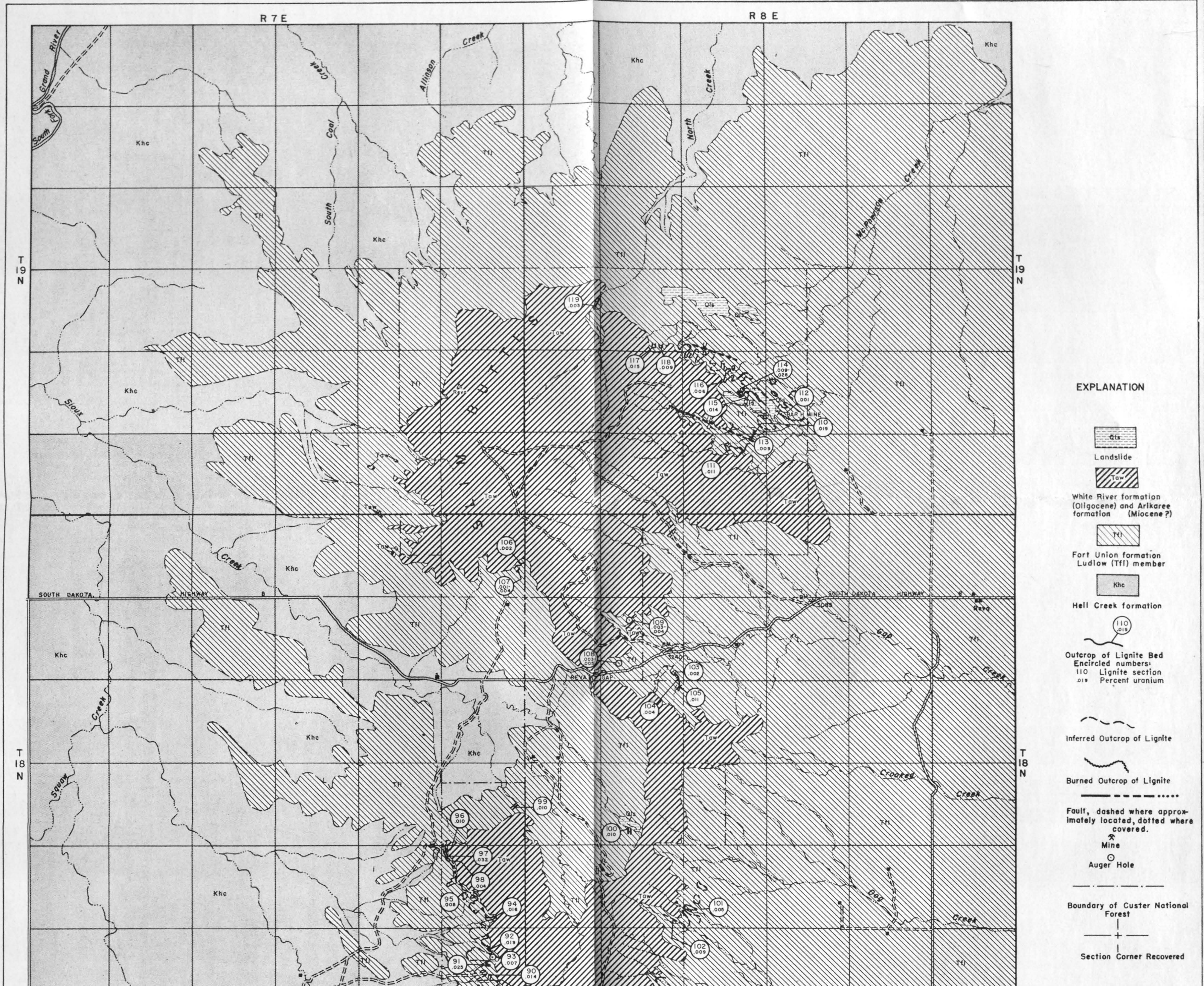


FIGURE 18.--GEOLOGIC MAP OF SLIM BUTTES AREA, HARDING COUNTY, SOUTH DAKOTA

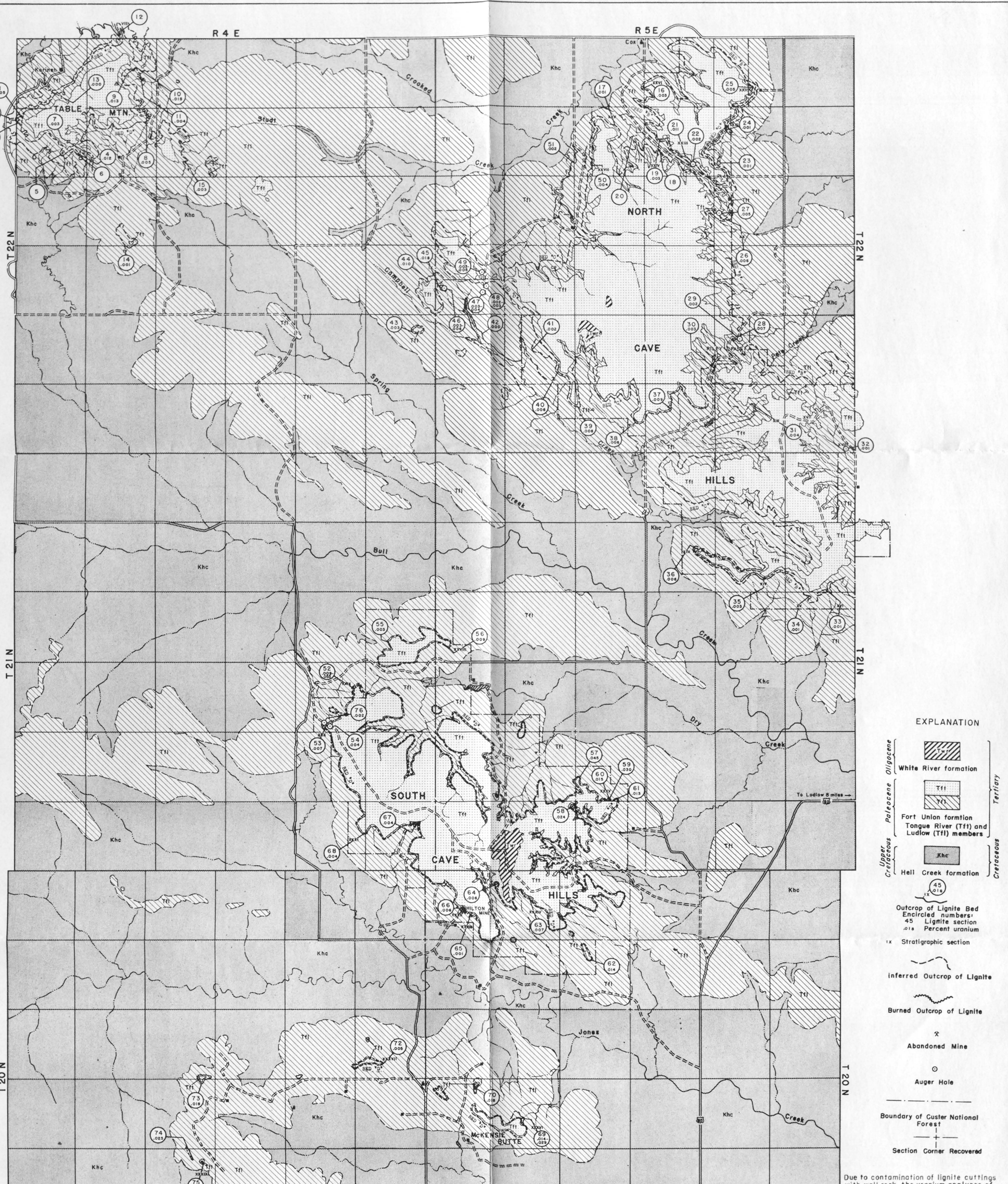
by

N. M. Denson, G. O. Bachman and H. D. Zeller

SCALE

0 1 2 3 4 5 Miles

1954



GEOLOGIC MAP OF CAVE HILLS AND TABLE MOUNTAIN AREA, HARDING COUNTY, SOUTH DAKOTA

by
N. M. Denson, G. O. Bachman and H. D. Zeller

SCALE
0 1 2 3 4 5 Miles

FIGURE 10

1954