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RECONNAISSANCE FOR URANIFEROUS LIGNITES IN NORTH DAKOTA, SOUTH DAKOTA, MONTANA, AND WYOMING

By
Ernest P. Beroni
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This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

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GEOLOGICAL SURVEY

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Trace Elements Investigations Report 123

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

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RECONNAISSANCE FOR URANIFEROUS LIGNITES IN NORTH DAKOTA, SOUTH DAKOTA, MONTANA, AND WYOMING

by Ernest P. Beroni and Herman L. Bauer, Jr.

ABSTRACT

Uraniferous lignites were discovered by D. G. Wyant and E. P. Beroni in North Dakota in the summer of 1948 during general reconnaissance studies for uranium. In 1949 more detailed studies were made at Bullion and Sentinel Buttes, in Slope, Billings, and Golden Valley Counties, N. Dak. Investigations of these areas were followed by a general reconnaissance for uraniferous lignites in North Dakota, eastern Montana, north-central Wyoming, and northwestern South Dakota. Deposits of uraniferous lignites were discovered at Blue Buttes, eastern Montana; and at North Cave Hills, South Cave Hills, and at Slim Buttes in northwestern South Dakota.

The only lignites that contain appreciable amounts of uranium are in the upper part of the Sentinel Butte shale member of the Fort Union formation in southwestern North Dakota and eastern Montana, and in the Ludlow formation in northwestern South Dakota.

The uraniferous lignites are as much as 26 feet thick; the thickest is the Bullion Butte bed in the Sentinel Butte shale member of the Fort Union formation which at Bullion Butte averages about 15 feet. The maximum measured thickness of the other uraniferous lignites is 7 feet; about a third of the deposits have an average thickness of more than 3 feet. Sixty-two localities were examined and 170 samples were collected of lignites, carbonaceous clays, natural ash, clinker, and surface waters.

The uranium content of the individual lignite beds ranges from 0.002 to 0.033 percent uranium and after ignition the uranium content of the ash ranges from 0.010 to 0.091 percent uranium.

Natural ash contains as much as 0.025 percent uranium; natural clinker or scoria and carbonaceous clay are lower grade than the lignites; and some spring waters contain as much as 0.09 parts per million of uranium.

The source of the uranium is believed to be in volcanic ash that was deposited in the clays, shales, sandstone, and siltstones interbedded with uraniferous lignite. Studies made of these rocks indicate that analcite, sodium montmorillonite, and glass shards (?) are common in these rocks. These analcite-rich rocks probably formed in saline playa lakes. Uranium appears to have been released from volcanic ash during the formation of analcite and was transported laterally and downward and deposited in nearby organic rich beds that later were carbonized to form uraniferous lignite.

The inferred reserves of uraniferous lignites in North Dakota, South Dakota, and Montana are estimated to be 183,320,000 short tons that contain a weighted average of 0.009 percent uranium. The potential energy and amount of material available for liquid fuel conversion in this quantity of lignite is very large. The inferred reserve of ash which would result from the burning of these uraniferous lignites is 60,266,000 short tons containing 0.023 percent uranium. The total amount of uranium (metal) in the known uraniferous lignite in North Dakota, South Dakota, and Montana is estimated to be about 12,600 short tons.

The potential reserve of uranium in these lignites is believed to be twice as large. Additional exploration work in these areas, and other western states, is being done by the Fuels Branch of the U. S. Geological Survey in order to appraise adequately the uranium resources in our western coal deposits.

The prospect of finding additional radioactive lignite beds is believed to be good.

INTRODUCTION

During the summer of 1948, a reconnaissance investigation of the Cretaceous, Tertiary, and Pleistocene deposits in North Dakota and eastern Montana (Wyant and Beroni, 1950), carried out by the Geological Survey on behalf of the Atomic Energy Commission, resulted in the discovery of uraniferous lignite beds in the Sentinel Butte shale member of the Fort Union formation of Tertiary age in southwestern North Dakota. Results of additional sampling of these lignites early in 1949 by Wyant and Beroni (1950) suggested that detailed mapping in selected areas might yield data on the source and manner of transportation of the uranium, and also additional information on the inferred reserves of uranium in these lignites. Bullion Butte, in Billings, Slope, and Golden Valley Counties (fig. 1), and Sentinel Butte in Golden Valley County were selected as the most favorable areas for detailed study because of the good exposures.

Detailed mapping and sampling of the uraniferous lignites at these localities were started by the writers in mid-August and completed in late September 1949. Bullion Butte was mapped on aerial photographs at a scale of 1/6,000 (fig. 2). Vertical and horizontal control were established by

plane table and alidade; both the geology and topography were plotted on photographs by use of the mirror stereoscope. The upper part of Sentinel Butte in Golden Valley County (fig. 1) was mapped on uncontrolled aerial photographs at a scale of approximately 1/24,000. This map was enlarged to a scale 1/6,000 (fig. 3). In addition, reconnaissance sampling of lignites was carried out at Flat Top Butte and in the Killdeer Mountains, as well as in the Fryburg, Beulah, Hebron, and Riverdale areas (fig. 1). In early October a two weeks' reconnaissance investigation was made of the upper Paleocene lignites in eastern Montana, northern Wyoming, and northwestern South Dakota (fig. 1). During this investigation lignites were sampled in the North Cave Hills, South Cave Hills, Slim Buttes, and East Short Pine Hills, S. Dak.; the Blue Buttes, Mont.; and the Gillette area, Wyo.

Accessibility

All of the areas in which uraniferous lignites have been found are accessible by dirt roads during the summer months. Travel by automobile is exceedingly difficult or impossible after heavy rains or snows.

Acknowledgments

The writers gratefully acknowledge the assistance of Roland W. Brown and William E. B. Benson of the U. S. Geological Survey in making available the results of unpublished field data, including their interpretation of the various stratigraphic problems, and of Donald G. Wyant, who supervised the field work and made many valuable suggestions during the compilation of this report. X-ray diffraction studies were made for the U. S. Geological

Survey by N. C. Schieltz in the U. S. Bureau of Reclamation laboratories at Denver, Colo.

Instrumentation

During the investigation an uncalibrated El-tronics survey meter with a six-inch beta-gamma probe, Model SG-18A, was used for measuring the radioactivity. Throughout the area the normal background reading ranged from 1-1/2 to 3 on the 0.2 scale, whereas the meter readings at the uraniferous lignite exposures were 1-1/2 to 6 times greater than the average background.

GEOLOGY

The lignites examined in southwestern North Dakota, northeastern South Dakota, eastern Montana, and northern Wyoming are in a sequence of continental deposits of Tertiary age. The rocks within this sequence are conformable, except for an erosional disconformity that marks the boundary between the Eocene and the Oligocene. Stratigraphic correlations in this region are difficult and as a result considerable controversy has arisen among the many geologists who have worked in this region. Leonard (1908), Leonard and Smith (1909), Taff (1909), Winchester (1913, 1916), Quirke (1918), Leonard, Babcock, and Dove (1925), Hares (1928), Laird (1944), and Brown (1948) have summarized the geology of local areas.

Paleocene rocks

The Paleocene rocks (fig. 1) exposed in the region have been divided into the Ludlow and Fort Union formations. The Fort Union formation has, in turn, been divided into the Tongue River member and

the overlying Sentinel Butte shale member. In North Dakota the uraniferous lignites are in the Sentinel Butte shale member; in South Dakota they are in the Ludlow formation.

Ludlow formation

The Ludlow formation of Winchester (1916), which contains the uraniferous lignites in South Dakota, was examined only in northwestern South Dakota, where it is 300 to 350 feet thick and consists of interbedded, light and dark clays, shales, sandstones, and commercial lignites. X-ray, petrographic, and mineralogic studies of specimens from these uraniferous lignite and adjacent clays, shales, sands, and sandstones at North and South Cave Hills, and Slim Buttes show that the rocks near the uraniferous lignites contain analcite ($Na\ Al\ Si_2O_6 \cdot H_2O$) (tables 1 and 5). The silty clays contain, in part, quartz (13 to 15 percent), feldspar (5 to 7 percent), and analcite (trace). The siltstones and sandstones contain, in part, quartz (22 to 50 percent), feldspar (3 to 4 percent), analcite (1 to 2 percent), an amorphous clay-like mineral, and hematite. The lignite contains, in addition to organic material, quartz silt, an amorphous clay-like mineral, gypsum, analcite, hematite, hauynite, and hoelite.

Fort Union formation

The Fort Union formation, 1,300 to 1,800 feet thick, is composed of fluviatile and lacustrine sandstones, sands, shales, clays, siltstones, claystones, marls, limestones, and lignites. Two members can usually be recognized in the field on the basis of gross color differences: (1) the

Table 1.--Mineral composition of Ludlow and Fort Union formations as determined by X-ray diffraction patterns 1/

			MINERALS							
Locality	Position in section	Lithology	Quartz (percent)	Analcite (percent)	Calcite (percent)	Feldspar (percent)	Dolomite (percent)	Illite (percent)	Not determined (percent)	Remarks
South Cave Hills, S. Dak.	Ludlow formation, 5-10 feet above "radioactive bed"	Clay, gray, silty	13-15	Trace	----	5-7	----	----	78-81	
Do.	Ludlow formation, 5-10 feet below "radioactive bed"	Siltstone, gray	22-27	1-2	----	3-4	----	----	67-74	
Do.	Ludlow formation, 20 feet above "radioactive bed"	Sandstone, red to buff	40-50	1-2	----	3-4	----	----	44-56	
North Cave Hills, S. Dak.	Massive sandstone capping hills. Winchester's basal Fort Union sandstone	Sandstone, buff	40-45 2/	30-40 2/	----	5-10 2/	----	1-5 2/	0-24	Pattern E on plate 4

1/ N. C. Schieltz, analyst, U. S. Bureau of Reclamation, Denver, Colo.

2/ Approximate percentage. (X-ray comparison of this sandstone with White River formation is shown on plate 4.)

lower, light-colored Tongue River member, and (2) the upper, dark-colored Sentinel Butte shale member. The HT lignite bed of Hares (1928), and bed F of the Sentinel Butte lignite group, and probably bed R, of Leonard and Smith (1909, pp. 30 and 105), at the base of the Sentinel Butte shale member are the same bed. This lignite bed forms one of the more persistent stratigraphic horizons of the Fort Union formation in southwestern North Dakota.

Tongue River member.--The Tongue River member, which is 700 to 1,000 feet thick, is the thickest stratigraphic unit examined in the area underlain by uraniferous lignites in southwestern North Dakota. The Tongue River member is composed largely of interfingering sandstones, sands, shales, clays, claystones, and lignites. The predominant color of the clays, claystones, and shales is grayish-yellow (f Y 8/4)_/. Pale

_/ Color symbols used in this report follow the usage of Goddard, E. N., Trask, P. V., DeFord, R. K., Rove, O. N., Singewald, J. T., Jr., Overbeck, R. M. (1948), Rock-color chart, National Research Council.

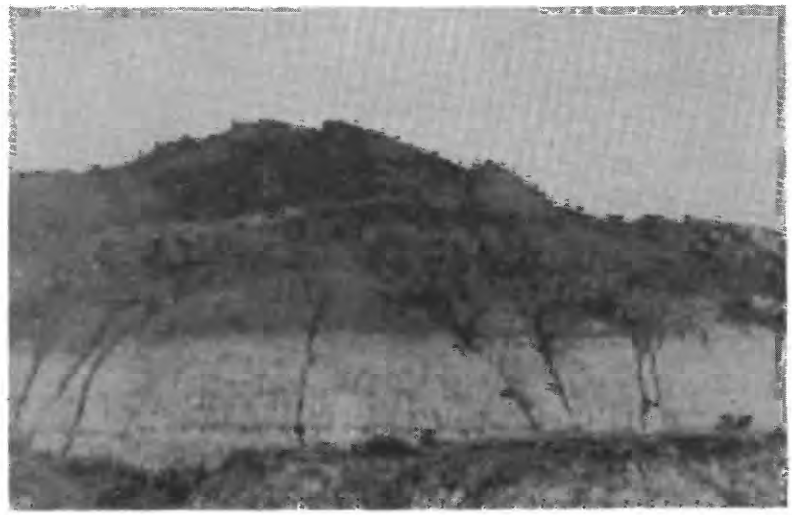
greenish yellow (10 Y 8/2) clay or shale is common, and bluish-white clay or shale (5 Y 9/1) is rare. Most of the sands and sandstones are yellowish-orange (10 Y 6/6), slightly cross bedded, and fine- to medium-grained. The yellow color is the result of disseminated iron oxide. In some places iron oxide forms dark, rust-brown, ferruginous nodules or concretions, commonly ranging from an inch to 3 feet in diameter. Many of the clay beds are thin and are associated with lignite. Most of the thick, commercial lignites in North Dakota, eastern Montana, and northern Wyoming are in the Tongue River member.

Sentinel Butte shale member.--The Sentinel Butte shale member, at Sentinel Butte (figs. 1 and 3), Golden Valley County, N. Dak., is composed largely of dark somber clays, shales, lignites, and sandstones interbedded with a few sands, siltstones, claystones, marls, and thin freshwater limestones. In southwestern North Dakota this member is between 300 and 500 feet thick and is conformable with both the underlying Tongue River member and the overlying rocks tentatively identified as Golden Valley formation (?).

The beds of the Sentinel Butte shale member are similar to those of the Tongue River member, and, for the most part, identification of individual lithologic units is questionable. One lithologic unit, however, called the "White Bed" in this report, can be recognized over a rather large area in southwestern North Dakota (pl. 1 and figs. 2 and 3). All the observed radioactive lignites in North Dakota are stratigraphically between this bed and the base of the White River formation of lower Oligocene age; therefore, the "White Bed" is an important marker for use in locating and correlating uraniferous lignites in this area (figs. 4, 5 and 6).

The "White Bed", a clay bed near the middle of the Sentinel Butte shale member, is the lowest bed in North Dakota in which analcite was found. At Bullion Butte the "White Bed" has a distinctive color, varying from a yellowish-gray (5 Y 7/2) at the base to a grayish yellow (5 Y 8/4) near the top. At Flat Top Buttes and at Sentinel Butte the same bed has a distinctive color, varying from a light greenish gray (5 GY 8/1) to a yellowish gray (5 Y 8/1). It is 10 to 15 feet thick and lighter in color than the overlying and underlying clays, shales,

"White bed" at Sentinel Butte



Close-up of "White bed" at Flat Top Butte

PLATE 1. TYPICAL EXPOSURES OF "WHITE BED" IN SOUTHWESTERN NORTH DAKOTA

sandstones, sands, claystones, and siltstones. This bed is overlain by a crumbly clay that swells and cracks on a weathered surface. At many localities there are thin carbonaceous clay layers near both the top and bottom of the "White Bed".

X-ray diffraction patterns indicate that the "White Bed" at Flat Top, Bullion, and Sentinel Buttes, N. Dak., is composed predominantly of micas, quartz, and some dolomite (table 2 and pl. 2). Minor quantities of sodium montmorillonite, illite, analcite, chlorite, and feldspar were identified. Analcite constitutes as much as 25 percent of some of the Paleocene and Eocene rocks above the "White Bed".

Eocene rocks

The Eocene rocks conformably overlie the Fort Union formation. These rocks are made up by the Golden Valley formation (?) in North Dakota, and the equivalent Wasatch formation in Wyoming.

Golden Valley formation (?)

The Golden Valley formation (?), which is 20 to 40 feet thick in southwestern North Dakota, is composed of sands, interbedded with slightly sandy clays, shales, a few sandy and calcareous siltstones, an carbonaceous or lignitic clays. In general this formation is more micaceous than the underlying Fort Union formation. The sands, shales, and clays in the Golden Valley formation (?) are readily recognized in Bullion, Flat Top, and Sentinel Buttes by their yellowish-orange color (10 YR 7/6), which contrasts sharply with the gray colors of the underlying Sentinel Butte shales and clays.

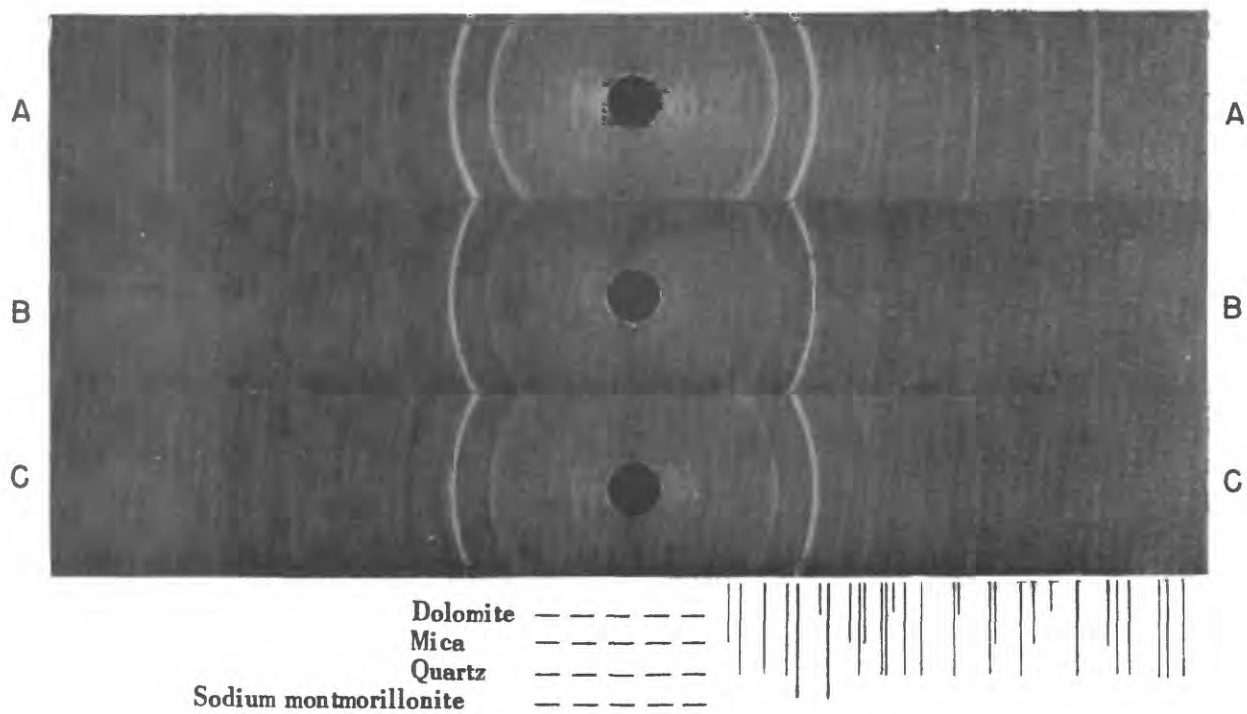
Table 2.--Mineral composition of Sentinel Butte Shale member in southwestern North Dakota, determined by X-ray diffraction patterns 1/

Locality	Position in section	Lithology	MINERALS: Quartz (percent)	Analcite (percent)	Mica (percent)	Sodium montmorillonite (percent)	Feldspar (percent)	Gypsum (percent)	Dolomite (percent)	Calcite (percent)	Chlorite (percent)	Undetermined (percent)	Remarks
			Specimens above base of "White Bed"										
H. B. -10 (specimen No. 1) (figs. 3 and 5) west end of Sentinel Butte	79.5 feet above base of "White Bed"	Sandstone buff, fine-grained, micaceous	15	25	40	3-5	3-4	1-2	----	----	----	9-13	
H. B. -10 (specimen No. 2) (figs. 3 and 5) west end of Sentinel Butte	120.5 feet above base of "White Bed"	Sand, buff, clayey	12-13	1	20	----	5	4-5	----	2	----	54-56	
H. B. -10 (specimen No. 3) (figs. 3 and 5) west end of Sentinel Butte	130 feet above base of "White Bed"	Clay, gray, marly	2-3	----	10	----	----	----	1-2	70-75	1	9-16	
H. B. -11 (specimen No. 4) (figs. 3 and 5) east end of Sentinel Butte	155 feet above base of "White Bed"	Clay, gray, sandy	14-15	15	35-40	5-10	5-6	----	Trace	----	2-3	11-24	
E. P. B. -22 (specimen No. 5) (figs. 2 and 4) west side of Bullion Butte	39 feet above base of "White Bed"	Mudstone, white, limy, hard	4	Trace	5	----	----	----	1-2	75-80	----	9-15	

1/ N. C. Schieltz, analyst, U. S. Bureau of Reclamation, Denver, Colo.

Table 2.--Mineral composition of Sentinel Butte Shale member in southwestern North Dakota, determined by X-ray diffraction patterns 1/--Continued

			MINERALS										
[illegible]	Position in section	Lithology	Quartz (percent)	Analcite (percent)	Mica (percent)	Sodium montmorillonite (percent)	Feldspar (percent)	Gypsum (percent)	Dolomite (percent)	Calcite (percent)	Chlorite (percent)	Undetermined (percent)	Remarks
			Specimens of "White Bed"										
.B.-11 (specimen No. 6) figs. 3 and 5) east end of entinel Butte	----	Clay, white	13-14	Trace	60	15-18	1-2	----	4-5	----	4-5	0-3	Pattern C on plate 2
.P.B.-18 (specimen No. 7) igs. 2 and 4) south end of ullion Butte	----	Clay, yellowish white to greenish, sandy	14-15	Trace	40	15-20	5	----	2	----	----	18-24	Pattern B on plate 2
.B.-16 (specimen No. 8) ig. 6) west end of lat Top Butte	----	Clay, white to light green	30	Trace	50	3-5	Trace	----	----	----	1-2	14-16	Pattern A on plate 2
			Specimens below base of "White Bed"										
.B.-11 (specimen No. 9) figs. 3 and 5) east end of entinel Butte	84 feet below base of "White Bed"	Clay, gray, marly	4-5	----	----	----	----	----	3-5	70-80	----	10-18	
.P.B.-18 (specimen No. 10) igs. 2 and 4) south end of ullion Butte	39 feet below base of "White Bed"	Claystone, yellow, calcareous, with sandy lenses	4-5	----	3-5	----	----	----	3-5	80	----	5-10	
[illegible]-5 (specimen No. 11) igs. 2 and 4) north end of ullion Butte	127 feet below base of "White Bed"	Claystone, yellow, sandy, calcareous	4	----	5	----	----	----	1-2	75-80	----	9-15	



A. "White bed," Flat Top Butte, North Dakota

B. "White bed," Bullion Butte, North Dakota

C. "White bed," Sentinel Butte, North Dakota

PLATE 2. X-RAY DIFFRACTION PATTERNS OF THE "WHITE BED"

Only the upper part of the Golden Valley formation (?) occurs in southwestern North Dakota. The lower part of the formation, which contains the index fossil fern Salvinia pre-auriculata Berry described by Benson and Laird (1947) was not identified. It was impossible for the writers to make any split in the Golden Valley (?) formation in southwestern North Dakota.

The shales and clays in the upper part of the Golden Valley formation (?) at Bullion Butte, N. Dak. contain varying proportions of quartz, mica, and sodium-bearing montmorillonite, and small quantities of analcite and carbonates--siderite (?) and calcite. The mineralogical composition, as determined by X-ray diffraction patterns, of some of the shale and clay beds of this formation at Bullion, Sentinel, and Flat Top Buttes, is shown in table 3 and plate 3.

The uppermost uraniferous lignite in North Dakota has been mapped by the writers as the top of the Sentinel Butte shale member, but, because of the difficulty in identifying the basal contact of the Golden Valley formation (?), it is possible that this or lower lignites are actually in the Golden Valley formation (?).

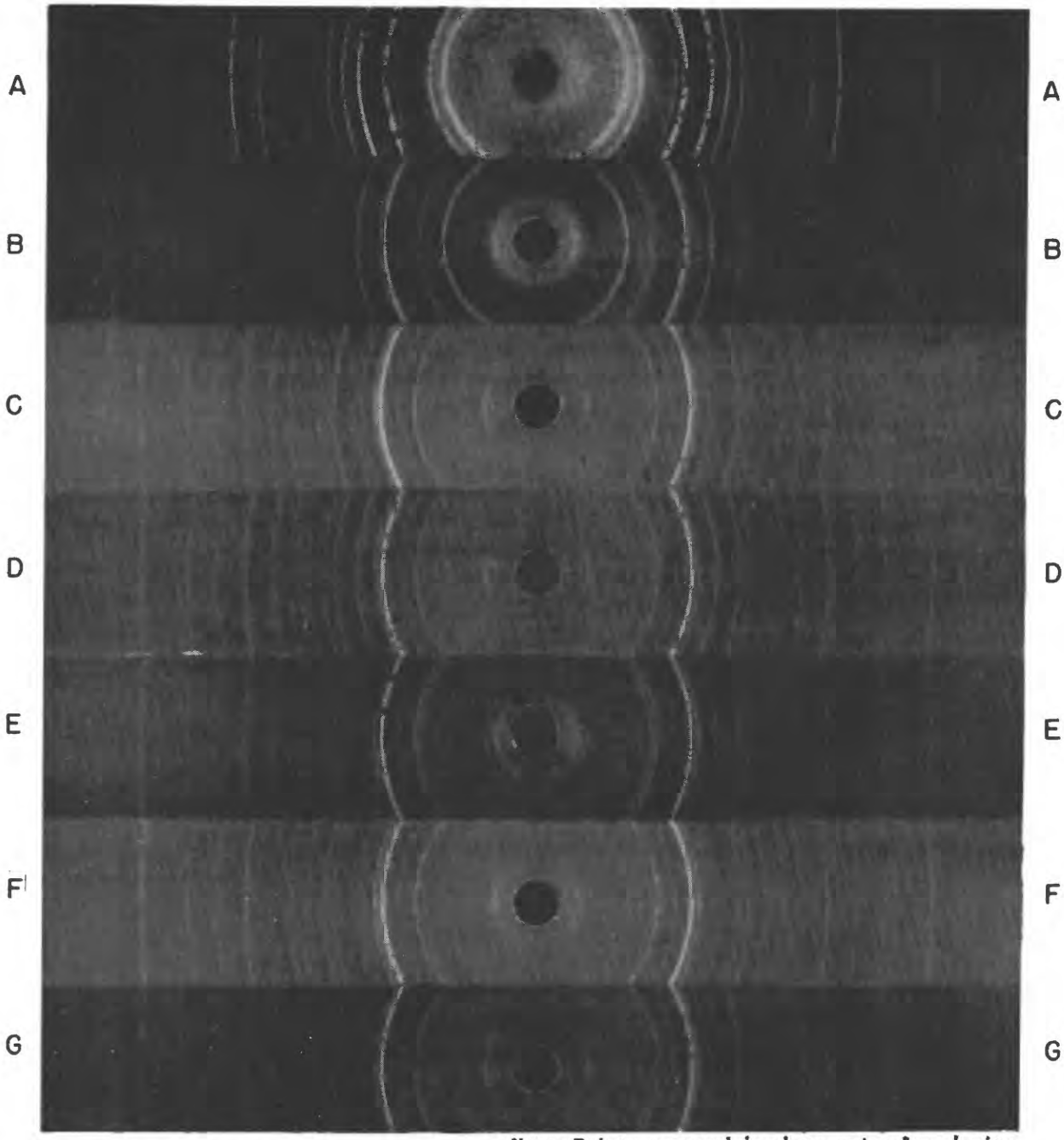
Wasatch formation

The Wasatch formation in the Sheridan coal field in north-central Wyoming (fig. 1) consists of an unknown thickness of varigated clays and shales and minor quantities of massive, hard sandstone. Beds of gravel, or conglomerate composed of rounded, silicious pebbles such as jasper, flint, and quartz are common.

Table 3.--Mineral composition of the Golden Valley formation (?) as determined by X-ray diffraction patterns 1/

Locality	Position in section	Lithology	MINERALS: Quartz (percent)	Analcite (percent)	Mica (percent)	Sodium montmorillonite (percent)	Feldspar (percent)	Dolomite (percent)	Chlorite (percent)	Gypsum (percent)	Undetermined (percent)	Remarks
E.P.B.-18 (specimen No. 1) (figs. 2 and 4) south end of Bullion Butte	122.5 to 172 feet above base of "White Bed"	Sand and clay, variegated	12-13	1	35-40	30-40	5-6	5-6	Trace	----	0-12	Pattern E on plate 3
E.P.B.-18 (specimen No. 2) (figs. 2 and 4) south end of Bullion Butte	do.	Sand, yellow, with clay lenses	19-20	3	30	15-20	10-12	----	----	Trace	18-24	Pattern F on plate 3
E.P.B.-18 (specimen No. 3) (figs. 2 and 4) south end of Bullion Butte	do.	Clay, yellow, silty	5	25-30	----	50	1-2	----	----	----	13-19	Pattern B on plate 3
H.B.-11 (specimen No. 4) (figs. 3 and 5) east end of Sentinel Butte	164 to 190 feet above base of "White Bed"	Sand, green	15-16	2	50-55	----	2-3	6-7	1-2	Trace	14-24	Pattern D on plate 3
H.B.-11 (specimen No. 5) (figs. 3 and 5) east end of Sentinel Butte	do.	Clay, green, silty	14-15	----	50-55	10	3-4	2	2-3	----	11-19	Pattern G on plate 3
H.B.-16 (specimen No. 6) (fig. 6) west end of Flat Top Buttes	201 to 228 feet above base of "White Bed"	Clay, light green to light-yellow, silty	12	Trace	50-55	15	3-4	2	2-3	----	9-16	Pattern C on plate 3

1/N. C. Schieltz, analyst, U. S. Bureau of Reclamation, Denver, Colo.



Note: Prints arranged in above order for clarity.

A. Analcite standard.
B. Bullion Butte, North Dakota, clay, yellow, silty, containing analcite, quartz, feldspar, and sodium montmorillonite.
C. Flat Top Butte, North Dakota, clay, light green to light yellow, silty, containing trace analcite, quartz, feldspar, sodium montmorillonite, mica, chlorite, and dolomite.
D. Sentinel Butte, North Dakota, sand, green containing analcite, quartz, feldspar, mica, chlorite, dolomite, and trace of gypsum.
E. Bullion Butte, North Dakota, sand and clay, variegated, containing analcite, quartz, feldspar, sodium montmorillonite, mica, trace of chlorite, and dolomite.
F. Bullion Butte, North Dakota, sand, yellow, with clay lenses, containing analcite, quartz, feldspar, sodium montmorillonite, mica, and trace of gypsum.
G. Sentinel Butte, North Dakota, clay, green, silty, containing quartz, feldspar, sodium montmorillonite, mica, chlorite, and dolomite.

PLATE 3. X-RAY DIFFRACTION PATTERNS OF ROCKS IN THE GOLDEN VALLEY FORMATION(?) SOUTHWESTERN NORTH DAKOTA

Oligocene rocks

Sandstones, conglomerates, siltstones, and clay of the White River formation are the only Oligocene rocks exposed in southwestern North Dakota and northwestern South Dakota.

White River formation

The White River formation, 75 feet to 125 feet thick, is composed predominantly of a medium- to coarse-grained (grain size 0.25 mm to 1.0 mm), cliff-forming, white to buff, massive, cross-bedded sandstone. In places the sandstone contains clay pellets and 2-inch pebbles. The upper 10 to 20 feet of the formation, as exposed in the area examined in North Dakota, is a siltstone and clay. In some localities on Bullion Butte, N. Dak., the lower 10 to 35 feet of this sandstone is slightly calcareous, and the weathered surfaces are very irregular. At other localities on Bullion Butte the lower part of the formation is a highly calcareous, micaceous, and friable sandstone.

The upper 2 to 4 feet of this massive sandstone is a grayish red (5 R 4/2) sandstone similar to those of the Bridger formation.

On Flat Top Butte, N. Dak. (fig. 1), the massive White River sandstone is colored green by an unidentified mineral with characteristics similar to glauconite. The index of refraction of this mineral is approximately 1.575. This mineral, however, contains little or no iron as determined from the X-ray studies, whereas glauconite contains appreciable iron. The green color that characterizes the White River sediments in the East Short Pine Hills and Slim Buttes, Harding County, S. Dak. (fig. 1) is due to the presence of the same mineral. The mineral

composition of the White River formation as determined by X-ray diffraction patterns is shown on table 4 and plate 4.

The siltstone and clay beds of the upper part of the White River formation in southwestern North Dakota are fine-grained, calcareous, and siliceous; they commonly form remnants at the top of the buttes. On Sentinel Butte these upper calcareous and siliceous clays and siltstones contain small green pellets, composed of calcite (40 to 50 percent), illite (10 to 12 percent), quartz (10 to 12 percent) and feldspar (3 to 4 percent). Surrounding the clay pellets is a white matrix composed either entirely of calcite, or of calcite and silica.

Fossil fish remains, similar to a modern crappie, were found in these upper calcareous siltstones and clays. Bones and teeth fragments of vertebrate fossils were found on Flat Top Butte, N. Dak.

Miocene rocks

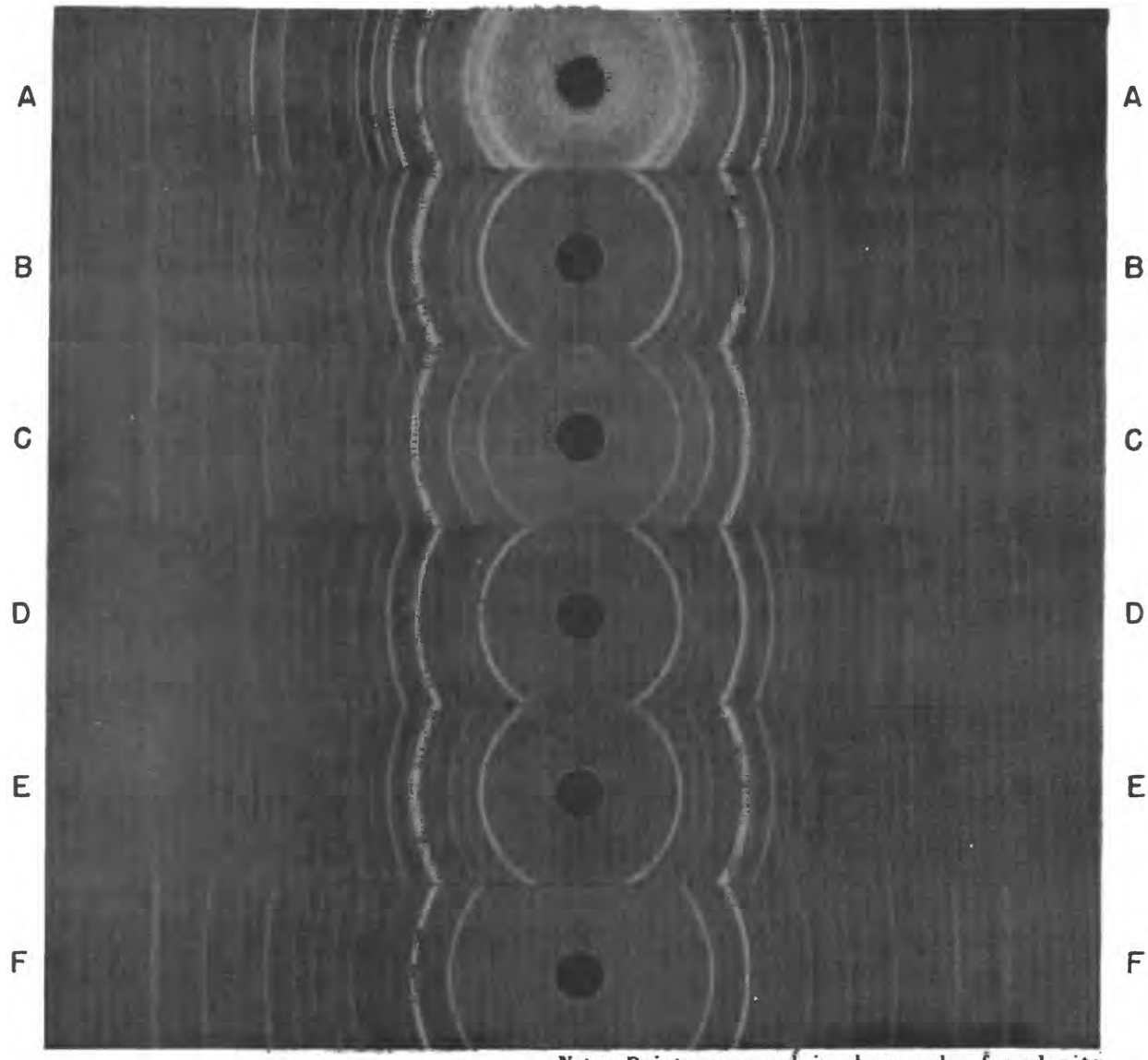
Arikaree (?) sandstone

The Miocene rocks in northwestern South Dakota consist of sediments that are similar to those of the Arikaree (?) sandstone in Wyoming. According to Winchester (1916, p. 34) they are 75 to 225 feet thick in Slim Buttes and in East and West Short Pine Hills (fig. 1), and are composed of sandy tuffaceous beds, some of which show peculiar concretionary forms on weathering. The base of the formation is a cliff-forming, greenish-gray, cross-bedded, massive, very fine-grained, calcareous sandstone; thin lenses of conglomerate occur near the base of the Arikaree (?). The sandstone contains angular to subangular grains of quartz, feldspar, augite, hornblende, epidote, biotite, calcite, and volcanic glass.

Table 4.--Mineral composition of White River formation as determined by X-ray diffraction patterns 1/

lity	Position in section	Lithology	MINERALS: Quartz (percent)	Analcite (percent)	Calcite (percent)	Feldspar (percent)	Dolomite (percent)	Illite (percent)	Not determined (percent)	Remarks
end of inel Butte, ak.	Clay above massive cross-bedded sandstone	Clay, white, calcareous, silty	10-11	----	40-50	3-4	----	25-35	0-12	Locality 9 (B.-11 (fig. 5)
.	Sandstone capping butte	Sandstone, white	10-15	60-70	----	----	----	10-15	0-20	Pattern B on plate 4
end of on Butte, ak.	Sandstone at base of White River formation	Sandstone, gray	20-30	50-55	----	10-12	----	2-3	0-18	Pattern C on plate 4
end of Butte, k.	Sandstone capping butte	Sandstone, white	25-35	20-25	----	13-14	----	10-15	11-32	Massive cross-bedded sandstone. Locality E.P.B.-18 (fig. 2)
o.	Sandstone 1 to 5 feet thick near top of butte	Sandstone, purple	12-13	60-70	----	----	----	----	17-29	Pattern D on plate 4
.	Clay at top of butte	Clay, white, silty	45-55	1-2 (?)	----	----	Trace	10-15	28-44	Pattern F on plate 4

. C. Schieltz, analyst, U. S. Bureau of Reclamation, Denver, Colo.



Note: Prints arranged in above order for clarity.

A. Analcite standard.
B. Sentinel Butte, North Dakota, sandstone, white, containing analcite, quartz, and illite.
C. Bullion Butte, North Dakota, sandstone, gray, containing analcite, quartz, feldspar, and illite.
D. Bullion Butte, North Dakota, sandstone, purple, containing analcite and quartz.
E. South Cave Hills, South Dakota, sandstone buff, containing analcite, quartz, feldspar, and illite.
F. Bullion Butte, North Dakota, clay, white, silty, containing analcite(?), quartz, illite, and trace of dolomite.

PLATE 4. COMPARISONS OF X-RAY DIFFRACTION PATTERNS OF ROCK IN THE WHITE RIVER FORMATION OF NORTH DAKOTA AND WINCHESTER'S BASAL FORT UNION SANDSTONE IN SOUTH DAKOTA.

Structure

The major structural feature in southwestern North Dakota and southeastern Montana is the northwest-trending Glendive anticline. In southwestern North Dakota the Tertiary rocks on the east flanks of this structure have a regional dip of approximately half a degree per mile to the northeast. At the Bullion Butte, however, the beds dip northeast as little as 15 feet per mile and at Blue Buttes in Montana, the rocks dip approximately 1 degree per mile to the northeast. In the vicinity of Terry, Mont., on the west flank of this structure, the beds dip gently to the west.

The structure of northwestern South Dakota is not well known, but most of the Tertiary beds that are exposed are nearly flat-lying. The apparent steep dips in the White River formation Winchester (1916, p. 80) and in the upper part of the Ludlow formation of Benson and Denson, are due to cross-bedding.

In the Sheridan coal field, Wyoming, according to Taff (1909, p. 132), the rocks are essentially horizontal in the eastern part of the field. In the Powder River valley the beds are nearly horizontal, but dips of 3 and 4 degrees have been measured in the western part of the area.

URANIFEROUS LIGNITES

Distribution

Uraniferous lignites are present in isolated areas in southwestern North Dakota, northwestern South Dakota, and in eastern Montana (fig. 1). In North Dakota and Montana the lignites are confined to the upper parts

of isolated buttes ranging in areal extent from 2.5 to 4 square miles, but in South Dakota they underlie much larger areas. Slim Buttes and North Cave Hills occupy 21 and 13.6 square miles respectively. There are from one to five uraniferous lignite beds in each area and in places these beds grade laterally into lignitic clays and sands. Ash and clinker beds resulting from the burning of the uraniferous lignites underlie small areas on all the buttes. On the southwest end of Bullion Butte, N. Dak. (fig. 2) and the northeast end of North Cave Hills, S. Dak. (fig. 7), the uraniferous lignite beds have burned out over a considerable area.

Thickness

The lignites in the upper part of the Ludlow formation and in the upper part of the Sentinel Butte shale member of the Fort Union formation are more uraniferous than others in the region examined. The uraniferous lignites range in thickness from less than an inch to 26 feet; the thickest lignite is the Bullion Butte at Bullion Butte, N. Dak., of the Sentinel Butte shale member, Fort Union formation, which is as much as 26 feet thick and has an average thickness of about 15 feet. The maximum measured thickness of all other uraniferous lignite beds is 7 feet. Only a third of the lignite beds that were examined are more than 3 feet thick.

Petrography

The uraniferous lignites are slacked at the outcrop to a black or gray powdery mass. About 3 feet below the surface they are black,

dense, and only partly broken into chips or small blocks. In places gypsum, sulphur, and jarosite (?) are abundant at surface outcrops of the lignite beds. Petrographic descriptions of 10 samples of lignite, natural ash, and lignitic clay are given in table 5.

The lignite contains, in addition to carbonized wood material, varying proportions of clay, quartz, gypsum, and analcite. The lignitic clay contains oligoclase and iron oxide. The natural ash from the burned lignite beds is a gray-white soft porous material composed dominantly of a silicic glass that is almost entirely devritified to a montmorillonite-type clay, fine-grained calcium carbonate, and gypsum. In places iron-oxide is relatively abundant.

N. C. Schieltz of the U. S. Bureau of Reclamation has identified hauynite (3 Na, Al SiO_4, $CaSO_4$) by an X-ray diffraction pattern made of an ash sample from South Cave Hills, S. Dak. Analcite has also been identified by X-ray pattern studies of lignites and lignitic clays from North Dakota and South Dakota.

A spectrographic analysis made by the U. S. Bureau of Reclamation of a blue material in a natural ash sample from South Cave Hills, S. Dak., indicates that the major constituents are magnesium and calcium. Other constituents reported are silicon and aluminum (1 to 10 percent), strontrium, iron, zinc, titanium, and manganese (0.1 to 1 percent); boron (0.01 to 1 percent); lead vanadium, chromium, yttrium, and uranium less than 0.01 percent.

Becquerelite (?) ($2UO_3.3\ H_2O$), was tentatively identified by Joseph Berman (Wyant and Beroni, 1950, p. 39) of the Geological Survey Trace Elements Section Denver Laboratory. An autoradiograph of a specimen of

Table 5.--Mineralogic and petrographic descriptions of samples from North Dakota, South Dakota, and Wyoming

Sample Number	Location	Material	Mineralogic and petrographic descriptions 1/
19199	Fryburg, N. Dak.	Lignitic clay	The sample is an unconsolidated sediment containing minor amounts of lignitic material. It is composed predominantly of finely crystalline calcium carbonate, analcite trapezohedra, subangular to subrounded oligoclase feldspar, clay, and iron oxide. Part of the analcite is weakly birefringent and fibrous, and some of it is altered to a clay-like material.
19200	Fryburg, N. Dak.	Lignite	The sample is composed wholly of lignite with no visible mineral material.
19201	Fryburg, N. Dak.	Lignite	The sample is composed of lignitic material with minor amounts of clay and fine quartz silt.
19202	Gillette, Wyo.	Lignite	The sample is similar to No. 19201, but contains a greater proportion of clay.
19203	South Cave Hills, S. Dak.	Natural ash	The sample is composed predominantly of a soft, porous silicic glass almost wholly devitrified to a montmorillonite-type clay. Some fine-grained calcium carbonate and gypsum, as well as minor amounts of iron oxide, are present.
19204	South Cave Hills, S. Dak.	Lignite	The sample is composed of lignite with rare, minute particles of quartz silt.
19205	South Cave Hills, S. Dak.	Lignite	The sample is composed of lignite with minor amounts of gypsum and rare quartz silt.
19206	South Cave Hills, S. Dak.	Natural ash	The sample is a grey-white, soft, and porous material that has the appearance of being an ignited lignite. It is now composed predominantly of calcium carbonate substantial amounts of clay-like material intermixed with the carbonate, a blue colored refractory mineral of unknown composition (contains some manganese), and minor amounts of iron oxide.
19207	North Cave Hills, S. Dak.	Lignite	The sample is composed of lignite with a creamy white "amorphous" clay filling cracks and interstices.
19208	Slim Butte, S. Dak.	Lignite	The sample is a sediment composed of analcite trapezohedra, soft microcrystalline material with optic properties similar to the mineral hoelite, lignite, lignite showing apparent partial ignition and some material similar to lignite ash.
			Some of the analcite shows alteration to a colorless glass, and some to a clay-like mineral.

1/By J. Berman of the Geological Survey Trace Elements Section Washington Laboratory.

the uranium-bearing lignite showed the presence of a few, minute, disseminated strongly radioactive particles; the bulk of the specimen was weakly but uniformly radioactive.

Radiometric examinations

Radiometric examinations were made with a portable El-Tronics survey meter. The normal background rate meter reading was between 1-1/2 and 3 on the 0.2 scale. The background was determined in each individual area, usually at the base of the butte in clays or shales of the lower Sentinel Butte shale member. The radioactivity of the uraniferous lignites ranges from 1-1/2 to 6 times the normal background reading, whereas that of the natural ash ranges from 6 to 11 times the normal background reading. At a few localities the lignite beds were not sufficiently radioactive to allow accurate measurement with a rate meter. The radioactivity of these beds, therefore, was measured at exposures of natural ash where the radioactive constituents had been concentrated by burning.

Sampling

Channel samples were cut from all abnormally radioactive lignite, natural ash, and clinker beds, and also from the sand and clay beds adjacent to the radioactive lignites. Special precautions were taken against collecting samples from slump blocks and slide areas. Surface debris that had infiltrated the lignite bed was included in some samples.

At many localities, particularly on Bullion Butte, 1 to 4 feet of residual mantle and 1 to 3 feet of slacked lignite was removed to expose

relatively unweathered lignite beds. At Bullion Butte, 3- to 6-pound channel samples, 1 to 2 feet long and 1 foot wide, were taken across the exposed bed to determine whether the uranium was uniformly distributed throughout the lignite. Clay partings, from a knife edge to 3 inches in thickness, were included and account for most of the high ash content (25 to 60 percent) in many of the samples. At Sentinel Butte and other areas, all slacked lignite was removed before channel samples were taken.

Duplicate 500-pound samples of the uppermost uraniferous lignite bed at Sentinel Butte were collected for metallurgical studies by Battelle Memorial Institute and by Massachusetts Institute of Technology. Eight additional samples, collected from Bullion and Sentinel Buttes and from the Fryburg area, N. Dak., were sent to Battelle Memorial Institute for metallurgical studies.

Nine water samples were collected from springs issuing from the two uraniferous lignite beds, and two water samples from springs in the Golden Valley formation (?), and one water sample from a pond in the Sentinel Butte shale member below the "White Bed" at Bullion Butte, N. Dak. In addition, one water sample was taken from the Little Missouri River in the vicinity of this butte.

Chemical and spectrographic analyses made by Battelle Memorial Institute of a 50 pound composite sample of comparatively fresh lignite from Bed no. 5 on Sentinel Butte, are given in table 6. The chemical analysis of this sample showed 0.013 (dry basis) and 0.051 (ash basis) percent uranium. The ash content ranged from 18.7 to 25.8 percent and contained in excess of 30 percent gypsum.

Table 6.--Chemical and spectrographic analyses of a 50 pound lignite sample from Sentinel Butte, North Dakota 1/

	Chemical analysis		Spectrographic analysis	
	Dry basis	Ash basis	Ash basis	
Component	(percent)	(percent)	Component	Percent
Uranium	0.013	0.051	----	----
Fe_2O_3	4.2	16.6	Fe_2O_3	10-30
Al_2O_3	1.9	7.5	Al_2O_3	1-5
CaO	6.3	24.9	CaO	30-60
MgO	0.86	3.4	MgO	3-10
Na_2O	1.49	5.9	Na_2O	1-5
K_2O	0.08	0.3	K_2O	0.1-1.0
SiO_2	3.11	12.3	SiO_2	10-30
SO_4 sulphur	2.11	8.3	MoO_3	0.5-2
Total sulphur	2.52	----	TiO_2	0.1-1
P_2O_5	0.06	----	MnO_2	0.05-0.5
Total carbon	49.8	----	Others less than 0.1	
Volatile matter	49.3	----	Cu, Cr, V, Zr, B,	
Ash	25.3	----	Yt, Yb	

1/ Analyses made by Battelle Memorial Institute

That uranium in some lignite samples is not in equilibrium with its decay products is shown by differences between the "equivalent uranium" and the uranium in some of the tables. The percent equivalent uranium is higher than the uranium content of many samples. Because of this discrepancy, the K_2O content was determined in 22 lignite samples. It ranged from nil to as much as 0.77 percent. The radiation resulting from the decay of potassium in these samples, therefore, would be less than 0.0004 percent equivalent uranium, and the high equivalent uranium content of the samples is clearly not caused by potassium. The excess radioactivity may be caused by the presence of thorium, but the writers believe that it is probably caused by differential leaching of uranium from its daughter products in the weathered outcrop.

Grade

The average grade of all uraniferous lignite beds examined in southwestern North Dakota, northwestern South Dakota, eastern Montana, and northern Wyoming, ranges between 0.001 and 0.033 percent uranium. The no. 3 lignite bed at Flat Top Butte, N. Dak. (fig. 6) contained 0.033 percent (based on one sample), the highest content noted. All five lignite beds in Sentinel Butte, N. Dak. (fig. 5) show less lateral variation in grade than do the other lignites examined. The range in uranium content within each of the five lignite beds in Sentinel Butte is, on the average, from 0.005 to 0.16 percent uranium.

All other uraniferous lignite beds examined ranged between 0.001 and 0.01 percent uranium. In the Bullion Butte lignite bed at Bullion Butte, the variation in uranium content, both laterally and vertically,

is slight; but in the "Hot Bed" the variation is marked (table 10). The wide variations in uranium content appear to be directly connected with the proportion of hard vitreous lignite in the sample; the higher grade samples contain a higher proportion of this material. Woody fragments, "bony" coal, and clay seams contain less uranium than does the lignite.

Origin of the uranium

Two hypotheses were presented by Wyant and Beroni (1950, p. 40) to explain the association of uranium and coal in North Dakota: (1) the 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, and (2) the uranium was deposited from surface waters by the action of living organisms or dead organic matter during the accumulation of the carbonaceous debris that later was converted to lignite.

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. If the uranium was deposited after the carbonization of the lignite material, it is probable that its distribution in any one bed would be more erratic than indicated by the analyses, and that the radioactive lignites probably would not be confined to a limited stratigraphic zone. Consequently the writers favor the second hypothesis, namely, a syngenetic origin of the uranium. The original source of the uranium in the lignites is believed to be volcanic ash that was altered in saline

playa lakes to analcite and sodium montmorillonite rocks. Uranium contained in the ash went into solution and was transported laterally and vertically in a highly reducing environment resulting from accumulation of decaying organic debris. Here the uranium was fixed by physical or chemical processes before carbonization of the organic matter.

An autoradiograph of lignite from Sentinel Butte, exposed for approximately 3 weeks, shows small discrete particles of very radioactive material disseminated in the lignite. The bulk of the specimen is weakly radioactive. The autoradiograph showed an even clouding effect for the bulk of the specimen, suggesting homogenous distribution of the uranium. This in turn would suggest introduction of uranium before coalfication.

An autoradiograph made of a fresh water limestone interbedded with the uraniferous lignite from Sentinel Butte, exposed for 8 1/2 days, shows small discrete particles of very radioactive hydrocarbons in the limestone.

Ross (1928, pp. 195-197) has suggested that the analcite in such sediments results from "volcanic ash showers" that frequently deposited beds of glassy ash in playa lakes. He states (1928, p. 197) "Material of this kind commonly alters to bentonite but in the presence of concentrated sodium salts it might form analcite". In discussing the origin of zeolite beds in the Green River formation, Bradley (1928, pp. 73-74) says "Field and microscopic study of these two types of zeolite-bearing rocks indicates that both minerals (analcite and apophyllite) formed in place on the lake bottom (or when only shallowly buried in ooze) as a result of interaction between various salts dissolved in the lake water and the dissolution products of volcanic ash that fell

into the ancient Green River lakes." The writers believe that the foregoing statements adequately explain the origin of analcite in the sedimentary rocks associated with the uraniferous lignites in North and South Dakota. Glass shards have been tentatively identified in thin sections of siltstones interbedded with the uraniferous lignites. Thin section studies also show that some of the analcite is authigenic.

The breakdown of volcanic material in saline solutions to form analcite would release uranium, and by analogy with metallurgical practices the uranium might be carried in these waters until it reached an environment favorable for precipitation. The accumulation of decaying organic material would provide such an environment. This environment would be at or near the lake bottom, therefore, the fixation of uranium would be before carbonization of the organic debris.

The available data strongly suggest that these environments existed during Ludlow and Sentinel Butte times.

The presence of analcite in beds of White River age suggests a similar environment. Therefore, uranium derived from volcanic ash in White River times could have been precipitated by organic material such as bone and plant fragments.

After deep burial and carbonization of the lignites, the uraniferous lignite beds were leached by surface waters, as indicated by the uranium content of springs issuing from these lignites (table 10). Also many samples collected are out of equilibrium and contain an excess of radioactivity as compared to the uranium content. The variation in uranium content both laterally and vertically can be readily explained by uneven

distribution of decaying organic remains in the peat bogs. However, in general the uranium content of individual beds appears to be remarkably uniform over wide lateral extent on the surface.

The above hypothesis of origin is based on limited data and its substantiation would require additional field and laboratory work, particularly as to distribution of uranium in lignites, and as to which constituents of decaying vegetation would fix the uranium.

Denson, Bachman, and Zeller (1950) believe the source of the uranium to be volcanic ash in the overlying White River formation of Oligocene age, and have described three conditions necessary for the presence of uraniferous lignite: (1) Uraniferous lignites are, say Denson et al., in several formations, but always are the first lignites beneath the pre-Oligocene unconformity; (2) there is a concentration of uranium near some fractures; and (3) there is less uranium in lignite beneath impervious cap rock.

The writers wish to make the following comments on the foregoing statements by Denson et al.: (1) Lignites examined by the writers were found in the Sentinel Butte shale member of the Fort Union formation in southwestern North Dakota, and in the Ludlow formation in northwestern South Dakota. However, lignites of Fort Union age found underlying the pre-Oligocene unconformity in the Killdeer Mountains are not radioactive. The writers believe that this lignite is not uraniferous because the Sentinel Butte shale member of the Fort Union formation is locally absent. Therefore, the lignites were deposited in Tongue River time, i.e., prior to the time that volcanic ash fell in saline playa lakes allowing for concentration of secondary analcite, and release of uranium;

(2) Concentration of uranium or other minerals along fractures is common. Surface waters tend to concentrate uranium along porous or weak zones within the rocks. This is especially significant if there is a concentration of iron-stains. Therefore, uranium being leached by surface water from lignite beds laterally or vertically will concentrate along fractures or porous zones.

If the uranium comes out of the White River sandstone or any overlying sandstone, the highest concentration of uranium would be expected in the upper lignite beds. At Sentinel Butte, N. Dak., the lowest exposed bed has a grade of 0.013 percent, and the upper bed has a grade of 0.012 percent uranium. At Flat Top Butte, the upper bed has a grade of 0.003 percent, and the next lower bed has a grade of 0.033 percent uranium. At Bullion Butte the uppermost "Hot Bed" has a grade of 0.003 percent , and the underlying Bullion Butte bed has a grade of 0.002 percent uranium. Within the "Hot Bed" at some localities the highest grade samples came from the upper part of the bed, in others the middle portion, and still others at the base of the bed (table 10).

The analyses of uranium in spring waters from Bullion Butte (table 10) show that the uranium is being leached from uraniferous lignites, and not from underlying and overlying volcanic-rich sediments by present surface waters. If uranium is not now being leached from the overlying and underlying volcanic-rich sediments by the surface waters, it seems unlikely that it was in the past. Therefore, an entirely different hypothesis must be postulated to derive the uranium from volcanic ash.

If the uranium was leached from the overlying White River formation, the sandstone, (comprising over 50 percent of the rock in this formation)

should be a favorable host for deposition of secondary uranium minerals by analogy with deposits in the Colorado Plateau and at Pumpkin Butte, Wyo., especially around organic remains that occur in this formation. Also, the unconformable surface separating the Eocene and Oligocene sediments would be a favorable place for precipitation of secondary uranium minerals.

Samples collected by Wyant and Beroni (1950, p. 27) show the White River sandstone to contain between 0.001 and 0.003 percent equivalent uranium, which is comparable to many other sedimentary rocks examined by the writers in North and South Dakota except for the uraniferous lignites. Only a few slightly radioactive bones have been reported by W. E. Benson (personal communication) in the White River formation; this would be expected because of the affinity of uranium for phosphate. Thus, there appears to be little evidence of radioactive materials in the White River formation which could make it a source bed for the radioactive materials in the lignites.

Localities examined in North Dakota

Sentinel Butte

Sentinel Butte (fig. 1), in T. 139 N., R. 104 W., Golden Valley County, N. Dak., is 4 miles south of the town of Sentinel Butte and the Northern Pacific railroad. The top of the butte can be reached by a state-maintained road.

The base of the uraniferous lignite zone on Sentinel Butte is marked by the "White Bed" in the upper Sentinel Butte shale member

and the top by the no. 5 lignite bed, which is considered in this report to be immediately below the Eocene Golden Valley (?) formation.

Five uraniferous lignite beds (fig. 3), ranging in thickness from 0.2 foot to 6 feet, are present in the upper part of the Sentinel Butte shale member of the Fort Union formation. The no. 5 bed at the top of this sequence is the thickest and, in the sections measured, averages 4.8 feet. Bed nos. 3 and 4 have the next greatest thickness and are on the average 2.2 and 2.5 feet thick respectively. The stratigraphic interval between the uraniferous lignite beds is from 10 to 65 feet (fig. 5). All five lignite beds are lenticular, commonly thinning or thickening by as much as 2 feet within a horizontal distance of 100 feet. The exact shape and size of the lenses are obscure, because there are no good exposures of the beds in the center of the butte. Exposures on the east and west end of the butte indicate that one bed is a partly eroded lens with linear dimensions of about 400 to 5,000 feet. It averages between 5 and 6 feet in thickness near the center and thins both eastward and westward.

On opposite ends of the butte, at localities H.B.-10 and H.B.-11 (fig. 3), facies changes are readily apparent, especially in beds nos. 4 and 5. At these localities there is a complete gradation from lignite to carbonaceous clay and sands within 100 feet. This gradation in lithology was noted only on the extreme edges of the butte, and it is believed that lignites and lignitic material are more prevalent towards the center of the butte.

The uranium content of the five uraniferous lignite beds ranges from 0.004 percent to 0.016 percent and the radioactivity ranges from 3 to 6 times normal background on the lignite beds and 6 to 11 times

normal background on the ash beds. Twenty samples (table 7) of lignite, natural ash, and carbonaceous clay were taken at Sentinel Butte. Two samples of lignite from bed no. 1 contained 0.005 and 0.016 percent uranium, and ash from their combustion contains 0.009 and 0.069 percent, respectively. The lignite in bed no. 2 contains 0.010 and 0.009 percent uranium, and its ash contains 0.033 and 0.013 percent, respectively; natural ash and clinker contained 0.003 percent. The lignite in bed no. 3 assayed 0.004 to 0.005 percent uranium; the ash ranged from 0.012 to 0.11 percent. The uranium content in bed no. 4 is similar to that in bed no. 3 but the ash ranged from 0.009 to 0.016 percent uranium. Two samples of carbonaceous clay in bed no. 4 contained 0.001 and 0.005 percent uranium. One sample of lignite from bed no. 5 contained 0.010 percent uranium; 0.02 percent in the ash. Natural ash from this bed assayed 0.005 percent uranium and carbonaceous clay contained 0.001 to 0.002 percent. Four samples from lignite beds below the "White Bed" contained 0.001, 0.002, and 0.002 and 0.000 percent uranium.

Flat Top Butte

Flat Top Butte, in T. 139 N., R. 103 W., Golden Valley county, N. Dak. (fig. 1), is 8 miles southeast of the town of Sentinel Butte and 4 miles from U. S. highway 10 and Northern Pacific railroad. A rough, non-maintained road goes to within 150 feet of the top of the butte.

Only one locality, H.B.-16, was examined on Flat Top Butte, and this was on the west end where four uraniferous lignite beds are exposed above the "White Bed" in the Sentinel Butte shale member (fig. 6). These lignite

Table 7.--Analyses of samples from Sentinel Butte, North Dakota

Locality and sample number	Bed number	Thickness of bed and length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O at 105° C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	K_2O (percent)	Remarks
S.B.-10(S:15)	1	0.5	Lignite	0.006	0.005	51.4	7.9	0.009	0.010	0.00	Lignite; contains soil
S.B.-11(S:29)	1	1.0	do.	.021	.016	27.7	13.0	.069	.058	.26	1.0 foot sandy carbonaceous clay below lignite bed
S.B.-10(S:16)	2	0.4	do.	.010	.010	37.2	9.7	.033	.027	.00	Lignite
S.B.-10(S:19)	2	3.0	Natural ash and clinker	.009	.003	81.5	11.2	.006	.004	.12	1.5 foot natural ash; clinker above and below ash bed
S.B.-11(S:30)	2	2.0	Lignite	.019	.009	62.6	9.8	.013	.014	.17	Lignite, good
S.B.-10(S:17)	3	3.0	do.	.006	.004	32.6	8.9	.012	.012	.07	Do.
S.B.-10(S:18)	3	3.0	do.	.008	.004	27.5	9.9	.11	.015	.19	Do.
S.B.-11(S:31)	3	1.4	do.	.008	.005	20.1	10.9	.27	.025	.17	Lignite, good, contains iron sulphates
S.B.-10(S:20)	4	0.6	Carbonaceous clay	.001	.001	40.0	9.6		.003		0.2 foot of lignite seam near center of carbonaceous clay
S.B.-10(S:21)	4	1.5	Lignite	.008	.005	39.3	9.6	.014	.013	.00	Lignite, good
S.B.-10(S:22)	4	1.5	do.	.008	.004	31.4	12.2	.016	.013	.00	Do.
S.B.-11(S:32)	4	4.5	Carbonaceous clay	.007	.005	66.6	5.1	.009	.008	.77	Carbonaceous clay; contained no lignite seams
S.B.-10(S:23)	5	2.0	do.	.003	.001	79.6	2.7	.002	.001	.70	Carbonaceous clay, very sandy

Table 7.--Analyses of samples from Sentinel Butte, North Dakota--Continued

Locality and sample number	Bed number	Thickness of bed and length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O at 105° C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	K_2O (percent)	Remarks
H.B.-10(S:24)	5	0.6	Natural ash	0.010	0.005	82.6	14.3	0.007	0.006	0.12	Clay below ash bed slightly radioactive on surface
H.B.-10(S:27)	5	5.0	Lignite	.011	.010	38.1	11.9	.020	.026	.00	Lignite, very good, and hard
H.B.-11(S:33)	5	4.0	Carbonaceous clay	.003	.002	86.8	2.4		.002		Upper 0.5 foot becomes lignitic
H.B.-10(S:14)	-	2.0	Lignite	.001	.001	38.1	9.6		.003		Lignite bed 10 feet below "White Bed"
H.B.-10(S:25)	-	1.0	do.	.002	.002	57.9	6.3		.003		Lignite bed 2 feet below "White Bed"
H.B.-11(S:28)	-	4.0	do.	.002	.002	31.6	10.9	.002	.009		Lignite bed 62 feet below "White Bed"
H.B.-16A(S:49)	-	20.0	do.	.001	.000	13.6	7.0	.001	.001	.00	Lignite from mine on east end of butte.

beds range from less than an inch to 0.5 foot thick and contain between 0.002 and 0.059 percent uranium in the lignite, and 0.007 to 0.22 percent uranium in the ash (table 8). Sample DW-91-281 collected by Wyant (Wyant and Beroni, 1950, p. 35) of bed no. 3 contained 0.059 percent uranium in the lignite and 0.22 percent uranium in the ash.

Fryburg area

The Fryburg area is in Billings County, N. Dak. (fig. 1), near the southeast corner of Theodore Roosevelt National Park in the vicinity of the towns of Fryburg and Sully Springs. The area is easily accessible from U. S. Highway 10.

Tentative identification of the "White Bed" in vicinity of Sully Springs suggests that the Sentinel Butte shale member of the Fort Union formation is present.

Probably two lignite beds with a maximum thickness of 3 feet are exposed in this area. Slightly abnormal radioactivity was detected in the upper bed, but chemical analyses have indicated that the uranium is not in equilibrium with its decay products. A sample collected from the upper lignite bed at locality H.B.-5 (S:8) contained 0.006 percent equivalent uranium and 0.002 percent uranium in the lignite and 0.003 percent uranium in the ash by chemical analyses (table 9). A sample taken of natural ash, 1 mile south of Fryburg, N. Dak., contained 0.004 percent equivalent uranium and 0.000 percent uranium. A sample collected from the lower lignite bed at the Hezer Mine, H.B.-15 (S:41) contained 0.001 percent uranium in the lignite and 0.002 percent uranium in the ash. All other lignite samples collected from this area contained between 0.000 and 0.002 percent uranium in the ash.

Table 8.--Analyses of samples from Flat Top Butte, North Dakota

Locality and sample number	Bed number	Thickness of bed and length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O at 105° C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	K_2O (percent)	Remarks
H.B.-16(S:42)	1	0.5	Lignite and clay	0.003	0.003	39.1	9.1		0.008		Lignite, badly weathered
H.B.-16(S:43)	2	0.5	do.	.004	.003	32.0	11.8		.009		Do.
H.B.-16(S:44)	3	0.5	Carbonaceous clay	.003	.002	20.8	10.8	0.008	.009	0.00	Do.
H.B.-16(S:45)	4	0.5	do.	.002	.002	29.1	12.1		.007		Do.
H.B.-16(S:46)	-	2.0	do.	.001	.001	72.1	5.6		.001		Bed 10 feet below "White Bed"

Table 9.--Analyses of samples from Fryburg area, North Dakota

Locality and sample number	Thickness of bed and length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O at 105° C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
H.B.-4(S:7)	1.0	Natural ash	0.004	0.000	82.1	2.0		0.000	One mile south of Fryburg, N. Dak.
H.B.-5(S:8)	0.5	Lignite	.006	.002	80.6	2.5	0.003	.002	Twenty miles southwest of Fryburg, N. Dak.
H.B.-6(S:9)	1.0	Natural ash	.001	.001	76.6	6.8		.001	Sample taken near airplane beacon
H.B.-7(S:10)	1.0	do.	.001	.001	79.5	2.9		.001	Ten miles southwest of Fryburg, N. Dak.
H.B.-7(S:11)	1.0	Lignite	.000	.000	25.4	10.4		.000	Do.
H.B.-8(S:12)	1.0	Natural ash	.002	.001	96.8	0.5		.001	One mile east of Fryburg, N. Dak.
H.B.-9(S:13)	1.5	Lignite	.001	.000	33.6	9.8		.000	U. S. highway 10, 0.2 mile west of Billings County line
H.B.-14(S:38)	2.0	do.	.001	.000	36.2	9.0		.000	Four and three tenths miles north of highway 10, and Fryburg junction
H.B.-14(S:39)	3.0	do.	.000	.000	18.3	11.8	.001	.000	Road cut on U. S. highway 10; 0.5 mile west of Fryburg junction
H.B.-15(S:41)	5.0	do.	.000	.001	21.1	9.0	.002	.001	Eight miles south of Fryburg, N. Dak.

Bullion Butte

Bullion Butte is in T. 137 N., R. 102 W., Billings and Golden Valley Counties, N. Dak. (fig. 1). It is approximately 15 airline miles southeast of the town of Sentinel Butte, but 35 miles by road. The area is generally accessible in the summer by automobile, but the top of butte can be reached only by a vehicle with four wheel drive and a short wheel base.

Two uraniferous lignite beds, the "Hot Bed" described by Wyant (Wyant and Beroni, 1950) and the Bullion Butte bed, in the upper part of the Sentinel Butte shale member, are exposed on this butte. These two uraniferous lignite beds are more uniform in thickness than the other uranium-bearing lignites examined by the writers.

The older, or Bullion Butte, bed ranges from 12 to 26 feet in thickness and averages about 15 feet.

The younger lignite, or "Hot Bed", ranges in thickness from 4 to 8 feet; the average is 5.5 feet. The thickest part of the bed is in the center of the butte, ranging between 6 and 8 feet throughout approximately 4,000 feet of outcrop.

The radioactivity of the Bullion Butte bed ranges from 1-1/2 to 2-1/2 times the normal background reading. The natural ash of burned lignite from this bed gave readings between 2 and 4 times background. Natural ash horizons in this bed range between 6 and 10 times the normal background reading.

Seven carbonaceous clay samples taken from above and below the uraniferous lignite beds exposed on Bullion Butte were used to determine if uranium was concentrated in carbonaceous clay adjacent to

lignite. Analyses of these samples show that overlying and underlying carbonaceous clays contained between nil and 0.007 percent uranium, approximately equal to the range of uranium content in lignite. Seven natural ash and clinker samples were taken to determine the uranium content and also the state of equilibrium of uranium. One sample of natural ash contained 0.003 percent equivalent uranium and 0.002 percent uranium. The others ranged between 0.013 and 0.025 percent equivalent uranium and 0.010 and 0.013 percent uranium. The one sample of clinker from the "Hot Bed" contained 0.001 percent.

A total of 36 samples (table 10) were taken at the outcrop of the Bullion Butte bed; 24 were of lignite, 6 were of carbonaceous clay or lignite and clay, 1 was of natural ash, and 6 were of spring waters from the lignite bed. These samples come from 10 localities. At two localities, 14 sections of lignite were sampled at intervals of 1 to 2 feet (table 10) to show the vertical distribution of uranium within the bed.

The uranium content of samples taken from the Bullion Butte lignite bed ranges between nil and 0.007 percent. Analyses of the natural ash of samples taken from this bed range from 0.002 to 0.016 percent uranium. The average ash content of this bed is 41.4 percent and artificial ash has been determined to contain as much as 0.016 percent uranium.

The "Hot Bed" was sampled at 13 localities (table 10); 5 samples were taken, including 30 of lignite, 3 of lignitic soil, 1 of carbonaceous clay, 6 of natural ash or clinker, and 4 of spring waters from the bed. At 5 localities the lignite bed was sampled every 1 to 2 feet to determine the vertical distribution of uranium in the bed.

Table 10.--Analyses of samples from Bullion Butte, North Dakota

ocality and ample number	Location of sample	Length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105°C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
PB-2 (S:5)	0 to 2 feet above base of Bullion Butte bed	2.0	Lignite	0.001	0.002	31.0	6.1		0.007	Lignite, good
PB-2 (S:6)	2 to 4 feet above base of Bullion Butte bed	2.0	do.	.001	.002	17.8	7.9	0.011	.012	Do.
PB-2 (S:7)	4 to 6 feet above base of Bullion Butte bed	2.0	do.	.000	.001	11.0	8.0	.016	.010	Do.
PB-2 (S:8)	6 to 8 feet above base of Bullion Butte bed	2.0	do.	.001	.002	19.0	6.9	.008	.011	Lignite contains some woody fragments
PB-2 (S:9)	8 to 10 feet above base of Bullion Butte bed	2.0	do.	.000	.001	24.0	5.5		.004	Do.
PB-2 (S:10)	10 to 12 feet above base of Bullion Butte bed	2.0	do.	.002	.001	58.1	3.9		.002	Lignite, good, contains some disseminated clay
PB-2 (S:11)	12 to 14 feet above base of Bullion Butte bed	2.0	do.	.001	.001	18.3	7.6		.006	Do.
PB-2 (S:15)	14 to 16 feet above base of Bullion Butte bed	2.0	do.	.001	.002	14.6	7.9	0.013	.015	Do.
	TOTAL THICKNESS OF BED	16								
	WEIGHTED AVERAGES			.001	.0015	24.3	6.7		.008	
PB-3 (S:30)	0 to 2 feet above base of Bullion Butte bed	2.0	do.	.000	.001	29.0	8.1		.003	Do.

Table 10.--Analyses of samples from Bullion Butte, North Dakota--Continued

Locality and sample number	Location of sample	Length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105°C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
EPB-3 (S:29)	2 to 4 feet above base of Bullion Butte bed	2.0	Lignite	0.000	0.001	11.0	8.2	0.005	0.010	Lignite, good, contains very little disseminated clay
EPB-3 (S:28)	4 to 6 feet above base of Bullion Butte bed	2.0	do.	.000	.001	23.9	9.0		.004	Do.
EPB-3 (S:27)	6 to 8 feet above base of Bullion Butte bed	2.0	do.	.001	.000	8.3	10.3		.006	Do.
EPB-3 (S:26)	8 to 10 feet above base of Bullion Butte bed	2.0	do.	.000	.000	11.9	10.7	.002	.000	Do.
EPB-3 (S:25)	10 to 12 feet above base of Bullion Butte bed	2.0	do.	.000	.000	10.9	10.1	.002	.000	Do.
EPB-3 (S:24)	12 to 14 feet above base of Bullion Butte bed	2.0	do.	.001	.001	18.1	9.0		.006	Do.
EPB-3 (S:23)	14 to 16 feet above base of Bullion Butte bed	2.0	do.	.001	.001	26.7	8.7		.004	Do.
EPB-3 (S:22)	16 to 18 feet above base of Bullion Butte bed	2.0	do.	.000	.001	21.1	9.5		.005	Do.
EPB-3 (S:21)	18 to 20 feet above base of Bullion Butte bed	2.0	do.	.001	.001	16.8	9.3	.004	.007	Do.
EPB-3 (S:20)	20 to 22 feet above base of Bullion Butte bed	2.0	do.	.001	.001	14.7	10.2		.007	Do.

Table 10--Analyses of samples from Bullion Butte, North Dakota--Continued

Locality and sample number	Location of sample	Length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105°C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
EPB-3 (S:19)	22 to 24 feet above base of Bullion Butte bed	2.0	Lignite	0.000	0.001	13.6	10.5		0.007	Lignite, good contains very little disseminated clay
EPB-3 (S:18)	24 to 26 feet above base of Bullion Butte bed	2.0	do.	.003	.003	23.0	10.4	0.011	.014	Do.
	TOTAL THICKNESS OF BED	26								
	WEIGHTED AVERAGES			.001	.001	17.5	9.6		.006	
EPB-3 (S:31)	0 to 1 foot below base of Bullion Butte bed	1.0	Carbonaceous clay	.002	.001	81.6	2.8		.001	Carbonaceous clay directly underlying lignite bed (not included with the lignite)
EPB-3 (S:32)	1 to 2 feet below base of Bullion Butte bed	1.0	do.	.003	.004	73.2	4.2		.005	Do.
EPB-3 (S:17)	At top of Bullion Butte bed	1.0	do.	.005	.004	89.1	2.3		.004	Carbonaceous clay directly overlying lignite bed (not included with the lignite)
EPB-6 (S:37)	Bullion Butte bed	1.0	do.	.007	.007	74.3	4.1	.011	.010	Bed not in place. Lignite contains large amount of soil
EPB-6 (S:38A)	do.	2.0	do.	.000	.001	71.0	10.1		.001	Do.
EPB-6 (S:38B)	do.	1.5	do.	.002	.003	74.5	6.5		.004	Do.
EPB-18 (S:88)	do.	16.0	Lignite	.001	.001	21.0	10.9		.005	Lignite, good; contains large amount of gypsum

Table 10.--Analyses of samples from Bullion Butte, North Dakota--Continued

Locality and sample number	Location of sample	Length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105°C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
EPB-19 (S:93)	Bullion Butte bed	5.5	Lignite	0.001	0.001	32.1	11.4		0.003	Lignite, good; upper portion
EPB-19 (S:94)	do.	5.5	do.	.001	.001	21.6	10.5		.005	Lignite, good; lower portion
EPB-22 (S:97)	do.	0.5	Natural ash	.003	.002	89.9	3.4		.002	
EPB-4 (S:33)	0 to 1.5 feet above base of "Hot Bed"	1.5	Lignite and soil	.004	.003	82.3	3.3		.003	Large amount of soil cove Lignite badly weathered
EPB-4 (S:34)	1.5 to 3 feet above base of "Hot Bed"	1.5	do.	.004	.004	71.1	4.5		.006	Do.
EPB-4 (S:35)	3 to 4.5 feet above base of "Hot Bed"	1.5	do.	.006	.005	74.6	4.7		.007	Do.
EPB-4 (S:36)	4.5 to 6 feet above base of "Hot Bed"	1.5	Lignitic clay	.004	.002	85.9	3.2		.002	Do.
	TOTAL THICKNESS OF BED	6								
	WEIGHTED AVERAGES			.0045	.0035	78.5	4.3		.0045	Do.
EPB-8 (S:39)	"Hot Bed"	0.5	Natural ash	.013	.010	86.2	3.4	0.011	.012	Burning of lignite caused slumping of ash and clinker beds

Table 10.--Analyses of samples from Bullion Butte, North Dakota--Continued

Locality and sample number	Location of sample	Length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105°C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
EPB-8 (S:40)	"Hot Bed"	0.5	Natural ash	0.017	0.012	85.0	2.9	0.013	0.015	Burning of lignite caused slumping of ash and clinker beds
EPB-8 (S:41)	do.	.5	do.	.014	.011	87.4	2.1	.011	.013	Do.
EPB-8 (S:42)	do.	1.0	Lignite	.002	.003	89.3	1.9		.003	One foot of unburned lignite taken near ash bed
EPB-8 (S:43)	do.	2.0	Clinker	.001	.001	95.8	0.3		.001	Burning of lignite caused slumping of ash and clinker beds
EPB-8 (S:44)	do.	1.0	Natural ash	.016	.012	88.6	3.0	.012	.014	Do.
EPB-11 (S:48)	0 to 1.5 feet above base of "Hot Bed"	1.5	Lignite	.003	.002	32.8	9.3		.006	Lignite, good, with 2-inch clay seam in lower 1.5 feet
EPB-11 (S:47)	1.5 to 3 feet above base of "Hot Bed"	1.5	do.	.002	.002	15.2	10.9	.008	.015	Lignite, good
EPB-11 (S:46)	3 to 4.5 feet above base of "Hot Bed"	1.5	do.	.002	.001	24.7	10.3		.004	Do.
	TOTAL THICKNESS OF BED	4.5								
	WEIGHTED AVERAGES			.002	.002	24.2	10.2		.008	

Table 10--Analyses of samples from Bullion Butte, North Dakota--Continued

Locality and sample number	Location of sample	Lengtn of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105° C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
EPB-12 (S:51)	0 to 2 feet above base of "Hot Bed"	2.0	Lignite	0.002	0.003	20.3	9.6	0.015	0.016	Lignite,very good, containing hard, vitreous seams
EPB-12 (S:50)	2 to 4 feet above base of "Hot Bed"	2.0	do.	.002	.003	16.4	9.6	.012	.020	Do.
EPB-12 (S:49)	4 to 6 feet above base of "Hot Bed"	2.0	do.	.002	.001	22.3	9.2		.004	Do.
	TOTAL THICKNESS OF BED	6.0								
	WEIGHTED AVERAGES			.002	.002	19.7	9.5	.0135	.013	
EPB-10 (S:52)	0 to 1 foot above base of "Hot Bed"	1.0	Lignite	.002	.002	18.1	10.0	.013	.012	Lignite, very good, containing hard, vitreous seams
EPB-10 (S:53)	1 to 2 feet above base of "Hot Bed"	1.0	do.	.003	.002	14.6	9.0	.012	.015	Do.
EPB-10 (S:54)	2 to 3 feet above base of "Hot Bed"	1.0	do.	.003	.002	15.8	9.7	.011	.014	Do.
EPB-10 (S:55)	3 to 4 feet above base of "Hot Bed"	1.0	do.	.003	.003	15.5	10.7	.017	.022	Do.
EPB-10 (S:56)	4 to 5 feet above base of "Hot Bed"	1.0	do.	.002	.002	13.2	9.8	.018	.017	Do.
EPB-10 (S:57)	5 to 6 feet above base of "Hot Bed"	1.0	do.	.004	.004	22.1	8.9	.017	.020	Do.
	TOTAL THICKNESS OF BED	6								
	WEIGHTED AVERAGES			.003	.0025	16.5	9.7	.015	.017	

Table 10--Analyses of samples from Bullion Butte, North Dakota--Continued

Locality and sample number	Location of sample	Length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105^{o} C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
EPB-13 (S:66)	0 to 1 foot above base of "Hot Bed"	1.0	Lignite	0.004	0.004	58.3	6.7		0.007	Lignite, very good, containing hard, vitreous seams
EPB-13 (S:65)	1 to 2 feet above base of "Hot Bed"	1.0	do.	.004	.003	66.6	5.2		.005	Do.
EPB-13 (S:64)	2 to 3 feet above base of "Hot Bed"	1.0	do.	.005	.005	23.6	10.8	0.019	.024	Do.
EPB-13 (S:63)	3 to 4 feet above base of "Hot Bed"	1.0	do.	.003	.003	29.4	8.8	.009	.011	Do.
EPB-13 (S:62)	4 to 5 feet above base of "Hot Bed"	1.0	do.	.004	.003	19.7	9.8	.017	.017	Do.
EPB-13 (S:61)	5 to 6 feet above base of "Hot Bed"	1.0	do.	.004	.003	16.6	9.2	.015	.020	Do.
EPB-13 (S:60)	6 to 7 feet above base of "Hot Bed"	1.0	do.	.003	.002	14.4	9.0	.012	.015	Do.
EPB-13 (S:59)	7 to 8 feet above base of "Hot Bed"	1.0	do.	.002	.002	19.4	8.0	.008	.011	Do.
EPB-13 (S:58)	8 to 9 feet above base of "Hot Bed"	1.0	do.	.005	.004	21.1	9.1	.020	.021	Do.
	TOTAL THICKNESS OF BED	9								
	WEIGHTED AVERAGES			.004	.003	29.9	8.5	.016	.0145	

Table 10.--Analyses of samples from Bullion Butte, North Dakota--Continued

Locality and sample number	Location of sample	Length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105° C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
EPB-14 (S:67)	"Hot Bed"	2.5	Lignite	0.002	0.003	21.0	12.0	0.012	0.016	Upper portion of lignite. Slumped area
EPB-14 (S:68)	do.	2.0	do.	.002	.003	23.0	11.5	.012	.015	Lower portion of lignite. Slumped area
EPB-14 (S:69)	do.	1.0	do.	.013	.011	54.5	9.3	.017	.022	
EPB-14 (S:71)	do.	0.5	Natural ash	.025	.013	84.1	5.7	.016	.016	
EPB-14 (S:89)	do.	1.5	Lignite	.006	.005	32.2	9.7	.013	.016	Upper portion of lignite. Slumped area. 0.00 percent K_2O
EPB-14 (S:90)	do.	2.5	do.	.005	.005	36.6	9.1	.013	.014	Lower portion of lignite. Slumped area. 0.34 percent K_2O
	TOTAL THICKNESS OF BED	8.5								
EPB-20 (S:95)	"Hot Bed"	1.0	Lignite	.003	.002	19.8	10.7	.011	.010	Bed not in place. 0.10 percent K_2O
EPB-1 (S:3)	-	-	Soil	.002	.001	92.8	0.6		.00	
EPB-5 (S:91)	-	5.0	Lignite	.001	.001	23.9	10.9	0.	.002	Lignite above HT bed of Hares
EPB-5 (S:92)	-	2.0	do.	.001	.001	36.5	10.5	.002	.003	Lignite 48 feet below Bullion Butte bed
	TOTAL THICKNESS OF BED	7.0								
EPB-18 (S:87)	-	3.0	do.	.000	.000	36.9	10.8		.000	Lignite 229 feet above HT bed of Hares
EPB-18 (S:98)	-	4.0	do.	.001	.001	34.1	6.4		.002	Lignite 70 feet above HT bed of Hares
EPB-18 (S:99)	-	2.5	Lignite and carbonaceous clay	.002	.002	58.4	5.8	0.	.002	Lignite 143 feet above HT bed of Hares.

Table 10.--Analyses of samples from Bullion Butte, North Dakota--Continued

Locality and sample number	Location of sample	Length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O 105° C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
EPB-18(S:100)	-	1.5	Lignite and carbonaceous clay	0.000	0.000	17.5	9.0		0.000	Lignite 156 feet above HT bed of Hares
EPB-18(S:101)	-	1.5	Lignite	.002	.000	74.7	7.1		.002	Lignite 166 feet above HT bed of Hares
	TOTAL THICKNESS OF BED	12.5								
EPB-22(S:102)	-	5.0	Natural ash	.001	.001	26.5	10.7		.002	
EPB-23(S:103)	-	0.1	Carbonaceous clay	.003	.001	86.8	2.4		.001	Carbonaceous clay seam in Golden Valley formation (?)

(Water samples)			Uranium in parts per million	Total solids in parts per million	
EPB-1(S:1)	Base of Bullion Butte bed	Spring water from lignite bed	0.030	-	-
EPB-1(S:2)	do.	do.	.030	-	-
EPB-2(S:4)	do.	do.	.024	-	-
EPB-2(S:16)	do.	do.	.058	-	-
EPB-9(S:45b)	do.	do.	.054	-	-
EPB-9(S:45a)	Base of "Hot Bed"	do.	.032	-	-
EPB-14(S:70)	do.	Spring water from ash bed	.090	-	-
EPB-7(S:105)	do.	Spring water from lignite bed	.018	-	-
EPB-16(S:85)	---	Spring water	.00	700	-
EPB-21(S:96)	25 feet above top of "Hot Bed"	Spring water from lignite bed	.02	710	-
EPB-15(S:84)	---	Spring water	.00	240	From Golden Valley formation (?)
EPB-17(S:86)	----	Pond water	.00	9820	Water from Sentinel Butte shale member Fort Union formation, 10 feet below "White Bed". Sample taken from large pond on south end of Bullion Butte
EPB-24(S:104)	Base of Bullion Butte	River water	.01	1210	Little Missouri River, in vicinity of Bullion Butte.

The samples from the "Hot Bed" contained from 0.001 to 0.011 percent uranium in lignite and 0.010 to 0.013 percent uranium in the natural ash. The average ash content of this lignite after burning is 19.7 percent as compared with average ash contents of 25.9 to 46.5 percent in all other uraniferous lignites sampled by the writers. The determined uranium content in artificial ash is as much as 0.02 percent.

In addition, fifteen 50- to 100-pound samples collected from the Bullion Butte bed and "Hot Bed" were shipped to Battelle Memorial Institute for metallurgical tests.

Ten miscellaneous rock samples and 3 water samples were taken in the area; 7 samples were of lignites or lignite and carbonaceous clay below the "White Bed" (fig. 4 and table 5). Three of these contained no uranium; three contained 0.001 percent, and one contained 0.002 percent. One sample, EPB-5 (S:92), taken of a 4 to 5-foot lignite bed (fig. 4) 10 feet above the "White Bed", contained 0.001 percent uranium in the lignite and 0.003 percent uranium in ash. The horizontal extent of this lignite bed probably is not greater than three-quarters of a mile and within this distance lignite grades into carbonaceous shale (columnar section E-F, fig. 4). The bed then thins rapidly and grades into the overlying and underlying sandy clays.

Thirteen water samples were taken in the vicinity of Bullion Butte (table 10). Six were from springs issuing from the slightly radioactive Bullion Butte bed and contained between 0.03 to 0.06 parts per million of uranium. The four water samples from springs issuing from the more radioactive "Hot Bed" contained between 0.00 and 0.03 parts per million of uranium.

The Bullion Butte bed is a permanent aquifer and the water issuing from it may have been in contact with the uraniferous lignite longer than water in the "Hot Bed" which is a periodic aquifer. One water sample taken from a spring in a natural ash of the "Hot Bed" contained 0.090 parts per million of uranium. This higher uranium content is probably caused by the presence of high proportions of sulfur and an increased acidity. One water sample, EPB-24-104, taken from the Little Missouri River in the vicinity of Bullion Butte contained 0.01 parts per million of uranium. In the spring of 1949 Wyant collected a water sample that contained 0.008 parts per million of uranium from the same river in the vicinity of Medora, N. Dak., 15 miles north of Bullion Butte. These samples suggest that the uranium content of this larger body of water is nearly uniform over a large area. Two other samples, EPB-15 (S:84) and EPB-15(S:85), of water from springs issuing from the Golden Valley formation (?) did not contain any uranium.

Killdeer Mountains

The Killdeer Mountains in Dunn County, N. Dak. (fig. 1), southwest of the town of Oakdale, were examined for radioactive lignites. This area, which is capped by the White River formation, makes up the largest highland surface in southwestern North Dakota. Two samples taken at the north end of these mountains, H.B.-13 (S:35) and H.B.-13 (S:36), did not contain any uranium. One sample, H.B.-13 (S:37), taken on the east flank of the mountains assayed 0.001 percent uranium. Dark somber-colored clays, similar to the Sentinel Butte shale member of the Fort Union formation were seen, in this area; these somber-colored clays are only

a dark facies of the Tongue River member of the Fort Union formation according to Benson (personal communication). The absence of the Sentinel Butte shale member in this area could account for the absence of the uraniferous lignites that occur in other highlands in southwestern North Dakota.

Hebron area

Three samples, H.B.-1 (S:1, S:2, and S:3), taken from the 12-foot thick Harnish lignite bed at the Harnish coal mine north of Hebron, N. Dak. (fig. 1), contained between 0.001 and 0.002 percent uranium. The Harnish lignite bed is the uppermost bed in the Tongue River member of the Fort Union formation.

Beulah area

One lignite sample, H.B.-2 (S:5), taken of a 1-foot lignite bed above Benson's (1947) marker horizon in the Golden Valley formation south of Beulah, N. Dak. (fig. 1), contained 0.001 percent uranium.

Riverdale area

Examination of several lignite beds, 1 to 3 feet thick, in the Tongue River member of the Fort Union formation in the vicinity of Riverdale, N. Dak. (fig. 1), showed no radioactivity above background. The one sample assayed, H.B.-3 (S:6), did not contain uranium.

Localities examined in South Dakota

Four areas--South Cave Hills, North Cave Hills, Slim Buttes, and East Short Pine Hills--contain uraniferous lignites in the Ludlow formation and younger rocks. The lignites are capped by a massive cross-bedded sandstone.

South Cave Hills

The South Cave Hills uraniferous lignite area, in Harding County, S. Dak. (figs. 1 and 7), is on a butte that occupies an area of 5.7 square miles. The area is accessible from U. S. Highway 85 by a well graded dirt road. Four localities were examined and 7 samples were taken in the area (table 11). In the upper part of the butte, only one lignite bed in the Ludlow formation was found to be radioactive. Of the four lignite beds sampled, two did not contain uranium and two contained 0.001 percent. A sample from the upper uraniferous bed, called the "radioactive bed" by Wyant (Wyant and Beroni, 1950) contained 0.004 percent uranium in lignite and 0.01 percent in the ash. Two samples of natural ash contained 0.002 and 0.015 percent uranium.

North Cave Hills

The North Cave Hills area, in Harding County, S. Dak. (figs. 1 and 7), is 13.6 square miles in extent. The area is accessible by a well graded dirt road, from U. S. Highway 85. One locality was examined, and two samples were taken of lignites in this area (table 11). Only an upper lignite was found to be significantly radioactive. One sample, H.B.-23 (S:62), taken of this 5-foot lignite bed contained 0.009 percent uranium

Table 11.--Analyses of samples from Harding County, South Dakota

Area	Locality and sample number	Thickness of bed and length of sample (feet)	Material	Equivalent uranium (percent)	Uranium (percent)	Ash (percent)	H_2O at 105° C (percent)	Uranium in ash determined (percent)	Uranium in ash calculated (percent)	Remarks
South Cave Hills:	H.B.-19(S:55)	0.3	Natural ash	0.018	0.015	86.0	3.7	0.015	0.013	
	H.B.-19(S:56)	6.0	Lignite	.001	.001	24.3	9.3	.002	.001	Lignite from "radioactive bed"
	H.B.-19(S:57)	----	Sandy clay	.002	.001				.002	Hematitic-stained clay
	H.B.-19(S:58)	15.0	Lignite	.002	.001	25.5	7.0	.002	.001	Lignite bed, being mined, below "radioactive bed"
	H.B.-20(S:59)	15.0	do.	.000	.000	22.1	6.8		.000	Do.
	H.B.-21(S:60)	----	Natural ash	.001	.002	88.4	7.7	.001	.001	Ash sample from lignite bed being mined
	H.B.-22(S:61)	5.0	Lignite	.000	.000	10.6	10.0	.001	.000	Lignite directly below "radioactive bed"
North Cave Hills:	H.B.-23(S:62)	5.0	Lignite	.009	.010	29.6	10.4	.030	.009	
	H.B.-23(S:63)	2.0	Lignite and clay	.002	.002	25.8	10.4		.008	Lignite directly below "radioactive bed"
Slim Buttes:	H.B.-24(S:64)	2.0	Lignite; contains large amount of soil	.005	.005	30.0	6.6		.017	Badly slumped area
East Short Pines Hills:	H.B.-18(S:53)	1.0	Lignitic clay	.003	.001	83.1	2.3		.002	Lignite in Golden Valley formation (?)
	H.B.-18(S:54)	1.0	do.	.003	.001	85.8	2.6		.002	Lignite in Golden Valley formation (?) contains 0.36 percent K_2O

in the lignite, and 0.030 percent uranium in the ash. A massive clinker bed on the northeast end of the area correlates with this lignite bed.

One sample, H.B.-23 (S:63), of lignite and clay from a lower bed contained 0.002 percent uranium.

Slim Buttes

The uraniferous lignites of Slim Buttes in Harding County, S. Dak. (fig. 7), underlie an area of about 21 square miles in the northern half of the area. One sample, H.B.-24 (S:64) (table 11) taken of the uppermost exposed lignite, contained 0.005 percent uranium in the lignite. The ash content of this sample was calculated to be 30.0 percent, and the calculated percent uranium in the ash is 0.017.

At a second locality, H.B.-25 (fig. 7), on South Dakota Highway No. 18, a lower lignite bed showed no radioactivity above the normal background.

East Short Pine Hills

East Short Pine Hills, in the southern part of Harding County, S. Dak. (fig. 7), is accessible by a dirt road from U. S. Highway 85.

One locality was examined and two samples H.B.-18 (S:53 and 54), were taken from two 1-foot lignitic clay beds. These samples contained 0.001 percent uranium (table 11).

A natural ash bed, locality H.B.-26, between Table Mountain and the North Cave Hills (fig. 7) has a radioactivity of as much as 5.5 times the normal background.

Localities examined in Montana

Blue Buttes

Blue Buttes in Wibaux County (fig. 1), comprising an area of approximately 4 square miles, is 35 miles northwest of Sentinel Butte, N. Dak. The one lignite sample taken in this area is comparable in uranium content to the lignites found at Sentinel Butte. The true thickness of this lignite bed could not be determined because of poor exposures, but one grab sample, H.B.-12 (S:34), representing a half-foot thickness of lignite and a large amount of soil, was taken from a slumped area. The high ash content, 64.2 percent, was therefore unusually high. The sample contained 0.009 percent uranium and 0.014 percent uranium in the ash.

Approximately 25 feet of clay and soil overlie the uraniferous lignite bed. The massive White River sandstone capping is absent from these buttes, though remnants of this sandstone can be found over a wide area.

Terry area

In the section of undivided Fort Union formation immediately north of Terry, Prairie County (fig. 1), locality H.B.-27, no abnormal radioactivity was noted during a radiometric traverse of six lignites. These lignites average 6 feet in thickness and are in places already being mined. No samples were taken. It is probable that the Sentinel Butte shale member is not exposed here.

Wyola area

A 5-foot nonradioactive lignite bed is exposed immediately southeast of Wyola, Big Horn County (fig. 1), at locality H.B.-28. This lignite is in sediments similar to the Tongue River member of the Fort Union formation, although Brown's (1949) Paleocene map shows the area to be underlain by Cretaceous rocks. No samples were taken.

Decker area

No abnormal radioactivity was noted of a radiometric traverse of three lignite beds, averaging 4 feet thick, in the Tongue River member of the Fort Union formation, north of Decker, Big Horn County, locality H.B.-30 (fig. 1). No samples were taken.

Localities examined in Wyoming

Sheridan area

Two days in October 1949 were spent in the vicinity of Sheridan, (fig. 1), checking ten sections of sub-bituminous coals in the Tongue River member of the Fort Union formation. Two of the coals examined, the Monarch and Dietz-3 beds, are as much as 20 feet thick. Where examined at localities H.B.-29 and H.B.-31, these coals showed no appreciable abnormal radioactivity. Coal beds higher in the section, probably the Dietz-1 and the Smith, were examined radiometrically in the vicinity of Springwillow, Sheridan County, at localities H.B.-32 and H.B.-33, and east of Wyarno, at localities H.B.-34 and H.B.-35. These beds, average 4 feet in thickness and showed no appreciable abnormal radioactivity either in the coals or in their ashes.

Coals and clinker horizons were radiometrically examined in the vicinity of Ulm (fig. 1), localities H.B.-36 and H.B.-37. These beds were probably the Ulm 1 and 2 of the Ulm coal group, thickness undetermined, but shown by Taff (1909, pl. 8), to be 10 to 13 feet thick, respectively. No appreciable abnormal radioactivity was detected in these coal or clinker horizons. No good exposures of natural ash beds were found in these horizons.

No samples were taken in the Sheridan, Wyo. coal field.

Gillette area

One 2-foot lignite bed was sampled in a road cut 2 miles west of Gillette, Campbell County (fig. 1). It gave a meter reading of 2 times the normal background and one sample, H.B.-17 (S:52), contained 0.003 percent uranium in the lignite, and 0.004 percent uranium in the ash. It is possible that the lignites higher in the section, and further east of this locality, are more radioactive.

RESERVES OF URANIFEROUS LIGNITES

The total inferred reserves of uraniferous lignite in all deposits sampled are estimated to be 183,320,000 short tons that contain a weighted average grade of 0.009 percent uranium (table 12). The weighted average grade of individual lignite beds ranges from 0.002 to 0.033 percent uranium. The uranium is concentrated in the ash after burning and the grade of the ash from the sampled lignites ranges from 0.010 to 0.091 percent uranium. The degree of concentration is a function of the ash content of the lignite; the concentration ratio ranges from 1.5-to-1 to 9-to-1 in the lignites sampled.

Table 12.--Inferred reserves of uraniferous lignites in North Dakota, South Dakota, and Montana

Locality	Bed	Number of samples	Average thickness (feet)	Area underlain by lignites (sq. ft.)	Inferred reserves of lignite (short tons)	Weighted average of uranium in lignite (percent)	Weighted average of uranium in ash (percent)	Ash in lignite after burning (percent)	Inferred reserves of ash (short tons)	Inferred reserves of uranium metal (short tons)
Sentinel Butte, N. Dak.	1	3	1.8	19,120,000	1,377,000	0.013	0.038	33.9	467,000	179
	2	5	1.5	15,175,000	911,000	.009	.023	46.5	424,000	82
	3	3	2.5	12,978,000	1,298,000	.004	.018	25.9	335,000	52
	4	4	2.2	11,086,000	976,000	.005	.010	59.7	583,000	49
	5	4	4.6	9,106,000	1,676,000	.012	.039	31.1	520,000	201
Totals		19 1/		67,465,000	6,238,000	0.009	0.028	37.5	2,329,000	563
Bullion Butte, N. Dak.	Bullion Butte bed.	30	15	34,317,000	20,600,000	.002	.005	41.4	10,764,000	538
	"Hot Bed"	26	5.5	21,109,000	4,040,000	.003	.011	19.7	795,000	88
Totals		56		55,426,000	24,640,000	0.002	0.006	37.8	11,559,000	626
Flat Top Butte, N. Dak.	1	1	.5	12,000,000	240,000	.003	.008	39.1	93,600	7
	2	2	.5	12,000,000	240,000	.003	.009	32.0	76,800	7
	3	2	.5	12,000,000	240,000	.033	.091	41.5	98,400	79
	4	2	.4	12,000,000	192,000	.003	.008	41.3	77,900	6
Totals		7 1/		48,000,000	912,000	0.010	0.024	37.8	346,700	99

1/ Includes samples taken by D. G. Wyant in 1948 and 1949

Table 12.--Inferred reserves of uraniferous lignites in North Dakota, South Dakota, and Montana--Continued

Locality	Bed	Number of samples	Average thickness (feet)	Area underlain by lignites (sq. ft.)	Inferred reserves of lignite (short tons)	Weighted average of uranium in lignite (percent)	Weighted average of uranium in ash (percent)	Ash in lignite after burning (percent)	Inferred reserves of ash (short tons)	Inferred reserves of uranium metal (short tons)
Blue Butte, Mont.	--	1	0.5	111,514,000	2,230,000	0.009	0.014	64.2	1,432,000	201
Totals	--	1	0.5	111,514,000	2,230,000	0.009	0.014	64.2	1,432,000	201
North Cave Hills, S. Dak.	--	1	5.0	379,340,000	75,900,000	.010	.030	29.0	22,000,000	7,590
Totals	---	1	5.0	379,340,000	75,900,000	0.010	0.030	29.0	22,000,000	7,590
South Cave Hills, S. Dak.	---	3	2.3	157,840,000	14,500,000	.004	.014	34.0	4,900,000	580
Totals	---	3 1/	2.3	157,840,000	14,500,000	0.004	0.014	34.0	4,900,000	580
Slim Buttes, S. Dak.	---	1	2.5	1,126,030,000	58,900,000	.005	.017	30.0	17,700,000	2,945
Totals	---	1	2.5	1,126,030,000	58,900,000	0.005	0.017	30.0	17,700,000	2,945
FINAL TOTALS		88	0.4 to 15	1,945,615,000	183,320,000	0.009	0.023	32.8	60,266,000	12,604

The average thickness of the radioactive lignite beds ranges from 0.4 to 15 feet. Only about a third of the lignite beds are more than 3 feet thick.

In addition, to the beds that were sampled, geologic evidence suggests that there may be an additional reserve of 378,000,000 tons of uraniferous lignites, probably averaging 2 feet thickness, in Harding and Perkins Counties, S. Dak., and in the Ekalaka lignite field, Carter County, Mont.

The available data suggest that the one lignite bed at North Cave Hills, S. Dak., may be of great potential value. It is estimated that this bed averages 5 feet in thickness and contains 75,900,000 short tons of uraniferous lignite. The grade, as determined from one assay, is 0.010 percent uranium. The validity of such scant data is strengthened by results of radiometric scanning of the lignite outcrops. In addition, in areas studied in more detail, variations in assays along individual beds are small, indicating that the uranium is essentially uniformly distributed throughout each uraniferous bed. The large tonnage and apparent high grade of the uraniferous lignite in the North Cave Hills, combined with an ash content of 29 percent, which is low compared to the other uraniferous lignite beds, make this area of particular interest. Inasmuch as the sample was from a weathered outcrop, it is probable that the fresh lignite at North Cave Hills would reduce to a lower percentage of ash than did the lignite represented by the sample. The area is easily accessible by third-class roads.

The lignite beds at Sentinel Butte are probably second in importance as a possible source of uranium. Five radioactive beds, more than 1.5 feet thick, are estimated to contain 5,430,000 short tons of lignite that has an average grade of 0.009 percent uranium. The uppermost bed (No. 5) is considered of most economic value because it has an average thickness of 4.6 feet; it is inferred to contain 1,676,000 short tons of lignite with a weighted average of 0.012 percent uranium. The bed ranges from 3 to 6 feet in thickness, over an area about 400 by 5,000 feet. It is 5 to 6 feet thick in the center of this area, and thins eastward and westward. In addition to the uranium, spectrographic analysis made by Battelle Memorial Institute on ash from part of a 500 pound sample from this bed shows 0.5 to 2 percent MoO_3. Assuming the average content of MoO_3 of the ash to be 0.5 percent and the ash to be 31 percent of this bed; bed No. 5 contains 2,600 tons of MoO_3.

The other uraniferous lignite beds at Sentinel Butte have an average thickness of 2.5 feet or less and are stratigraphically separated by as much as 65 feet of clay and shale. The three uppermost lignite beds combined have an average thickness of about 8 feet, and are within a stratigraphic interval of about 37 feet (fig. 5). If rock containing about 0.003 percent uranium could be treated economically it might be possible to mine these three beds as a unit.

The uraniferous lignite bed at Blue Buttes, Mont. is the only deposit studied that might be suitable for strip-mining, as it is overlain by only 25 to 30 feet of shale and clay. The scant data available, however, indicate that the bed is only 0.5 feet thick--too thin to be mined profitably--and the ash content is high.

The other uraniferous lignite beds examined are considered less favorable for mining as either their average thickness is less than 2.5 feet or their average grade is less than 0.005 percent uranium.

The average grade of each of the uraniferous lignite beds in each butte was obtained by weighting the assays of samples proportionally to the length of sample and then proportionally to the thickness of the lignite bed at each locality sampled. Areas of the uraniferous lignite beds were determined by measuring the beds on the maps with a planimeter. Tonnage of these beds was computed by using an average thickness for each uraniferous bed and assuming that 25 cubic feet of unmined lignite weighs 1 ton.

The content of uranium metal was computed from assays of lignite rather than ash, because the uranium content of some ash was calculated and not determined by analyses.

ECONOMICS

In addition to the uranium content of the lignite deposits, other products and factors must be considered when evaluating them from an economic viewpoint. Some of these are: 1) the possibility of concentration of uranium by burning the lignite, 2) the value of heat, energy, and other products obtainable by burning or destructive distillation of the lignite, 3) the cost of mining and exploration of the lignite beds, 4) the suitability of the uranium compound, after burning, to subsequent metallurgical processes, and 5) the accessibility of the deposits.

The results of the writers' sampling show that the ash content is somewhat higher than previous estimates (Wyant and Beroni, 1950, p. 44),

however, the percent of ash probably would be less in fresh lignite. Large, fresh samples are needed to adequately evaluate the amount of concentration of uranium that could be effected by burning.

The heating value of the North Dakota lignites, according to Hares (1928, pp. 54-55), is 5,000 to 6,000 BTU per pound of coal. This energy, if converted to electricity, would appreciably lower the cost of producing uranium metal. Experiments on the conversion of lignite to liquid fuel were in progress in 1950 at a pilot plant at Grand Forks, N. Dak. The production of liquid fuel would probably yield uraniferous residues if uranium-bearing lignites were used, and the combined operation might be economic under present conditions.

In addition to uranium in the ash there are several compounds, such as molybdenum oxide, that might have byproduct value.

It is recommended that underground methods might be used in the mining of the upper three beds (Beds Nos. 3, 4, and 5, fig. 5) at Sentinel Butte, N. Dak. Although the average thickness of these beds is 2.5, 2.2, and 4.6 feet, respectively, the stratigraphic interval between them is only 5 to 37 feet.

Both the Bullion Butte Bed and the "Hot Bed" at Bullion Butte, N. Dak., probably could be mined by underground methods, as their average thickness is 15 and 5.5 feet, respectively.

In general, all areas in North and South Dakota, examined by the writers are overlain by a massive sandstone, 75 to 125 feet thick, which caps the steep-walled buttes. This massive sandstone capping is missing only at Blue Buttes, Mont. and at the northern part of Slim Buttes, S. Dak.

Most of the radioactive lignite deposits are readily accessible by third-class roads. Sentinel Butte and Flat Top Butte are within four miles of the Northern Pacific railroad.

Detailed exploration of the uraniferous lignites is required for their detailed economic appraisal. Fresh samples that could be obtained from drill holes are needed to establish grade. To penetrate the uraniferous lignite beds in any of the areas discussed, no more than 300 feet of drilling per hole would be required; in some areas considerably less drilling would explore the uraniferous beds. Water for drilling is readily available.

SUMMARY AND CONCLUSIONS

Reconnaissance and detailed studies in southwestern North Dakota, northwestern South Dakota, and eastern Montana, indicate that an area of at least 69.8 square miles is underlain by uraniferous lignites. The grade of the uranium deposits and their extent, however, are incompletely known because of poor surface exposures and the lack of sufficient detailed studies. Prospects for finding richer and more extensive deposits appear promising.

Future prospecting for uraniferous lignites in this area should be guided by the following facts:

(1) All uraniferous lignites found by the writers in southwestern North Dakota and eastern Montana were above the HT lignite bed of Hares, that is, the basal lignite bed of the Sentinel Butte shale member of the Fort Union formation. The uraniferous lignites in northwestern South Dakota are included in units mapped as part of the Ludlow formation by Winchester (1916).

(2) In North Dakota, lignites and lignitic clays above the "White Bed" of the Sentinel Butte shale member are radioactive. Only one stratigraphically lower lignite, a non-continuous bed 10 feet below the "White Bed" at the center of Bullion Butte, N. Dak., is slightly radioactive. The "White Bed" is 10 to 15 feet thick and contains analcite; it is a light greenish gray (5 GY 8/1) to yellowish clay bed that lies about 300 feet above the HT lignite bed of Hares.

(3) All uraniferous lignites examined by the writers are below a prominent, yellow to white sandstone, approximately 100 feet thick, that caps the buttes. It was mapped in southwestern North Dakota by Hares (1928) and Leonard (1908) as the White River formation. A similar sandstone in northwestern South Dakota has been mapped by Winchester (1916) as basal Fort Union. X-ray diffraction patterns made of the two sandstones show that they each contain between 60 to 70 percent analcite; thin sections show that they have a similar mineral assemblage--orthoclase, albite, analcite, and quartz. Both sandstones contain very angular grains and only slightly weathered feldspar. It is probable that both sandstones are White River in age.

The stratigraphic relations of the uraniferous lignites suggest that the lignites underlying Table Mountain, Eagle Nest, Lodgepole Buttes, and the southern half of Slim Buttes in Harding County, S. Dak. (fig. 7), are also uraniferous. The lignites in these areas are conservatively estimated to underlie an area of 35 square miles. An additional area of 6.5 miles in Perkins County, S. Dak. (fig. 8), has a stratigraphic sequence that has been interpreted from the geologic map as being favorable for the presence of uranium-bearing lignites.

The geologic map of the Ekalaka lignite field in Carter County, Mont. (fig. 9), suggests that 137 square miles are underlain by lignite of about the same age as the uraniferous lignites in North and South Dakota. Recently these lignites have been reported by Denson (personal communication), to be uraniferous. More detailed reconnaissance sampling and mapping will be necessary before the exact areal extent and grade of these uraniferous lignites are known.

The uraniferous lignites occurring in Tertiary sediments in North Dakota, South Dakota, Montana, and Wyoming, are thought to be syngenetic in origin. Also they are related to analcite-rich rocks. Therefore, organic materials having this mineral association warrant additional study.

Inferred reserves of uraniferous lignites in southwestern North Dakota, northwestern South Dakota, and eastern Montana, are 183,320,000 short tons, containing 12,600 short tons of uranium metal. This preliminary estimate is based only on reconnaissance work in 1948 and 1949, but serves to show that lignites in the western United States are potentially economic low grade uranium deposits.

It has been conservatively estimated that only a third of these uraniferous lignite beds examined are 3 or more feet thick. These beds, therefore, account for approximately 61,106,666 short tons of uraniferous lignites that could be recovered by underground mining. Estimates of tonnage include all uraniferous lignite beds examined, regardless of thickness. The thinner beds were included because they are lenticular and it is possible that these lignites might in some places be thicker than where they were examined. An additional possibility is that some of the thinner beds of lignites that are interbedded

with clays and sands, e.g., the three upper beds on Sentinel Butte (fig. 5), are close enough together, stratigraphically, so they could be mined as one unit.

Due to slacking of lignite on a weathered surface, and the slumping of the overlying clays, it is difficult to obtain reliable measurements even where the rocks are well exposed.

RECOMMENDATIONS

Diamond drilling, detailed mapping, and sampling should be carried out in areas known to contain uraniferous lignites. This is necessary to determine the true thickness and grade of the lignite and to obtain fresh lignite samples for additional metallurgical tests. Additional reconnaissance mapping should be done in the Ekalaka lignite field, Carter County, Mont. (fig. 9), in the vicinity of Gillette, Wyo., and in Harding and Perkins Counties, northwestern South Dakota (figs. 7 and 8). Other areas that may contain uraniferous lignites are: Kettinger area, Adams County, N. Dak.; Red Lodge coal field, Carbon County, Mont.; Broadus-Ulm area in Powder River County, Mont.; and Sheridan County, Wyo.

On the basis of this reconnaissance work, some of the above mentioned areas are currently (1952) being studied by the U. S. Geological Survey. Detailed studies were started first in Slim Buttes, and North and South Cave Hills in northwestern South Dakota.

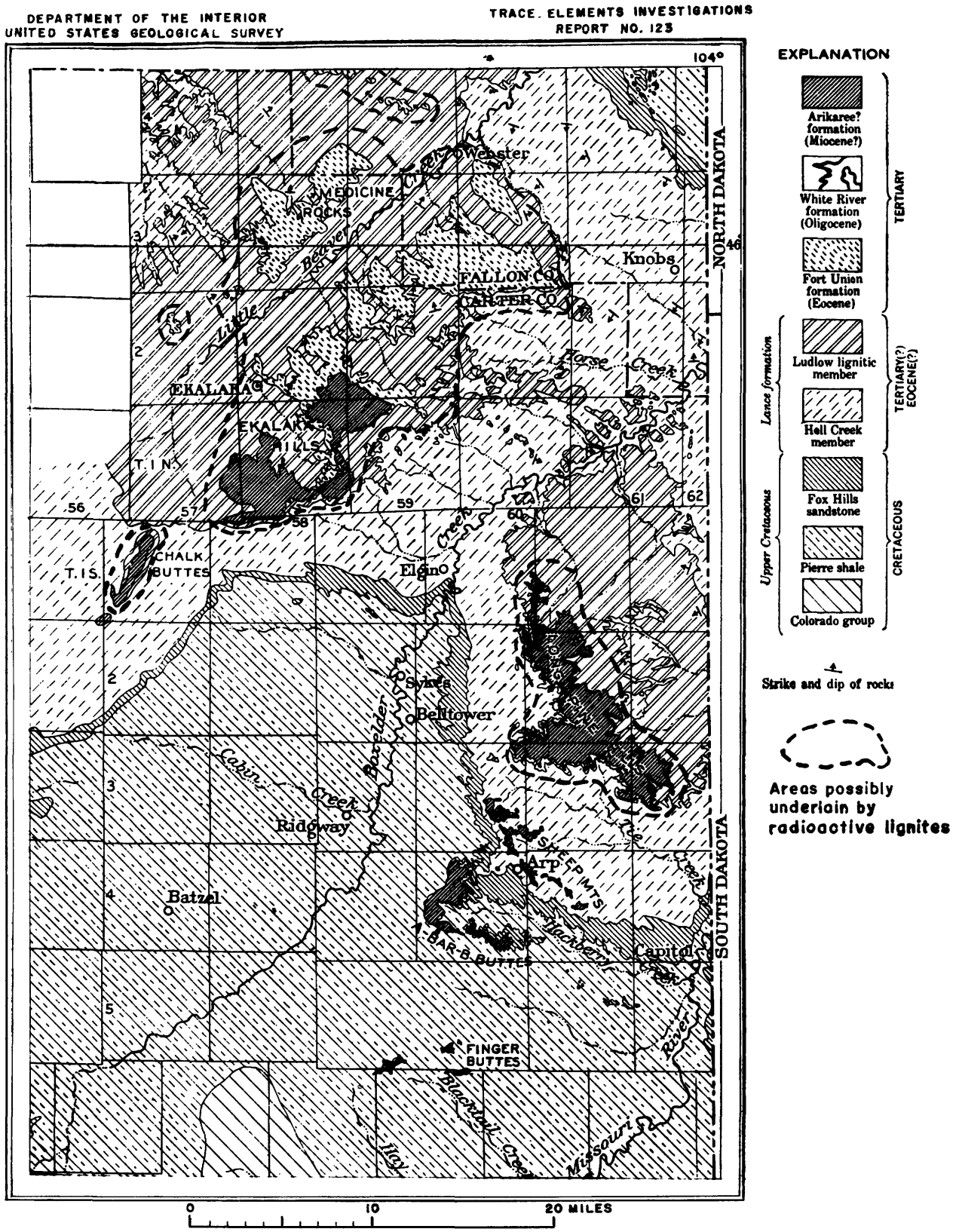


FIGURE 9 - GEOLOGIC MAP OF THE EKALAKA LIGNITE FIELD CARTER COUNTY, MONTANA

(After Bauer, C.M., The Ekalaka lignite field, southeastern Montana: U. S. Geol. Survey Bull. 751 F, pl. 30, 1924

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