(200)

UNCLASSIFIED

Trace elements investigation
TEI-61(Pts. 1 and 2) report

GEOLOGY AND MINERALOGY

U. S. DEPARTMENT OF THE INTERIOR

RECONNAISSANCE FOR TRACE ELEMENTS IN NORTH DAKOTA AND EASTERN MONTANA PART 1. GEOLOGY AND RADIOACTIVITY PART 2. RESERVES AND SUMMARY

By
Donald G. Wyant
Ernest P. Beroni

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

February 1950

U. S. Geological Survey
Washington, D. C.

Prepared by
Geological Survey for the
UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service Extension, Oak Ridge, Tennessee

UNCLASSIFIED

Date Declassified: March 9, 1956.

This report has been reproduced directly from the best available copy.

Printed in USA. Price $1.00. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

AEC Technical Information Service Extension
Oak Ridge, Tennessee

CONTENTS

Page

PART I—GEOLOGY AND RADIOACTIVITY

PART II—RESERVES AND SUMMARY

RECONNAISSANCE FOR TRACE ELEMENTS IN NORTH DAKOTA AND EASTERN MONTANA

ABSTRACT

A reconnaissance for sources of radioactive material in North Dakota and eastern Montana was made in 1948. This reconnaissance was followed by a more detailed survey of parts of Golden Valley and Slope counties, southwestern North Dakota, in June 1949.

The radioactivity of representative sections of all formations known to be exposed in the area and of three manganiferous spring deposits was determined with portable Geiger-Mueller counters. At 86 localities 82 samples were taken of these formations and also of 10 ground and surface waters.

Only the lignites in the upper part of the Sentinel Butte member of the Fort Union formation in the southwestern part of N. Dak. contained more than 0.005 per cent equivalent to U_3O_8. The ground and surface waters tested were for the most part non-radioactive. Water sample number 291 from locality 100, however, contained 0.17 parts per million U_3O_8.

The radioactive lignites of N. Dak. appear to be limited to the higher buttes, such as Sentinel, Flat Top (Square Top), Bullion, H-T(Black), and White(Chalky) Buttes. One to five lignite beds are found in a 90-foot stratigraphic interval near the top of the Sentinel Butte member of the Fort Union formation, and from about 40 to 140 feet beneath the base of the overlying White River formation. The thickness of the beds ranges from a few inches to over six feet. The nomenclature, and therefore correct correlation, of all the beds above the middle part of the Sentinel Butte member is in doubt. The lignites and associated sand and clay beds are believed to be either equivalent to, or close to the base of, the Eocene Golden Valley formation.

The exact mode of origin of the uranium in the lignite is not known. Uranium may have accumulated in swamps at the same time as the organic debris, or it may have been introduced by ground water after the formation of lignite. In either case carbon or carbon compounds apparently caused the precipitation or fixation of uranium. Further work is needed to determine the origin of this type of uranium deposit.

INTRODUCTION

Reconnaissance for sources of radioactive materials in North Dakota and eastern Montana was carried out between May 25 and July 7, 1948, by Donald G. Wyant, assisted by Ernest P. Beroni. A more detailed survey of the southwestern part of the state was made from June 1 to 11, 1949, by Wyant. These studies were made as part of the reconnaissance phase of the Trace Elements program of the U. S. Geological Survey and were under the general supervision of William P. Huleatt.

The reconnaissance in 1948 was undertaken primarily to test the radioactivity of the many lignites and ash beds in North Dakota because rocks in the Red Desert of Sweetwater County, Wyoming, were reported by Slaughter and Nelson* to contain from 0.01 to 0.025 per cent equivalent uranium, and from 0.002 to 0.005 per cent uranium. In addition to the lignites and ash beds, all other possible sources of radioactivity in the area were examined, and accordingly, the reconnaissance was expanded to include a complete section of the Fort Union formation as well as glacial deposits in northeastern Montana.

Representative sections of all the formations exposed in North Dakota were measured in detail and radiometrically scanned, where possible, at type sections. Eighty-six localities were examined and 82 samples were taken during 1948 and 1949.

The more detailed examination in 1949 was undertaken to obtain large samples for further study of the radioactive lignite discovered the previous year, to examine new localities, and to plan future geologic studies in the region.

In 1948 the radioactivity at the outcrop was measured with a Geiger-Mueller counter of the U. M. D. C. type, equipped with a cyclotron recorder and a gamma probe. The normal background averaged from 45 to 55 counts per minute. The average background count subtracted from the total count was recorded as the net count per minute. Counts were generally taken for one minute, however, if a count appreciably higher than the background was recorded, counting was continued for four minutes. Where the count per minute at the outcrop over a four-minute period warranted, chip samples were taken and their equivalent uranium content was determined in the field. The instrument was checked periodically by determining the count per minute from a standard sample. Samples with an equivalent uranium content of approximately 0.002 or more per cent were submitted to the Survey's Denver laboratory for more accurate analysis.

In June 1949, a Beckman Model MX-5 Geiger-Mueller counter equipped with a gamma-beta probe was used to measure the radioactivity at the outcrop. Field determinations of equivalent uranium were not made because of the knowledge of local geology acquired in 1948.

Various geologic problems in the general region are being investigated by geologists of the U. S. Geological Survey, by Roland W. Brown of the American Museum of Natural History, and by Wilson M. Laird of the North Dakota State Geological Survey. A definitive study of the Fort Union formation by Dr. Brown is expected to be published in the near future. W. E. Benson of the U. S. Geological Survey is continuing his study of the Golden Valley formation.

The aid of Wilson Laird, Irving Witkind, William Benson, and Garland Gott, who have furnished useful information concerning the area, is gratefully acknowledged.

GENERAL GEOLOGY

Eleven formations, mostly of terrestrial origin, crop out in North Dakota and they have been deformed only slightly since deposition. The lithologic components in the formations of terrestrial origin vary in short distances from sand through silt to clay, or any combination of these lithologic types. This variation makes detailed stratigraphic correlation difficult.

In general, the northeastern half and the extreme southwestern corner of North Dakota are underlain by Upper Cretaceous rocks, whereas the western and southern parts of the state are underlain by Tertiary rocks. Glacial deposits cover a large part of the state north of the Missouri River.

---

*Slaughter, A. L., and Nelson, John N., Trace Elements reconnaissance in South Dakota and Wyoming, Preliminary report: Unpublished U. S. Geol. Survey Trace Elements Investigations report No. 20, pp. 13–17, March 1946.

General Stratigraphy

The formations exposed in North Dakota range in age from Upper Cretaceous to Recent* and are:

Quaternary
- Recent
  - Alluvium, etc.
- Pleistocene
  - Glacial till
  - Fluvioglacial sand and gravel

Tertiary
- Oligocene
  - White River formation
- Eocene
  - Golden Valley formation
- Paleocene
  - Fort Union formation
    - Sentinel Butte member
    - Tongue River member
  - Cannonball formation
  - Ludlow formation

Upper Cretaceous
  - Hell Creek formation
    - Breien tongue
- Montana Group
  - Fox Hills sandstone
    - Colgate member
  - Pierre shale
- Colorado Group
  - Niobrara formation
  - Benton formation

The Colorado and Montana groups of Upper Cretaceous age were deposited in a marine environment and, in general, are widespread and fairly uniform in lithology. The sediments of Hell Creek to White River age, except for the Breien tongue and the Cannonball formation, were deposited in a continental environment, and are, therefore, lenticular and of varied lithology. The Breien tongue of the Hell Creek formation and the Cannonball formation were deposited in bays of an oscillating, but generally retreating sea, and resemble, in their continuity and uniform lithology, the formations of the Colorado and Montana groups. The Ludlow formation crops out in southwestern North Dakota and is the non-marine equivalent of the Cannonball formation farther east where two formations interfinger.

Lignite beds occur in the Hell Creek and Ludlow formations, in the Tongue River and Sentinel Butte members of the Fort Union formation, and in the Golden Valley formation.

---

*Wilmarth, M. Grace, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, 1938.

Laird, Wilson M., Stratigraphy and structure of North Dakota: North Dakota Geol. Survey Bull. 18, 1944.

Benson, W. E., and Laird, Wilson M., Eocene in North Dakota: Geol. Society America Abstracts, vol. 58, No. 12, pt. 2, December 1947.

They are thickest, most extensive, and best in quality in the Tongue River member. The lignite beds are commonly lenticular, but some beds have been traced for many miles. The lignite probably accumulated in several local basins such as the Minot-Garrison field, the Marmarth-Bowman field, and the Bismarck field.

Several members have been recognized in the continental formations, but mapping is at best difficult, and correlations over even short distances tend to be uncertain. The Golden Valley formation is one of the few widely recognizable units in this entire terrestrial sequence. The uncertainties of correlation have caused a great deal of controversy among the many geologists who have worked in the region. Leonard, Hares, Dobbin, Laird, and Brown* summarize the geology or deal with some of the controversial subjects connected with the area.

The nomenclature of formations and members in this report follows the usage of the U. S. Geological Survey's Committee on Geologic Names, but recent work may require a revision of this nomenclature particularly that of the upper Paleocene, Eocene, and Oligocene formations. The thicknesses of the formations used are those given by Laird.†

Glacial till, sand, and gravel mantle most of the surface of North Dakota north and northeast of the Missouri River, and, except where streams have cut through them, effectively mask the underlying rocks.

Structure

The structure of North Dakota, especially that of the Paleozoic and lower Mesozoic rocks, is poorly known. The overlying rocks are nearly flat-lying with few structural features. In the southwestern part of the state, the Fort Union, White River, and Golden Valley formations generally dip a few feet per mile to the east and northeast. This dip reflects their position on the southwest flank of the Williston basin and the northeast flank of the adjoining Cedar Creek anticline, a broad gentle fold the axis of which trends through southeastern Montana. On the central part of the Cedar Creek anticline erosion has removed most of the upper part of the Fort Union formation, including the radioactive lignites of the Sentinel Butte member.

RADIOACTIVITY

The radioactivity of all formations exposed in North Dakota and eastern Montana was determined. Lignites in the uppermost part of the Sentinel Butte member of the Fort Union formation were the only materials found to be appreciably radioactive.

Data obtained in the field by using the U. M. D. C. type and the Beckman Model MX-5 counters, and in the laboratory by chemical and radiometric analysis, showed that at the outcrop a net count (i.e., the number in excess of background) of more than 40 per minute normally meant that the equivalent uranium content of a sample taken from the outcrop was at

---

*Leonard, A. G., The geological history of North Dakota: North Dakota Geol. Survey, 5th Bienn. Rept. pp. 227–44, 1908.

... Babcock, E. J., and Dove, L. P., The lignite deposits of North Dakota: North Dakota Geol. Survey Bull. 4, pp. 1–240, 1924 (1925).

Hares, C. J., Geology and lignite resources of the Marmarth field, southwestern North Dakota: U. S. Geol. Survey Bull. 775, 1912 (1928).

Dobbin, C. E., and Reeside, J. B., Jr., The contact of the Fox Hills and Lance formations: U. S. Geol. Survey PP 158-B, pp. 9–25, 1926 (1929).

Laird, Wilson M., Stratigraphy and structure of North Dakota: North Dakota Geol. Survey Bull. 18, 1944.

Brown, Roland W., Correlation of Sentinel Butte shale in western North Dakota: Amer. Assoc. Petroleum Geologists Bull., vol. 32, no. 7, pp. 1265–74, July 1948.

†Laird, Wilson M., op. cit.

least 0.002 per cent. Net counts per minute at the outcrop were plotted against per cent equivalent uranium and per cent uranium in samples taken from the outcrop. These data, however, show only a general concordance.

In the following section the radioactivity of the various formations is discussed. Reference should be made to plate 1* for localities discussed in the section on non-radioactive or slightly radioactive rocks, and to plates 1, 2, and 3,† for the location and graphic description of localities discussed in the section on radioactive rocks. In the discussion, the per cent of equivalent U_3O_8 is the figure obtained in the laboratory, and not that obtained in the field, unless so stated.

Non-radioactive or Slightly Radioactive Rocks

The formations discussed below were examined and found to be either non-radioactive, or only slightly radioactive. Although the Cretaceous rocks are incompletely exposed throughout the state they are best exposed south and southwest of the Missouri River. Because of the poor exposures these beds have not been adequately examined. The Paleocene and younger formations, on the other hand, are better exposed, especially south and southwest of the river, and these formations have probably been adequately examined.

Benton formation

The Benton formation is of marine origin. At locality 6, (plate 1) west of Concrete, North Dakota, it consists predominantly of dark gray to black, bentonitic and sandy shales, some of which are petroliferous. The thickness of this formation ranges from 500 to 1,000 feet, but only the upper part was exposed and examined. The net count at the outcrop was 14 per minute, indicating a low radioactivity and therefore no samples were taken.

Niobrara formation

The marine Niobrara formation was examined at localities 4 and 5 (plate 1) near Concrete, North Dakota. The formation consists of dark-gray silty limestone, lighter-gray, calcareous shale, and an overlying, plastic, bentonitic shale. Its total thickness is from 200 to 250 feet, but the formation is incompletely exposed. Counts at the outcrop indicated a low radioactivity; sample 141 taken from locality 4 at a point where the net count at the outcrop was 20 per minute contained only 0.002 per cent equivalent U_3O_8.

Pierre shale

The Pierre shale is incompletely exposed in North Dakota. It would, however, be the surface rock of a large area east of the Missouri River were it not mantled by glacial drift. The formation is reported to be from 930 to 2390 feet thick. The basal part of the Pierre at locality 1 (plate 1), near Jamestown, and at locality 5 (plate 1), near Concrete, North Dakota, consists of black to dark-gray or olive shale, containing some local sand lenses and half-inch beds of Fuller's earth. At locality 1, samples 138 and 139 taken from a point where the net count per minute was 14, contained respectively, 0.005 and 0.001 per cent equivalent U_3O_8, 0.002, and 0.001 per cent U_3O_8. At locality 5, sample 142 was taken from a short section near the base of the Pierre where the net count was 68 per minute; it contained 0.006 per cent equivalent U_3O_8, 0.005 per cent U_3O_8.

---

*Plate 1, Localities in North Dakota and northeastern Montana examined for radioactive rocks.

†Plate 2, Localities examined in the Sentinel Butte member of the Fort Union formation, and the White River formation.

Plate 3, Columnar sections of the Sentinel Butte member of the Fort Union formation, and of the White River formation in Golden Valley and Slope counties, North Dakota.

The upper part of the Pierre shale was examined at localities 2, 3, and 62 (plate 1), which are, respectively, near Valley City, near Devil's Lake (Fort Totten), and near Linton, North Dakota. At the two former localities the rocks are chiefly light gray shale containing sparse, small ferruginous nodules. Near Linton, locality 62, the Pierre consists of dark green or olive shale and silt which clearly grade upward into the overlying Fox Hills sandstone. At locality 2, sample 140, black mudstone, counted at the outcrop 18 per minute above background; it contained 0.005 per cent equivalent U_3O_8, 0.002 per cent U_3O_8. Counts at the outcrop at localities 3 and 62 were too low, from 2 to 15, to warrant sampling. As previously noted, the formation is not well exposed in North Dakota, and, although little radioactivity was found during this reconnaissance, the Pierre shale cannot be entirely disregarded as a possible source of radioactive material.

Fox Hills sandstone

The Fox Hills sandstone is not completely exposed at any one locality in North Dakota or eastern Montana, but it is reported to be over 300 feet thick. At localities 56, 59, 62, and 63, (plate 1) this formation is composed essentially of light gray, or yellow-brown, friable sandstone with some intercalated layers of olive-green or buff clay or silty clay. There are many marine fossils in the formation. At locality 56 in the Marmarth region of North Dakota, the massive light-gray sandstone in the upper part of the Fox Hills sandstone is called the Colgate sandstone member. At locality 63 near Linton, North Dakota, glauconitic sandstone contains pelecypod shells.

Radioactivity at the outcrop in all localities examined ranged only from 2 to 10 counts per minute above background, therefore, no samples were taken.

Hell Creek formation

The Hell Creek formation is the oldest unit in a thick sequence of continental sediments. It is reported to be from 100 to 500 feet thick. It was examined at localities 28, 56, 57, 59, and 60 (plate 1). The thickest sections were found at localities 56 and 57 in the Marmarth area of North Dakota where the Hell Creek is composed of an alternating, predominantly rythmically-bedded sequence of clay, silt, sandy clay, and sand, with a few beds of lignitic clay up to four inches thick, and some papery, carbonaceous clay beds. Numerous concretions, some of which were calcareous, and some of which were siderite-cemented, were observed. At locality 28, on Mortarstone Bluff near Brockton, Montana, the formation is quite similar. The predominant colors are gray, buff, olive green, and chocolate, and at a distance the Hell Creek beds are distinguishable from the overlying sediments by the uniformly dark "sombre-color." In detail, however, the upper contact is drawn only with difficulty because of the similarity of the continental sediments. The Breien marine sand tongue was examined at locality 59 near Solen, North Dakota. Net counts per minute at the outcrop of the Hell Creek formation ranged from 0 to 8 and therefore no samples were taken.

Ludlow formation

The continental Ludlow formation and its marine time-equivalent, the Cannonball formation, were formerly considered to be members of the Lance formation, but are now treated by the U. S. Geological Survey as formations, and the "Lance" has been restricted to its type locality in Wyoming.* The Ludlow formation interfingers with the marine Cannonball formation in the southwestern part of North Dakota. It was examined at localities 55, 57, 58, and 60 (plate 1). In the Marmarth area, at localities 57 and 58, the unit was observed to be over 145 feet thick, and is reported to be as much as 250 feet thick. Here the Ludlow comprises alternating beds of clay, sand, intergrade sediments, and lignite, with abundant ferruginous and

---

*Wilmarth, M. Grace, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, 1938.

calcareous concretions. The dominant color of the rocks is a buff or drab gray that is characteristically of a lighter tone than the underlying Hell Creek formation. Lignite of commercial quality has been produced from some of the thicker beds, such as the T-Cross bed south of Rhame, North Dakota, but most of the numerous lignite beds examined in the Ludlow formation are less than a foot thick.

Net counts at the outcrop ranged from 0 to 29 per minute which was considered too low to merit sampling.

Cannonball formation

The Cannonball formation is reported to be as much as 300 feet thick along the Cannonball and Heart Rivers, but thins as it interfingers with the Ludlow formation to the west, and is not found farther west than near Haley, North Dakota. The formation at localities 60, 61, 64, and 65 (plate 1), is composed largely of thick-bedded, gray to buff, calcareous or ferruginous sandstone, and alternating beds of yellow to buff clay, silty limestone, and thin-bedded sand. Numerous concretions—"cannonballs"—ranging in diameter from six inches to ten feet are common in the formation.

Net counts at the outcrop ranged from 0 to 10 per minute and no samples were taken.

Fort Union formation

The Fort Union formation, a thick non-marine unit, contains most of the important lignite deposits in the region, and is the surface rock of most of southwestern North Dakota. The Fort Union has been divided into several units of which are recognized locally, the Lebo, Tullock, Tongue River, and the overlying Sentinel Butte members. Only the latter two members are recognized in surface exposures in North Dakota. The Sentinel Butte member, the youngest member in the formation, will be discussed under the section on radioactive rocks.

The Tongue River member of the Fort Union formation is composed chiefly of yellow or other light-colored alternating beds of sand, clay, and dark, lignitic, papery shale. Lignite beds, calcareous concretions, and silicified and carbonized stumps are abundant. A characteristic of the unit is the extensive orange or brick-red "clinker" and white ash beds formed by the burning of the extensive lignite beds of the member. The formation is 300 feet thick.

As previously remarked, most of the lignites of commercial quality and thickness in North Dakota and eastern Montana are in the Tongue River member. The average thickness of these commercial lignites is between five and ten feet. They appear black or very dark brown, and are sometimes referred to as "brown coal." The following composition has been given as representative of the lignites of North Dakota "as mined:"*

Moisture: about 36.0 per cent; Volatile matter: about 27 to 29.0 per cent; Fixed carbon: about 30 to 28.0 per cent; Ash: about 5.0 to 7.0 per cent; Sulfur: about 0.7 per cent; Heating value: about 6600 B.T.U. per pound.

The Tongue River member was examined at 34 localities: numbers 11 to 29 inclusive, 37, 40 to 48 inclusive, 55, 61, 66, 67, and 68 (plate 1). Most of the lignite beds now being mined in the state as well as some that have been mined in the past were examined. In the Minot-Garrison field and the Marmarth field, two of the principal fields in North Dakota, all beds of any commercial importance were counted radiometrically. It is believed that the Tongue River member has been adequately prospected.

Analyses of 28 samples taken from 17 localities are tabulated below. No samples were taken at the other localities because counts at the outcrop were too low to warrant sampling. Net counts per minute at the outcrop ranged from 0 to 49 per minute, and samples contained from 0.001 to 0.005 per cent equivalent to U_3O_8, 0.001 to 0.002 per cent U_3O_8.

*Babcock, E. J., "The lignite of North Dakota, its character, composition, and utilization," in Leonard, A. G., and others, The lignite deposits of North Dakota: North Dakota Geol. Survey Bull. 4, p. 172, 1925.

Uranium content of samples from the Tongue River member of the Fort Union Formation

Locality Sample No.	Qual. net c/m otc.*	Analysis: Field % eU_3O_8	Analysis: Laboratory % eU_3O_8	Analysis: Laboratory % eU_3O_8	Description
			North Dakota		
DW-					
11–143	8	< 0.002	0.002	0.002	3 ft lignitic clay
14–144	40	< 0.002	0.002	0.002	5 ft ash, Burlington Bed
145	40	< 0.002	0.002	0.002	clinker, Burlington Bed
15–146		< 0.002	0.001	0.001	1 ft clay below the Burlington Bed
147		< 0.002	0.001	0.001	1 ft lignite, Burlington Bed
148		< 0.002	0.001	0.002	1 ft clay above Burlington Bed
17–149	–16	< 0.002	0.001	0.001	5 ft lignite, Coteau Bed, lower half
150	–7	< 0.002	0.001	0.001	5 ft lignite, Coteau Bed, upper half
20–151	19	< 0.002			1.5 ft green limy clay
21–152	17	< 0.002			3 ft baked clay
24–153	20	< 0.002			1 ft clinker, Garrison Creek Bed
154	11	< 0.002			0.6 ft ash, Garrison Creek Bed
155	11	< 0.002			5 ft baked clay, above Garrison Creek Bed
25–156	11	< 0.002			3 ft baked clay, above Garrison Creek Bed
25–157	15	< 0.002			3 ft ash and clinker, Garrison Creek Bed
158	12	< 0.002			6 ft baked clay, above Garrison Creek Bed
26–159	20	< 0.002			3 ft lignite and clay, Garrison Creek Bed
27–160	21	0.002			5 ft silty clay
161	23	< 0.002			5 ft clay
162	34	< 0.002			2 ft lignitic shale
37–165	20	0.002			2 ft ash and clinker
40–178		0.002	0.002	0.001	3 ft ash and baked clay
42–179	31	< 0.002	0.002	0.002	5 ft ash and clinker
45–180	27	0.002	0.005	0.001	- baked clay, Harmon Bed
181	24	< 0.002	0.004	0.002	- ash, Harmon Bed
47–182	49	0.004	0.004	0.001	4 ft clinker of "H" Bed of Harmon
			Montana		
28–163	17	0.002			1.5 ft lignitic shale
29–164	15	0.002			0.6 ft ash and baked clay

*Net counts per minute at the outcrop.
Average background about 40 counts/minute.

Golden Valley formation

The Golden Valley formation, recently described and named by Benson and Laird,* overlies the Tongue River and Sentinel Butte members of the Fort Union formation. Its Eocene age is attested by the presence of the index fossil fern Salvinia pre-auriculata Berry. The formation has a maximum thickness of 100 feet and consists predominantly of micaceous sands and light-colored clays with a few thin lignite beds. A red and yellow-weathering light-gray clay is characteristic of the middle portion of the basal part of the formation. Recent work indicates that the radioactive lignites in the Sentinel Butte member of the Fort Union described below under the section on radioactive rocks are close to the base of the Golden Valley formation and may be part of it.

The Golden Valley formation was examined at localities 67, 69, and 70 (plate 1) near Beulah and Werner, North Dakota. Counts at the outcrops ranged from 4 to 7 per minute above background and no samples were taken.

White River formation

The White River formation caps most of the higher buttes in southwestern North Dakota. This Oligocene formation consists predominantly of white, buff to pale-green, or purple, coarse-grained, resistant sandstone and conglomerate, some of which contains abundant green clay galls, or pellets. Locally, marly limestone, white and green clays, and limestone are present. The formation rests unconformably on the underlying Golden Valley and Fort Union formations, and is from 100 to 200 feet thick. A redefinition of the rocks called White River in the area may be necessary.

The White River formation was examined at localities 39, 53, and 99 (plate 1) at Sentinel Butte, White Butte, and East Rainy Butte respectively. Counts at the outcrop ranged from 0 to 42 per minute above background. No samples were taken, but by comparison with other samples, a net count of 42 per minute may represent from 0.002 to 0.004 per cent equivalent U_3O_8.

Pleistocene and Recent deposits

Pleistocene deposits, largely glacial or glaciofluviatile in origin, were examined at locality 7 (plate 1), near Rolla, North Dakota, and at localities 30 to 34 inclusive, and 36, near Plentywood, Montana (plate 1). The deposits include alluvium, eskers, kames, glacial outwash sands and gravels; "Altamont" till; stream and outwash terrace deposits; and recent "calichified" soil. No counts above background were observed, and no samples were taken.

Mineral deposits

Mineral deposits were examined in two areas. Three manganiferous springs near Dunseith, North Dakota are, at present, depositing marl and wad or other manganese oxide minerals. The deposits, at localities 8, 9, and 10 (plate 1), are not radioactive and no samples were taken. Glauber salts (hydrous sodium sulfate) formed at the margin of a small unnamed lake were counted at locality 35 (plate 1). Counts of neither the salt nor the muddy silt below the salt incrustation showed any variation from background, so no samples were taken.

RADIOACTIVE ROCKS

Sentinel Butte member of the Fort Union formation

The Sentinel Butte member of the Fort Union formation is the uppermost member of this Paleocene formation in western North Dakota. Lignites and associated shales, referred to as the "Hot" bed, or beds, in the uppermost part of the member are the only rocks in North

---

*Benson, W. E., and Laird, Wilson M., Eocene in North Dakota: Geol. Soc. America Abstracts, Vol. 58, No. 12, Pt. 2, December 1947.

Analysis of 23 samples of radioactive lignite and associated clay beds are tabulated below:

Analysis of samples of radioactive lignites at Sentinel, Flat Top, Bullion, H-T, White Buttes, North Dakota

Sentinel Butte

Date sampled	Sample number	Locality	Analyses: eU_3O_8 %	Analyses: U_3O_8 %	Analyses: Loss on ignition %	Analyses: U_3O_8 in ash* %	Thickness in feet	Description
6/7/49	277	DW-89	0.002	0.002	25.10	0.003	2.1	clay, over and underlying sample 278
6/7/49	278	DW-89	0.009	0.010	92.65	0.14	6.0	lignite, 25 pound channel sample; partially slaked
6/7/49	279	DW-90	0.018	0.015	67.07	0.04	2.5	lignite, lower bed, slaked
6/7/49	280	DW-90	0.011	0.012	66.58	0.04	2.0	lignite, middle bed 50 feet above sample 279
				Flat Top Butte				
6/7/49	281	DW-91	0.069	0.090	58.23	0.22	0.8 0.55	lignite, 0.25 ft ash, carbonaceous clay; lower bed
6/9/49	285	DW-94	0.006	0.006	34.00	0.009	1.0	0.2 ft lignite, 0.1 ft gray clay, 0.7 ft papery clay; upper bed
6/9/49	286	DW-94	0.005	0.002	43.50	0.004	0.7	0.2 ft lignite, 0.5 ft red ochre; lower bed 12 ft below 285
				Bullion Butte				
6/8/49	282	DW-92	0.004	0.003	96.12	0.08	5.2	lignite, slaked, the Bullion Butte bed of Hares; the bed is thicker than 5.2 feet
				H-T Butte				
6/4/49	271	DW-49	0.027	0.035	93.43	0.53		grab sample, fresh lignite, from bottom trench, see sample 270 below

H-T Butte (Cont'd)

Date sampled	Sample number	Locality	Analyses eU_3O_8 %	U_3O_8 %	Loss on ignition %	U_3O_8 in ash* %	Thickness in feet	Description
6/4/49	270	DW-49	0.033	0.024	78.64	0.11	3.1	lignite; 33-lb channel sample the upper foot partially slaked, the lower 2.1 fresh vitreous. See samples 184–187 incl. below, previously taken from same place
6/22/48	187	DW-49	0.029	0.024	69.6	0.07	3.1	lignite, slaked; entire bed
6/22/48	184	DW-49	0.029	0.024			1.2	lignite, basal part of No. 187 bed
6/22/48	185	DW-49	0.028	0.029			1.0	lignite, middle part of No. 187 bed
6/22/48	186	DW-49	0.033	0.032			0.9	lignite, top part of No. 187 bed
6/4/49	272	DW-54	0.014	0.011	80.53	0.06	2.6	lignite, 23-lb channel sample; partially slaked, but fresher than sample 195, previously taken from same place, see below
6/24/48	195	DW-54	0.013	0.012	79.4	0.06	2.1	lignite, slaked
6/6/49	273	DW-85	0.011	0.011	81.27	0.06	2.3	lignite, black to dark brown, blocky
6/6/49	274	DW-85	0.086	0.10	57.12	0.24	0.3	clayey lignite, 5.5 ft below No. 273
				White Butte				
6/23/48	189	DW-50	0.014	0.014			2.3	lignite
6/23/48	191	DW-52	0.033	0.028			0.7	lignite, and hematite (?)
6/23/48	192	DW-52	0.004	0.001			5.0	sandstone, overlying No. 191
6/23/48	193	DW-53	0.014	0.011			1.5	lignite
6/6/49	275	DW-86	0.013	0.007	28.70	0.01	0.6	0.1 ft lignite, 0.5 ft hematite (?)

*Calculated from the per cent U_3O_8 in lignite and the per cent loss on ignition.

The ash of sample 176 of the Hot bed contained montmorillinite-, kaolinite-, and illite-types of clay; whereas, the ash of sample 181 of nonradioactive lignite (the Harmon bed) contained only the illite-group of clay minerals. More samples must be studied to establish this variation before conclusions may be drawn from it.

Origin of Uranium in the Radioactive Lignite

Radioactive coals have been noted by previous workers* but little has been suggested in explanation of the mode of origin of the occurrences.† As a result of the brief studies in North Dakota it seems probable that one of two theories may account for the association of uranium and coal; (1) that uranium was deposited with other detrital minerals in sediments overlying or marginal to the lignite and subsequently leached from them, carried downward, or laterally, and fixed by the carbon of the lignite; or (2) that uranium was deposited from surface waters by the action of living organisms or dead organic matter at the same time as the carbonaceous debris from which the lignite formed.

The connotations of these hypotheses are that a source of radioactive material was being leached or eroded, and the "Hot" bed was the first carbonaceous material encountered by uranium-bearing solutions. This would explain the lack of radioactive lignites lower in the section, but requires a source of either the detrital uranium minerals or the uraniferous solutions different from the source of all the rest of the underlying Fort Union sediments. Deposition of radioactive volcanic ash, or diversion of drainage from abnormally radioactive source rocks into the area, either during or after accumulation of lignitic material may fit the necessary conditions.

Recent work in the area suggests that the lignite and the Golden Valley formation may be contemporaneous. This suggests that geologic conditions prevailing in Golden Valley time may have been favorable for, or influenced the formation of radioactive lignite. If this is true, similar geologic environments should be searched for uranium. The Golden Valley formation is a sedimentary unit of continental origin remarkable in its lithologic uniformity over a wide area.

It is possible that the widespread lignites of Eocene-Paleocene age may be generally radioactive.

PART II RESERVES AND SUMMARY

ABSTRACT

The inferred reserve of radioactive lignite in North Dakota is estimated to be 23,000,000 tons containing a weighted average of 0.008 per cent U_3O_8. The potential energy in this quantity of lignite is large. The inferred reserve of natural ash which has resulted from the burning of the radioactive lignite at Sentinel Butte, North Dakota, is 1000 tons containing 0.047 per cent U_3O_8. The potential reserve of radioactive lignite in the region investigated is not yet known.

Reserves of Radioactive Lignite

The inferred reserve of radioactive lignite in southwestern North Dakota is estimated to be 23,000,000 tons. The average grade of this reserve, weighted against thickness and tonnage,

---

*Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 770, pp. 315–23, 722–27, 760, 1924.

†Frederickson, A. F., Some mechanisms for the fixation of uranium in certain sediments: Science, August 20, 1948.

is 0.008 per cent U_3O_8. The inferred reserves of natural ash which has resulted from the burning of the radioactive lignite at Sentinel Butte, North Dakota is 1,000 tons containing 0.047 per cent U_3O_8. The potentialities of the region have not been exhausted. Preliminary estimates of the inferred reserve at the various Buttes are tabulated below:

Reserves of radioactive lignite at Sentinel, Flat Top, Bullion, H-T, and White Buttes, North Dakota

Butte	Sentinel	Flat Top	Bullion	H-T	White
Area underlain by lignite (square feet)	34,850,000	20,909,000	43,560,000	38,861,800	‡
Average thickness (feet)	5	1	5* 10†	2.02	
Volume (cubic feet)	174,250,000	20,909,000	217,800,000 435,600,000	 78,671,000	 ‡
Inferred reserve of lignite (tons)	6,700,000	804,000	8,380,000 16,752,000	3,000,000	‡
Average grade, weighted (% U_3O_8)	0.012	0.05	0.003 251*	0.011 330	 ‡
Inferred reserve of U_3O_8 (tons)	804	402	503†		

*Minimum.
†Maximum.
‡Not estimated.

In making estimates of tonnage the areas of the Buttes shown on Hares' map,* and on the county highway maps, are assumed to be correct. The average thickness of the radioactive beds is assumed to be uniform throughout the areas; and 26 cubic feet of lignite are assumed to weigh one ton.

The average grade at each Butte was obtained by weighting grade with the thickness of lignite represented by each sample. The average grade for the area was obtained by weighting the average grade at each Butte with the tonnage at each Butte.

Because these samples were taken at the outcrop, they are not truly representative of unweathered lignite. Leaching or enrichment of uranium may have taken place. However, analyses of a few samples taken two to four feet beneath the surface adjacent to the same points sampled at the surface do not vary significantly in uranium content.

Factors affecting recovery

Some of the factors which should be considered in evaluating the district as a potential source of uranium are (1) the degree to which uranium will be concentrated by burning of the lignite, (2) the available energy, (3) the amount of overburden, (4) the solubility of the uranium minerals, and (5) the accessibility of the deposits. These factors are considered briefly below.

*Hares, op. cit. (1928)

The loss in weight and the corresponding concentration of uranium in the ash resulting from the ignition of uraniferous lignite is indicated by the following analyses:

Analyses of 4 samples of lignite and clay

Sample No.	187	195	A*		B†
Per cent loss at 1000°C	69.6	79.4	89.9	91.3	
Per cent free H_2O‡	8.5	9.7			
Per cent ash	30.4	20.6	10.1	8.7	
Per cent U (as rec'd basis)	0.021	0.012	0.008	0.008	0.001
Per cent U (ignited basis)	0.060	0.044	0.080		
Per cent U (ignited basis calculated)§	0.069	0.058	0.079		

*A is a composite of better quality lignite picked from 7 samples of lignite.

†B is a composite of clay underlying the lignite and included in the samples of it taken in 1948.

‡Determined by evacuation under P_2O_5.

§Calculated from the per cent ash and from the per cent U on an "as received" basis.

These samples were all collected from the slacked outcrop and would, therefore, have been subjected to contamination and dehydration resulting in a higher ash content, and therefore a lower percentage of uranium in the ash than would be indicated by the analyses of fresh, unslacked, and uncontaminated samples. This is illustrated by the low ash content and corresponding increase of uranium in the ash of sample A. Sample A contains about the same amount of ash as that given as the average for all North Dakota lignites, about 8 per cent.*

If it is assumed that the unweathered and uncontaminated radioactive lignite has an average ash content of 8 per cent, a given quantity of lignite would be reduced to one-twelfth of its former weight upon burning and the uranium content of the ash would be increased twelve times. Thus, 1,000,000 tons of lignite containing 0.01 per cent U_3O_8 would, upon burning, leave 80,000 tons of ash containing 0.12 per cent U_3O_8. The available heating value in representative samples of North Dakota lignite, according to Hares,† amounts to 5,000 to 6,000 BTU per pound of coal, and according to Babcock,‡ 6,600 BTU per pound. This energy released in burning could be used to help defray costs, or directly in the process, of producing uranium metal.

The U_3O_8 content concentrated in the ash of the most radioactive lignite, sample 274, is 0.24 per cent, and the U_3O_8 content concentrated in the ash of one of the least radioactive beds, the Bullion Butte bed, is 0.08 per cent.

The relationship between the uranium content of lignite, the loss of weight on ignition, the concentration of uranium in the ash, and the energy released in burning are graphically presented on page 21

---

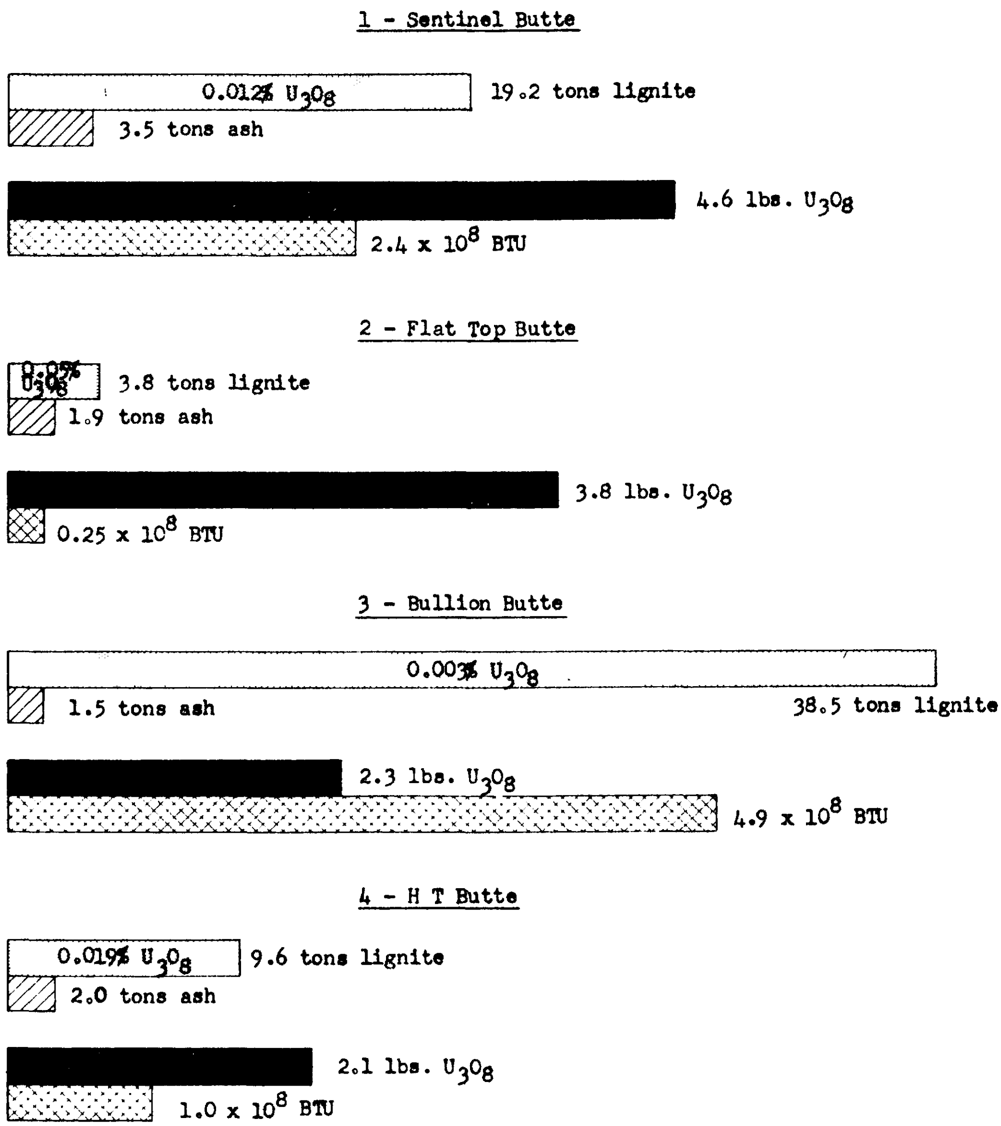
*Hares, C. J., op. cit. pp. 54, 55.

†Idem.

‡Babcock, E. J., in Leonard, A. G., op. cit. p. 172.

SOME PRODUCTS FROM RADIOACTIVE LIGNITE BEDS IN NORTH DAKOTA

(calculated for blocks 100 feet long × 1 foot deep × the average thickness of the beds at the several buttes)*



---

*In the calculations 26 cubic feet of lignite are assumed to weigh one ton. No factor was applied for dilution or loss in mining. Where several lignite beds are present at a given butte, they were combined, for the purpose of calculation, into one bed. The accepted average figure for the heating value of North Dakota lignites, 6600 British Thermal Units (BTU) per pound, was used.

A new experimental plant at Grand Forks, North Dakota, has recently been placed in operation to run pilot tests on the conversion of lignite to liquid fuel. Residues from such operations might well be a source of uranium if uranium-bearing lignites were used.

The lignite beds in the Buttes discussed on page 21 are overlain by 100 to 150 feet of overburden, the upper 60 to 80 feet of which is resistant sandstone and conglomerate of the White River formation.

Although field studies suggest that the uranium in the ash might be soluble, laboratory analyses do not confirm this. George J. Petretic* states that it is probable that after combustion of the lignite, the uranium is in the form of an oxide, and therefore relatively insoluble.

Most of the areas underlain by radioactive lignites are readily accessible over poor roads, some of which are hard-surfaced. Sentinel and Flat Top Buttes are within 4 miles of the Northern Pacific railroad; Bullion Butte is from 22 to 25 miles from the same railroad; H-T and White Buttes are within 17 miles of the Chicago, Milwaukee, St. Paul, and Pacific railroad. Native wood is scarce. Water, especially from wells, is plentiful.

SUMMARY

The great majority of rocks exposed in North Dakota and eastern Montana are either barren of radioactivity or only slightly radioactive. In the southwestern part of North Dakota, the upper part of the Sentinel Butte member, the topmost member of the Fort Union formation, contains decidedly radioactive lignite. Twenty-three million tons of inferred ore contain approximately 0.008 per cent U_3O_8. From one to five beds of lignite occur throughout a stratigraphic range of as much as 90 feet; the total aggregate thickness varies between 1 and 10 feet.

The lignite beds are thinner, more divided, and the individual beds are more widely separated at Flat Top Butte than they are 6 miles west at Sentinel Butte, and at White Butte than they are 4 miles west at H-T Butte. This thinning, division, and separation apparently progressed eastward, and the possibility of discovering an extensive deposit to the east where the normal dip of the Fort Union beds would place the lignite at the present ground surface is thus unlikely, but should not be overlooked.

A more extensive investigation was started early in August, 1949 with emphasis placed on the tonnage and grade available at several buttes, and a detailed study of the relations of the radioactive lignite to the stratigraphy and sequence of sedimentation.

General studies are required to determine the areal limits of the Sentinel Butte member and its radioactive lignites. The correlatives of the Sentinel Butte member, the Golden Valley, and perhaps the White River formations in adjoining areas and states should be determined and outlined so that these correlatives also can be examined. The general relation of the Sentinel Butte member, and particularly the lignite, to surrounding sediments should be determined so that a better understanding may be reached of the factors controlling distribution and localization of the uranium.

---

*Petretic, George J., Informal communication.

APPENDIX A

Samples

Sample No.	Locality	Field: otc net c/m	Field: % eU_3O_8	Laboratory: % eU_3O_8	Laboratory: % U_3O_8	Description
138	DW-1 Jamestown, N. D.	14	<0.002	0.005	0.002	5 ft sandy shale, Upper Pierre?
139	DW-1 Jamestown, N. D.		<0.002	0.001	0.001	1 ft gravel, Upper Pierre?
140	DW-2 Valley City, N. D.	18	0.002	0.005	0.002	5 ft black mudstone Lower Pierre?
141	DW-4 Walhalla, N. D.	20	<0.002	0.002	0.002	5 ft black shale, Benton-Niobrara
142	DW-5 Concrete, N. D.	68	0.004	0.006	0.005	5 ft black shale, Niobrara-Pierre
143	DW-11 Donnybrook, N. D.	8	<0.002	0.002	0.002	3 ft lignitic clay, Tongue River
144	DW-14 Burlington, N. D.	40	<0.002	0.002	0.002	- ash, Burlington bed, Tongue River
145	DW-14 Burlington, N. D.	40	<0.002	0.002	0.002	- clinker, Burlington bed, Tongue River
146	DW-15 Burlington, N. D.		<0.002	0.001	0.001	1 ft clay, Tongue River
147	DW-15 Burlington, N. D.		<0.002	0.001	0.001	1 ft lignite, Burlington bed, Tongue River
148	DW-15 Burlington, N. D.		<0.002	0.001	0.002	1 ft clay, Tongue River
149	DW-17 Truax-Traer, N. D.	−16	<0.002	0.001	0.001	5 ft lignite, Coteau bed, Tongue River
150	DW-17 Truax-Traer, N. D.	−7	<0.002	0.001	0.001	5 ft lignite, Coteau bed, Tongue River
151	DW-20 Garrison, N. D.	19	<0.002			1.5 ft limy shale, Tongue River
152	DW-21 Garrison, N. D.	17	<0.002			3 ft baked shale, Tongue River
153	DW-24 Garrison, N. D.	20	<0.002			1 ft clinker, Garrison Creek bed, Tongue River

APPENDIX A (Cont'd.)

Sample No.	Locality	Field: otc net c/m	Field: % eU_3O_8	Laboratory: % eU_3O_8	Laboratory: % U_3O_8	Description
154	DW-24 Garrison, N. D.	11	<0.002			0.6 ft ash, Garrison Creek bed, Tongue River
155	DW-24 Garrison, N. D.	11	<0.002			5 ft baked clay, Tongue River
156	DW-25 Riverdale, N. D.	11	<0.002			3 ft baked clay, Tongue River
157	DW-25 Riverdale, N. D.	15	<0.002			3 ft ash & clinker, Wolf Creek bed, Tongue River
158	DW-25 Riverdale, N. D.	12	<0.002			6 ft baked clay, Tongue River
159	DW-26 Riverdale, N. D.	20	<0.002			3 ft lignite, clay, Garrison Creek bed, Tongue River
160	DW-27 Riverdale, N. D.	21	0.002			5 ft silty clay, Tongue River
161	DW-27 Riverdale, N. D.	23	<0.002			5 ft clay, Tongue River
162	DW-27 Riverdale, N. D.	34	<0.002			2 ft lignitic shale, Tongue River
163	DW-28 Brockton, Mont.	17	0.002			1.5 ft lignitic shale, Tongue River
164	DW-29 Culberson, Mont.	15	0.002			0.6 ft ash & baked clay, Tongue River
165	DW-37 Williston, N. D.	20	0.002			2 ft ash & clinker, Tongue River
166	DW-38 Sentinel Butte, N. D.	39	0.002	0.005	0.005	- clay, Sentinel Butte
167	DW-38 Sentinel Butte, N. D.	35	0.002	0.002	0.004	1.3 ft lignitic shale, Hot bed, Sentinel Butte
168	DW-38 Sentinel Butte, N. D.	44	0.002	0.007	0.002	0.7 ft clay, Sentinel Butte
169	DW-38 Sentinel Butte, N. D.	84	0.006	0.019	0.017	0.4 ft lignite, maroon sand, Sentinel Butte
170	DW-38 Sentinel Butte, N. D.	39	0.002	0.004	0.002	1.5 ft bentonitic clay, Sentinel Butte
171	DW-38 Sentinel Butte, N. D.	97	0.005	0.006	0.004	1 ft baked clay, Sentinel Butte
172	DW-38 Sentinel Butte, N. D.	121	0.01	0.015	0.007	0.4 ft ash, Sentinel Butte
173	DW-38 Sentinel Butte, N. D.	105	0.007	0.011	0.011	0.7 ft ash, Sentinel Butte
174	DW-38 Sentinel Butte, N. D.	92	<0.002	0.004	0.002	1.5 ft volcanic ash? Sentinel Butte

APPENDIX A (Cont'd.)

Sample No.	Locality	Samples Analyses Field otc net c/m	Field % eU_3O_8	Laboratory % eU_3O_8	Laboratory % U_3O_8	Description
175	DW-38 Sentinel Butte, N. D.	445	0.04	0.057	0.050	0.9 ft ash, Sentinel Butte
176	DW-38 Sentinel Butte, N. D.	400	0.041	0.099	0.071	0.1–0.2 ft ash, Sentinel Butte
177	DW-38 Sentinel Butte, N. D.	58	0.011	0.014	0.012	- limestone, Sentinel Butte
178	DW-40 Sentinel Butte, N. D.		< 0.002	0.002	0.001	3 ft ash & baked clay, Tongue River
179	DW-42 N. Roosevelt Park, N. D.	31	< 0.002	0.002	0.002	5 ft ash & clinker, Tongue River
180	DW-45 Rhame, N. D.	27	0.002	0.005	0.001	- baked clay, Harmon bed, Tongue River
181	DW-45 Rhame, N. D.	< 24	0.002	0.004	0.002	- ash, Harmon bed, Tongue River
182	DW-47 Rhame, N. D.	49	0.004	0.004	0.001	4 ft clinker, Harmon bed, Tongue River
183	DW-49 N. of Bowman, N. D.	32	0.004	0.004	0.004	0.1 ft lignitic shale, Sentinel Butte
184	DW-49 N. of Bowman, N. D.	160	0.009	0.029	0.024	1.2 ft lignite, Hot bed, Sentinel Butte
185	DW-49 N. of Bowman, N. D.	248	0.011	0.028	0.029	1 ft lignite, Hot bed, Sentinel Butte
186	DW-49 N. of Bowman, N. D.	248	0.014	0.033	0.032	0.9 ft lignite, Hot bed, Sentinel Butte
187	DW-49 N. of Bowman, N. D.	216?	0.013	0.029	0.024	3.1 ft lignite, Hot bed, Sentinel Butte
188	DW-49 N. of Bowman, N. D.	63	0.002	0.005	0.004	0.7 ft maroon sand, Sentinel Butte
189	DW-50 N. of Bowman, N. D.	106	0.005	0.014	0.014	2.3 ft lignite, Hot bed, Sentinel Butte
190	DW-51 N. of Bowman, N. D.	17	< 0.002	0.001	0.002	1.2 ft lignitic silt, Sentinel Butte
191	DW-52 N. of Bowman, N. D.	154	0.013	0.033	0.028	0.7 ft lignite, Hot bed, Sentinel Butte
192	DW-52 N. of Bowman, N. D.	29	< 0.002	0.004	0.001	5 ft sandstone, Sentinel Butte
193	DW-53 N. of Bowman, N. D.	136	0.005	0.014	0.011	1.5 ft lignite, Hot bed, Sentinel Butte
194	DW-54 N. of Bowman, N. D.	35	0.004	0.006	0.006	0.8 ft lignite & clay, Sentinel Butte
195	DW-54 N. of Bowman, N. D.	145	0.006	0.013	0.012	2.1 ft lignite, Hot bed, Sentinel Butte

APPENDIX A (Cont'd.)

Samples

Sample No.	Locality	Laboratory Analyses % eU_3O_8	% U_3O_8	% loss on ignition	% U_3O_8 in ash, calculated	Description (All samples from Bullion Butte Member)
270	DW-49 N. of Bowman, N. D.	0.033	0.024	78.64	0.11	3.1 ft lignite, 33 lb channel sample, fresher than samples 184—187 inclusive from same place
271	DW-49 N. of Bowman, N. D.	0.027	0.035	93.43	0.53	grab lignite, fresh, from base sample 270
272	DW-54 HT-Butte, N. D.	0.014	0.011	80.53	0.06	2.6 ft lignite, 23 lb channel sample, fresher than sample 195 from same place
273	DW-85 HT-Butte, N. D.	0.011	0.011	81.27	0.06	2.3 ft lignite, black to dark brown, blocky
274	DW-85 HT-Butte, N. D.	0.086	0.10	57.12	0.23	0.3 ft lignite, 5.5 ft below 273
275	DW-86 White Butte, N. D.	0.013	0.007	28.70	0.01	0.6 ft lignite, includes hematite?
277	DW-89 Sentinel Butte, N. D.	0.002	0.002	25.10	0.003	2.1 ft clay, over and under lignite
278	DW-89 Sentinel Butte, N. D.	0.009	0.010	92.65	0.14	6.0 ft lignite, 25 lb channel, partially slaked
279	DW-90 Sentinel Butte, N. D.	0.018	0.015	67.07	0.04	2.5 ft lignite, lower Hot bet, slaked
280	DW-90 Sentinel Butte, N. D.	0.011	0.012	66.58	0.04	2.0 ft lignite, middle Hot bed, 50 ft above 279
281	DW-91 Flat Top Butte, N. D.	0.069	0.090	58.23	0.22	0.8 ft lignite, 0.25 ft ash, 0.55 ft carbonaceous clay, lower Hot bed
282	DW-92 Bullion Butte, N. D.	0.004	0.003	96.10	0.08	5.2 ft lignite, the Bullion Butte bed? of Hares, slaked
285	DW-94 Flat Top Butte, N. D.	0.006	0.006	34.00	0.009	1 ft carbon, clay, lignite, and gray clay, upper Hot bed
286	DW-94 Flat Top Butte, N. D.	0.005	0.002	43.50	0.004	0.2 ft lignite, 0.5 ft red ochre, lower Hot bed 12 ft below 285

No. (186): "H" Bed. Predominantly a black lignite, but contains "segregations" of materials identical to No. (184). The small rhombs of highly birefringent, high index material are also present. Gypsum occurs in veinlets and some unidentified yellowish cryptocrystalline material with comparatively high indices is also present ($N_m = 1.745 \pm 0.01$).

No. (187): "H" Bed. Predominantly a black lignite containing many minute mineral particles. Gypsum occurs as "segregations" and veinlets.

Other minerals such as sphene, epidote, possibly some allanite, and white mica (muscovite), are rare but are concentrated locally. Small particles of detrital quartz occur in thin layers.

No. (195): "H" Bed. Predominantly a black-glossy lignite. Minor yellowish-green coatings of nontronite clay and white mica occur. Rarely small particles of detrital quartz are present.

No. (181): Ash, Harmon Bed. A buff-colored powdery material containing brown and gray rock fragments up to 20 mm across and some partially lignitic material. There are substantial quantities of finely divided calcite in the unconsolidated material and a large amount of cryptocrystalline glassy material. The larger fragments have a megascopic appearance of indurated shale or hornfels. One particle (5 mm across) of biotite was observed.

The light buff-colored extremely absorbent sample is an altered, partially fused, material, which is now essentially the clay mineral illite.

No. (176): Ash, "H" Bed. Predominantly an altered silicous glass mixed with finely divided calcite and possibly some gypsum. The silicious glass has been largely altered to a montmorillonite-type clay intermixed with a kaolinite-type clay as well as some zeolite and appreciable illite.

No. (191): "Oxidized" "H" Bed. A reddish-brown, limonite stained material as well as limonite concretions. Most of the sample is unconsolidated.

There are also present minor amounts of yellowish-green sandstone that appear identical to the Sentinel Butte sandstone described below as No. (192).

No. (192): Sandstone (Butte Sandstone). Predominantly detrital quartz grains associated with substantial amounts of white mica.

The light fraction (Sp. Gr < 2.78) contains quartz, appreciable amounts of fresh to severely altered plagioclase (calcic oligoclase), some vein quartz, and some fresh microcline-perthite.

The heavy fraction contains minor amounts of epidote, garnet, monazite, celadonite (perhaps glauconite), and rare staurolite. There appears to be some allanite and small, nearly perfect to broken, crystals of zircon are present.

Probably of igneous and metamorphic origin."

APPENDIX B

REPORT OF PETROGRAPHIC EXAMINATION

Joseph Berman* reports the following results of petrographic examination of selected samples of lignite and associated materials, submitted August 6, 1948.

"The thirteen samples were examined megascopically and with the petrographic microscope.

The highly lignitic specimens were placed in an oven to remove organic material and a microscopic study of the ash was made. Where clay minerals were present, organic dyes were used to assist in their identification.

The description of the samples which follows is a survey rather than a complete detailed investigation; this must be considered where conclusions are drawn as a result of the petrographic work.

Petrographic Examination

No. (147): Lignite, Burlington Bed. The sample is grey-black (reddish-brown, translucent under transmitted light) typical lignite. It contains appreciable amounts of gypsum, some anhydrite, and a substantial quantity of finely disseminated calcite. Rare minute crystals of detrital zircon and one grain of detrital white mica were observed.

No. (149 & 150): Lignite, Coteau Bed. A black lignite which appears reddish-brown and translucent through the microscope using transmitted light. An appreciable amount of finely disseminated calcite was observed and rare small particles of quartz were found.

No. (159): Lignite (clay), Garrison Creek Bed. A black lignite which has its apparent fracture and bedding surfaces coated with a powdery, yellowish-green epidote. The sample contains some anhydrite and possibly some gypsum, but no carbonate was observed.

No. (169): (Lignite and Maroon Sand), Sentinel Butte. A gray-black lignite containing powdery clay-like material, and appreciable quantities of gypsum, which occur as large crystals. The sample also contains some gibbsite as well as some buff-colored bauxite mixed with clay. Some of the powdery material may be boehmite.

No. (184): "H" Bed. The sample consists of an olive-green sandy material which is predominantly unconsolidated, and contains appreciable lignitic material. Some white mica (muscovite) is present. Layers of gypsum up to $^1/_8$ in. thick covered by a yellowish-green nontronite clay are common. This clay mineral probably gives the color to the specimen. Rare grains of euhedral orthoclase occur. Minute rhombs of high birefringent material are present throughout.

*Joseph Berman, Report No. TDM-2, Branch of Geochemistry and Petrology.